ISSN: 0001-5113 **AADRAY**	**ACTA ADRIAT.,** **50(1): 11 - 22, 2009**	**UDC: 597.541:591.134(262.3-12)** **597.541:639.2.053.2(262.3-12)**

Inter-annual fluctuations of the population structure, condition, length-weight relationship and abundance of sardine, *Sardina pilchardus* (Walb., 1792), in the nursery and spawning ground (coastal and open sea waters) of the eastern Adriatic Sea (Croatia)

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This paper presents inter-annual fluctuations in the population structure, condition, length-weight relationship and abundance of sardine, Sardina pilchardus *(Walb., 1792), the most important fish species in the Adriatic Sea. The random samples were obtained from the nursery ground (Zrmanja River estuary,* n*=2 893) and spawning ground (off Dugi Otok,* n *=1 628) of the sardine. Representative samples of catches obtained by purse seine fishing were collected during the 2002-2006 period. Total lengths ranged from 5.0 to 19.5 cm (mean lengths between 7.35±1.005 and 13.87±1.102 cm; Zrmanja River estuary) and 11.5 to 19.5 (mean lengths between 15.22±1.826 and 16.19±0.854, off Dugi Otok). The length-weight relationships of sardine from the Zrmanja River estuary and off Dugi Otok point to positive and negative allometry, respectively. A comparison of the allometric condition factor (K_a) of sardine specimens, which ranged from 13.0 to 16.0 cm, showed higher values in the area off Dugi Otok ($\overline{K}_a$ =0.467) than in the area of the Zrmanja River estuary ($\overline{K}_a$=0.331), especially during 2003 ($\overline{K}_a$ =2.653). In terms of the fish abundance index, seasonal fluctuations were noticed. The highest values were observed in the area off Dugi Otok during autumn and in the Zrmanja River estuary during spring.*

Key words: sardine, population structure, length-weight relationship, condition, abundance index

INTRODUCTION

Sardine, *Sardina pilchardus* (Walb., 1792), is the most abundant and one of the most commercially important fish species in the Adriatic Sea (SINOVČIĆ, 2001a, b). Its biomass and catches have experienced large, natural, interannual fluctuations in recent years (CINGOLANI *et al.*, 2003; SINOVČIĆ, 2003; SANTOJANNI *et al.*, 2005, 2006).

A severe, sudden collapse happened in 1991 and continued until 1997. Since then, sardine stock assessment indicates stabilization at low amounts in biomass throughout the entire Adriatic Sea (CINGOLANI *et al., ibid.*). The collapse was attributed to poor recruitment in that period (SINOVČIĆ *et al.*, 2001a). The reasons for recruitment failure are still unknown.

The Zrmanja River estuary is a nursery ground for sardine and other small pelagic fish species (SINOVČIĆ *et al.*, 2004a, b; SINOVČIĆ & ZORICA, 2006; SINOVČIĆ *et al.*, 2007). It is one of the most productive areas of the eastern part of the Adriatic (KRŠINIĆ, 1987; VILIČIĆ, 1989; VILIČIĆ *et al.*, 2001). The area off Dugi Otok is a well defined spawning ground of sardine in the Adriatic Sea (SINOVČIĆ & ALEGRIA, 1997; SINOVČIĆ, 2001b), where upwelling conditions predominate (REGNER *et al.*, 1987). Sardine stock supports predator populations of many larger fish, cephalopods, birds and mammals. Thus, sardine plays an important part in the trophic structure of the ecosystem.

The aim of the study was to examine not only sardine population structure, length-weight relationship, condition changes and differences, but also the annual fluctuation of its biomass, total catch and catch per unit effort (*CPUE*-t/vessel/day) as an index of sardine population abundance in coastal and open waters of the Adriatic Sea, as well as in the entire Adriatic, in order to provide better knowledge and protection of sardine stock in the area.

MATERIAL AND METHODS

The random samples of sardine (n=4 521) were collected seasonally from the sardine nursery ground (Zrmanja River estuary, n=2 893) and from its spawning ground (off Dugi Otok, n=1 628) (Fig. 1) during the 2002-2006 period. Sardine were caught by purse seine under artificial light during the night, but not during a full moon. The total length (TL, 0.1 cm accuracy) and gutted fish weight without gonads (W, 0.01 g accuracy) were measured.

The length–weight relationship was determined according to the logarithmic form of the exponential equation (RICKER, 1975):

$$\log W = \log a + b \log TL$$

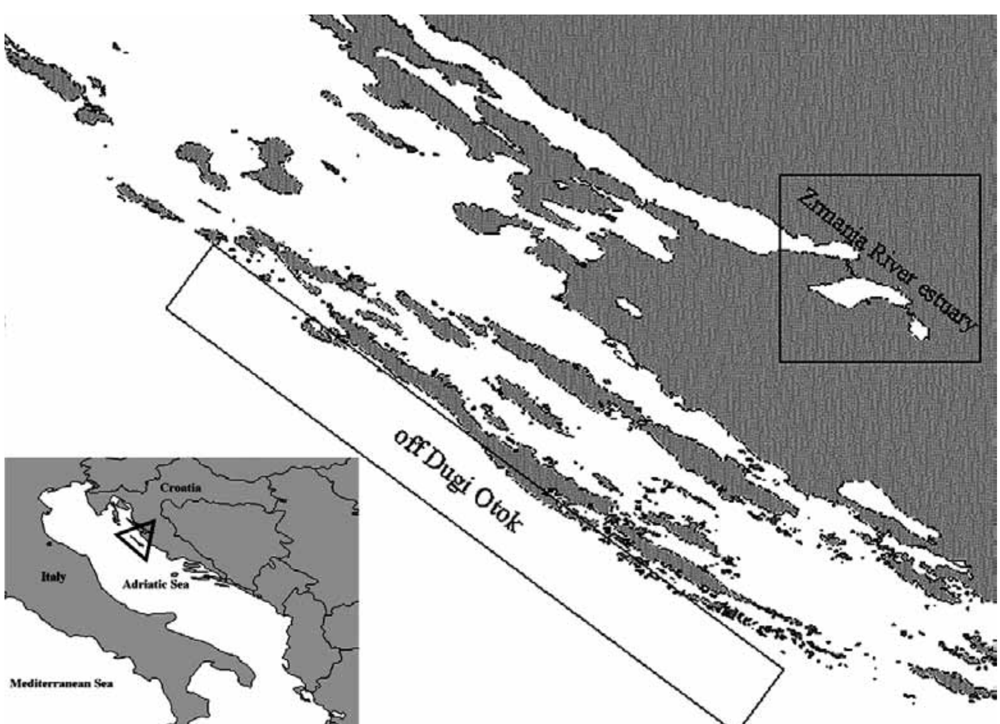

Fig. 1. Map of the study area

where W=fish weight in g, TL =total length in cm, a=intercept and b=regression coefficient. In order to establish deviations from isometric growth, the t-test was used. Kolmogorov-Smirnov (K-S) was used to confirm whether the data are normally distributed or not.

The allometric condition index was used to determine the condition of the fish (LE CREN, 1951)

$$K_a = W/a\ TL^b$$

where a and b are the coefficient and exponent of the annual TL–W relationship, respectively. To avoid a length/size bias in condition analysis, only fish of 13.0 and 16.0 cm in length were used to compare condition changes during all five research periods.

Daily mean data on sardine catches (C) and fishing effort (f) were obtained directly from ten fishing boats. The annual mean catch per unit effort ($CPUE$ =t/vessel/day) was calculated from these data.

RESULTS

Length structure

Total lengths ranged from 5.0 to 19.5 cm (with the mean between 7.35±1.005 and 13.87±1.102 cm, Zrmanja River estuary) and 11.5 to 19.5 cm (with the mean between 15.22±1.826 and 16.19±0.854 cm, off Dugi Otok) (Fig. 2). The minimum and maximum weights recorded were 0.69 and 60.20 g (with the mean between 4.79±8.3109 and 22.03±8.3112 g; Zrmanja River estuary) as well as 6.18 and 63.97 g (the mean between 30.40±7.023 and 33.51±7.558 g; off Dugi Otok).

The smallest specimen (5.0 cm, 0.69 g) and generally the highest share of smaller specimens were recorded in the catches of 2004 and 2005 in the Zrmanja River estuary, whilst the majority of large specimens were mainly caught in 2002, 2003 and 2006 in both investigated areas (Fig. 2). It is obvious, from the same figures, that length distribution was unimodal in the area off

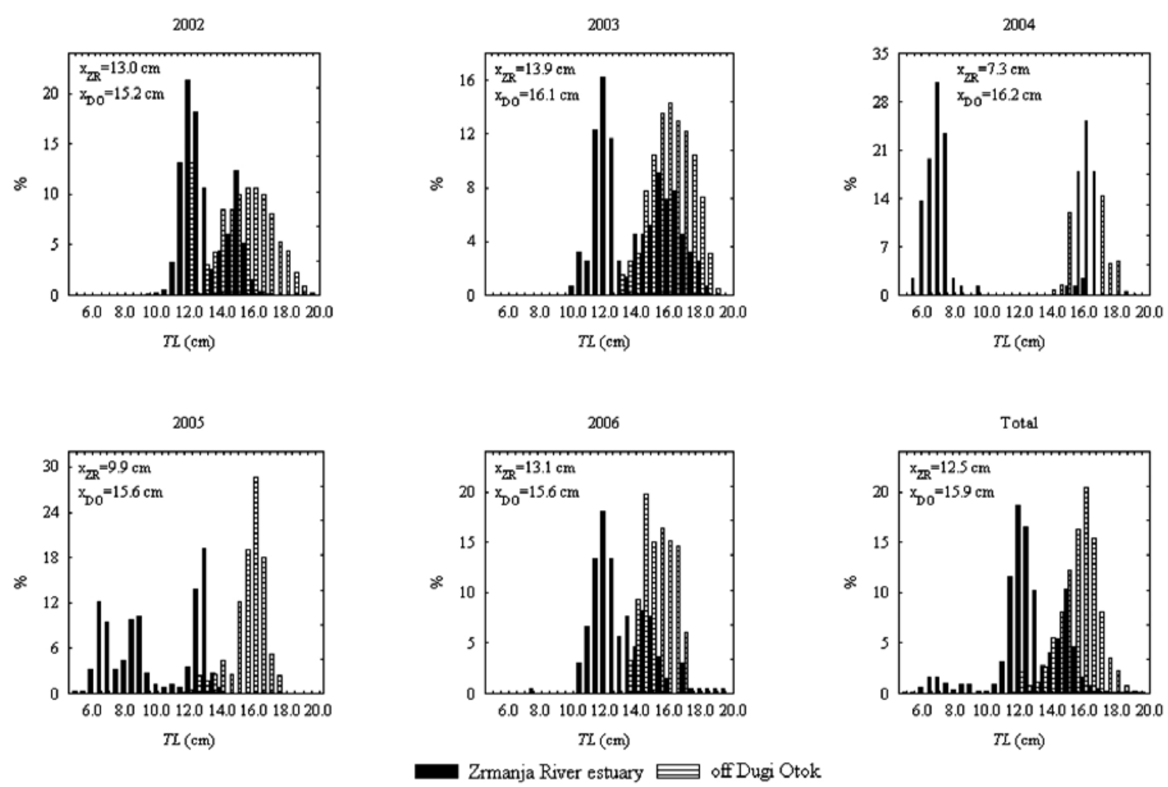

Fig. 2. Total length frequency distribution of Sardina pilchardus *from the catch samples obtained in the Zrmanja River estuary (ZR) and in the area off Dugi Otok (DO) during the 2002-2006 period*

Dugi Otok at the time of research and that it was polymodal in the Zrmanja River estuary. Mean sardine lengths have either increased gradually in the Zrmanja River estuary or stabilized in the area off Dugi Otok since 2004.

A Kolmogorov-Smirnov test (*d.*=0.03, *P*<0.001-Zrmanja River estuary; *d.*=0.06, *P*<0.001-off Dugi Otok) confirmed that all data sets were normally distributed.

Length-weight relationship

The length-weight relationships of sardine (*n*=4 521) were calculated for specimens from the Zrmanja River estuary and off Dugi Otok. The overall results are shown in Fig. 3 and Tab. 1. The regression coeficient (*b*) generally showed the lowest values during 2003 (2.671 and 2.563 in sardine from the Zrmanja River estuary and off Dugi Otok, respectively) and the highest during 2005 (3.552 and 3.405 in sardine from the Zrmanja River estuary and off Dugi Otok, respectively). Sardine specimens from the Zrmanja River estuary had a significantly (*t*=227.17; *d.f.*= 2616, *P*<0.001) higher regression coefficient (*b*=3.3139; r^2=0.9662) than those off Dugi Otok (*b*=2.8756; r^2=0.8301).

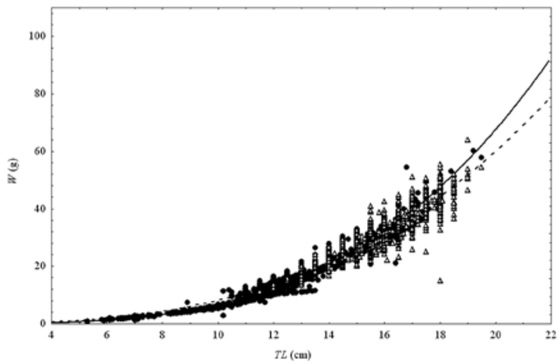

Fig. 3. Total length (TL, cm) - weight (W, g) relationship of Sardina pilchardus *from the catch samples obtained in the Zrmanja River estuary (●) and in the area off Dugi Otok (Δ) during the 2002-2006 period*

Namely, the length-weight relationships of sardine from the catch samples obtained in the Zrmanja River estuary showed a positive allometry (*t*=10.1277), whilst the samples from Dugi Otok indicated a negative allometry (*t*=1.9679; *P*<0.05). Coefficients of determination (r^2) were generally highly significant - they were between 0.876 and 0.981 for sardine from the Zrmanja River estuary and between 0.778 and 0.928 for sardine specimens from the area off Dugi Otok (Table 1) .

Table 1. Annual relationship between W (somatic weight, g) and TL (total length, cm) of Sardina pilchardus*; a is the intercept and b is the regression coefficient, n=number of fish,* $\bar{x}$ *=mean length, S.E.=standard error of a mean and* r^2*=coefficient of determination*

Zrmanja River estuary

Year	$\bar{x}$ (TL, cm)	S.E.	Range (TL, cm)	Range (W, g)	b	a (x10^{-3})	r^2	n
2002	12.99	0.015	9.5 – 17.0	5.06 – 39.48	3.196	4.70	0.876	2210
2003	13.87	0.089	10.0 – 18.5	9.27 – 54.39	2.671	0.18	0.971	154
2004	7.35	0.012	5.5 – 16.0	0.84 – 33.71	3.212	4.20	0.981	81
2005	9.85	0.083	5.0 – 14.0	0.69 – 20.32	3.552	1.70	0.971	254
2006	13.10	0.066	7.5 – 19.5	7.39 – 60.2	3.319	3.10	0.916	194
Total	12.54	0.019	5.0 – 19.5	0.69 – 60.2	3.314	3.3	0.966	2893

off Dugi Otok

Year	$\bar{x}$ (TL, cm)	S.E.	Range (TL, cm)	Range (W, g)	b	a (x10^{-3})	r^2	n
2002	15.22	0.429	12.0 – 19.5	12.46 – 63.97	3.003	7.80	0.870	469
2003	16.12	0.388	13.0 – 19.0	15.69 – 55.45	2.563	26.40	0.806	379
2004	16.19	0.255	14.0 – 19.0	19.23 – 50.90	2.959	8.30	0.778	496
2005	15.57	0.628	11.5 – 17.5	11.05 – 48.10	3.405	2.70	0.912	179
2006	15.57	0.685	13.5 – 17.5	18.03 – 48.03	3.214	4.40	0.928	105
Total	15.94	0.187	11.5 – 19.5	6.18 – 63.97	2.876	10.90	0.830	1628

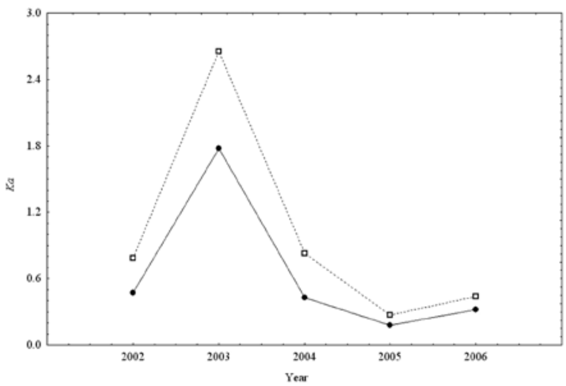

Fig. 4. Annual variations of the allometric condition indices (K_a) of Sardina pilchardus *from the catch samples obtained in the Zrmanja River estuary (●) and in the area off Dugi Otok (□) during the 2002-2006 period*

Conditions

The comparison of the allometric condition factor (K_a) of all sardine specimens ranging in length from 13.0 and 16.0 cm showed higher mean values in the area off Dugi Otok ($\overline{K}_a$=1.153±0.1111) than in the area of the Zrmanja River estuary ($\overline{K}_a$=0.331±0.0385), especially during 2003 ($\overline{K}_a$=2.653 and 1.774, respectively) (Fig. 4). The *t*-test showed that there were statistically significant differences among $\overline{K}_a$ values for the specimens from the investigated areas (t=19.99, *d.f.*=1382, P<0.05).

Inter-annual fluctuations in the mean values of the allometric ($\overline{K}_a$) condition factor of sardine specimens was noted as well. The highest condition factor was recorded in 2003 in both investigated areas ($\overline{K}_a$ =1.774±0.092, Zrmanja River Estuary; $\overline{K}_a$ =2.653±0.214, off Dugi Otok). After that, an abrupt decrease followed stabilization at the lower value levels in the Zrmanja River estuary ($\overline{K}_a$ between 0.177 and 0.429, standard deviations between 0.0087 and 0.0197), and in the area off Dugi Otok ($\overline{K}_a$ between 0.272 and 0.832, standard deviations between 0.0268 and 0.0728).

Abundance index

In terms of the fish abundance index (*CPUE*), seasonal fluctuations were noted (Fig. 5). The highest mean *CPUE* values in the Zrmanja River

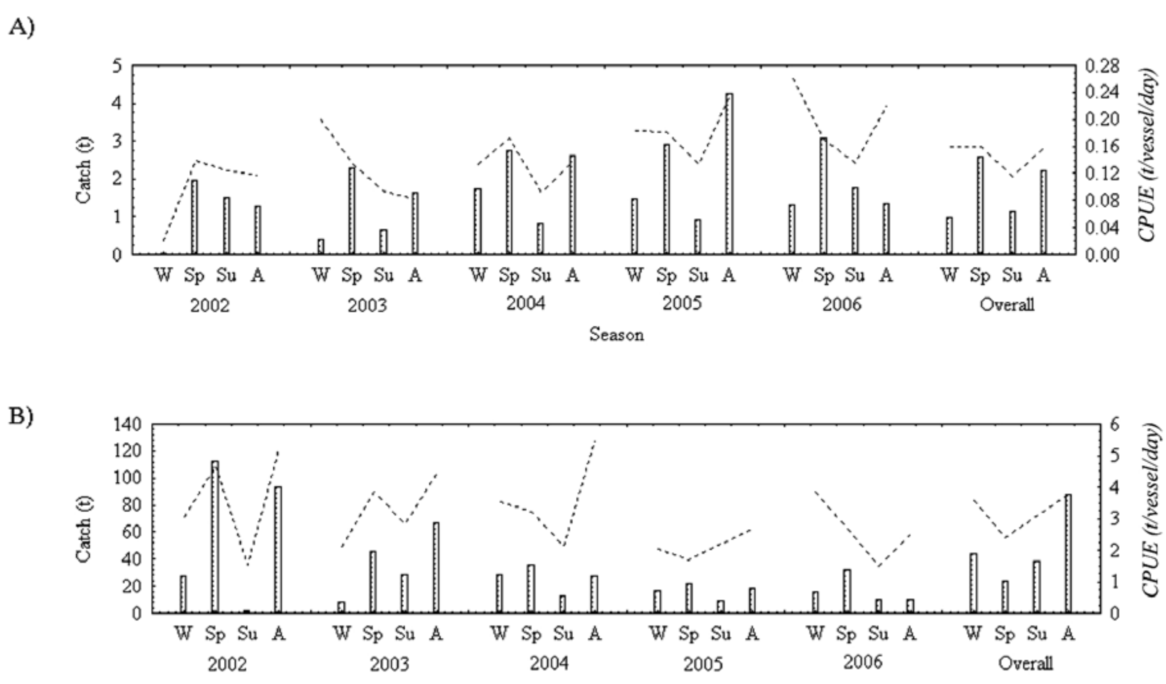

Fig. 5. Seasonal variations of sardine abundance index (CPUE) and catches in the Zrmanja River estuary (A) and off Dugi Otok (B) during 2002-2006 period

Table 2. Seasonal and annual variations of mean fishing effort (f) for sardine during 2002-2006 in the Zrmanja River estuary and in the area off Dugi Otok

Zrmanja River estuary

Season	f (2002)	f (2003)	f (2004)	f (2005)	f (2006)	f (mean)
Winter	2.0	2.0	13.0	8.0	5.0	6.0
Spring	14.0	17.0	16.0	16.0	18.0	16.2
Summer	12.0	7.0	9.0	7.0	13.0	9.6
Autumn	11.0	20.0	19.0	18.0	6.0	14.8
Mean	9.8	11.5	14.3	12.3	10.5	11.7

off Dugi otok

Season	f (2002)	f (2003)	f (2004)	f (2005)	f (2006)	f (mean)
Winter	9.0	4.0	8.0	8.0	4.0	6.6
Spring	24.0	12.0	11.0	13.0	12.0	14.4
Summer	1.0	10.0	6.0	4.0	7.0	5.6
Autumn	18.0	15.0	5.0	7.0	4.0	9.8
Mean	13.0	10.3	7.5	8.0	6.8	9.1

estuary were observed during both the winter-spring period (*CPUE*=0.159 t/vessel/day) and in autumn (*CPUE*=0.158 t/vessel/day). The lowest values of *CPUE* were noted during summer (*CPUE*=0.116 t/vessel/day) compared to mean catches which were highest in spring ($\overline{C}$ =2.59 tons) and autumn ($\overline{C}$ =2.22 tons) and lowest in winter ($\overline{C}$ =0.99 tons), in spite of the highest abundance index of fish. Mean fishing effort ($\bar{f}$) was also lowest in winter ($\bar{f}$ =6) (Table 2). In the area off Dugi Otok, the markedly highest *CPUE* was observed during autumn (*CPUE*=3.769 t/vessel/day) and winter (*CPUE*=3.587 t/vessel/day) and was lowest in spring (*CPUE*=2.383 t/vessel/day) (Fig. 5), even though the highest fishing effort was then used (Table 2).

Considering sardine mean abundance index (*CPUE*) values in the Zrmanja River estuary, it is evident that they showed a slight, gradual increase during the 2002-2005 period. They varied from 0.109 to 0.196 tons/vessel/day. In 2002 and 2006 amounts were 0.123 and 0.1777 tons/vessel/day, respectively. In the same area, the highest catches were achieved during 2005 as a result of a high abundance index, in spite of the reduced fishing effort (Table 2). Simultaneously, in the fishery ground off Dugi Otok, decreasing *CPUE* values are evident. They fluctuated between 4.518 and 2.065 tons, except in 2006 when a slight increase was registered (*CPUE*=2.512 t/vessel/day) (Fig. 6). More or less, trends of sardine catches (*C*) in the area reflected its abundance and the fishing effort, excluding the final year in the area off Dugi Otok.

DISCUSSION

The Zrmanja River estuary is a nursery ground for small pelagic fish species while the area off Dugi Otok is a well defined spawning ground for sardine in the Adriatic Sea (SINOVČIĆ & ALEGRIA, 1997; SINOVČIĆ, 2001b, 2003) where the influence of upwelling was evident (REGNER *et al.*, 1987). Thus, these areas are ideal for investigating the differences in sardine length structure, length-weight relationship, condition and abundance index, thus contributing to the management actions in the Adriatic Sea.

Sardine juveniles enter the Zrmanja River estuary at approximately the same time of year and they are of similar mean total lengths (KAČIĆ *et al.*, 1986; SINOVČIĆ *et al.*, 2008). Interannual differences in size composition of the stock would result in different reproductive strategies

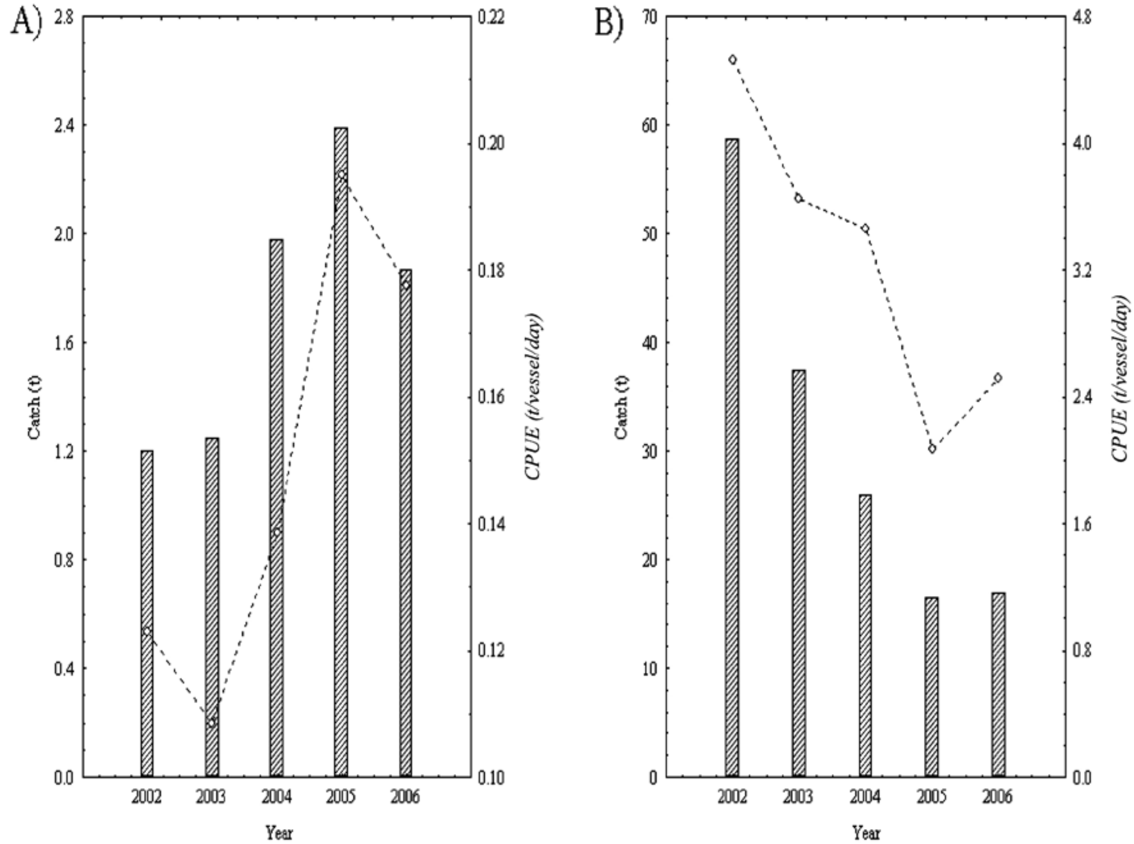

Fig. 6. Annual fluctuations of sardine mean catch per unit effort (CPUE; ----○---) and catches (histograms) obtained in the Zrmanja River estuary (A) and in the area off Dugi Otok (B) during the 2002-2006 period

and recruitment pattern in a given year (ZWOLINSKI *et al*., 2001). During 2004 and 2005, length size distributions were shifted towards small specimens. In the same years, the recruitment of sardine was very low (SANTOJANNI *et al.,* 2008). Smaller total lengths of sardine specimens from the estuary and coastal waters, in comparison with the ones from open sea waters which are presented in this paper, match the previous observations (MUŽINIĆ, 1954; SINOVČIĆ, 2000).

The length-weight relationship for sardine from the Adriatic Sea showed either negative (b=2.8756) or positive allometry (b =3.3139) (Fig. 3, Table 1). ALEGRIA (1983a) reported negative allometry for sardine length-weight relationship from the north Adriatic (b=2.757). Negative allometry was also found in the length-weight relationship for sardines from the Ionian Sea in 1995 (b=2.75) (PETRAKIS & STERGIOU, 1995) and in 2003 (b=2.75) (KOUTRAKIS & TSIKLIRAS, 2003). On the contrary, SINOVČIĆ (1984, 2000, 2001b) found positive allometry for sardine in most coastal waters of the Adriatic Sea during 1981-1987.

The comparison of the condition factor of sardine in the two areas revealed higher values in the area off Dugi Otok where upwelling conditions predominated (REGNER *et al*., 1987). SINOVČIĆ & ALEGRIA (1997) also found a high correlation between sardine catches and abundance index on one side and primary production and temperature on the other side in the area off Dugi Otok. The fish from year 2003 showed the best condition in both areas (Fig. 4). It probably had some impact on the higher sardine abundance index and catches during the next three years in the Zrmanja River estuary, though the fishing effort in 2004 and 2005 was also higher than during the 2002-2003 period (Table 2). In the area off Dugi Otok, the abundance index remained at a higher level only in the next year. In the Zrmanja River estuary, the population structure in the following year indicated the presence of sardine specimens which were smaller than in the previous research periods (Fig. 2). Similar was found for the area off Dugi Otok. In 2005 and 2006, the population structure and fish mean total length changes indicated the introduction of younger sardine specimens into the stock.

The decrease in the fish mean length in the catches might signify a larger recruitment of young year classes. Namely, it has been observed that a decrease in the mean length of a sardine population results in a catch increase in the following year, or two years later. The reduced mean length in sardine catches from open middle waters of the Adriatic was observed in 1982 and 1985; each reduction in length was followed by abundance index and catch increases (SINOVČIĆ & ALEGRIA, 1997; SINOVČIĆ, 2001a). This was not the case with the reduced length size in the Zrmanja River estuary during 2004 and 2005 as sardine recruitment was generally very low in the Adriatic Sea during the 2000-2007 period (SANTOJANNI *et al.*, 2008). The influence of higher fishing effort during the 2004-2005 period (Table 2) on reduced mean total lengths of sardine during the same period might be presumed.

The highest abundance index values in the Zrmanja River estuary were observed during winter-spring and in the area off Dugi Otok during autumn, but also in the winter period when the aggregation of sardine during spawning is mainly expressed (ALEGRIA, 1983b; SINOVČIĆ, 2001a) in each of these areas. Catches of sardine in the Zrmanja River estuary were the highest in spring and autumn and the lowest in winter, in spite of its highest abundance index (Fig. 5). The fact is that fishing effort is lowest in this area during winter - almost three times less than in spring (Table 2). Namely, the Zrmanja River estuary has been exposed to a very cold and strong northerly bora wind, which probably prevents higher catch amounts in the area, making fishing inefficient. This is not the case in the area off Dugi Otok, located more to the south, where only a slight influence of bora has been observed. Markedly the highest catches and abundance index were evident there during autumn, but also in winter, probably as a result of better environmental conditions in the area. The smallest catches were noted in spring, after the completion of sardine spawning in this area, when a strong aggregation influence ceased (ALEGRIA, 1983b; SINOVČIĆ, 2001a). The same results had been obtained earlier, but with two-fold greater values of *CPUE*s (SINOVČIĆ, *ibid.*).

Such data, together with the increase of sardine abundance index during the investigation period and condition increase during 2006 both in the nursery ground and in the spawning ground, will probably have positive repercussions on sustaining catches in successive years. A slight increase of sardine biomass and catches were already registered during 2007 (SANTOJANNI *et al.*, 2008).

ACKNOWLEDGEMENTS

The present study was supported by the MINISTRY OF SCIENCE AND TECHNOLOGY OF THE REPUBLIC OF CROATIA and was a part of the scientific project entitled „Biodiversity and management of pelagic and demersal resources of the Adriatic Sea.“ The authors extend special thanks to the anonymous reviewers for their useful comments on the manuscript.

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Received: 17 June 2008

Accepted: 26 February 2009

Višegodišnje fluktuacije u strukturi populacije, kondiciji, dužinsko-masenom odnosu i abundanciji srdele *Sardina pilchardus* (Walb., 1792), iz obalnog i otvorenog mora istočnog dijela Jadrana (Hrvatska)

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SAŽETAK

U radu su prikazani rezultati izučavanja višegodišnjih fluktuacija strukture populacije, kondicije, abundancije i dužinsko-masenog odnosa srdele *Sardina pilchardus* (Walb., 1792), iz obalnog (obitavalište, hranilište) i otvorenog mora (mrijestilište) istočnog dijela Jadrana. Tijekom razdoblja 2002.-2006. je ukupno analizirano 4 521 jedinki ove, za hrvatsko gospodarstvo jedne od najznačajnijih ribljih vrsta u Jadranskom moru. Totalne dužine su kolebale između 4,5 to 19,5 cm, s prosječnim dužinama između 7,35±1,005 i 13,87±1,102 cm u estuariju rijeke Zrmanje, te 11,5 i 19,5 s prosječnim dužinama između 15,22±1,826 i 16,19±0,854 cm u području Dugog otoka. Srdela iz područja Dugog otoka je imala negativnu alometriju, a iz područja estuarija Zrmanje pozitivnu. Usporedba indeksa kondicije (K_a) srdele raspona istih dužina jedinki u oba područja između 13,0 i 16,0 cm je pokazala da su više vrijednosti bile u srdele iz uzoraka lovina ostvarenih u području Dugog otoka ($\overline{K}_a$ =0.467) nego iz područja estuarija rijeke Zrmanje (Novigradsko more) ($\overline{K}_a$=0.331), posebice tijekom 2003 ($\overline{K}_a$ =2.653). U odnosu na indeks abundancije, primjećene su sezonske fluktuacije – najviši su iznosi zabilježni tijekom jeseni u području Dugog otoka, a u području estuarija rijeke Zrmanje tijekom proljeća.

Ključne riječi: srdela, struktura populacije, dužinsko-maseni odnos, kondicija, indeks abundancije