SCI. MAR., 67 (4): 501-511 SCIENTIA MARINA 2003

Spatial patterns and temporal trends in the fishery landings of the Messolonghi-Etoliko lagoon system (western Greek coast)*

GEORGE KATSELIS[1], CONSTANTIN KOUTSIKOPOULOS[2], EVAGELOS DIMITRIOU[3] and YIANNIS ROGDAKIS[1]

[1] Technological Educational Institute of Messolonghi, Department of Aquaculture and Fisheries Technology, 30200 Messolonghi, Greece. E-mail: gkatsel@teimes.gr
[2] University of Patras, Department of Biology, 26500 Patra, Greece.
[3] Aquaculture Center of Acheloos (ACEA), 30200 Messolonghi, Greece.

SUMMARY: The Messolonghi-Etoliko lagoon is one of the largest lagoon system in the northern Mediterranean coast. This area contains six clearly distinct lagoons with different topographic and hydrological features. The fishery landings of the lagoons are based on the ontogenic and seasonal migrations of the species. The total annual fishery landings of the barrier fish traps are estimated as 195 mt and are mainly composed of 16 species belonging to 8 families. Eel (*Anguilla anguilla*), the four species of Mugilidae (*Liza saliens, L. aurata, L. ramada* and *Mugil cephalus*), the two species of Sparidae (*Sparus aurata* and *Diplodus annularis*) and one species of Mullidae (*Mullus barbatus*) represent more than 92% of the total annual landings. The composition of the fishery landings varies between lagoons. The cluster analysis showed three groups of lagoons. The first group comprised lagoons in which the landings were dominated by eel, the second group was dominated by Mugilidae species and *S. aurata,* and the third by *L. ramada* and *M. cephalus.* The diversity index of the fishery landings is fairly constant in time, except for the Etoliko lagoon, where repeated anoxic crises decreased the diversity index value to almost zero in 1992. All the landing series showed a dominant annual cycle. Two seasonal patterns of the fishery landings were observed and linked to the fish spawning behaviour and/or their reaction to environmental forcings. The first one concerns species caught from summer to early autumn and the second pattern concerns species trapped during their autumn to winter offshore migration.

Key words: Mediterranean lagoon, fisheries landings, fish diversity, spatial pattern, seasonal fluctuations.

RESUMEN: VARIACIONES GEOGRÁFICAS DE LA PRODUCCIÓN PISCÍCOLA DE LA FORMACIÓN DE MARISMAS DE MESOLOGI-ETOLIKÓ (GRECIA OCCIDENTAL). – La formación de lagunas de Mesologi-Etolikó es una de las reservas naturales marinas más grandes de la franja septentrional del Mediterráneo. Este conjunto está compuesto por seis distintas marismas, con diferentes características topográficas e hidrográficas cada una de ellas. La producción piscícola de las marismas se basa en los movimientos estacionales de las especies hacia el mar. Del estudio del trampeo se concluye que los movimientos migratorios equivalen a 195 toneladas y se componen principalmente de 16 especies las cuales pertenecen a 8 familias: anguila (*Anguilla anguilla*), cuatro especies de Mugilidae (*Liza saliens, L. aurata, L. ramada*, y *Mugil cephalus*), dos especies de Sparidae (*Sparus aurata* y *Diplodus annularis*) y una especie de Mullidae (*Mullus barbatus*). Estas especies representan más del 92% de los desplazaminentos anuales. Estos varían entre las distintas marismas. El análisis cluster distingue tres tipos de marismas. El primer grupo incluye las marismas cuyos movimientos son principalmente de anguila; el segundo grupo de Mugilidae y de *S. aurata*, y el tercero con movimientos sobre todo de *L. ramada* y *M. cephalus*. Los desplazamientos de estas especies presentan un ciclo anual importante. Así mismo, se han observado dos clases de movimientos estacionales (en verano y a principios de invierno) que se asocian a los movimientos migratorios de estas especies hacia el mar para su reproducción y/o provocadas por consideraciones adversas.

Palabras clave: laguna marina mediterránea, desplazamientos, variedad de especies, Mesologi, movimientos estacionales.

*Received February 8, 2002. Accepted May 19, 2003.

INTRODUCTION

Around the Mediterranean, an area of at least 6500 km^2 of coastal lagoons (Pearce and Crivelli, 1994) is exploited as fishing grounds (Ananiades, 1984; Kapetsky, 1984; Ardizzone *et al.,* 1988; Peja *et al.,* 1996; Anonymous, 2001). Coastal lagoons and estuaries are key ecosystems and an intensive exploitation of the increased natural productivity of these ecosystems is carried out by large local fishing communities (Kapetsky, 1984).

Different types of fishing gears and methods are used, such as barrier traps, fyke nets, trammel nets and longlines (Kapetsky and Lasserre, 1984; Ardizzone *et al.,* 1988; Peja *et al.,* 1996; Anonymous, 2001). At a regional scale, the lagoon fisheries play an important role in both socio-economic and cultural aspects. Marine, fresh-water or brackish fish populations inhabit the majority of the Mediterranean lagoons, which may be resident or migrant. Also, most of these ecosystems play an important role as nurseries for numerous fish species, offering food and shelter to the larval and juvenile stages (Weinstein, 1979; Blader and Blader, 1980; Tzeng and Wang, 1986). Many papers have been published on the influence of gradients of some abiotic parameters (i.e. salinity, temperature, dissolved oxygen and type of substrate) in the spatial and temporal distribution of fish species (Harmelin-Vivien *et al.*, 1995; Rogers and Millner, 1996; Wang and Tzeng, 1997; Jenkins and Sutherland, 1997; Jenkins and Wheatley, 1998; Guidetti, 2000; Ishitobi *et al.*, 2000; Blanc *et al.*, 2001).

One of the most important types of exploitation is the use of barrier traps catching the fish during their seasonal or ontogenic offshore migration. The lagoon fisheries are based on the passage of fish from these important nursery and feeding grounds. These fishes are trapped at the lagoon-sea interface by passive and fixed gears during their movement from the lagoon ecosystem to the sea.

The aim of this paper is to analyse the barrier trap fishery landings in the different lagoons composing the Messolonghi-Etoliko lagoon system (Western Greek coast) during the period 1988-1998. In this area there are six clearly distinct lagoons with specific topographic and hydrological characteristics and different fish species compositions. The temporal changes, both seasonal and long term, are also analysed in order to define the migration pattern of the different species and to compare the migration timing in the different lagoons.

STUDY AREA

The Messolonghi-Etoliko lagoon system is one of the most important Mediterranean lagoons, located in the north part of the Gulf of Patras in the central west coast of Greece. It is a shallow area of

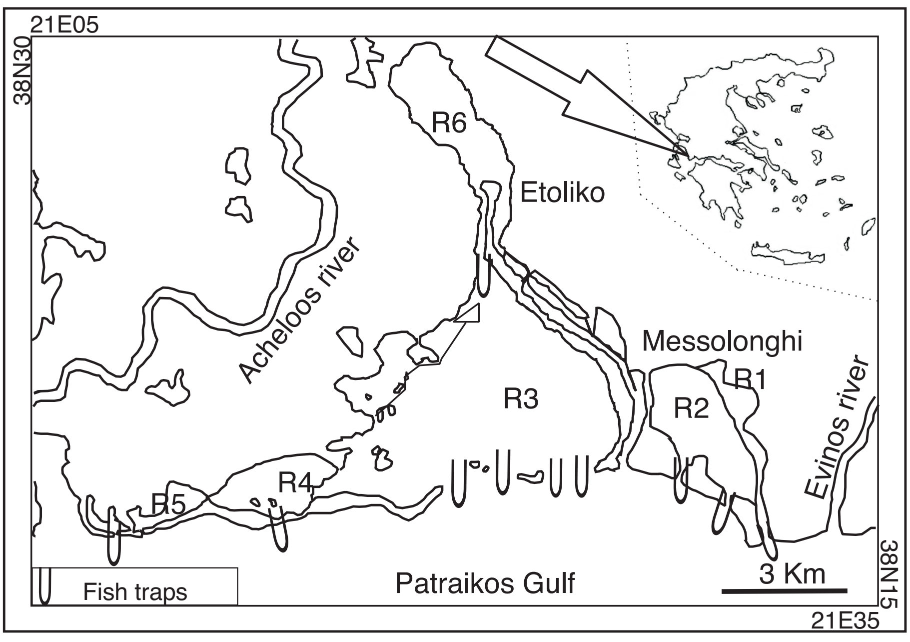

FIG. 1. – Map of the Messolonghi-Etoliko lagoon system. The six lagoons and the fish traps located at the lagoon openings communicating with the sea are presented.

TABLE 1. – Morphological and hydrological characters of the six distinct lagoons of the Messolonghi-Etoliko lagoon system.DPS, drainage pump station.

Lagoon	Common name	Area (ha)	Mean (max) depth in m	Communication Sea	Communication Fresh water	Salinity (psu)	Specific features
R1	Anatoliki Klisova	250	0.8 (1.2)	1 channel	1 DPS	0.5-42	Receives the sewage treatment
R2	Dytiki Klisova	1800	1 (1.5)	3 channels	-	30-68	Support area of salts works
R3	Centriki Limnothalasa	8000	0.8 (2.0)	Long frontal area	1 DPS in NW	30-45	
R4	Tholi	1400	1 (1.5)	2 channels	1 DPS	15-38	
R5	Paleopotamos	450	1 (2.5)	3 channels	10% of R5 DPS	35-55	
R6	Etoliko	2800	20 (30)	2 channels across R3	1 DPS in W	15-38	Anoxic conditions below 7-10 m

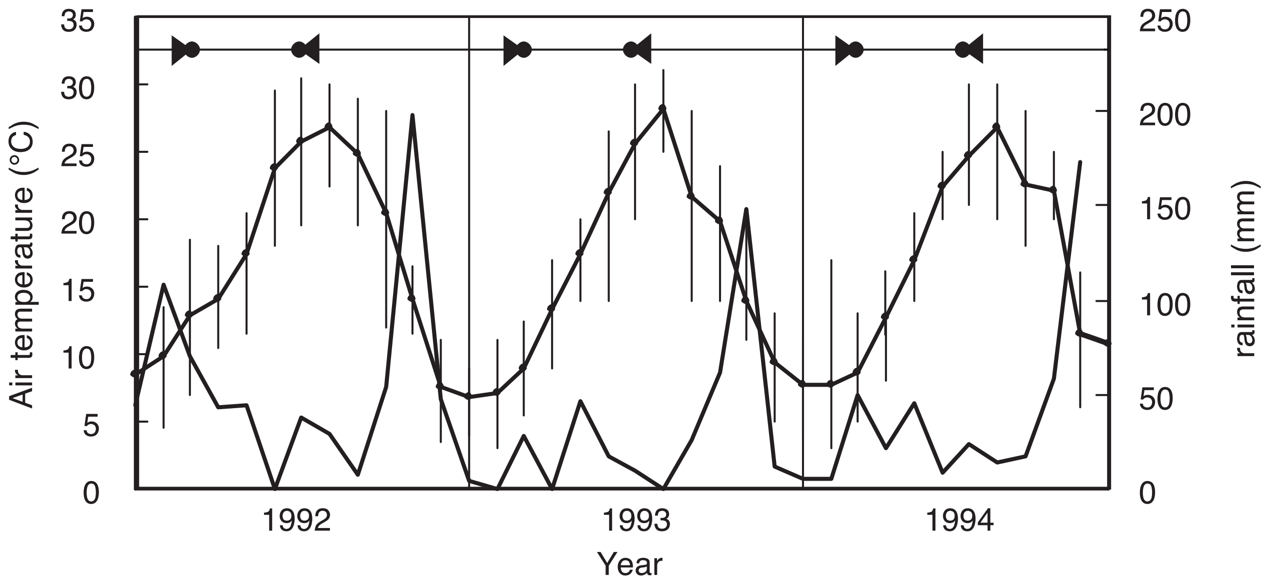

FIG. 2. – Mean monthly air temperature and total monthly rainfall for the period 1992 to 1994. The line that is limited by dots and arrows shows the entrance to the lagoons and the fishing periods respectively (data were collected from the meteorological station of the salt works of Messolonghi).

15000 ha extending between the Acheloos and Evinos rivers. The six distinct lagoons (Fig. 1) can be defined by their topographic and hydrological characteristics (Table 1) (Anonymous, 2001).

The bottom of the western and northwestern area of this system is muddy in contrast with the southern and south-eastern part of the R2 and R3, which is formed by sand and mud and is almost totally covered by *Cymodocea nodosa* (Bogdanos and Diapoulis, 1984).

Figure 2 presents the main seasonal changes of the air temperature and rainfall during the period 1992-1994, affecting the dynamics of both the abiotic and biotic parameters of the lagoons. Because of the limited depth of the lagoons, the meteorological changes rapidly affect the abiotic parameters of the water masses. The mean monthly air temperature ranged from 5 to 30^{o}C, with seasonal fluctuations typical of the Mediterranean climate. Two periods of high rainfall were observed, one in spring and one from October to December.

Fishing exploitation of the lagoons

The Messolonghi–Etoliko lagoon system is the property of the Greek State. The exploitation is a common extensive culture based on the seasonal entrance of young fish in the lagoons and the autumn to winter offshore fish migration. Eight fishing co-operative enterprises leasing the lagoons and exploiting the barrier traps installed at the interface between the lagoon and the sea supply the main fish catches. The so-called independent fishermen who fish mainly with lights, spears and longlines use the non-leased area of the lagoon system. Gill nets and dip nets are also used in the lagoon throughout the year. The total annual fish catches have decreased from 1500-2000 mt in the 1960s to 1300-1500 mt in recent years (Kotsonias, 1984; Dimitriou *et al.,* 1994) and are provided by 200 fishermen working at the barrier traps and 700 fishing in the lagoon. The barrier traps provide the main fish production. These are passive gears and remained unchanged (both their nature and the effective fishing period) during the period concerned by the study. The number of fishermen fishing in the lagoons outside the barrier traps (the independent fishermen) and their fishing practices were also stable. Thus, the total fishing effort providing the recorded landings was fairly stable in time.

MATERIAL AND METHODS

The available monthly fishery landing data from the barrier fish traps in the six regions were used. The available time series for R3, R4, R5 and R6 lagoons refer to 1988-1998, while those for R1 and R2 refer to 1995-98 and 1994-98 respectively. In practice, the fishing period starts in April and continues until March of the next year, so the annual landings considered in the study correspond to this period and to the annual landings of the year covering the April to December period. Data were provided by the fish-wharf of Messolonghi.

The species landings used in this study were computed by the sum of the landings of all the commercial categories defined by the different size ranges of the precise species.

A hierarchical cluster analysis (Ward method, Hair *et al.*, 1998) based on the arcsine-square-root transformation of the landing composition data was applied to determine the similarity/dissimilarity between regions. The squared Euclidean distance was used as a dissimilarity measure between regions for cluster analysis. The data transformation is necessary before analysis to normalize their distribution (Snedecor and Cochran, 1980). In order to observe annual changes in the composition of the fish production, the Shannon-Wiener diversity index

$$H' = -\sum p_i \cdot \ln(p_i),$$

where p is the relative importance, fraction, of biomass of the species I, was computed for the 6 lagoons and for the period 1988-1998. The analysis of variance (ANOVA) was applied to test for significant differences in mean H' between regions. Furthermore, Fisher's LSD test was applied to determine which lagoons differ from each other.

The average monthly species composition of landings from the different lagoons was used in a principal component analysis (PCA) in order to investigate the spatial and temporal patterns formed by the seasonal variability of the landing composition in the different lagoons. In particular, PCA was applied on the (species) X (arcsine-square-root of average monthly species landings proportion, period 1995-1998) data table. Only species representing a mean proportion higher than 5% of the total annual landings of each lagoon were retained in this PCA.

Fast Fourier Transform (FFT) analysis, based on log-transformed and detrended monthly landings, was used to identify the main frequencies (ω_1) describing the seasonal dynamics. A harmonic regression model (HREG) was adjusted to the time series of the dominant species landings:

$$X_t = c + f(t) + \sum b_{1i} \cos(\omega_i t) + b_{2i} \sin(\omega_i t),$$

where X_t is the logarithm of the species landings at time t, $f(t) = at + bt^2$ describe the temporal trends, c, a, b, b_{1i}, b_{2i} are coefficients estimated by least squares regression techniques, and ω_i is the frequency of a cyclic component (Diggle, 1990; Swokowski *et al.*, 1994). The frequencies, as well as time t and t^2, used in the final model were selected through stepwise variable selection. Thus, only the significant components for both trends and cyclic fluctuations were retained in the final model. All models were developed using the SPSS version 8 statistical package. From the solution of the first derivative of HREG models, the time (month) of maximum landings for each species was estimated (Swokowski *et al.*, 1994). In the case of presence of several peaks, their relative importance was expressed as a proportion of the landings in the month containing each peak to the total landings of all the months containing a defined peak in the same piscatorial year. All these calculations were performed for the year 1993 (t=61-72 months).

TABLE 2. – Annual fluctuations of the fishery landings (mt) of the barrier fish traps in the different Lagoons of the Messolonghi-Etoliko lagoons system during 1988-98. Ri, lagoons.

year	R1	R2	R3	R4	R5	R6	Total
1988			192.3	88.7	23.2	27.7	332.0
1989			138.8	60.4	20.1	31.9	251.2
1990			79.4	26.1	10.9	16.3	132.6
1991			95.2	44.5	9.4	15.6	164.7
1992			100.7	56.9	19.6	12.7	189.9
1993			81.8	34.8	21.1	24.2	165.5
1994		24.7	94.6	17.8	22.2	11.5	172.6
1995	12.6	18.7	123.3	27.6	22.3	13.3	217.9
1996	11.2	24.6	74.6	16.6	28.3	10.4	165.7
1997	20.8	25.1	102.7	20.7	10.3	9.5	189.2
1998	24.6	18.0	72.2	20.1	11.9	8.5	155.3
Mean	17.3	22.2	105.1	37.7	18.1	16.5	194.2
St. Dev.	6.4	3.5	35.4	22.8	6.4	7.9	55.8
CV%	37.2	15.9	33.7	60.6	35.2	47.9	28.7

TABLE 3. – Species composition (%) of the barrier fish traps landings of Messolonghi-Etoliko lagoon system during 1995-1998.

Family	Species	Code	R1	R2	R3	Lagoons R4	R5	R6	Total
Mugilidae	*Liza saliens*	Ls	2.7	12.4	25.7	21.2	11.1	4.8	18.8
Anguillidae	*Anguilla anguilla*	Aa	16.7	12.8	5.6	38.1	33.3	76.9	18.1
Mugilidae	*Liza aurata*	La	0.4	30.2	17.6	4.0	8.5	5.2	14.3
Sparidae	*Sparus aurata*	Sa	1.5	21.2	17.8	4.3	11.7	3.4	13.7
Mugilidae	*Mugil cephalus*	Mc	27.6	11.3	4.7	15.3	22.8	4.1	10.7
Sparidae	*Diplodus annularis*	Da	0.0	2.2	11.7	0.0	0.2	0.1	6.3
Mugilidae	*Liza ramada*	Lr	42.9	1.1	0.8	4.6	3.0	5.0	5.7
Mullidae	*Mullus barbatus*	Mb	0.0	3.2	8.1	0.2	0.0	0.0	4.6
Mugilidae	*Chelon labrosus*	Cl	4.3	3.8	0.7	5.2	5.6	0.1	2.4
Morronidae	*Dicentrarchus labrax*	Dl	3.7	1.0	0.7	3.7	1.9	0.3	1.4
Sparidae	*Diplodus puntazzo*	Pp	0.0	0.0	2.3	0.0	0.0	0.0	1.2
Sparidae	*Lithognathus mormyrus*	Lm	0.0	0.1	1.6	0.0	0.0	0.0	0.9
Sepiidae	*Sepia officinalis*	Sp	0.0	0.0	1.4	0.0	0.0	0.0	0.7
Soleidae	*Solea vulgaris*	Sv	0.1	0.0	0.3	2.9	0.1	0.0	0.5
Sparidae	*Sarpa salpa*	Ss	0.0	0.0	1.0	0.0	0.0	0.0	0.5
Gobiidae	*Gobius* sp.	Gsp	0.0	0.6	0.0	0.2	1.7	0.0	0.3
Total landings of 1995-1998 (mt)			69.8	87.4	382.1	86.9	75.4	41.7	743.2

RESULTS

The recorded annual fishery landings of the six regions are presented in Table 2. Lagoon R3 had mean annual landings 3 to 6 times greater than the rest of the lagoon system. The year-to-year fluctuations of the total regional landings were limited except for those of 1988 and 1989.

The mean annual landings of the last four years was about 195 mt and composed of fourteen species belonging to six families (Mugilidae, Sparidae, Moronidae, Mullidae, Anguillidae, Goibiidae and Soleidae) and one species of Cephalopoda (Table 3). The landings of eel (*Anguilla anguilla*), four species of Mugilidae (*Liza saliens, Liza aurata, Mugil cephalus* and *Liza ramada*), the two species of Sparidae (*Sparus aurata* and *Diplodus annularis*) and one species of Mullidae (*Mullus barbatus*) represented about 92.1% of the total annual landings (Table 3).

Three groups of regions based on their species composition were identified by cluster analysis (Fig. 3). The regional differences in the species composition are presented in Table 3. There is a marked difference in the composition of fish landings of the six regions. The eel dominated the annual landings of group A (Lagoons R4, R5 and R6), while the family of Mugilidae and *S. aurata* dominated the landings of group B (Lagoons R2, R3). In group C (Lagoon R1) the largest part of the annual landings consisted of eels and two Mugilidae species (*M. cephalus* and *L. ramada*). In 1995-1998 Lagoon R3 had the greatest species diversity, with a high presence of species like *Lithognathus mormyrus*, *Diplodus puntazzo*, *Sarpa salpa* and *Sepia officinalis,* while Lagoon R6 produced almost exclusively eels.

Significant differences between lagoons of the Shannon-Wiener Diversity index were observed (F=24.3, df=5,47, P<0.05). Fisher's LSD test showed that $H'_3>H'_1=H'_2=H'_4=H'_5>H'_6$, where H'_i the mean value of H' of the lagoon Ri. Fairly limited temporal fluctuations characterise the composition of the landings in lagoons R1 to R5, with lagoon R3 showing the highest diversity. The lowest diversity was recorded in lagoon R6, where the index decreased in 1991 and dropped to almost 0 in 1992 (Fig. 4).

The first and second factors of PC analysis, explaining 67.3% of the total variance (43.5 and 24.8% respectively) show that the monthly species compositions of the six lagoon landings were fairly similar. Furthermore, two major groups of monthly landing profiles were identified. The first (Group I) was defined by the seasonal fluctuations of the landings of *L. saliens*, *M. cephalus, D. annularis, L.*

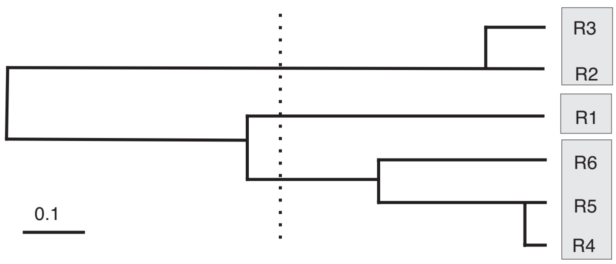

FIG. 3. – Dendrogram of six regions in the Messolonghi-Etoliko lagoons obtained by cluster analysis (Ward's methods) of the fisheries landings species composition during the period 1995-1998.

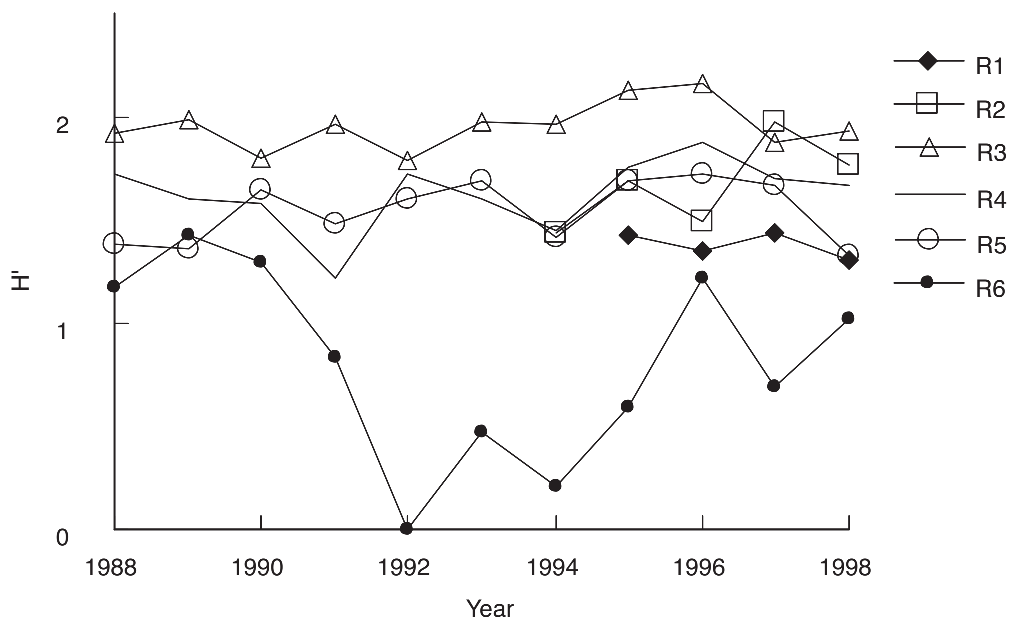

FIG. 4. – Shannon-Wiener diversity index (H') of the annual fishery landings in the six regions of the Messolonghi-Etoliko lagoons.

mormyrus, *D. puntazzo* and *S. officinalis*. The second (Group II) was composed of two distinct subgroups, the first related to the temporal pattern of the landings of *S. aurata, L. aurata*, *Chelon labrosus, L. ramada, Dicentrarchus labrax, M. barbatus*, *S. salpa* and *Solea vulgaris* (Sub-Group A), and the second was composed of the landings of *A. anguilla* and *Gobius* sp. (Sub-Group B) (Fig. 5).

The frequencies in the variability of the log-transformed and detrended monthly landings of the 8 dominant species during the 1988-1998 period identified through FFT analysis are shown in Table 4. Seven frequencies were identified in the series of monthly landings (cycles with period 0.2, 0.25, 0.33, 0.5, 1, 2.75 and 3.7 years: Table 4).

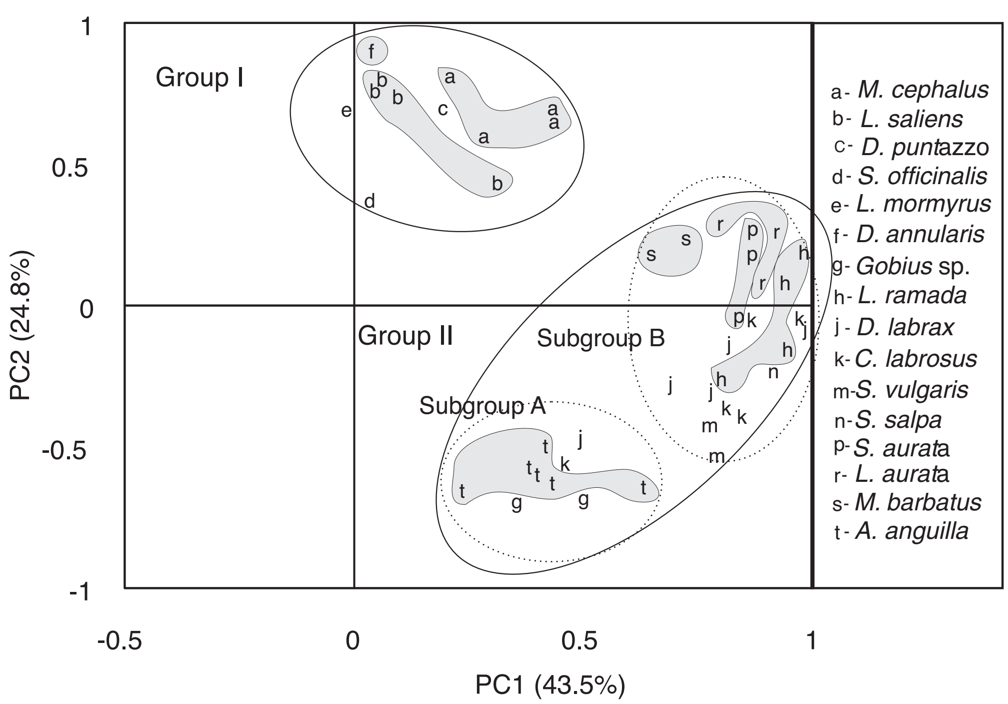

FIG. 5. – Principal component analysis (PCA) on the arcsine-square-root transformation of the average monthly proportion of the species landings by region (1995-1998). The shadow areas indicate the eight dominant species.

TABLE 4. – Frequencies identified through Fast Fourier Transform (FFT) analysis applied to the log-transformed monthly landings of the dominant species in the Messolonghi-Etoliko lagoon system, January 1988 - December 1998.

Species	Period of cycle (year) 0.20	0.25	0.33	0.50	1	2.78	3.70
L. saliens	+		+	+	+		+
A. anguilla	+		+	+	+		
L. aurata	+	+	+	+	+		
S. aurata	+		+	+	+		+
M. cephalus	+		+	+	+		+
D. annularis	+	+	+	+	+		
M. barbatus		+	+	+	+		
L. ramada	+		+	+	+	+	+

All catch series displayed a dominant annual cycle, whereas cycles with a period of less than one year represent harmonics generated by non-sinusoidal periodic variability. The arithmetic coefficients of the HREG models fitted to the monthly landings using the estimated frequencies (as well as time t and t^2) as independent variables and stepwise variable selection are shown in Table 5. The r^2 value of HREG models ranged from 0.64 for *A. anguilla* landings to 0.93 for *D. annularis* landings. In this table only the significant coefficient for both trends and cyclic fluctuations were presented after the stepwise component selection. In the same table the values of the coefficients of t and t^2 are significantly different from 0 ($P<0.05$). In the retained models for the different species only one of the t or t^2 components appears in the model and this indicates that the temporal trend, increasing or decreasing, is monotonous during the study period. From these values it is clear that the landings of *L. saliens, A. anguilla* and *S. aurata* are marked by a decreasing temporal trend, and an increasing trend appeared in the landings of *D. annularis* and *M. barbatus.*

In Figure 6 the recorded monthly landings of the four dominant species and the values estimated by the harmonic regression model (HREG) are presented. It is clear that the eel landings show an important decreasing trend. The landings of about 80 mt recorded in 1988-89 dropped to about 30-40 mt in the last few years of the period.

The solutions of the first derivative equations of the HREG models showed that the maximum quantities of landings occurred in two periods: (a) summer-autumn (August to October) maximum of landings defined for *L. saliens, M. cephalus* and *D. annularis*; and (b) the autumn to winter transition (November-December) for *L. aurata, A. anguilla*, *S. aurata*, *M. barbatus* and *L. ramada* (Table 5). However, lower landings of all species were recorded during the rest of the fishing period. These results, in combination with the results of PCA (Fig. 5), sug-

TABLE 5. – Arithmetic coefficients of the harmonic multiple regression (HREG) models between the log-transformed monthly landings of the eight dominant species and the various frequencies identified by the Fast Fourier Transform (FFT) analysis of the Messolonghi-Etoliko lagoons. Study period: January 1988 - December 1998 (t=1 to 132 months). c is a constant, m_1, m_2 are the months of maximum landings (B), Bm_1, Bm_2 are landings (mt) observed in m_1 and m_2 respectively, and Bm_1%, Bm_2% are their relative importance (in percentage).

				Period (T_i) in months , $x_i=(2\pi/T_i)t$												
				2.4	3.0		4.0		6.0		12.0		33.3	43.5		
Species	c	t	t^2	cos(x_i)	cos(x_i)	sin(x_i)	cos(x_i)	sin(x_i)	cos(x_i)	sin(x_i)	cos(x_i)	sin(x_i)	cos(x_i)	cos(x_i)	sin(x_i)	r^2
L. saliens	6.01	-0.008		0.60			1.69	-1.09				-3.38		-0.50		0.84
L. aurata	5.40			0.39		0.35	1.44	-1.10		-1.86		-2.19				0.87
A. anguilla	5.02		$-1.2\cdot10^{-4}$	0.85			1.09		1.87		2.20					0.64
S. aurata	3.91	-0.006		0.36				-1.59	0.48		2.19	-4.79		-0.38	0.60	0.92
M. cephalus	5.55						0.73				0.82	-2.80		-0.80	0.45	0.68
D. annularis	3.19		$5\cdot10^{-5}$			1.54	1.15	-0.83	-2.91		-1.55	-2.00				0.93
M. barbatus	1.03	0.020			-1.42				-0.64	-2.57		-1.15				0.77
L. ramada	4.31						0.89			-2.90			0.56		0.58	0.69

The frequencies, as well as time t and t^2, used in the final model were selected through stepwise variable selection.

Species	m_1	m_2	Bm_1	Bm_2	Bm_1%	Bm_2%
L. saliens	8	12	26.7	4.2	86.3	13.7
L. aurata	7	11	1.6	8.1	16.5	83.5
A. anguilla	7	12	0.2	31.8	0.5	99.5
S. aurata	8	11	1.4	20.0	6.4	93.6
M. cephalus	9	11	5.9	3.6	62.0	38.0
D. annularis	8	10	0.8	2.1	27.3	72.7
M. barbatus	8	11	0.0	1.3	0.5	99.5
L. ramada	7	11	0.0	2.2	0.7	99.3

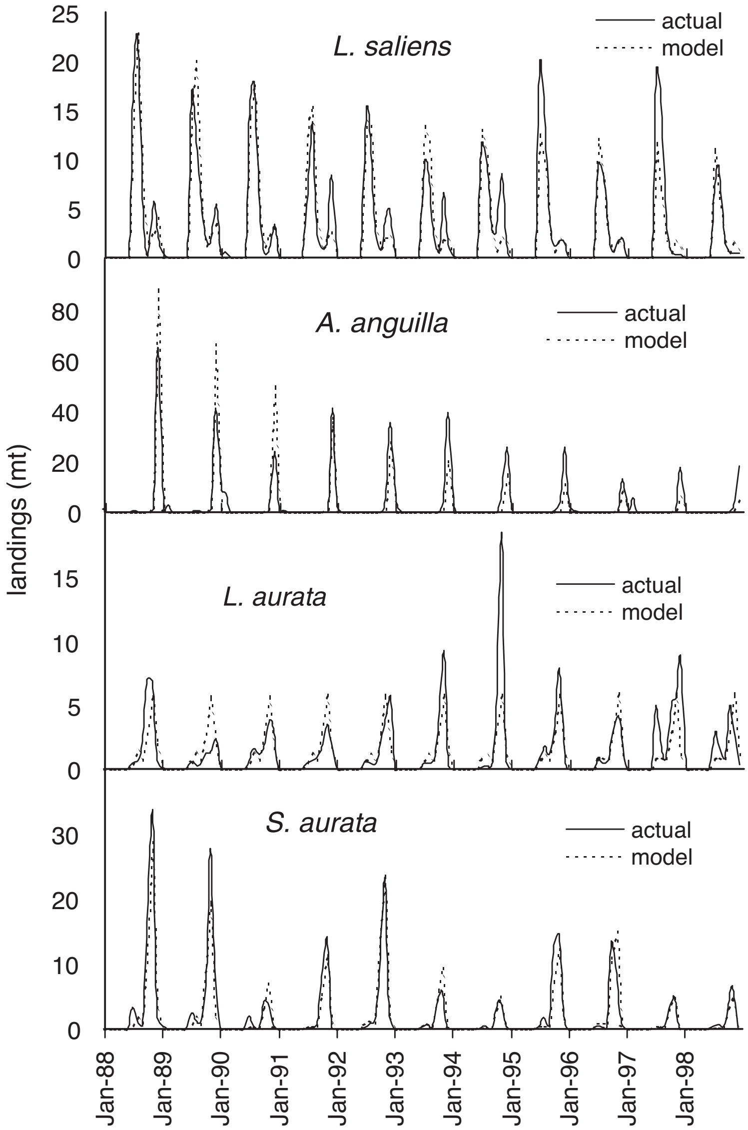

FIG. 6. – Recorded monthly landings of the four dominant species in the Messolonghi-Etoliko lagoons during the period 1988-1998 and the estimates produced by the harmonic regression model (HREG).

gest that the majority of the annual landings in the Messolonghi-Etoliko lagoon system occur in two periods: (a) summer-autumn and (b) the autumn to winter transition.

DISCUSSION

The Messolonghi-Etoliko lagoon system is a productive coastal ecosystem exploited by an important fishing community using fairly traditional fishing methods. The fisherman density in the area is about 4.6 fishermen per km^2, which is equal to the mean density of lagoon fisheries all over the world (Kapetsky, 1984).

The fish species composition of shallow coastal ecosystems depends greatly on the species-specific abiotic preferences and on their resistance to the important and frequent fluctuations in the abiotic parameters (Harmelin-Vivien *et al.*, 1995; Rogers and Millner, 1996; Wang and Tzeng, 1997; Jenkins and Sutherland, 1997; Jenkins and Wheatley, 1998; Guidetti, 2000; Ishitobi *et al.*, 2000; Blanc *et al.*, 2001). The composition of the fishery landings also depends on the selectivity of the fishing gears. The fish barrier traps used traditionally in the lagoons are passive gears and their efficiency depends only on the size. All fishes greater than a given size are caught: for example in the traps of the area all the individuals of *L. saliens* larger than

10 cm total length are trapped during their offshore migrations (Katselis, 1996). Thus, the composition of the fish landings reflects the species community migrating towards the sea and can therefore be used to analyse the migration patterns, which are governed by both ontogenic changes and environmental forcings. It should be also noted that the total fishing effort providing the recorded landings was fairly stable in time because both the barrier traps and the number of fishermen showed little change during the study period. The general decreasing trend in landings in the last years can also be linked to the decrease of about 50% in the eel landings since the mid-1980s. This decrease was synchronous in coastal ecosystems of both the Ionian and the Aegean Sea and coincided with the decrease in the entire European eel fishery production (Zompola *et al*., 2001).

Some of the dominant species (*L. saliens, A. anguilla* and *S. aurata*) showed a decreasing trend in the recorded landings, while some rare species (*D. annularis* and *M. barbatus*) showed an increase with time. Part of the observed fluctuations can be also linked to some technical aspects. For the first two years of the study some changes in the leasing regime of the lagoons may be responsible for a decreased accuracy of the declared landings (Dimitriou *et al*., 1994). In addition, any changes in the entrance probability of fishes in the lagoons may affect the fishery production. Thus, several technical modifications of the topography at the lagoon frontal openings of areas R1, R2, R4 and R5 during the early 1990s could be responsible for the decrease in fish landings recorded during this period (Klaoudatos and Konides, 1997).

Of the 56 species recorded in the Messolonghi-Etoliko lagoons, 6 are freshwater species, 29 are marine species entering the lagoons occasionally, 15 are euryhaline species spawning in the sea and migrating in and off the lagoons during their life cycle, five are species inhabiting the lagoons, and the last is the eel, which passed through these ecosystems during its inland and offshore migrations (Leonardos *et al.*, 2000). In the present study 92.1% of the barrier traps fishery landings was composed of eight euryhaline species of Mugilidae (4 species), Sparidae (*S. aurata* and *D. annularis*), Mullidae (*M. barbatus*) and eel (Table 3). The remaining part was composed of species entering the lagoons occasionally (*S. vulgaris*, *L. mormyrus*, *D. puntazzo* and *S. salpa*) and one Cephalopoda species (*S. officinalis*).

The composition of the recorded fish landings of the barrier traps revealed some important differences between the lagoons. In most cases the species composition depends on the nature of the bottom, the lagoon-sea exchanges and the freshwater runoff. For several species (*S. aurata*, *D. annularis*, *S. salpa*, *L. mormyrus* and *M. barbatus*), representing a large part of the landings, their presence in Lagoons R3 and R2 is linked to the sandy bottoms covered by seagrass beds (Bauchot and Hureau, 1986; Harmelin-Vevien *et al.*, 1995; Guidetti, 2000). In contrast, the increased landings of eel in Lagoons R4, R5 and R6 is linked to the muddy bottom (Deelder, 1984) of these regions (Bogdanos and Diapoulis, 1984). Furthermore, the increased landings of eel in the above lagoons is probably also linked to the increased freshwater inputs through natural and artificial channels and pumping systems draining the entire cultivated region east of the Acheloos river. The local fishermen also report the presence of eels in these channels. Thus, this system of channels is perhaps used by the eels as a feeding ground and/or pathway during their migrations from freshwater to the sea and vice-versa. These facts might explain the results of the cluster analysis (Fig. 3).

In the majority of the regions the inter-annual fluctuations of the species diversity index was low. The highest value of the index was observed in Lagoon R3 and was linked to the constant presence of several marine species entering the lagoon occasionally. This lagoon communicates with the sea through a long frontal area of 6 km enhancing the sea-lagoon exchanges. It is expected that the marked influence of the sea and the large surface of the lagoon lead to strong environmental gradients increasing the habitat heterogeneity which influences the diversity of the fish community. The species diversity in Lagoon R6 showed a particular pattern. A sharp decrease in the species diversity was observed in 1992, 1994 and 1997. Massive fish mortalities due to pronounced anoxic conditions were responsible for these fluctuations (Leonardos and Sinis, 1997). After these accidents, eel dominated the landings. Local fishermen reported that this species inhabits the inland ecosystems around the lagoon (natural and artificial channels and pumping systems draining the entire cultivated region), so it was not seriously affected by anoxic conditions.

The results of FFT analysis indicated that the monthly landings of species of Messolonghi-Etoliko lagoon system exhibited a strong seasonal cycle (Table 5). Indeed, the monthly landings of all species in barrier traps increased from a minimum in July to a maximum from August to December, depending on species, and declined thereafter. This marked seasonal cycle is most likely related to seasonal entrance of fish in the lagoons during the spring (inshore migrations) and their autumn to winter offshore migration.

Several species of Mugilidae, Sparidae and Moronidae just before and during their spawning season migrate massively offshore (Oren, 1981; Bauchot and Hureau, 1986; Smith, 1990). Massive displacements towards the deeper and more stable seawaters are also frequently observed during periods of unfavourable environmental conditions in the lagoons and shallow areas (Ishitobi *et al.*, 2000). The observed offshore migration of *L. saliens*, *L. aurata* and *M. cephalus* seems to be linked to their spawning behaviour. The highest landings of *L. saliens* were recorded in July and August and the majority of the individuals (66%) were in advanced reproductive maturity stages (Katselis, 1996). Similar results were obtained for *M. cephalus* and *L. aurata* during August to November respectively (Vidalis *et al.*, 1997; Hotos *et al.*, 2000). In October-November, 96% of the *S. aurata* individuals caught in the barrier traps were 0^+ age group (Dimitriou *et al.*, 1994) and 81% of them were males reaching their reproductive maturity (Dimitriou and Katselis, 1999).

The offshore migration of some species may be linked to their spawning behaviour and/or their reaction to environmental forcings. Large landings of *L. ramada* were recorded in October-November but only 34% of the individuals were close to their reproductive maturity (Minos, 1996). The main offshore movement of *D. annularis* and *M. barbatus* (October and November respectively) seems to be linked to the rapid seasonal decrease in the water temperature since spawning take place in spring and eggs and larvae are recorded in sea waters in late spring and early summer (Karagitsou *et al.*, 1997).

The eel landings seem to be concentrated in December. This is not due to a massive simultaneous migration but to the progressive stocking of trapped eels during the previous months and the global sale of the stocked production in December when the product price is higher (Messolonghi auction port, unpublished data). The main migration period coincides with the high rainfall period (Fig. 2). Deelder (1984) suggested that during the year two migrations can be observed, and both of them are linked to fishing activities. The first one concerns the eels migrating towards the sea during the period of heavy rainfall, usually a winter reproductive migration. In some other cases, massive offshore migrations can also be observed in early spring under the influence of important freshwater discharges (Westin, 1998).

In addition, the FFT analysis also indicated a 2-4 year periodicity in the landings of some species (Table 5). Cycles of the same period were also identified in the monthly fishery landings in the Greek seas (Stergiou *et al.,* 1997) and in different biotic and abiotic variables in the Mediterranean, Black and Azov Seas (Stergiou, 1992). Similar cycles have also been observed in the physical environment and marine populations in other areas of the world and have generally been related to short-term ocean-atmosphere interactions (Stergiou *et al*., 1997).

The landings of the barrier traps fisheries of the Messolonghi-Etoliko lagoon system are based on the migratory behaviour of several euryhaline species. These seasonal onshore-offshore movements are major events in the life cycle of the species, which take advantage of the increased productivity and the higher spring and summer temperatures of these particular ecosystems. Unfortunately, the barrier traps interrupt this life cycle and in some cases they do not allow the potential spawners to reach the spawning grounds and participate in the stock reproduction. In such a case, the lagoon exploitation seems completely independent from the regional coastal fisheries management. As the performance of the barrier traps increases, this separation will become more pronounced, with a negative impact on both coastal and lagoon fisheries. The results of the present study and the suggested models could be used for a more efficient management of the lagoon fishing activities, especially through the development of time limitations in the activity of the barrier traps. The main objective should be the integrated management of both the coastal and lagoon fishing activities.

ACKNOWLEDGEMENTS

The authors are grateful to C. Kapnisis and K. Kaltsoulas (staff of the fish-warf of Messolonghi) for their contribution to the data collection.

REFERENCES

Anonymous. – 2001. *Study of management of fishery exploitation of Greek lagoons. Project PESCA, task 12*. Ministry of Agriculture of Greece, Direction of Aquaculture (in Greek).

Ananiades, C. – 1984. Aspects of coastal lagoon and pond fishery management problems in Greece. *In:* Kapetsky, J.M and

Lasserre G. (eds), *Management of coastal lagoon fisheries, Amenagement des peches dans les lagunes cotieres,* pp. 478-515. Stud. Rev. GFCM/Etud.Rev.CGPM (61).

Ardizzone, G.D, S. Cataudella and R. Rossi. – 1988. *Management of coastal lagoon fisheries and aquaculture in Italy*. *FAO Fish. Tech. Pap. (293).*

Blader, S.J.M and T.G. Blader. – 1980. Factors affecting the distribution of juvenile estuarine and inshore fish. *J. Fish Biol*., 17:143-162.

Blanc, L., C. Aliaume, A. Zerbi and G. Lasserre. – 2001. Spatial and temporal co-structure analyses between ichthyofauna and environment: an example in the tropics. *C.R. Acad. Sci. Paris, Sciences de la vie/Life Sciences,* 324:635-646.

Bogdanos, K. and A. Diapoulis. – 1984. Contribution in the knowledge of the zoobenthos and phytobenthos of Messolonghi lagoon. *Thalassographica,* 7: 39-52.

Bauchot, M.L. and J.C. Hureau. – 1986. Sparidae. *In:* Whitehead, P.J., M.L. Bauchot, J.C. Hureau, J. Nielsen and E. Tortonese (eds), *Fishes of North–eastern Atlantic and Mediterranean*, pp. 883-907. UNESCO United Kingdom (Vol. 2).

Deelder, C.L. – 1984. *Synopsis of biological data on the eel, Anguilla anguilla (Linnaeus, 1758). FAO Fish. Synop*. (80) Rev. 1:73.

Diggle, P.J. – 1990. *Times series: A biostatistical introduction*. Oxford University Press Inc. New York. 257 pp.

Dimitriou, E., Y. Rogdakis, J. Leonadros and A. Athanasopoulos. – 1994. The quantitative and qualitative composition of fishes catch of Messolonghi Etoliko lagoon as index to fishing managment. *Fishing News* 155: 82-91 (in Greek).

Dimitriou, E. and G. Katselis. – 1999. The gonads maturity of the gilthead bream (*Sparus aurata*) in Messolonghi Etoliko Lagoon. *Proc. 21st Panhellenic meeting EEBE. May 28-30: 59-60* (English abstract).

Harmelin-Vivien, M., J. Harmelin and V. Leboulleux. – 1995. Microhabitat requirements for settlement of juvenile sparid fishes on Mediterranean rocky shores. *Hydrobiologia*, 300/301: 309-320.

Hair, G. F, R.E. Anderson, R.L. Tatham and W.C. Black. – 1998. *Multivariate data analysis*. Fifth Edition. Prentice-Hall International, Inc., 730 pp.

Hotos, G.N., D. Avramidou and I. Ondrias. – 2000. Reproduction biology of *Liza aurata* (Risso, 1810), (Pisces Mugilidae) in the lagoon of Klisova (Messolonghi, W. Greece). *Fish. Res.*, 47: 57-67

Guidetti, P. – 2000. Differences among fish assemblages associated with nearshore *Posidonia oceanica* seagrass beds, rocky-algal reefs and unvegetated sand habitats in the Adriatic Sea. *Estuar. Coast. Shelf Sci.,* 50: 515-529.

Jenkins, G.P. and C.R. Sutherland. – 1997. The influence of habitat structure on nearshore fish assemblages in the southern Australian embayment: colonisation and turnover rate of fishes associated with artificial macrophyte beds of varying physical structure. *J. Exp. Biol. Ecol*., 218: 103-125.

Jenkins, G.P and J. Wheatley. – 1998. The influence of habitat structure on nearshore fish assemblages in a southern Australian embayment: Comparison of shallow seagrass, reef-algal and unvegetated sand habitats, with emphasis on their importance to recruitment. *J. Exp. Biol. Ecol*., 221: 147-172.

Ishitobi, Y., J. Hiratsuka, H. Kuwabara and M. Yamamuro. – 2000. Comparison of fish fauna in three areas of adjacent eutrophic estuarine lagoons with different salinities. *J. Mar. Sys.,* 26: 171-181.

Karagitsou, E., A. Siapatis, K. Apostolopoulou and C. Papacostantinou. – 1997. Seasonal distribution of ichthyoplancton in Aegean Sea. *Proc. 5th Hel. Symp. Oceanogr. and Fish*., Vol. 2: 140-145 (in Greek with English abstract).

Kapetsky, J.M. – 1984. Coastal lagoon fisheries around the world: some perspectives on fishery yields, and other comparative fishery characteristics. In: Kapetsky, J.M and Lasserre G. (eds), *Management of coastal lagoon fisheries , Amenagement des peches dans les lagunes cotieres,* pp. 98-116. Stud. Rev. GFCM/Etud. Rev. CGPM (61).

Kapetsky, J.M and G. Lasserre. – 1984. *Management of coastal lagoon fisheries, Amenagement des peches dans les lagunes cotieres. Stud. Rev. GFCM/Etud. Rev. CGPM.,* (61).

Katselis, G. – 1996. *Biology of the leaping grey mullet (*Liza saliens *Risso, 1826) (Pisces: Mugilidae) in Messolonghi Etoliko lagoons*. PhD Thesis, University of Patras.

Klaoudatos S. and A. Konides. – 1997. Assessment of the effects of the Messolonghi Etoliko structural alterations on fisheries production of commercially important fish species*. Proc. 5th Hel. Symp. Oceanogr. and Fish.*,Vol. 2: 337-340 (in Greek with English abstract).

Kotsonias, G. – 1984. The Messolonghi-Etolico lagoon of Greece. Socio-Economic and ecological interactions of cooperative and independent fishermen. *In:* Kapetsky, J..M and Lasserre G. (eds), *Management of coastal lagoon fisheries, Amenagement des peches dans les lagunes cotieres*, pp. 521-528. Stud. Rev. GFCM/Etud. Rev. CGPM (61).

Leonardos, I. and A. Sinis. – 1997. Mass mortality in the Etoliko lagoon Greece: The role of local Geology. *Cybium* 21(2): 201-206.

Leonardos, I., A. Sinis and A. Kokkinidou. – 2000. Fish fauna of the Messolonghi and Etolikon lagoons. *Proc.6th Hel. Symp. Oceanogr. and Fish.* Vol.2: 239-244 (in Greek with English abstract).

Minos, G. – 1996. *Biology of the thinlip grey mullet (*Liza ramada *Risso, 1826) (Pisces:Mugilidae) in Messolonghi Etoliko lagoons*. PhD Thesis, University of Patras.

Oren, O.H. – 1981. *Aquaculture of Grey Mullets*. Cambridge University Press, Cambridge, pp. 507

Pearce, F. and A.J. Crivelli. – 1994. *Characteristics of Mediterranean wetlands.* MedWet Publications, Tour du Valat, Arles, France.

Peja, N., A. Vaso, A. Miho, N. Rakaj and A.J. Crivelli. – 1996. Characteristics of Albanian lagoons and their fisheries. *Fishery Research,* 27: 115-125.

Rogers, S.I. and R.S. Millner. – 1996. Factors affecting the annual abundance and regional distribution of English inshore demersal fish populations: 1973 to 1995. *ICES J. Mar. Sci.*, 53: 1094-1112.

Smith, C.L. – 1990. Moronidae. In: J.C. Quero, J.C. Hureau, C. Karrer, A. Post and L. Saldanha (eds.), *Check-list of the fishes of the eastern tropical Atlantic (CLOFETA),* pp. 692-694. JNICT, Lisbon; SEI, Paris; and UNESCO, Paris, Vol. 2.

Snedecor, G.W. and W.G. Cochran. – 1980. *Statistical Methods*. Seventh Edition. The Iowa State University Press, Ames, IA, USA, 507 pp.

Stergiou, K.I. – 1992. Variability of the monthly catches of anchovy, *Engraulis encrasicolus*, in the Aegean Sea. *Fish. Bull. U.S*., 90: 211-215.

Stergiou , K.I., E.D. Christou and G. Petrakis. – 1997. Modelling and forecasting monthly fisheries catches: comparison of regression, univariate and multivariate time series methods. *Fisheries Research*, 29: 55-95

Swokowski, E.W, M. Olinick, D. Pence and J.A. Cole. – 1994. *Calculus*. Sixth Edition. PWS Publishing Combany Boston. 1279 pp.

Tzeng W.N. and Y.T. Wang. – 1986. Structure, composition and seasonal dynamics of the larval and juvenile fish community in the mangrove estuary of Tanshui River, Taiwan. *Mar. Biol.,* 113: 81-490.

Vidalis, K., Y. Rogdakis and A. Kokkinidou. – 1997. Observations on the reproductive migration of grey mullet (*M. cephalus*) in the coastal lagoon “Buca” (estuary of Acheloos river). *Proc.5th Hel. Symp. Oceanogr. and Fish*.,Vol. 2: 253-256 (in Greek with English abstract).

Wang, Y. and W. Tzeng. – 1997. Temporal succession and spatial segregation of clupeoid larvae in the coastal waters off the Tanshui River Estuary, northern Taiwan. *Mar. Biol.,* 129: 23-32

Weinstein, M.P. – 1979. Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, North Carolina. *Fish. B.,* 77: 399-357.

Westin, L. – 1998. The spawning migration of European silver eel (*Anguilla anguilla* L.) with particular reference to stocked eel in the Baltic. *Fisheries Research*, 38: 257-270.

Zompola S., D. Vavoulis, I. Cladas, A. Kentrou, S. Pagoni and C. Koutsikopoulos. – 2001. European eel (*Anguilla anguilla* L. 1758) fisheries production in Greece. *Proc. 10th Panhellenic Symposium of Ichthyologists*, 237-240.

Scient. ed.: M. Harmelin-Vivien