Yield per recruit and spawning stock biomass models for the management of four Mugilidae species in Mesolonghi –Aitoliko lagoon (W. Greece)

George Katselis[*], Katerina Koukou, Dimitrios Moutopoulos

Dep. Aquaculture and Fisheries Management, TEI of Mesolonghi, Nea ktiria 30200, Greece

Abstract

The fishery exploitation of the most of Mediterranean lagoonal systems is a common extensive culture, based on the seasonal fish migration from sea to the lagoon and the summer-to-winter offshore fish migration. The Mugilidae group of species represents more than 50% of the total fishery landings in the Mesolonghi-Aitoliko lagoon system. Spawning stock biomass and yield per recruit models were developed for the four Mugilidae species *(Liza saliens, L. aurata, L. ramada* and *Mugil cephalus)* to estimate their exploitation level. Growth parameters (asymptotic length, L_∞ and growth rate, K, W-L relationships) and fecundity estimations were gathered from past surveys in the study area. Moreover, length frequencies data from four species caught from fish traps during 1992, 1994, 1998 and 2004 were also used. The results indicated that: (1) the exploitation of all species was occurred at first capture lengths that related to maximum yield per recruit, (2) for the most important fish species *(L. aurata, L. ramada* and *M. cephalus)* high values of exploitation rates (ranged from 0.66 to 0.87) was imposed and (3) the spawning stock of *L. aurata* and *L. ramada* were out of safe levels. At first view the results can be explained by the continuously decreasing landings of the exploited species in the Mesolonghi–Aitoliko lagoon during the last two decades. However, in the case of lagoon the models embodied both real and phenomenal total mortalities which could be explained an overestimate of total mortality in present study. Despite the above uncertainties a part of the above results could be attributed on a long-term effect of human actions (i.e. increasing of marine aquaculture) on coastal zone which modify the spatial fish distribution and increase fishing mortality in the sea species populations.

Keywords: Yield per recruit, Spawning potential ratio, Management, Lagoon, Mullet, Mesolonghi

Introduction

Coastal lagoons and estuaries are key ecosystems and an intensive exploitation of the increased natural productivity of these ecosystems is carried out by important local fishermen communities (Kapetsky 1984). The exploitation is commonly based on the species-specific inshore-offshore seasonal or ontogenic fish migrations (Ardizzone et al. 1988). Fluctuations of the lagoon fisheries landings might be attributed to the biological linkage between open sea and coastal lagoons and it could be attributed to ecosystem particularities, species-specific ecological requirements

(e.g., spatio-temporal migration attributed to reproduction, protection and feeding: Mariani 2001) and anthropogenic impacts on both sides of the systems.

In Mediterranean lagoons a variety of fishing gears and methods were used, such as barrier traps, beam trawls, fyke nets, trammel nets and longlines (Kapetsky 1984; Koutrakis et al. 2007). In Greece the exploitation in a great number of the lagoons (> 80%) is based on traditional barrier fish traps in fenced areas that separate the lagoons from the sea capturing the seaward migrated fishes (Koutrakis et al. 2007). Size selectivity of the traps could be considered as a trawl-type sigmoid curve (Pope 1976) defined by the lower retained fish size and the size corresponding to the 100% of retention (King 1995). Apart from traps, gill nets and dip nets are also used in the lagoons all year round. During 1992-2001 the recorded annual fishery landings of 50 lagoons cover an area of about 350 Km^2, is about 1000 t, with 56% of this production derived from five species (*L. aurata*, *L. saliens*, *L. ramada*, *Chelon labrosus* and *Mugil cephalus*) (Katselis et al. 2003; Koutrakis et al. 2007). Apart of *L. saliens* (which has rather low commercial interest), the mullet species have rather high commercial interest (Oren 1981). Especially, *M. cephalus* is a high commercially important species because of its well known high value of the dried and salted mature ovaries (Katselis et al. 2005).
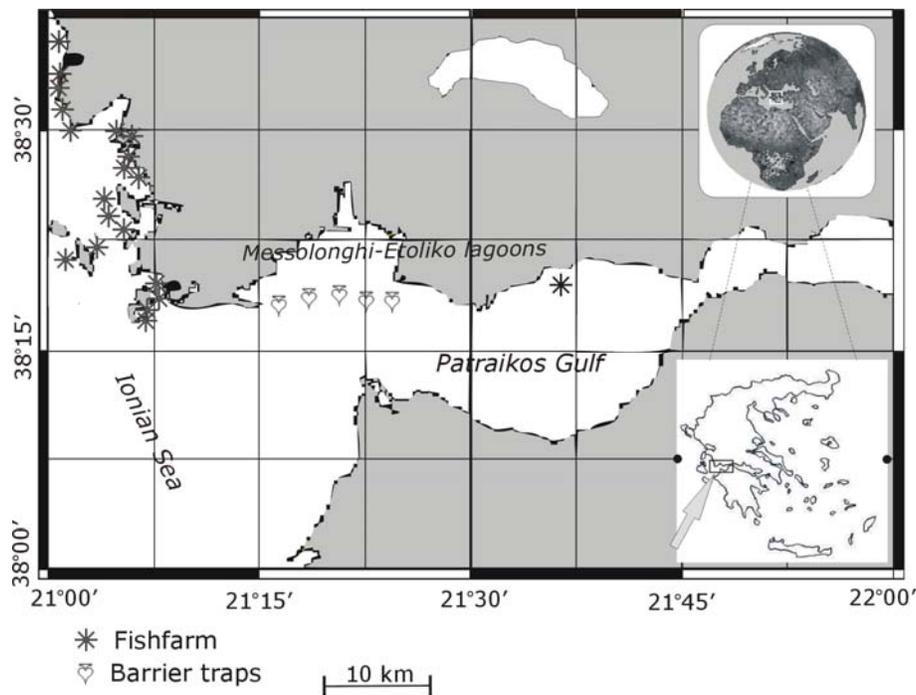

Fig. 1. Map of the study area

Mesolonghi-Aitoliko lagoons (W. Greece), covers an area of approximately 150 Km^2 and is one of the largest lagoon systems in the Mediterranean (Fig. 1). Based on the topography, hydrology and fish species composition, six sub-areas have been defined (Katselis et al. 2003). The largest portion consisted by the central lagoon, a shallow sea separated from the Patraikos Gulf and the Ionian Sea by a chain of sand islands. In the adjacent coastal area (Ionian Sea), twenty nine fish farms (more than 25% of the total number of Greek fish farms) are established that in 2004 produced more than 15% of the gilthead sea bream and sea bass Mediterranean fish farm production (Dimitriou et al. 2007).

The lagoons exploitation is a common extensive culture based on the seasonal entrance of young and adult fish in the lagoons and the autumn to winter offshore fish migration. In practice, the fishing period by fish traps starts from July and is continuous up to December of each year (Katselis et al. 2003). In the study area the estimated total annual fish landings decreased from 1500–2000 tones in the 1960s to 1300–1500 tones in recent years (Dimitriou et al. 1994) that is mainly derived from about 200 fishers exploiting the barrier traps and 700 fishers operating inside

and outside the lagoons using nets and longlines (Dimitriou et al. 1994). The barrier traps supply about of 30 % the fish catches (Koutrakis et al. 2007).

The aim of the present study was to develop spawning stock biomass and yield per recruit models for the four Mugilidae species (*L. aurata*, *L. saliens*, *L. ramada* and *Mugil cephalus*) in order to assess the exploitation condition in the Mesolonghi-Aitoliko lagoon complex. These models are designed to provide decision-makers with information on the relationship between population dynamics, socio-economic objectives, and management strategies (King 1995).

Materials and methods

Growth parameters, such as asymptotic length (L_∞), asymptotic weight (W_∞), growth rate (K), weight-length relationships, length and age of first mature (L_{m50} and t_{m50}, respectively) and fecundity estimations (Fq) were used from past studies in the same area (Table 1). Moreover, length frequency distributions from four species caught from fish traps during the years 1992, 1994, 1998 and 2004 were used.

Table 1. Biological parameters of the studied species

equation		L. saliens	Ref	L. aurata	Ref	M. cephalus	Ref	L. ramada	Ref
	L_∞ (cm)	32.99	1	65.30	2	79.10	3	56.30	5
	K (/year)	0.258	1	0.149	2	0.151	3	0.179	5
	t_0 (year)	-0.470	1	-1.140	2	-0.100	3	-0.856	5
	W_∞ (g)	299.8	1	2656.3	2	4960.2	4	1873.7	5
$W=a*L^b$	a	0.0078	1	0.0056	2	7.623E-06	3,4	0.0055	5
	b	3.018	1	3.130	2	3.041	3,4	3.160	5
$Fq=v*W^g$	v	10331	1	53682	2	1662	4,6	1568	5
	g	0.589	1	0.417	2	0.880	4,6	0.880	5
	t_{m50} (year)	2.9	1	1.8	2	4.0	4,6	3.0	5
	L_{m50} (cm)	19.16	1	24.9	2	36.51	4,6	28.06	6
	M (/year)	0.61	*	0.35	*	0.34	*	0.42	*
	tr (year)	1.77	*	0.55	*	1.24	*	0.81	*
	lr (cm)	14.50	**	14.50	**	14.50	**	14.50	**
	tc (year)	2.99	*	1.55	*	3.90	*	2.32	*
	lc (cm)	19.48	*	21.57	*	35.90	*	24.40	*

* Estimated in this study
 Ref: 1) Katselis 1996; 2) Hotos 1998; 3) Ontrias et al. 1994; 4) Katselis et al. 2005; 5) Oren 1981; 6) Minos 1996.
**Equal to the lower length of mullet which caught at fish traps (Katselis, 1996).
Explanations of abbreviations are in text.

The length at first capture lc (the length at which 50% of the fish at that size are vulnerable to capture) was estimated by the analysis of catch curve using the methodology proposed by Pauly (1984). From the estimated growth parameters (L_∞, K) and using the length converted catch equation (Pauly 1984) the instantaneous rate of total mortality (Z) was also estimated.

The instantaneous rate of natural mortality (M) was estimated by using Pauly's empirical formula (1) (Pauly 1981):

$$\ln M = -0.0152 - 0.279 \text{ X } \ln L_\infty + 0.6543 \text{ X } \ln K + 0.463 \text{ X } \ln T \tag{1}$$

where T is the annual water temperature in ^{o}C. From the estimated values of M and Z, the instantaneous rate of fishing mortality (F = Z − M) and the exploitation rate (E = F/Z) were estimated.

The effects of minimum length limits on harvest of species were simulated using a Beverton-Holt yield-per-recruit (YPR) model (2) (Beverton and Holt 1957):

$$\frac{Y}{R} = F \cdot e^{-M(t_c - t_r)} \cdot W_\infty \cdot \sum \frac{U_n \cdot e^{-nK(t_c - t_o)}}{F + M + nK} \tag{2}$$

where F is the fishing mortality, M is the natural mortality, tc is the mean age at first capture, tr is the age at recruitment, K and t_0 are parameters of the von Bertalanffy growth equation (Von-Bertalanffy 1938), Un is a summation parameter, $U_0=1$, $U_1=-3$, $U_2=3$ and $U_3=-1$ (Beverton and Holt 1957).

Recruitment overfishing occurs when fish are harvested from a population before they are able to replace themselves, thus leading to a population decline and an indication of a possible stock collapse. Recruitment overfishing is traditionally examined by assessing the reproductive potential of an exploited population relative to that of an unexploited population (Goodyear 1993).

Spawning potential ratio (SPR) (3) represents the proportion of lifetime egg production of an exploited population compared to that of an unexploited population and calculated as:

$$SPR\% = 100 * \frac{\text{Pr}_{Expl}}{\text{Pr}_{Un\exp l}} = \frac{\sum\limits_{t=tr}^{\max} e^{-Zt} \cdot Fq_t}{\sum\limits_{t=tr}^{\max} e^{-Mt} \cdot Fq_t} \tag{3}$$

where Pr is the lifetime egg production of a cohort of recruits. The critical level of SPR is imprecisely known in most species, but may be between 20 to 50% of the unexploited levels (King 1995).

Simulations were conducted using five minimum length limits that corresponding to the lower length are can be captured each species to length that corresponding to the maximum age appears in sample of each species by a step of one year. All population simulations were conducted in EXCEL software with an initial population of 1,000 recruits.

Results

In Figure 2, the length distribution per species and years were shown. Z value corresponding to the slope of the cumulated catch curve was ranged from 1.27 to 2.32/year for *L. aurata*, from 1.59 to 2.41/year for *M. cephalus*, from 0.84 to 1.23/year for *L. saliens* and from 2.23 to 2.84/year for *L. ramada* corresponding to sampling year. Lc_{50}, corresponding to the pooling curve of capture probability, was 21.5, 35.8, 19.5 and 24.3 cm for *L. aurata*, *M. cephalus*, *L. saliens* and *L. ramada*, respectively. Apart of *L. saliens*, an increase of Z value according to years was present (Fig. 3)

YPR as a function of Z showed that for the estimated Z value (1.27 to 2.32/year) for *L. aurata* the maximum YPR occurred at Lc=34.9 cm (about 195 g), while for Lc=21.5 cm (equal to Lc) the yield was relative lower (130-150 g). For *M. cephalus* the yield curves showed that for the estimated Z value (1.59 to 2.41/year) the maximum YPR occurred at Lc=42.4 cm (about 275 g), while for the current Lc=35.8 cm (equal to Lc) the yield was relative lower (250 g).

For the *L. saliens* the yield curves showed that for the estimated Z value (0.84 to 1.23/year) the maximum YPR occurred at Lc=14 to 15 cm (about 20-25 g), while for the current Lc=19.5 cm (equal to Lc) the yield was relative lower (15-24 g).

Finally for the *L. ramada* the yield curves showed that for the estimated Z value (2.23 to 2.84/year) the maximum YPR occurred at Lc=32.6 cm (about 150 g), while for the estimated Lc=24.3 cm (equal to Lc) the yield was relative lower (140 g).

For the estimated values of Z and Lc, SPR for *L. saliens* reached about 60% of the values estimated for *M. cephalus* and it was ranged from 22 to 40%. In contrast SPR for *L. aurata* and *L. ramada* was below to 20% of the values estimated for *M. cephalus*. It should be noted that for *L. aurata* and *L. ramada* the SPR values were higher 23 and 28%, respectively, of the Lc values corresponded to the next year (Fig. 4).
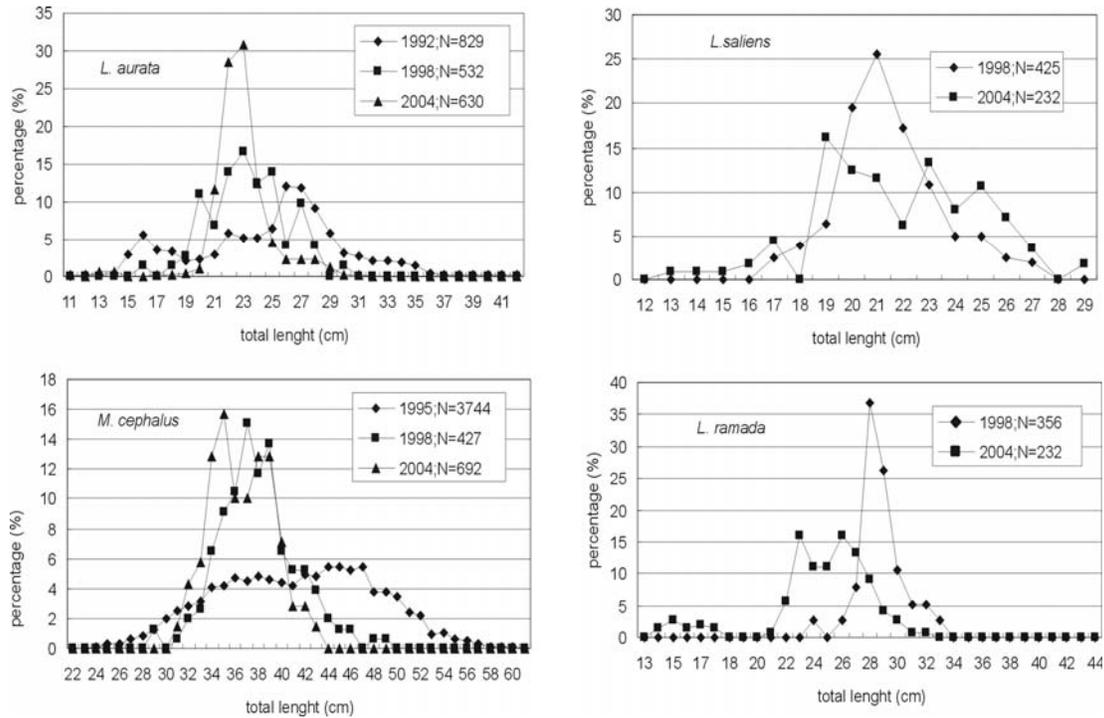
Fig. 2. Length frequency (%) distributions per mullet species caught by fish traps in different years from Mesolonghi-Aitoliko lagoons.
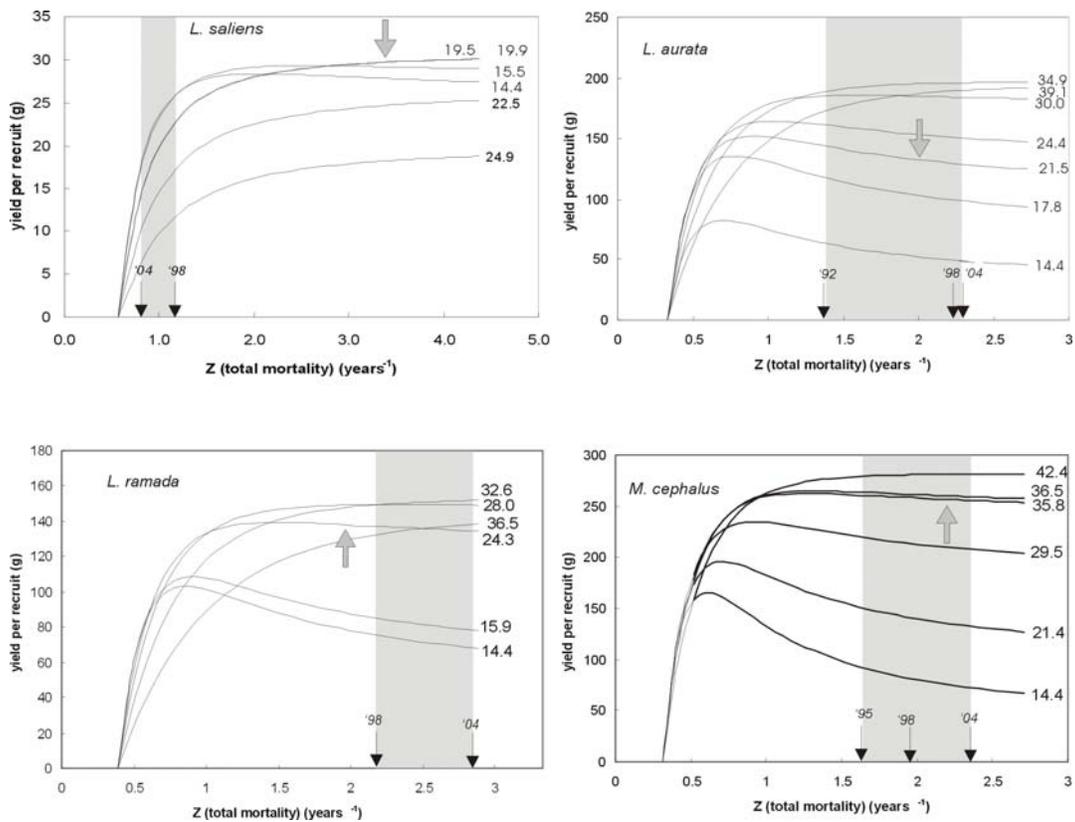

Fig. 3. Yield per recruit. The grey arrows mark the current Lc50, the dark mark the estimated Z at each year and the shadows area defined the estimated range of Z value.
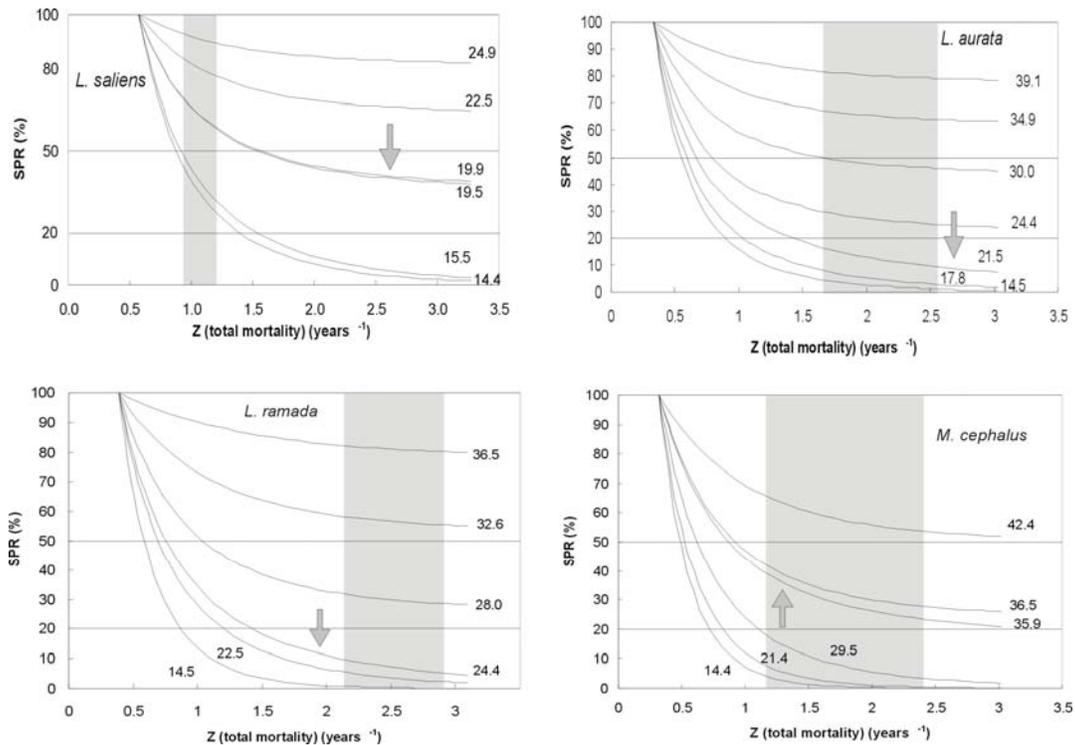
Fig. 4. SPR models. The grey arrows mark the current Lc50, and the shadows area defined the estimated range of Z values.

Discussion

The results of the present study indicated that the most important Mugilidae species *(L. aurata, L. ramada* and *M. cephalus*) showed high values of exploitation rates (> 0.66) and their exploitation was occurred at first capture lengths related to maximum yield per recruit. On the other hand, the spawning stock of *L. aurata* and *L. ramada* were out of safe levels. These results might be partially explained by the continuously decreasing landings of the study species in the Mesolonghi–Aitoliko lagoon during the last two decades (Fig. 5).

However, the high sensitivity of YPR models to uncertain natural mortality (Gallagher et al. 2004), while in the case of lagoon the model embodied both real and phenomenal total mortalities. Z values represent the decreasing rate of the number of individuals per age-class (King 1995). In the lagoons the age structure of the landings caught by fish traps during the seaward migration could be considered as the combined result of the sea-lagoon and lagoon-sea migrated populations and of the fishing and natural mortality rates encounter inside the lagoon and in the open sea.

The stocks of the study species could be also considered as a part of the open sea populations that seasonally enter into the lagoon. Thus, the estimated Z values from the cumulated catch curves of the samples caught from fish traps might be overestimated due to the possible different age-depended migration rates toward the lagoon or the seaward migration embodied a phenomenal Z in the model and the fishery exploitation operating with other gears that added a quantity of mortality on the total mortality of entry populations. This can be explained by the high values of estimated Z values for the samples of the present study.

On the other hand and apart from *L. saliens*, an increase of Z values with year was present (Fig. 3). Fishing gears and practices in the lagoon remained unchanged during the last two decades and this indicates a rather stable fishing effort and consequently fishing mortality can be considered unchanged. Also, given the Pauly equation for estimating natural mortality (M), changes in M values as a result to possible changes of ambient temperature and/or von Bertallanfy equation parameters could be considered small and could not be explained by the above results (Katselis and Koutsikopoulos 2000). Thus, the increase of Z values might be influenced by the increase of Z values from the open sea populations.

Moreover, during the last two decades important changes have been occurred in the coastal area. Twenty nine fish farms have been established and operated in the adjusted coastal area of the lagoon studied (Fig. 1) during 1989-1999 (Dimitriou et al. 2007). It has been reported that fish farms playing a role of attractive devices for the wild species populations (Dempster et al. 2002; Akyol and Ertosluk 2010) with the mullet species consists an important part of these populations in terms of weight (Akyol and Ertosluk 2010). Fishing activities close to farms is also a high yielding activity (Akyol and Ertosluk 2010).
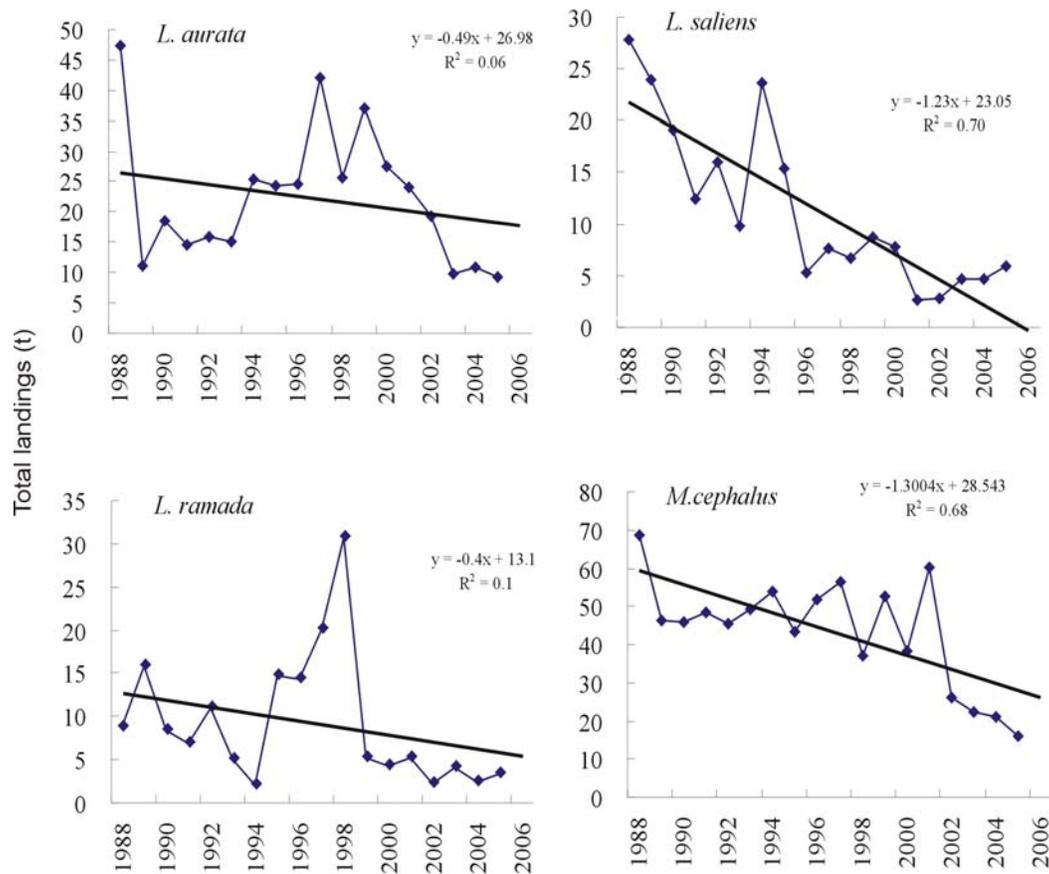

Fig. 5. Time series of annual landings per mullet species caught by fish traps in Mesologhi-Aitoliko lagoons during 1988-2006.

In our case, the farms are located in a distance about 4-80 Km from the studied lagoon (Fig. 1) where it considered to be the coastal migration path for the grey mullet (Virgona et al. 1998). Also, they are established near the coasts (mean distance of 160 m) with a mean distance within them of about 2 km, while each farm covers a mean surface area of about 11000 m^2 (Karras et al. 2010). Thus, the dense aggregation of the fish farms in the study area accompanied by their role as high technical attractive devices where possible fishing close to fish farms activities are occurred, might explain the decreasing landings in the lagoon with a concurrently increase of Z values.

In all cases and for safety rules, it should not be ignored from the management plan of lagoon the spawning stock of *L. aurata* and *L. ramada* were out of safe levels. For both species seems that if the first capture length shifted to length of next age then the Y/R increases about 14-16% while the SPR proportion for both species shifted in the safe band (20-50%) (King 1995).

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