UNIVERSITÀ DEGLI STUDI DI ROMA "TOR VERGATA"

FACOLTÀ DI SCIENZE MATEMATICHE, FISICHE E NATURALI

DOTTORATO DI RICERCA IN
BIOLOGIA EVOLUZIONISTICA ED ECOLOGIA

CICLO XXII

FISH ASSEMBLAGES IN THREE MEDITERRANEAN COASTAL LAGOONS: STRUCTURE, FUNCTIONING AND SPATIO-TEMPORAL DYNAMICS

Ph.D. Thesis

Cristina Manzo

A.A. 2009/2010

Docenti Guida/Supervisors: Dr. Eleonora Ciccotti
Dr. Raffaele D'Adamo

Coordinatore: Prof. Patrizia B. Albertano

UNIVERSITÀ DEGLI STUDI DI ROMA "TOR VERGATA"

FACOLTÀ DI SCIENZE MATEMATICHE, FISICHE E NATURALI

DOTTORATO DI RICERCA IN
BIOLOGIA EVOLUZIONISTICA ED ECOLOGIA

CICLO XXII

A.A. 2009/2010

FISH ASSEMBLAGES IN THREE MEDITERRANEAN COASTAL LAGOONS: STRUCTURE, FUNCTIONING AND SPATIO-TEMPORAL DYNAMICS

Ph.D. Thesis

Cristina Manzo

Docenti Guida/Supervisors: Dr. Eleonora Ciccotti
Dr. Raffaele D'Adamo

Coordinatore: Prof. Patrizia B. Albertano

A Rita e Mario,

pilastri nella mia vita e grazie ai quali sono la persona che sono

INDEX

1. INTRODUCTION

1.1 Mediterranean coastal lagoons

Coastal lagoons are semi-enclosed basins of water separated from the sea by sandbars which are crossed by one or more channels, often artificially maintained (Barnes, 1980; Guelorget and Perthuisot, 1992). These ecosystems are characterised by shallow waters, limited hydrodynamics, great changeability of abiotic parameters, high rate of sedimentation and high productivity.

Compared to Atlantic lagoons, Mediterranean coastal lagoons are less affected by the tide, have lower freshwater inputs, salinity is not significantly reduced and average water temperature is higher. Because of the meagre tidal currents, the connections with the sea tend to silt up and coastal lagoons are filled after a long time (Brambati, 1988). Therefore, the conservation of these ephemeral ecosystems is closely related to human management, which is mostly concerned with control of the connections with the sea (Crivelli and Ximenes, 1992; Peja et al., 1996; Quinn et al., 1999).

Therefore, coastal lagoons are complex and dynamic ecosystems with pronounced environmental heterogeneity. The high ecological complexity is not due to a high species richness but to a high environmental heterogeneity (i.e., great number of environmental factors, several environmental gradients, high connectivity of food webs and several interfaces into the system and among the lagoon system and the others). The several environmental gradients found in Mediterranean coastal lagoons, generated by the hydrographic dynamic in particular due to the plurality of boundary conditions, explain the high complexity, resilience and productivity of the ecosystem (Carrada and Fresi, 1988).

Precisely because of the different boundary conditions and the diversity of local climatic conditions, to which the heterogeneous morphology, hydrology and geochemistry of Mediterranean lagoons have to be added, many authors consider that each lagoon should be regarded as a story in itself (Cognetti, 1988). Nevertheless, in the early '80s the originality and the structural homogeneity of the lagoon communities were also highlighted. Guelorget and Perthuisot (1983) observed that a number of species tend to recur in such environments, where they live and grow therefore, from that moment, the idea of coastal lagoons as ecotones was abandoned (Carrada and Fresi, 1988). The same authors assigned these environments to a larger system including other types of semi-enclosed environments that share analogous biological communities, and called this system "paralic", meaning, by this term, water environments that have a relationship with the sea. Carrada and Fresi (1988) related the substantial uniformity of Mediterranean lagoons in terms of flora and fauna with a low structural diversity but a high functional complexity of communities, especially regarding feeding aspects for the crucial role of detritus in lagoon food webs. Thus, according to the authors, the differences among lagoon communities of different biotopes do not occur in the taxonomic composition, but in the structure of dominance, depending on the trophic status, which in turn is function of interface degree with the continental system.

Coastal lagoons cover an area of 6500 km^2 in Mediterranean region (Crivelli et al., 1995) and Italy is the third country for extension of territory occupied by these systems (Pihl et al., 2002). Hence, is not unexpected that coastal lagoons have a high socio-cultural and socio-economic interests, not only for the high secondary productions that can be obtained from them. In reality, many interests and demands of use gravitate to coastal lagoons and surrounding littoral zones in general, related to agriculture, urbanisation, industrialization, fisheries and aquaculture, and recently to environmental preservation (Ardizzone et al., 1988; Bianchi, 1988). Certainly, fisheries and extensive aquaculture have been practiced for many years in Mediterranean coastal lagoons, exploiting the migratory movements of the euryhaline marine species between marine and lagoon environments. Italian productive management started long ago and has been a reference point for other geographical areas, particularly in Mediterranean region (Ardizzone et al., 1988). Among the numerous management models, *vallicoltura* is one of the most ancient forms of aquaculture, developed in Italy in the upper Adriatic region. To exploit the seasonal movements of many euryhaline marine fish, large brackish areas of the large North Adriatic lagoons (named *valli*) were enclosed to prevent the fish return toward the sea by means of complex permanent capture systems, *lavorieri*, placed in the tidal channels. Later, this technique, from the simple ponding of fry free-moving into the lagoon, evolved to the introduction into the lagoon of fry captured elsewhere, allowing it to grow there for a few years and capturing it by artisanal fisheries or by entrapment in the *lavoriero* when trying to escape back to sea for reproduction. To enhance production, management of the environment became progressively more articulated, envisaging hydraulic management as well as bottom dredging or providing basins. Accordingly, also fish management evolved, by including movements of fish, active restocking, wintering.

In contrast, more Mediterranean coastal lagoons rely to natural recruitment, hold artisanal fisheries inside the barriers and usually lack hydraulic management (D'Ancona, 1955). This simple management scheme is indeed characteristic of most Italian lagoons in the Tyrrhenian side, such as Orbetello in Tuscany, a number of costal lakes in Latium or the numerous "ponds" in Sardinia. Here, notwithstanding local traditions and specific management models, fisheries and aquaculture, as well as environmental protection of these ecosystems have received only marginal attention in the past (Ardizzone et al., 1988). Rather, activities associated with the urbanisation, agriculture and industry have often affected coastal lagoons (and in general the coastal zone) originating negative impacts, including pollution, to which lagoon ecosystems are particularly vulnerable due to the high residence times of both waters and sediments. In particular, the land-reclamation has been the most aggressive leading to the disappearance or reduction of many estuarine and lagoon environments.

The environmental damage of the coastal zones, due to the unsustainable exploitation of the many resources concentrated there, and to the negative impacts engendered by human activities (such as input of pollutant wastes), has increased the need for a sustainable management of these areas. Integrated Coastal Zone Management (ICZM) is a concept born in 1992 during the Earth Summit of Rio de Janeiro precisely to meet this requirement. ICZM is a process for the management of the coast using an integrated approach, regarding all aspects of the coastal zone, in an attempt to achieve an optimal balance between environmental protection and the development of economic and social sectors (i.e., sustainability) (FAO, 1996).

In the course of last 30 years, the awareness of the importance of coastal lagoons, and more generally of wetlands, for the maintenance of the biodiversity at all levels, in the climatic change adaptation, in the mitigation of erosion, and as regulators of water regimes, has been growing. Ramsar Convention (1971) represented the first modern international treaty, for international cooperation for the wetland conservation promoting the wise use of their resources, their restoration and rehabilitation. Actually, many Italian lagoons are part of parks and/or are declared Ramsar Sites or Sites of Community Importance. Moreover, the increasing attention by European citizens on environmental issues, increased the focusing on protection, conservation and monitoring of natural environments, including estuaries and coastal lagoons. In December 2000, the European Water Framework Directive (WFD) (2000/60/EC) was adopted by the European Commission in order to establish a framework for the protection of all water systems that encompass transitional systems. The key aims of the Directive are the achieving of a “good ecological status” and a “good chemical status” for all waters by 2016. Good ecological status is defined in the WFD in terms of the quality of the biological communities, and the hydrological and chemical characteristics. Different biological components are the quality criteria used for the classification of ecological status in water ecosystems, including fish communities.

1.2 Fish assemblages and use of habitats by fish in transitional water systems

Coastal lagoons, and generally transitional environments, were considered from long time important sites for fish species, as nursery areas, overwintering sites, migration routes and areas which naturally support large numbers of fish (McHugh, 1967; Haedrich, 1983; Whitfield, 1999; Koutrakis et al., 2005; Franco et al., 2006a). Transitional water (TW) systems are characterised by a relatively low species diversity but high abundance of individual taxa, most of which exhibit wide tolerance limits to the fluctuating conditions found within these systems. Species that are broadly tolerant to biotic and abiotic unpredictability have a considerable advantage over those species that cannot survive such variations, because the former group is able to inhabit a food-rich environment from which possible competitors are excluded (Whitfield, 1998).

No consistent latitudinal gradient of fish species richness was identified in Europe TW systems (Elliott and Dewailly, 1995; Pihl et al., 2002). Anyway, Pihl et al. (2002) detected some differences among TW systems of different biogeographical eco-regions (mostly estuaries and some estuarine and coastal lagoons). The Baltic/Skagerrak estuarine systems appeared to be less rich in species with a regional average of 48.2 species, while the estuarine systems of the Boreal/NW Atlantic region held on average 61.3 fish species. The Boreal/NW Atlantic region encompasses estuaries possessing predictable and pronounced influence from semi-diurnal tides in opposition to the TW systems of the other regions. The estuarine systems of this region thus possess intertidal habitats (tidal freshwater, intertidal soft and intertidal hard substrata) with respect to the TW systems of the other two regions, which have only subtidal habitats. The higher number of fish habitats can explain the higher species richness in the estuaries of Boreal/NW Atlantic region, coupled to the area of habitat available (Woottom, 1990). No clear trends can be evidenced by the authors for the TW systems in Mediterranean region. They considered only two sites in the Mediterranean area, that showed high variability in species number (24 fish species in Ebro Delta vs. 62 species in Messolonghi Lagoon). These species richness values are easily biased by differences in sampling effort and timescale of the study, making the difference of datasets really problematic as underlined by the same authors.

The high variability in fish species richness among the Mediterranean TW systems was confirmed by two recently studies. Pérez-Ruzafa et al. (2007) observed a high range of variability in species richness (from 6 to 48) of Atlanto-Mediterranean coastal lagoons taken into account, with a mean of 23.4 species. In contrast, Franco et al. (2008) investigated on comparative basis various Mediterranean coastal lagoons and calculated a mean number of species per site of 40. It should be stressed that the latter is the only study, where the sampling effort leading to the compilation of the species list in each site under consideration has been measured and taken into account.

Several factors, abiotic and biotic, have been found to influence the distribution of fish species in TW ecosystems: temperature, salinity, turbidity, availability of food, presence of predators and competitors, and the structural characteristics of the habitat, especially plant coverage and substrate, i.e., type of sediment (Blaber and Blaber 1980; Cyrus and Blaber 1992; Gisbert et al., 1996; Maes et al., 1998; Marshall and Elliott, 1998; Gordo and Cabral, 2001; Franco et al., 2006a). Whitfield (1999) summarized the major biotic and abiotic factors which determine the distribution and abundance of fish in southern African estuaries (Fig. 1.1) highlighting how these factors interact directly and indirectly with the fishes that live in estuaries. The importance of these factors in influencing the occurrence and distribution of fish seem to differ from species to species and vary from one ecosystem to another. Because no two coastal lagoons or two estuaries are identical in terms of both biotic and abiotic (including morphology, hydrology, climate, local boundary conditions) characteristics, it could be postulated that the fish fauna of each system will also differ. However, if the resident and marine migrant fishes respond to the environment in a same manner, then the assemblages occupying similar types of transitional systems in a particular region would be expected to reflect this similarity (Whitfield, 1999).

The several types of habitats in transitional systems are used by fish species for various purposes, as spawning grounds, nursery areas, feeding grounds and pathways in diadromous migrations. Fish species are grouped into ecological guilds according to the use they make of the TW systems (Elliott and Dewailly, 1995). These include (a) resident species, which spend their entire life cycle within the transitional system, (b) marine seasonal species, which reproduce in the sea but migrate to the transitional systems especially for feeding, (c) marine juveniles migrants, which use transitional environments as nursery areas, (d) adventitious marine species, which occasionally enter the TWs and are generally found near the tidal channels, (e) freshwater species, which usually remain close to the mouth of river inputs and (f) diadromous species, which migrate over long distances and between sea and brackish and freshwaters.

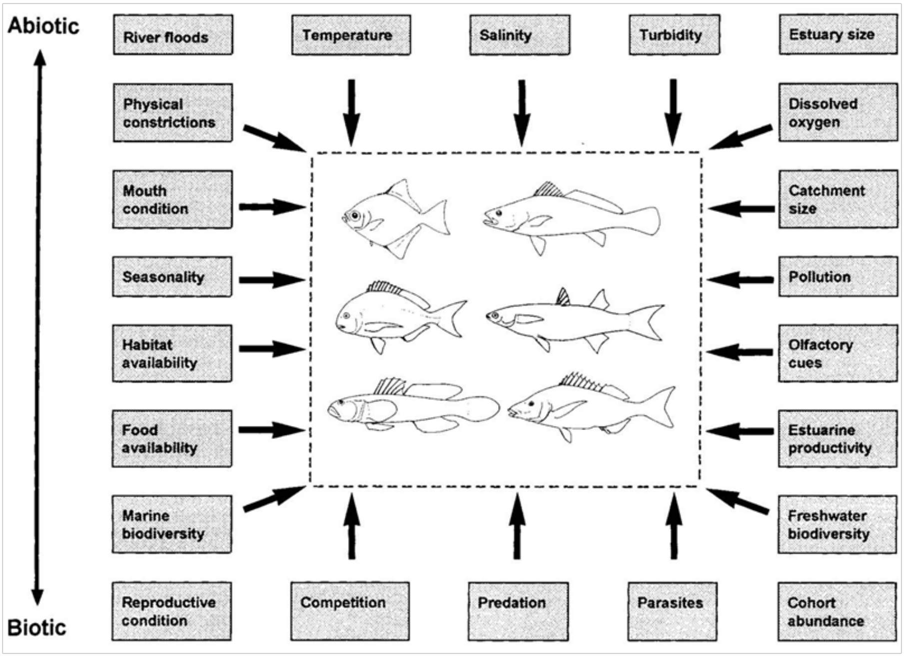

Figure 1.1. Environmental factors influencing fish occurrence and distribution in southern African estuaries (by Whitfield, 1999).

To deposit and release their eggs and to mate, fish select specific areas on the basis of their environmental features, in order to enhance the survival of eggs and the earliest stages of larval life, while catadromous and many marine species go back to the sea and anadromous species to freshwaters for reproduction (Pihl et al., 2002). In Italian lagoons, spawning by resident species (e.g., *Aphanius fasciatus* (Valenciennes), *Atherina boyeri* Risso, *Knipowitschia panizzae* (Verga)) occurs mainly during spring, but some species may begin to breed as early as in late winter and prolong spawning until summer (Gandolfi et al., 1991). These fish species grow very quickly in the warm, highly productive waters and, with the arrival of the next winter, have already reached sexual maturity.

Diadromy obligates fish to migrate between marine and brackish or freshwater basins for the reproduction and, in doing that, they can use some estuarine and lagoon habitats. In the Mediterranean, coastal lagoons often are not patchways in catadromous migrations, but may be considered nursery areas for the early stages when they are unable to access the adjacent freshwater catchment.

Adult fish of euryhaline marine species often enter into estuaries and coastal lagoons and colonise habitats where they preferably or exclusively forage. The feeding migrations are based on diurnal, tidal or seasonal basis (Pihl et al., 2002). Actually, as above mentioned, many marine species (e.g., *Liza aurata* (Risso), *Liza ramada* (Risso), *Mugil cephalus* Linnaeus, *Sparus aurata* Linnaeus) migrate into TW systems during the early life stages using these systems as nursery areas.

Pihl et al. (2002) looked at a set of European TW systems emphasized some common characteristics among the three biogeographic regions (Baltic/Skagerrak, Boreal/Atlantic and Mediterranean) in terms of ecological guilds. In general, the marine seasonal migrants and the diadromous species were less well represented in the fish fauna of the selected areas. The guilds contributing most to the fish fauna of the sites under consideration were the resident and the marine adventitious species in terms of number of species. The findings showed that the fish fauna of the Baltic systems were characterised by a strong freshwater component likely due to the relatively large tidal freshwater influence possessed by them. In the Boreal/Atlantic systems, marine adventitious species and marine juvenile migrants were more represented, while resident and freshwater species were less represented. Finally, Mediterranean systems showed a very strong contribution of marine adventitious and a slight contribution of freshwater and resident species respect to the systems of the other regions. Recently, Franco et al. (2008) analysed data on fish assemblages from various Mediterranean coastal lagoons and confirmed that in this region fish assemblages were dominated, on average, by marine species but with a majority of marine migrants (juveniles and adults) than marine stragglers. In addition, categorising fish species also according to feeding mode, the authors found that microbenthivores dominate in Mediterranean lagoons, followed by detritivores and omnivores. The dominance of microbenthivores and the lowest occurrence of herbivores was a common element with European transitional fish assemblages. In turn, detritivores and omnivores presented higher proportions of species in Mediterranean lagoons than in European transitional environments, which showed a higher numbers of piscivores, planktivores and macrobenthivores. Finally, they found that a higher similarity among fish assemblages of Mediterranean coastal lagoons was measured when considering functional structure of fish assemblages, in relation to habitat use, feeding modes and reproductive modes, instead of taxonomical compositions.

1.2.1 Recruitment and nursery function of transitional water systems

Nurseries can be defined as areas where juveniles fish are aggregated and separated from adults fish in space and time (Elliott and Hemingway, 2002). In the specific case of the juveniles of euryhaline marine species, often economically important, TWs often function as nurseries, providing abundant food and optimal environmental conditions for rapid growth, thus helping them to quickly get through the critical phase of their life history (Haedrich, 1983; Miller et al., 1991; Walters and Juanes, 1993; Sogard, 1994). In addition, in these environments, the pressure on these organisms from predators is lower than the nearby marine environment functioning as refuge (Blaber and Blaber, 1980; Peterson and Whitfield, 2000).

The young-of-the-year (YOY) of euryhaline marine species start to recruit at 10-30 mm standard length (SL) into the TW basins (Blaber, 1997). After a variable residence period these fish return to the sea, as spawning generally occurs in marine environment. YOY migrations to lagoons are in agreement with the breeding time of each species at the sea, the distance from the coast of the spawning grounds and depends on the meteoclimatic factors varying from year to year (Rossi, 1986). The immigration of marine fish larvae and postlarvae into large, well-flushed estuaries of the Northern Hemisphere mainly takes place using passive and/or selective tidal transport both for entry to and retention within these systems (Weinstein et al., 1980; Fortier and Leggett, 1982; Boehlert and Mundy, 1988). In contrast, in microtidal estuaries in South Africa, New Zealand and Australia the larvae and marine juveniles migrants go into these systems on the flood tide and are retained by rapidly settling along the banks or on the bottom where water movements are reduced (Beckley, 1985; Roper, 1986). In the micro-nanotidal Mediterranean lagoons, motile

juveniles may likely move in the tidal channels by keeping to the borders where water movements are attenuated swimming toward the lagoon in a series of steps.
Many natural factors affect the recruitment of YOY marine fish to coastal lagoons, first of all breeding population size, reproductive success, rate of eggs degeneration, mortality rates of larvae and pre-recruits, which varying from species to species. The hydrogeographic processes, which control the retention or passive transport of larvae towards the coasts, the morphology of coastal areas and the mouths efficiency of TW systems then may play an important role in the replenishment of estuarine or lagoon adult populations and therefore can be responsible for the success or failure of recruitment (Costa et al., 2002). Finally, wind direction and force, current speed and the tidal currents seem to be important factors for the determination of the amount of YOY fish into TW systems facilitating their entrance into brackish environments (Raynie and Shaw, 1994). Other factors such as temperature, salinity and food availability seem to be involved in the attraction of larvae and juveniles into estuarine and coastal lagoons and for recruitment-related processes such as growth and mortality (Gandolfi et al., 1984; Tongiorgi et al., 1986; Marchand, 1988; 1991).

1.3 State of knowledge and aims of the study

Fish assemblages in TW systems have been extensively studied in many parts of the world (Potter *et al.*, 1986; Sedberry and Carter, 1993; Pollard and Box, 1994; Whitfield *et al.*, 1994; Elliott and Dewailly, 1995; Mathieson *et al.*, 2000; Mariani, 2001; Lobry *et al.*, 2003; Akin *et al.*, 2005; Koutrakis *et al.*, 2005; Pombo *et al.*, 2005; Franco *et al.*, 2006a, b; Poizat *et al.*, 2004; Maci and Bassett, 2009). Similarly, the human-induced impacts on fish habitats and the importance of studies on fish fauna in order to manage estuarine and coastal lagoons ecosystems have encountered a great attention (e.g., Elliott et al., 1988; Costa and Elliott, 1991; Pérez-Ruzafa et al., 2006). Many factors may threaten fish and their incidence change from one biogeographical area to another (Bruton, 1995). These factors generally include habitat degradation or destruction, disruption of essential ecological processes, hydrological manipulations, environmental pollution, overfishing, climatic change, genetic contamination and impacts of introduced allochthonous species (Whitfield 1999; Elliott, 2002).

In the course of the last thirty years, the increasing consciousness about the extinction of fish species has led to a proliferation of international and national regulations which aim to protect fish species. Other environmental regulations, which concern environmental impact assessment, may additionally set standards based on necessities to maintain fish populations. The most known and important legislations are the European Union Directive for the Protection of Habitats and Species (92/43/EEC) and the Council of Europe Berne Convention (82/72/EEC), which identified those species needing protection. In particular, the Habitat Directive ratifies the principle that the conservation of threatened species for the maintenance of global biodiversity entails the preservation of the habitats in which the species lives and reproduce. Additionally, the conservation of certain habitats are achieved by the UNESCO Ramsar and World Heritage Sites, IUCN Biosphere reserves, Council of Europe Biogenetic Reserves, and the Oslo and Paris Commission.

The recent environmental legislation, especially in Europe, such as Habitat Directive and Water Framework Directive require management plans for species and habitats. These will need the determination of expected status as Favorable Conservation or Reference Conditions, and then the assessments to establish if an area or a species has not met these conditions. In particular, as a consequence of the adoption of the WFD by the European Council and the determination of fish communities as a key biological component in the monitoring of TW systems, many studies in order to set up fish-based indices for the assessment of the ecological status of TWs were thrived (Harrison and Whitfield, 2004; Breine et al., 2007; Coates et al., 2007; Branco et al., 2008; Uriarte and Borja, 2009). Many indices are based on structural aspects of fish assemblages, such as species richness and taxonomical composition which are explicitly indicated by the WFD as transitional fish quality elements. Others are grounded on the functional properties of areas for the fish assemblages, such as nursery areas, to assess the functioning of TW systems considering these more robust than structural ones. Some authors instead proposed fish-based indices derived from both approaches. Obviously, the calibration and application of these indices requires the identification of biological reference conditions, which are specific for the typology of TW system examined. The majority of the fish-based indices are proposed for estuaries and they need to be calibrated in Mediterranean coastal lagoons. For these also it is necessary to identify the biological reference conditions specific for this typology of TW system. Recently, some studies in order to provide abiotic descriptors for the adequate sorting of water body types in Mediterranean eco-region have been proposed, and some reliable type-specific biological reference conditions can be resulted from were performed (Pérez-Ruzafa et al., 2007; Franco et al., 2008). However, further efforts are essential due to the scarce literature regarding fish assemblages structure and functioning in Mediterranean coastal lagoons. Pihl et al. (2002) estimated an amount of “known data” of 0-27% on Mediterranean TW fish assemblages, a percentage very low if compared to that existing for the North Europe sites. In addition, information about fish assemblages in Mediterranean coastal lagoons, when existing, issues from grey literature and local (unpublished) knowledge of the lagoon systems and thus is often difficult to obtain. Therefore, new studies are needed to increase the knowledge about Mediterranean lagoon fish assemblages, by investigating sites for which information is scarce and using an ecosystem approach to relate the structure and functioning of fish assemblages to the environmental factors including human activities.

This research aims at giving a contribution to the knowledge of Mediterranean coastal lagoons, and primarily to the understanding of small lagoon environments, quite common in Italy as well as in the whole Mediterranea region. Three Italian coastal lagoons have been considered: Lesina Lagoon situated along the Adriatic side of Italy, and the coastal lakes of Fogliano and Caprolace located along the Tyrrhenian side of the Italian peninsula. The investigation of the fish assemblage structure in the three case studies, also in relation to some environmental factors, has taken in account both the taxonomical and functional aspects of the fish community, as recently required by the scientific community (Elliott and Quintino, 2007; Franco et al., 2007). This approach may contribute to identify some ecological descriptors for this TW tipology, that could represent useful tools in defining the specific biological reference conditions in the light of the WFD implementation.

Studies on temporal trends of catches (De Angelis, 1964; Rossi and Villani, 1980; Lumare and Villani, 1989) and fry recruitment patterns of marine species (Villani et al., 1981-82; Priore et al., 1994; Villani, 1998) are scarce in Lesina Lagoon, and investigations on the fish assemblage in this lagoon are lacking up to the present study. On the other hand, some previous investigations were carried out on the fish assemblage of Circeo coastal lakes (Mariani, 2001; Manzo et al., 2006b) and abundant information was available on fishing yields (Della Valle, 1961; AGEI, 1997; Tancioni *et al.,* 1998).

Therefore, results also give a contribution in assessing the impacts of disturbances on lagoon ecosystem. In the case of Fogliano and Caprolace, results also offer the opportuniy for a long-term comparison in order to evidence eventual temporal variations in fish assemblages. Also, results provide support for the development of management strategies in the three lagoons, to enhance and preserve the functioning and persistence of these important lagoon systems.

In this context, the specific objectives of the current study were to 1) characterise fish assemblages of Lesina, Fogliano and Caprolace lagoons, 2) describe the spatial and temporal variations of the fish assemblage structure in the three costal lagoons and 3) investigate any relations with the main environmental factors that typically influence TW fish communities. Additionally, only for Lesina Lagoon recruitment patterns of YOY marine fish were investigated. Particularly, the objectives were 1) to verify migration calendar of the economically important marine species entering the Lesina Lagoon, 2) to assess the volume of the recruitment and 3) to describe the spatial distribution patterns of these species in the lagoon.

2. MATERIAL AND METHODS

2.1 Study areas

2.1.1 Lesina Lagoon

The Lesina Lagoon is situated on the Adriatic coast of Central-Southern Italy (15°45′ E, 41°88′ N) (Fig. 2.1). This lagoon is included in the Gargano National Park and it has been acknowledged in 1995 as a Site of Community Importance. Its area amounts to 5136 ha, with a average depth of 0.7 m and a maximum depth of 1.5 m. The eastern side of the lagoon is mostly taken up by a large marshy area.

Figure 2.1. Geographic position of the study areas.

The lagoon is connected to the sea by two tidal channels, Acquarotta and Schiapparo (Fig. 2.2). The Acquarotta Channel, connecting the western side of the lagoon to the sea, is about 3 km long, 6-10 m wide and 0.8-2 m deep. The Schiapparo Channel, joining the eastern side of the lagoon to the sea, is 0.8 km long, 25 m wide, and 2-4 m deep. Both channels are endowed with sluices to regulate water exchanges between the lagoon and the sea, and *lavorieri*, to catch adult fish moving towards the sea.

Figure 2.2. The Lesina Lagoon showing the location of sampling stations, population centres (▲), drainage pumping stations (◆), livestock and fish farms (★).

Two year-round tributaries, the Lauro River and the Zannella Channel, a number of agricultural drainage channels and two drainage pumping stations, Lauro and Pilla, are the principal freshwater inputs. They are mostly concentrated on the south-eastern side of the lagoon, accounting for east-west salinity gradient, more pronounced during summer.

The catchment basin, about 460 km^2 (Bullo, 1902), includes some livestock farms as well as seed and irrigated crops. Several fish farms discharge their waters, after treatment, into the western and central-eastern side of the lagoon, on the southern shore. Moreover, the partially treated urban waste waters of three municipalities, with a cumulated population amounting to 30 000 inhabitants, flow into the lagoon.

The Lesina Lagoon is a non-tidal system, where winds produce longitudinal flows, thus accounting for the water mixing (Crisciani, 1994). The residence time of the water is estimated to be about 70-100 days (Manini et al. 2003). Due to the limited depth, the thermal regime is influenced mostly by climatic conditions (Palmegiano et al., 1985; Roselli et al., 2009). The salinity, once ranging from 5 to 51, has shown a continuous decrease since 1999, and ranges today between 6 and 38 (Fabbrocini et al., 2008; Roselli et al., 2009). The salinity gradient has also become less severe. Dissolved oxygen and pH are strongly affected by primary production, showing a maximum saturation of 214% and a maximum value of 9.93 mg/l, respectively (D'Adamo et al., 2009). Nutrient concentrations in the water column depend on season, primary production, organic matter mineralization and inputs from the catchment basin (Lumare and Palmegiano, 1980). They show higher values nearby the freshwater channels and the river outflows, especially nitrates, ammonium, silicates and total dissolved nitrogen and phosphorus (D'Adamo et al., 2009).

The phytoplankton community is composed mainly by diatoms (Bacillariophyceae). There is very little zooplankton, mainly Calanoida, with *Calanipeda aquaedulcis* Kritchagin which is the most abundant species (Brugnano and D'Adamo, 2007).

Few data are available on macrophytes. Two are the seagrass species recorded: *Nanozostera noltii* (Hornemann) Tomlinson et Posluzny and *Ruppia cirrhosa* (Petagna) Grande (Cozzolino 1995) with differences over time in densities and spatial distributions. In 1990, *N. noltii* was present throughout the lagoon (Cozzolino, 1995), while in 2005, *N. noltii* was absent in the western part, as a consequence of hypoxic conditions, widely replaced by the macroalga *Valonia aegagropila* C. Agardh. In contrast, *R. cirrhosa* colonised the eastern and less saline part of the lagoon with dense meadows (Sfriso et al., 2006). Macroalgae are often mixed to seagrasses. In total, 27 taxa were recorded, including *Gracilaria gracilis* (Stackhouse) Steentoft, L Irvine & Farnham, *Cladophora prolifera* (Roth) Kützing and *Cladophora fracta* (O.F. Müller ex Vahl) Kützing (D'Adamo et al., 2009). The benthic macrofauna is represented mostly by bivalves (93.8 %) (Cilenti et al., 2002) and the dominant species is *Abra segmentum* (Récluz), accounting for 83% of the biomass (Breber, 1994).

Information on fish community originates from fisheries assessments in the lagoon and on recruitment of YOY marine fish monitorings. Mugilid species, especially

Liza aurata, *Liza ramada*, *Liza saliens* (Risso) and *Mugil cephalus* represent the greater part of the yields together with *Anguilla anguilla* (Linnaeus), *Atherina boyeri*, *Dicentrarchus labrax* (Linnaeus), *Sparus aurata*, *Zosterisessor ophiocephalus* (Pallas) and *Gobius niger* Linnaeus have also been recorded in the Lesina Lagoon (Lumare and Villani, 1989). Some specimens of *Gasterosteus aculeatus* Linnaeus, *Cyprinus carpio* Linnaeus, *Mullus barbatus* Linnaeus and *Diplodus sargus* (Linnaeus) were also been found.

Some alien species have been recorded, such as the fish *Oreochromis niloticus* (Linnaeus), the crab *Callinectes sapidus* Rathbun, the crayfish *Procambarus clarkii* Girard and the clam *Musculista senhousia* (Benson in Cantor) (Florio et al., 2008).

The fishers' cooperatives manage the fishing areas under concessions, granted at the beginning of each fishing season. The artisanal fisheries practiced in the lagoon are based mainly on the use of fixed nets, known locally as *paranze*. These are nylon seines with a 6-mm mesh stretched across the lagoon from one side to the other, which convey the fish into fyke-nets (also with a 6-mm mesh) positioned at regular intervals along them. The paranze are installed in September and kept in use until February of the following year.

Over the years, fishing yields have fallen drastically. In the period 1935-1960 yields reached about 140 kg/ha (De Angelis, 1964). From 1962 to 1984 the yield fell from 65.7 to 39.2 kg/ha. In 2003 it was 20.5 kg/ha and consisted mostly of mullets, eels and big-scale sand smelts (AGEI, 2004).

2.1.2 Fogliano and Caprolace lakes

The Fogliano and Caprolace coastal lakes, together with Monaci and Sabaudia, are included in the Circeo National Park on the Italian coast of the Tyrrhenian Sea (41°21'N and 12°58'E) (Fig. 2.1). In 1978, they were declared "Wetlands of International Importance" under the Ramsar Convention and, in 1995, the lagoons were proposed for the status of a Site of Community Importance, being included within the Natura 2000 Network (92/43/CEE, the Habitat Directive).

The lakes are the remnants of a large reclamation in the '30s. The morphology, hydrology and physico-chemical characteristics of the whole area was modified by the dredging of the bottom, the embanking, the canalisation of the tributaries and the opening of efficient connections with the sea, and the work gave individuality to each lake (Della Valle, 1961).

Today, the Fogliano Lake has a surface area of 404 ha and extends for about 5 km parallel to the coast, with an average depth of 0.9 m (maximum depth is 2 m) (Bono et al., 1985). The lagoon is connected to the open sea by a single tidal channel, Del Duca Channel, 270 m long and 16 m wide (Fig. 2.3), endowed with a *lavoriero* managed by the local fishers.

The maximum tidal amplitude is 23 cm and the theoretical renewal time of lagoon water is estimated at about 60 days (Bono et al., 1985).

Figure 2.3. Sampling stations in Fogliano Lake.

In the ‘80s, the freshwater drainage channels were closed due to their high nutrient loads. This has led to a gradual increase in salinity values. At present, the salinity ranges from 28.5 to 48.9 with an average salinity of 39. The water temperature is strongly influenced by air temperature because of the shallow depth and ranges from 8.7°C in winter to 29.8 °C in summer. pH ranges from 8.95 to 9.64 (Signorini et al.,

2009a) and dissolved oxygen actually shows an increase in daily DO fluctuations and a decrease in the peak values. The average values are much lower and hypoxia occurs in the warmer months (<2 mg/l) (Signorini et al., 2008).
Phytoplankton community includes 85 taxa, of which the 64% is constituted by diatoms (Fumanti et al., 1996). *Pleurosigma elongatum* W. Smith, *Navicula* (Bory) sp., *Cyclotella striata* (Kützing) Grunow, *Asterionella japonica* P.T. Cleve in Cleve & Möller, *Chaetoceros affinis* Lauder and *Chaetoceros gracilis* Apstein are the most frequent species (Fumanti et al., 1996). Zooplankton is less abundant. Calanoida is the most represented with *Acartia italica* Steuer which is the most abundant species. Benthic meroplankton autochthonous groups are also well represented (Manzo et al., 2006a).
In the Fogliano Lake, the submerged macrophytes include two angiosperms, *Cymodocea nodosa* (Ucria) Asch, and *R. cirrhosa*, associated with ten macroalgae (Signorini et al., 2008). *R. cirrhosa* is the dominant species, forming a thick and continuous meadow over 99% of the lagoon surface. In contrast, *C. nodosa* develops only in the central part of the lagoon, opposite the tidal channel. The benthic macrofauna is mainly represented by the polychaetes *Nainereis laevigata* (Grube), *Capitella capitata* (Fabricius) and *Malacoceros fuliginosus* (Claparède), and by the amphipods *Gammarus insensibilis* Stock, *Microdeutopus gryllotalpa* Costa and *Corophium insidiosum* Crawford (Gravina, 1986).
The fish assemblage of Fogliano Lake consists mostly of marine species (seasonal migrants and occasional), but the most abundant species are two resident species, *A. boyeri* and *Aphanius fasciatus* (Manzo et al., 2006b).
Artisanal fisheries practiced in the lagoon include the use mainly of fyke-nets and trammel nets. In winter catch at the fish barrier also occurs, that capture adult fish when returning to sea. Until the mid-twentieth century, in the Fogliano Lake yields reached about 130 kg/ha (Fusari et al., 2006). Recent years the yield fell to 30-50 kg/ha (AGEI, 1997). The catches consist mainly of gilthead sea-bream, eel and crab.
The Caprolace Lake has an area of 226 ha, extending for a length of 3.68 km parallel to the coastline. The average depth is about 1.3 m (maximum depth is 2.9 m). It has a single communication with the sea, the San Niccolò Channel, about 250 m long

and 20 m wide (Fig. 2.4). A *lavoriero* is installed in the tidal channel, also managed by the fishermen.

Figure 2.4. Sampling stations in Caprolace Lake.

The tidal maximum amplitude is 21 cm, and theoretical renewal time of the water is estimated at about 90 days (Bono et al., 1985).

In the early 1980s, freshwater inputs were cut off due to the high level of nutrients flowing in the lagoon. As consequence, lagoon salinity increased and, at present, it ranges between 34.8 and 42.9, with an average annual value of 38. In the Caprolace Lake, the water temperature is also strongly influenced by air temperature due to the lagoon shallow depth, and range from 7.6 °C in winter to 28.6 °C in summer (Signorini et al., 2009b). pH values range between 8.1 in the coldest months and 9.5 in summer (Izzo et al., 2005).

Phytoplankton community includes 40 taxa, of which diatoms represent the 63%. As in Fogliano Lake, *A. japonica*, *C. affinis* and *C. striata* are among the most abundant (Fumanti et al., 1996). Calanoida is the most represented group in the zooplankton assemblage of Caprolace Lake, with *A. italica* being the most abundant species.

Benthic meroplankton autochthonous groups are also well represented (Manzo et al., 2006a).

The benthic vegetation of Caprolace Lake includes three Spermatophyta and several macroalgae. *C. nodosa* is the dominant species, covering 78.9% of the surface colonizing the central and deepest area of the lagoon. *R. cirrhosa* is present only near the tidal channel and *N. noltii* is limited to partially emerged areas (Signorini et al., 2009b). The benthic macrofauna is mainly represented by the polychaetes *Genetyllis rubiginosa* (de Saint-Joseph), *Glycera tridactyla* Schmarda and *Lumbrinereis latreilli* Audouin & Milne Edwards and by the bivalves *Venerupis aurea* (Gmelin) and *Tapes decussatus* (Linnaeus) (Gravina, 1986).

The fish assemblage of Caprolace Lake also consists mainly of marine species. Juveniles of euryhaline marine species including *L. aurata*, *L. ramada*, *L. saliens* and *S. aurata* are abundant (Manzo et al., 2006b), but the most abundant species is the resident species *A. boyeri*.

At present, fishing is carried out by means of *lavoriero*, fyke-nets and trammel nets. Over the years, the catch obtained from the Caprolace Lake has fallen drastically and actually yields 10-15 kg/ha (Tancioni et al., 1998) and consist mostly of eels, gilthead sea-breams and crabs (Fusari et al., 2006).

2.2 Sampling protocol

In the Lesina Lagoon, sampling was carried out once a month from October 2006 to August 2007 at nine sampling stations (Fig. 2.2), whereas in Circeo coastal lakes, samplings were carried out from March 2007 to February 2008 (with the exception of December 2007, that failed because of adverse weather) at four stations in each lake (Fig. 2.3 and 2.4).

Stations were chosen on the basis of some environmental characteristics (distance from tidal channels, salinity, distance from freshwater inputs, composition and quantity of vegetation cover and presence of human impacts). In Lesina Lagoon, stations L1 and L2 were near the Acquarotta channel; the bed here was covered by a meadow of *N. noltii*, in places mixed with macroalgal species such as *Cladophora* spp. Stations L3 and L5 were close to the mouths of intermittent freshwater channels in the central area of the lagoon; the muddy bed was sparsely covered with patches of seagrasses (*N. noltii* and *R. cirrhosa*) and macroalgae (generally *Cladophora* spp. and *Gracilaria* sp.). Stations L7 and L8 were located near the mouths of the year-round tributaries, where the bed was colonised by meadows of *R. cirrhosa*. Stations L4 and L6 were located on the seaward side in the central part of the lagoon. The bed at station L4 was characterized by a meadow of *N. noltii* with macroalgae in places. The bed at station 6 had mixed meadows of *N. noltii* and *R. cirrhosa*. Station L9 were located near the Schiapparo Channel; the muddy bed was covered by *R. cirrhosa* and to a lesser extent by *N. noltii*.

Moreover, L3 and L8 were situated in areas that received partially treated waste waters of three municipalities (for a total of about 30 000 inhabitants). L5 was placed in a zone in which waters drained from nearby arable land are discharged into the lagoon by the Pilla Channel. L1 and L7 were positioned in areas in which discharge effluents from buffalo and fish farms are carried on the western side by small channels and on the eastern side by the Zannella River.

In Fogliano Lake, station F4 was near the tidal channel where the bed was covered with meadows of *R. cirrhosa*. Stations F1, F2 and F3 were located away from the tidal channel. F1 was situated in the northern side of the lake close to the mouth of Mastro Pietro Channel; the bed was colonised by meadows of *R. cirrhosa* mixed with the macroalga *Chondria capillaris* (Hudson) M.J. Wynne. F2 was placed near the mouth of the Cicerchia Channel in the eastern side of the lagoon, where the bed was covered with meadows of *R. cirrhosa*. This area is affected by summertime anoxia (Signorini et al. 2009). F3 was located in the southern side of the lake near the mouth of Rio Martino River. Here the bed was covered with meadows of *R. cirrhosa* mixed with *Chaetomorpha linum* (O.F. Müller) Kützing.

In Caprolace Lake, stations C4 was close to the tidal channel; the bed here was covered by a meadow of *N. noltii*. The other stations were chosen in confined areas of the lake. The bed was covered with the seagrass *C. nodosa* at all stations. C1 was situated in the northern side of the lake near the Bufalara Channel. C2 was located in the southern side of the lagoon. In this area there is a buffalo farm. Finally, C3 were placed in the eastern side of the lagoon.

Fish were caught by trawling a manual beach seine (11 m long and 1.30 m high, the central section having a 2-mm mesh and the two lateral sections a 4-mm mesh) with a central bag (about 3 m long and 0.8 m in diameter with a 2-mm mesh) (Fig. 2.5). The area sampled in each haul was about 150 m^2. The fish were anaesthetised in Eugenol diluted in water and then fixed in 4% neutralized formalin solution.

Figure 2.5. Sampling of fish fauna in the lagoons of Lesina and Fogliano using manual beach seine.

At each sampling, water temperature, salinity, pH and dissolved oxygen were recorded using a YSI 6920 multi-parametric probe equipped with a 650 MPS data logger in Lesina Lagoon and a Hydrolab Datasonde 4a in Circeo coastal lakes. Only in the lakes of Fogliano and Caprolace, values of chlorophyll *a* were recorded using the multi-parametric probe and water samples were taken in duplicate for analysis of nutrients and turbidity.

In Lesina Lagoon, the recruitment of YOY marine fish were monitored during the maximum recruitment period for euryhaline marine species (Villani, 1998). Fortnightly between September 2006 and May 2007 a fyke-net with a 2-mm mesh and wings about 130 cm long was placed in each channel near the lagoon end for 24 hours with the mouth towards the sea (Fig. 2.6). The juvenile specimens captured were separated from the rest of the sample and fixed in 4% buffered formaldehyde. Due to the time dynamics that characterize the migration of glass eels while coloninizing continental waters, glass eel presence was monitored daily in Acquarotta Channel, in the period between January and March 2007, known to be the maximum recruitment period for *A. anguilla* in the Lesina Lagoon (Villani, 1998). Two fyke-nets, modified for the capture of the glass eels (1.6 m long, 0.43 m wide, with a 2 mm mesh and wings of different lengths - 1.3 m and 1.65 m) were placed on the two sides of the channel. Glass eels were counted *in situ* and a sub-sample of these was taken to the laboratory.

Figure 2.6. Sampling of young-of-the-year marine fish in the Acquarotta Channel using fyke-nets.

2.3 Laboratory analysis

In the laboratory, all specimens were identified at species level using the manuals of FAO, "I pesci delle acque interne italiane" and "Fauna d'Italia. Osteichthyes. Pesci ossei. Seconda parte" (Tortonese, 1975; Fisher et al., 1987; Gandolfi et al., 1991). Then fish were counted.

The standard length (SL) and weight were measured for YOY marine fish subsamples collected in the tidal channels of Lesina Lagoon. Glass eels were anaesthetised in Eugenol diluted in water, and their total length (TL) and weight were measured. Pigmentation stages were assessed for each individual according to the sequence defined by Elie et al. (1982). On waking, glass eels were returned to the lagoon.

The analysis of nutrients on water samples from lakes of Fogliano and Caprolace was performed using the following spectrophotometric methods:

- (Indophenol blue method) ammonium
- (diazotization method) nitrite
- (cadmium reduction method) nitrate
- (Ascorbic acid method) phosphorus.

Suspended particulate matter was concentrated using fibre-glass Whatman GF/F filters, then dried to determine the quantity of total suspended matter (TSM).

2.4 Data analysis

Total fish abundance (number of individuals) and species richness (the total number of species caught in each station) were calculated for each sampling station and sampling month. According to the use that they make of lagoon environments and their feeding behaviours, fish species were grouped by ecological and feeding guilds, following the definitions of Elliott and Dewailly (1995) and according to literature information on the biology of each species in Italian lagoon environments (Tortonese, 1975; Gandolfi et al., 1991). Six ecological guilds were detected in the study areas: resident species (R), marine seasonal species (MS), marine juvenile migrants (MJ), marine adventitious species (MA), freshwater adventitious species (FW) and catadromous species (C). Six feeding groups were identified:

planktivorous (PS), invertivorous (IS), invertebrate-fish feeders (IF), carnivorous fish (CS, other than PS, IS or IF), herbivorous-carnivorous (HC) and omnivorous feeders (OV). Total fish abundance for each of these functional guilds was calculated.

Two-way analysis of variance (ANOVA) was used to test for differences among stations and seasons in terms of species richness, total abundance, species diversity indices (Shannon (H) and Dominance (D) indices), number of species and individuals in each of these guilds. Monthly data were pooled by season. Abundance values were transformed using $\log_{10}(N + 1)$ in order to meet the assumption of homogeneity of variances. Tukey's test was used for post-hoc comparisons after ANOVA and p-values < 0.05 were considered significant.

Cluster Analysis and Non-metric multi-dimensional scaling (nMDS) were carried out, with Bray-Curtis similarity, to look into the differences in fish assemblages among all stations and months. Analysis of similarities (ANOSIM) was used to determine whether the fish assemblage separated by MDS ordination differed significantly ($p < 0.001$). As a post-hoc test, pairwise ANOSIM comparisons were made between all groups identified in the plots. p-values < 0.05 were considered significant. Both presence/absence and abundance data were used. Fish abundances were $\log_{10}(N + 1)$ transformed and averaged by sampling station and month.

Similarity percentage analysis (SIMPER) was used to determine which species contributed most to the differences, considering those species that contributed >50% of total average dissimilarity to be discriminators.

Finally, canonical correspondence analysis (CCA) was used to explore the relationships between species distribution and environmental variables. The annual averages of fish abundances were used. Rare species were excluded from the analysis to reduce their effects. For the analysis performed on fish assemblage of the Lesina Lagoon, vegetation coverage (VC), water temperature (T), salinity (S), pH, dissolved oxygen (OD), chlorophyll *a* concentration (Chla), total suspended matter (TSM), particulate organic matter (POM), soluble reactive silicate (SRSi) and dissolved inorganic nitrogen (DIN) were the environmental variables considered. Data for Chla, TSM, POM, SRSi and DIN were issued from a parallel study in the lagoon (Roselli et al., 2009). For the analysis performed on the fish assemblage of the Circeo coastal lakes, T, S, pH, OD, Chla, TSM, phosphate and nitrate concentrations were taken into consideration. VC was not considered in the analysis as it showed no relevant differences in composition and quantity in each coastal lake. Moreover, the option scaling type 2 of Legendre and Legendre (1998), available on PAST, was utilized to emphasizes the relationships among species.

All multivariate analyses were performed using PAST, version 1.92 (Hammer et al., 2001).

For the study on recruitment of the YOY marine fish at the tidal channels of Lesina Lagoon fish collected in all samplings of the same month were pooled and CPUE (Catch per Unit Effort) was calculated for each species as abundance per fyke-net, to evaluate the monthly variations in juvenile abundance in both tidal channels. The recruitment patterns of marine species juveniles were investigated by length-frequency distributions. For each species, fish from the fyke-net samplings were pooled and length-frequency distributions were produced on a monthly basis from the observed size distributions in the samples and from the total number of individuals. For each station of each lagoon basin and for each species, the abundances from temporal replicate seine hauls were pooled in order to study the spatial variation in juvenile abundance in the lagoon basin.

3. THE FISH ASSEMBLAGE IN LESINA LAGOON: STRUCTURE, FUNCTIONING AND SPATIO-TEMPORAL DYNAMICS

3.1 Results

3.1.1 Environmental parameters

Water temperature ranged from 9.4 °C (December at station L9) to 29.3 °C (July at station L6). Temperature showed a typical temporal trend with the highest mean values recorded in spring-summer months (Fig. 3.1). Mean water temperature showed the lowest value at L3 and the highest at L7.

Salinity values ranged from 8 (March at station L8) to 37.6 (August at station L2). The highest and lowest mean salinity values were obtained for late spring-summer and autumn-winter months, respectively (Fig. 3.1). Salinity, on the other hand, showed a spatial gradient along the length of lagoon. Stations of the western sub-basin of the lagoon (L1, L2, L3, L4) had higher values than those of eastern sub-basin (L5, L6, L7, L8, L9). Within each sub-basin, the stations nearer the tidal channels and located on the seaward side of the lagoon showed the highest values.

Dissolved oxygen attained the maximum value in December (189 % of saturation at station L7) and the minimum value in July (58.8 % of saturation at station L5). Autumn, winter and early spring months had higher mean values than late-spring and summer ones (Fig. 3.1). Instead, stations L3, L6 and L8 showed the highest mean values.

pH ranged from 7.6 (October at station L8) to 9.3 (March at station L1). The highest mean values were shown in March and April, whereas the lowest values in July and August (Fig. 3.1). In general, pH had lower mean values in the stations nearer the freshwater inputs (L5, L7, L8) than the others and had higher mean values in the western stations (L1, L2, L3 and L4) than the other ones.

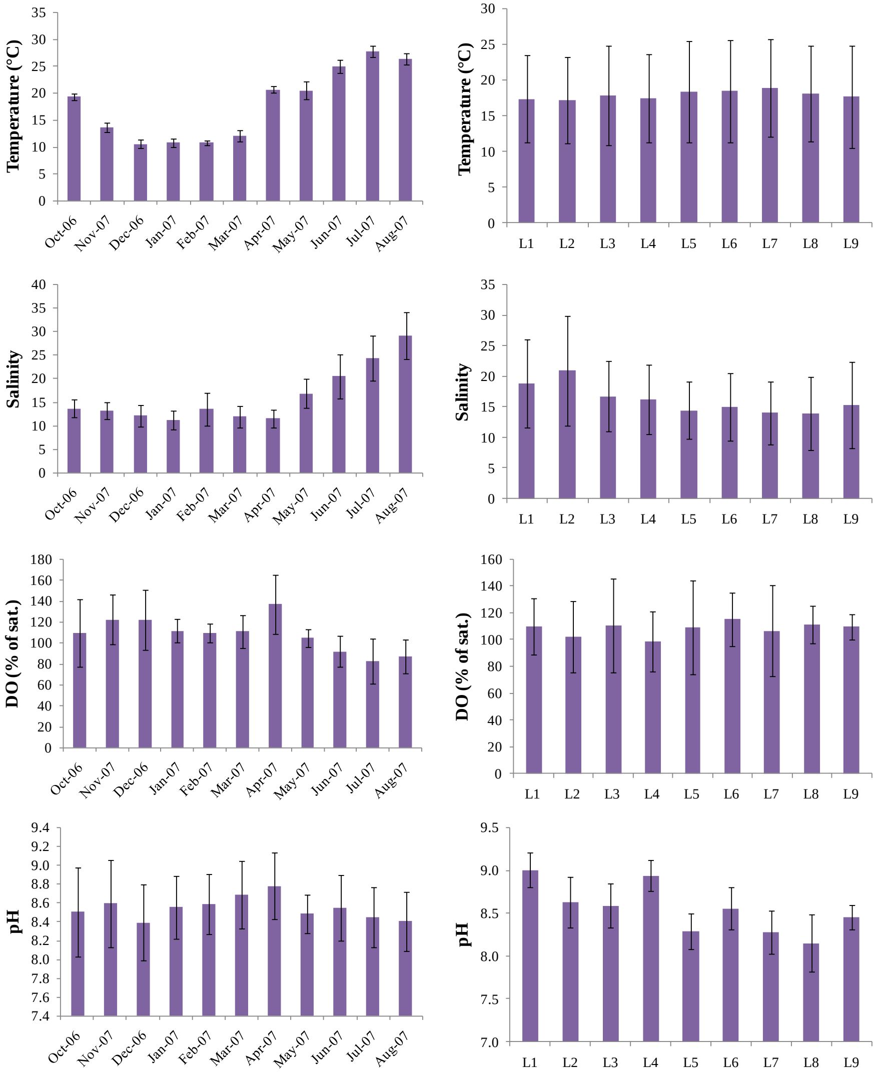

Figure 3.1. Temporal and spatial variations in mean (±SD) temperature, salinity, DO and pH in Lesina Lagoon.

3.1.2 Fish assemblage of Lesina Lagoon

During the study period, 38 028 specimens were captured, belonging to 15 species and 11 families (Table 3.1). Mugilidae was the family more represented (5 species).
Four ecological guilds were found: resident species (R) (6 species), marine juvenile migrants (MJ) (6), migrant marine species (MS) (2), and freshwater adventitious species (FW), the last of these represented by only one species, the non-indigenous Nile tilapia *Oreochromis niloticus*. In terms of abundance, R was the dominant ecological guild (35 708 specimens, about 94% of the total catches). *Atherina boyeri* was the most abundant species (15 255 specimens, 40% of the total catches), followed by *Aphanius fasciatus* (14 340 specimens, 38% of the total catches) (Fig. 3.2). The MJ guild accounted for about 6% of the total catches (2277 specimens), and was composed almost entirely of Mugilid species. The other guilds accounted for less than 1% together (43 specimens).
Among the feeding guilds, the most abundant group was that of invertebrate feeders (IS: 20 453 individuals, 54% of the total catches; 5 species), followed by carnivorous feeders (CS: 15 225 individuals, 40% of the total catches; 1 species), omnivorous fish (OV: 1332 individuals, 3.5% of the total catches; 4 species) and herbivorous-carnivorous fish (HC: 852 individuals, 2% of the total catches; 3 species). Invertebrate fish feeders (1 species) and plankton feeders (1 species) together accounted for less than 1% of the total abundance.

3.1.3 Temporal and spatial variations in abundance and diversity

Both species richness and total number of fish showed temporal patterns of variation, with the highest values reported in spring (Fig. 3.3a and c). In contrast, no clear spatial pattern was detected. However, the highest species richness and total abundance values were found at the stations located nearest to the tidal channels (stations L1, L2 and L9) (Fig. 3.3b and d).

Table 3.1. Total abundance (number of fish) of the species caught in each station of Lesina Lagoon. EG, ecological guilds; FG, feeding guilds.

Family	Species	Code	EG	FG	L1	L2	L3	L4	L5	L6	L7	L8	L9	*Total number*
Atherinidae	*Atherina boyeri*	Abo	R	CS	1776	2503	829	2523	976	874	2696	1688	1390	15255
Belonidae	*Belone belone*	Bbe	MS	IF	1	3	2	5	0	0	1	0	1	13
Cichlidae	*Oreochromis niloticus*	Oni	FW	HC	0	0	0	0	5	0	6	13	0	24
Cyprinodontidae	*Aphanius fasciatus*	Afa	R	IS	2002	4339	566	1496	2085	1089	1373	240	1150	14340
Engraulidae	*Engraulis encrasicolus*	Een	MS	PS	0	0	5	0	0	0	0	1	0	6
Gasterosteidae	*Gasterosteus aculeatus*	Gac	R	IS	0	0	0	1	0	0	1	40	10	52
Gobiidae	*Knipowitschia panizzae*	Kpa	R	IS	720	250	459	279	309	134	619	408	214	3392
Mugilidae	*Chelon labrosus*	Cla	MJ	OV	2	1	0	0	0	0	0	0	22	25
	Liza aurata	Lauj	MJ	HC	18	6	0	1	39	4	6	4	15	93
	Liza ramada	Lraj	MJ	OV	55	113	13	2	359	12	43	5	76	678
	Liza saliens	Lsaj	MJ	HC	35	74	29	8	657	5	11	14	19	852
	Mugil cephalus	Mcej	MJ	OV	96	33	8	4	270	1	206	1	2	621
Poeciliidae	*Gambusia holbrooki*	Gho	R	IS	11	13	3	22	53	94	79	148	144	567
Sparidae	*Sparus aurata*	Sau	MJ	OV	0	0	2	0	0	0	6	0	0	8
Syngnathidae	*Syngnathus abaster*	Sab	R	IS	338	248	337	357	113	110	222	150	227	2102
Total number					5054	7583	2253	4698	4866	2323	5269	2712	3270	38028

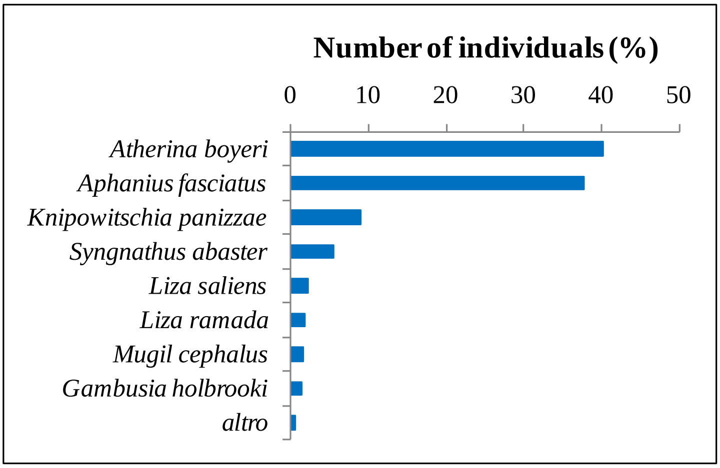

Figure 3.2. Total abundances of the species captured in the Lesina Lagoon.

ANOVA indicated highly significant differences in the mean species richness and diversity indices (Table 3.2). Species richness varied significantly among seasons ($p < 0.001$). Tukey's test showed that it was significantly higher in spring than in the other seasons. The Dominance and Shannon indices varied significantly among both stations and seasons ($p < 0.001$) and significant interactions between the two factors were detected ($p < 0.05$). Tukey's test indicated that the Dominance index value was significantly lower in spring than in autumn and winter and significantly lower in the station L2 than in L1. On the contrary, the Shannon index was significantly higher in spring than in the other seasons and significantly higher in the station L1 than in L2. In terms of ecological guilds, the number of R species showed significant variations across stations ($p < 0.01$) with a significant higher number of species in the station L3 than in the stations L8 and L9, as highlighted by Tukey's test. The number of MJ species showed significant seasonal variations ($p < 0.01$) and the number of species resulted significant higher in spring than in autumn and summer (Table 3.2).

Total fish abundance showed a significant seasonal variation ($p < 0.01$) with a significant higher value in spring than in autumn and winter (Table 3.2). The number of R fish varied significantly among seasons ($p < 0.01$), whereas MJ abundances varied significantly ac

ross stations ($p < 0.001$). Tukey's test showed that R fish abundance was significantly higher in spring than in the other seasons and that the number of MJ fish was significantly higher in the station L5 than in L3, L4, L6 and L8. Finally, ANOVA indicated significant variation of MS abundance among seasons ($p < 0.001$) and of FW abundance both among seasons and stations ($p < 0.01$ and $p < 0.05$, respectively), with significant interaction between the factor in the latter case ($p < 0.001$).

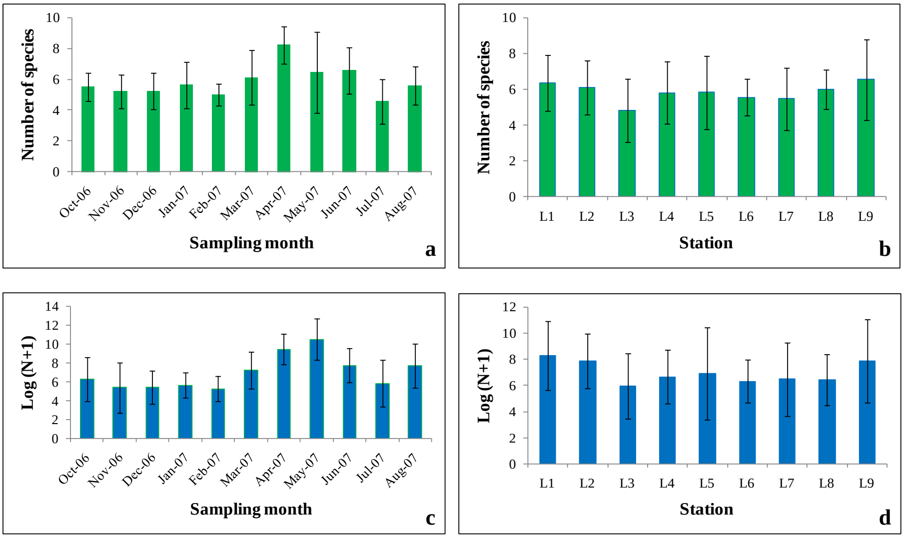

Figure 3.3. Differences in mean number of species and fish among months (a and c) and stations (b and d).

3.1.4 Fish assemblage structure: temporal and spatial variations

nMDS analysis was supported by cluster analysis performed on the same matrices. The nMDS ordination plots based on presence/absence and abundance showed clear monthly separation of samples and similar temporal patterns (Fig. 3.4). In both cases, the nMDS ordination plots separated the fish assemblages into two monthly groups and one individual month. In the ordination plot shown in Figure 3.4a, group

A consisted of autumn-winter months plus July, while group B included April, May and June, with August plotting separately from the others. In the nMDS ordination plot showed in Figure 3.4b, group A consisted of autumn-winter months and group B of spring months plus August, while July was separate. ANOSIM demonstrated that the identified groups were significant different in terms of both presence/absence ($R = 0.84$, $p < 0.001$) and abundance ($R = 0.91$, $p < 0.001$). Pairwise comparisons for the groups A and B resulted significant in both cases. SIMPER analysis showed that the majority (>50%) of total dissimilarity was accounted for by A. *fasciatus*, *Syngnathus abaster* Risso, *Liza ramada* juv., *Knipowitschia panizzae* and *Gambusia holbrooki* Girard (Table 3.2). All species showed the highest abundance in spring and August except *G. holbrooki* found with the highest abundance in July.

The assemblage structure also differed among sampling stations (Fig. 3.5). In the nMDS ordination plot based on presence/absence data, group A included stations L5, L6 and L8, located in the east of the lagoon (Fig. 3.5a). Group B consisted of stations L1, L2, L4, located in the western area of the lagoon, and station L9, located near the Schiapparo Channel. Stations L3 and L7 were separate from each other and from the others. ANOSIM calculated a p-value equal to the threshold ($R = 0.89$, $p = 0.001$) with significant pairwise comparisons for the groups A and B. The nMDS ordination plot based on abundance data showed two groups of stations and station L3 and L5 separate from each other and from both of groups (Fig. 3.5b). Group A consisted of stations L6, L7 and L8, located in the eastern sub-basin, and group B of stations L1, L2, L4, located in the western sub-basin, and L9, located near the Schiapparo Channel. ANOSIM showed also in this case a p-value equal to the threshold ($R = 0.84$, $p = 0.001$) with significant pairwise comparisons for the group B and L5. SIMPER revealed that the resident *A. fasciatus*, *A. boyeri*, *K. panizzae*, *S. abaster*, *G. holbrooki* and *Gasterosteus aculeatus*, and the YOY fish of *Liza aurata*, *L. ramada*, *Liza saliens* and *Mugil cephalus* accounted for most of the total dissimilarity (Table 3.3). The samples of group B showed higher abundance of *A. fasciatus* and *S. abaster* than the others. The samples of group A showed higher abundance of *G. holbrooki* and *G. aculeatus* than the other samples. L3 was characterised by the highest abundance of *K. panizzae* and the absence of *G. aculeatus* and *L. aurata* juv. Finally, L5 differed for the highest abundance of *L. aurata*, *L. ramada*, *L. saliens* and *M. cephalus* juveniles.

Table 3.2. Results of 2-way ANOVA performed on species richness, diversity indices, total abundance (log (N+1) transformed) and number of species and individuals (log10 (N+1) transformed) in each ecological guild. Levels of significance: ns, not significant; *p < 0.5; **p < 0.01; ***p < 0.001.

Source	Lesina Lagoon	Station		Season		Station x season	
df		8		3		24	
Species richness	**Mean square**	2.94		20.45		1.39	
	F Ratio	1.15	ns	7.99	***	0.54	ns
Dominance	**Mean square**	0.09		0.19		0.05	
	F Ratio	3.44	**	7.50	***	1.96	*
Shannon	**Mean square**	0.25		0.74		0.17	
	F Ratio	2.77	**	8.30	***	1.89	*
number of R species	**Mean square**	2.09		1.68		0.49	
	F Ratio	2.09	**	1.68	ns	0.49	ns
number of MJ species	**Mean square**	2.26		7.01		0.96	
	F Ratio	1.70	ns	5.29	**	0.72	ns
Total abundance	**Mean square**	0.30		1.02		0.14	
	F Ratio	1.45	ns	4.88	**	0.66	ns
R abundance	**Mean square**	0.47		0.94		0.16	
	F Ratio	1.89	ns	3.79	**	0.64	ns
MJ abundance	**Mean square**	1.43		0.48		0.35	
	F Ratio	3.90	***	1.31	ns	0.96	ns
MS abundance	**Mean square**	0.02		0.14		0.01	
	F Ratio	1.37	ns	8.44	***	0.88	ns
FW abundance	**Mean square**	0.04		0.08		0.05	
	F Ratio	2.49	*	5.21	**	3.43	***

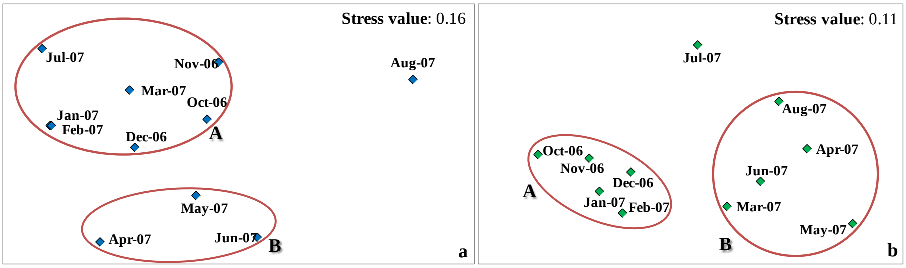

Figure 3.4. nMDS ordinations of months based on presence/absence (a) and abundance (b) of species collected in Lesina Lagoon. Stress values are given in top right corner of each plot.

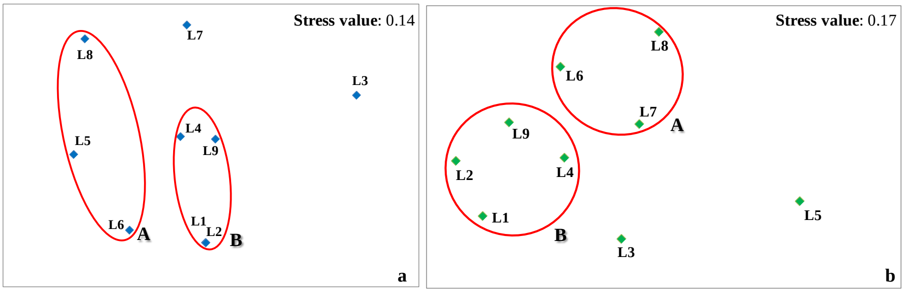

Figure 3.5. nMDS ordinations of sampling stations based on presence/absence (a) and abundance (b) of species collected in Lesina Lagoon. Stress values are given in top right corner of each plot.

Species distribution was found to be strongly influenced by environmental variables (Fig. 3.6). Juveniles of *L. ramada*, *L. saliens* and *M. cephalus*, characteristic of station L5, located near the intermittent Pilla Channel, were positively correlated with DO, DIN, SRSi and Chla, whereas they were negatively correlated with VC, pH and salinity. On the contrary, the resident *A. boyeri*, *G. holbrooki*, *K. panizzae* and *S. abaster* were positively correlated with temperature and negatively correlated with TSM, POM and chlorophyll *a* concentration, unlike *A. fasciatus*.

Table 3.2. Results of SIMPER analysis performed on fish abundance data of Lesina Lagoon. In the table, are reported the species which accounted for most of the total dissimilarity among groups and their mean abundance in each group.

Species	group A	group B	Jul-07
Aphanius fasciatus	0.71	1.93	1.70
Syngnathus abaster	0.80	1.30	0.78
Liza ramada juv.	0.12	0.51	0.07
Knipowitschia panizzae	1.07	1.38	0.42
Gambusia holbrooki	0.27	0.27	0.87

Table 3.3. Results of SIMPER analysis performed on fish abundance data of Lesina Lagoon. In the table, are reported the species which accounted for most of the total dissimilarity among groups and their mean abundance in each group.

Species	group A	group B	L3	L5
Aphanius fasciatus	1.28	1.67	0.95	0.92
Syngnathus abaster	0.80	1.26	1.15	0.72
Atherina boyeri	1.90	1.98	1.71	1.44
Liza ramada juv.	0.17	0.31	0.18	0.72
Gambusia holbrooki	0.58	0.35	0.07	0.42
Knipowitschia panizzae	0.99	1.24	1.32	1.11
Liza saliens juv.	0.16	0.33	0.26	0.71
Mugil cephalus juv.	0.14	0.21	0.13	0.55
Liza aurata juv.	0.09	0.16	0.00	0.25
Gasterosteus aculeatus	0.16	0.05	0.00	0.00

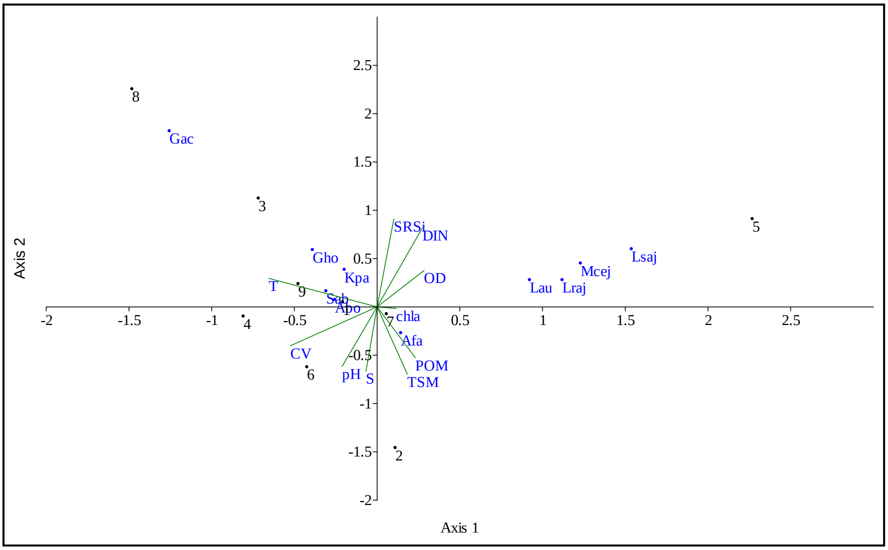

Figure 3.6. CCA plot of site and species sampled in Lesina Lagoon with 10 environmental variables in the first two CCA axis. Axis 1, 60% of the total variance; axis 2, 28% of the total variance. Codes of fish species were reported in Table 4.1.

3.2 Discussion

The fish assemblage structure in Lesina Lagoon reflects the structure found in other European and Mediterranean TW systems, characterised by a small number of opportunistic species quantitatively dominant (Pihl et al., 2002). The great abundance of the resident species *A. boyeri* is also common in other Mediterranean coastal lagoons (Andreu-Soler et al., 2003; Koutrakis et al., 2005; Franco et al., 2006b; Maci and Basset, 2009).

Most of the species found during the study are frequent in Mediterranean coastal lagoons (Pérez-Ruzafa et al., 2007) and only *G. aculeatus*, *K. panizzae* and *O. niloticus* are uncommon. The latter is an alien species in Italian TW systems and its presence in Lesina Lagoon is likely to be due to escapement from some neighbouring fish farms, and a successful colonization of some freshwater channels that flow in three lagoon (Florio et al., 2008). The other two fish species are, on the contrary, indigenous in Italian TW and freshwater systems, and present a fragmented geographical distribution. The discontinuous distribution of *G. aculeatus* is due to both the particular environmental requirements and numerous local extinctions of the species. In contrast, *K. panizzae* is a sub-endemic species in Italy and its native geographical distribution encompasses the continental water bodies of North Adriatic and Dalmatia. The population of Lesina Lagoon is a naturalised population originated from some individuals accidentally introduced with fry of commercial fish species, an occurrence shared with other water bodies of central-southern Italy (Zerunian, 2006). *K. panizzae* is listed in the Appendix III of the Bern Convention together with *A. fasciatus* and *S. abaster*; the species is also listed in the Annex II of the European Habitat and Species Directive together with *A. fasciatus* as "species of community interest whose conservation requires designation of special areas of conservation". No major widespread threats are instead known for *G. aculeatus*. However, the species has been listed as threatened in some areas of its range, such as in Croatia. In the Italian Red List it is considered vulnerable.

Notwithstanding, these similarities shared with Mediterranean coastal lagoons, the fish assemblage of Lesina Lagoon was found to be composed of a modest number of species if compared to the Mediterranean average (Pérez-Ruzafa et al., 2007; Franco et al., 2008). Indeed, a lower number of marine species and no marine adventitious species were found during the study if compared to most Mediterranean coastal lagoons (Pihl et al., 2002; Pérez-Ruzafa et al., 2007; Franco et al., 2008). Lacking was the Sparidae family, except for some juvenile individuals of gilthead seabream *Sparus aurata*, and the catadromous species *Anguilla anguilla* frequently found in Mediterranean lagoons (Pérez-Ruzafa et al., 2007).

The lower species richness can only partly be explained by the selectivity of the fishing method and by the sampling effort. Beach seines are appropriate for the capture of small fish (< 100 mm TL) and sedentary species (e.g., *A. boyeri*, *A. fasciatus*, Gobiidae, and YOY marine fish), which anyway predominate in coastal lagoons, and not for large and vagile fish (e.g., *A. anguilla*, *S. aurata*, *Dicentrarchus labrax* or *Diplodus* spp.), which may consequently be underestimated. Species richness in TW systems is generally affected, apart from sampling effort and methods used, to geographical variations in the distribution of marine and/or freshwater species, as well as to differences in size, morphology, hydro-dynamism, vegetation type and complexity, physical and chemical gradients of the TW systems, and to human-induced impacts (Kneib, 1997; Bianchi, 2007; Pérez-Ruzafa et al., 2007; Franco et al., 2008). In the case of Lesina Lagoon, the restricted list of fish species is most likely to be due to the system's high degree of confinement, i.e. the rate of renewal of seawater (sensu Guelorget and Perthuisot, 1983), which is a measure of marine influence. In several studies, species richness has been found to be related to the degree of marine and freshwater influence and the efficiency of the connections with the sea. In the coastal lakes of Fogliano and Caprolace, Mariani (2001) stated that the high number of marine species found was due to the lack of freshwater inputs and the efficiency of the connections with the sea, which increases the marine influence in the lakes. In the Vaccarès Lagoon, Poizat et al. (2004) linked the inter-annual fluctuation of freshwater and marine species to variations in the connections with the sea and the volume of freshwater inputs. Perez-Ruzafa et al. (2007) examined several Mediterranean lagoons and found a significant positive correlation of fish species richness with lagoon area, cross-section of the tidal channels and the openness parameter, which indicates potential marine influence on hydrological factors. They also found a negative correlation with the absolute difference between lagoon and marine salinities.

Lesina Lagoon is a very shallow basin and for this reason its hydrological conditions are strongly influenced by climatic conditions, particularly precipitation, continental inputs and exchanges with the sea, as asserted by Roselli et al. (2009). In addition, the nano-tidal range and the morphology and size of the tidal channels, especially of Acquarotta Channel, strongly limit communication with the open sea, keeping lagoon-sea exchanges to a minimum. The shallowness and the absence or minor steadying effect of the sea on the lagoon system probably make the environment less suitable for species which have little tolerance for sudden oscillations in environmental parameters. On the contrary, only a few opportunistic species (such as *A. boyeri*, *A. fasciatus* and Mugilidae) which are known to have a wide ecological amplitude, may live in and take advantage of this "naturally stressful environment" (*sensu* Elliott and Quintino, 2007).

The abundant rainfall of recent years and the resulting increasing inputs from rivers and drainage channels have affected the hydrological conditions of the lagoon. To this, the simultaneous decreased efficiency of the tidal channels due to engineering works must be added, together with the poor management of the sluices and *lavorieri*. As a consequence of this situation, water exchanges between sea and lagoon have become increasingly difficult, leading to a change in the hydrology and a weakening of environmental gradients, especially that of salinity, and therefore to a reduction of habitat heterogeneity. During the study period, salinity varied between 8 and 37.6, showing a reduction of the range if compared to the range measured in the 90s (5-51). In the following period, average salinity has decreased further on, attaining values around 10 in August 2008 (personal data). A further effect of the inadequate sea-lagoon water exchanges is the scarce flow throughout the tidal channels, that brings about an accumulation of nutrients from farmland and wastewater discharges from livestock and domestic sources. At the beginning of summer 2008, the eutrophication processes jointly with other causes (high water temperatures, absence of wind, microbial decomposition of vegetation biomass) has brought about a dystrophic crisis in the western sub-basin of the lagoon, with a production of sulphide fumes and extended fish mortalities. In contrast, the greater freshwater input and the more efficient sea-lagoon exchanges across the Schiapparo Channel have contributed to maintain an equilibrium in the eastern part of the lagoon (Roselli et al., 2009).

The state of the tidal channels also affects the nursery role of Lesina Lagoon. Many researchers emphasize the fact that juveniles of euryhaline marine species migrate to TW systems in response to olfactory cues carried by fresh or lagoon waters (Whitfield, 1999) or to the salinity gradient generated by the fresh or lagoon water outflow (Quinn et al., 1999). As a consequence, in Lesina Lagoon a lower efficiency of these connections brings about possibly a lower attractiveness exerted on marine juveniles in the open sea.

As regards the functional structure, Lesina Lagoon fish assemblage appears to be composed by approximately the same number of resident and marine migrant species. The functional composition showed some differences respect to the

Mediterranean average mainly due to a lower number of marine migrants and the absence of marine adventitious species observed in Lesina Lagoon (Franco et al., 2008). In contrast, as regards the feeding mode, the dominance of invertivorous was a common feature with European and Mediterranean TW fish assemblages (Franco et al., 2006a; 2008).

The fish assemblage structure and most ecological indices showed both temporal and spatial variations, with temporal patterns more pronounced than spatial ones. Total fish abundance and species diversity exhibited the highest values in warmer months. This temporal variation in ecological indices was accompanied by shifts in fish assemblage structure. Specifically, in Lesina Lagoon, monthly changes in fish assemblage structure were a consequence of the monthly shift in species abundance and composition, reflecting both spawning events within the lagoon and seasonal migration from the nearby marine environment, especially of YOY marine fish, as confirmed by ANOVA, MDS and SIMPER analysis and as found in other TWs of South Europe (Gordo and Cabral, 2001; Matic-Skoko et al., 2007; Ribeiro et al., 2006). Indeed, the marine migrants *Belone belone* and *Engraulis encrasicolus*, the juveniles of *Chelon labrosus* and *S. aurata*, and the only freshwater species *O. niloticus* colonised the lagoon during the warmer months primarily the spring ones likely because of the more stable environmental conditions. Furthermore, the highest abundance of marine juveniles also occurred in spring, mostly *L. ramada* juveniles, straight after the maximum recruitment period for marine species. This is consistent with the recruitment calendar observed during the study year (see Chapter 4) and the findings of previous studies in Lesina Lagoon (Villani et al., 1981-82; Priore et al., 1994; Villani, 1998). Finally, in spring and summer, except July, the fish assemblage was characterised by higher abundances of the resident species *A. fasciatus, K. panizzae, S. abaster* and *G. holbrokii* since they breed during spring; for some of them the reproductive period lasts until August (Cottiglia, 1980; Gandolfi et al., 1991), precisely when changes in their abundance occur.

The spatial analysis of the fish assemblage showed substantial differences in species composition and abundance between eastern and western stations, with the fish assemblage of the station near the Schiapparo Channel more similar to that observed in the western stations. The differences in the fish assemblages between the two sub-basins were due to the occurrence of some marine species, even if with low abundance, in the western stations and in the station near the Schiapparo Channel, and to the preference of the most dominant resident species for different sites. The fish assemblage at station L5, close to the freshwater Pilla Channel, differed from the others because of high abundances of Mugilid juveniles (*L. ramada*, *L. saliens* and *M. cephalus*), indicating that this area has an important function as a nursery ground for Mugilidae.

CCA analysis indicated that the high abundances of Mugilidae juveniles near the mouth of Pilla Channel, that discharges the waters drained from nearby arable land, may be due to a higher food availability of this area. In numerous lagoons production has been found to be significantly correlated with fluvial inputs, due to the high load of both nutrients and detritus carried downstream, which stimulate planktonic food webs (Hilmer and Bate 1991; Whitfield and Wooldridge 1994; Franco et al., 2006a). In addition, the organic substance-rich sediments that are found near freshwater inputs can constitute a source of food for Mugilidae (Marais, 1982; Gordo and Cabral, 2001).

In contrast, *G. aculeatus*, *G. holbrooki*, *K. panizzae* and *S. abaster* showed a preference for sites with warmer and more limpid water, and with a more developed vegetation coverage according to that found in literature (Zerunian, 2006). Conversely, *A. fasciatus* showed a predilection for more turbid water.

In particular, *G. aculeatus* and *G. holbrooki* characterised the eastern sites of the lagoon covered by meadows composed of *Ruppia cirrhosa* and more affected by freshwater inputs according to their environmental requirements. On the contrary, *S. abaster* and *K. panizzae* showed a preference for the western sites of the lagoon covered by meadows of *Nanozostera noltii*. In particular, the former species is closely associated with seagrass beds due to their specific morphological and behavioural adaptations (Howard and Koehn, 1985). Finally, *A. boyeri* was ubiquitous and abundant across all stations as found by Franco et al. (2006b) in Venice Lagoon, Koutrakis et al. (2005) in Porto-Lagos Lagoon and Maci and Basset (2009) in Acquatina Lagoon.

4. RECRUITMENT OF THE YOUNG-OF-THE-YEAR MARINE FISH TO LESINA LAGOON

4.1 Results

4.1.1 Environmental parameters

Temperature ranged from 5.8 °C in January to 26.6 °C in May, and from 6 °C to 25 °C, respectively in Acquarotta and Schiapparo channels (Tables 4.1 and 4.2). Salinity ranged from 10.1 in December to 39 in March in Acquarotta and from 7.8 in January to 39 in March in Schiapparo (Tab. 4.1 and 4.2). Dissolved oxygen ranged from 11.2% of saturation in October to 174.7% of saturation in April in Acquarotta and from 52% of saturation in May to 168.9% of saturation in April in Schiapparo (Tab. 4.1 and 4.2). pH ranged from 8.6 in May to 9.3 in April in Acquarotta and from 8.5 in May to 8.9 in October in Schiapparo (Tab. 4.1 and 4.2).

Table 4.1. Temporal variations in minimum and maximum values of temperature, salinity, DO and pH in Acquarotta Channel. MS, missing data.

	Temperature (°C)		Salinity		DO (% of sat.)		pH	
	min	max	min	max	min	max	min	max
September '06	22.9	23.4	36.6	38.4	72.0	96.8	MS	MS
October '06	15.3	23.4	16.2	30.1	11.2	115.4	8.6	9.0
November '06	10.3	13.1	15.5	15.7	82.0	126.0	8.5	8.7
December '06	10.0	12.6	10.1	16.2	82.0	152.2	8.1	8.9
January '07	5.8	11.2	13.8	20.0	87.8	110.5	8.5	8.7
February '07	9.5	11.0	16.0	20.0	MS	MS	8.4	8.6
March '07	11.3	15.3	14.0	39.0	92.0	132.0	8.3	8.8
April '07	18.4	22.6	14.2	16.0	85.1	174.7	9.1	9.3
May '07	22.1	26.6	19.4	36.2	52.0	91.5	8.6	8.9

4.1.2 Catch composition

In the tidal channels, a total of 24 047 YOY marine fish were captured entering the lagoon: 14 218 individuals in the Acquarotta Channel and 9829 individuals in the Schiapparo Channel (Tables 4.3 and 4.4). The Mugilidae family was the most represented with five species (*Chelon labrosus* (Risso), *Liza aurata*, *Liza ramada*, *Liza saliens* and *Mugil cephalus*). *L. ramada* was the species that recruited to the lagoon in largest numbers (66.7% of the total catches). *L. aurata* (16.9%) and *M.*

cephalus (15.2%) were also abundant, whereas *L. saliens* and *Sparus aurata* had a lower number of recruits (0.5%). *C. labrosus*, *Diplodus vulgaris* (Geoffroy Saint-Hilaire) and *Dicentrarchus labrax* were observed with few individuals. A total of 306 glass eels were captured in the Acquarotta Channel between January and February ‘07.

Table 4.2. Temporal variations in minimum and maximum values of temperature, salinity, DO and pH in Schiapparo Channel. MS, missing data.

	Temperature (°C)		**Salinity**		**DO (% of sat.)**		**pH**	
	min	**max**	**min**	**max**	**min**	**max**	**min**	**max**
September '06	22.3	23.8	16.1	38.6	78.6	96.0	MS	MS
October '06	15.7	23.3	11.7	37.2	65.4	112.8	8.2	8.9
November '06	11.2	13.4	11.7	12.0	98.1	160.9	8.4	8.5
December '06	10.1	12.4	9.3	15.8	98.1	160.9	8.4	8.5
January '07	6.0	10.2	7.8	18.0	91.1	120.0	8.4	8.6
February '07	8.0	11.0	16.0	36.0	MS	MS	8.3	8.5
March '07	10.9	15.3	11.0	39.0	89.0	109.0	8.3	8.5
April '07	17.7	22.3	11.0	28.3	103.0	168.9	8.3	8.5
May '07	22.0	25.0	14.6	36.2	52.0	85.3	8.5	8.6

The highest CPUE values of YOY marine fish were recorded in winter months (Fig. 4.1). In Acquarotta Channel, YOY fish recruited with the largest number of individuals between December and February. In contrast, in Schiapparo Channel, they migrated into the lagoon with the highest abundances in November and, in a greater number, in January.

A total of 2277 juveniles of euryhaline marine species were captured from October 2006 to August 2007 (see Chapter 3). *L. saliens* was the most abundant species, accounting for 37.4% of the total catches, followed by *L. ramada* (29.8% of total catches), *M. cephalus* (27.3% of total catches), *L. aurata* (4.1% of total catches), *C. labrosus* (1.1% of total catches) and *S. aurata* (0.3% of total catches).

Table 4.3. Species composition, number of individuals (N) and catch per unit effort (CPUE) within Acquarotta Channel

Acquarotta	Sep		Oct		Nov		Dec		Jan		Feb		Mar		Apr		May		Total
	N	CPUE	N	CPUE	N	CPUE	N	CPUE	N	CPUE	N	CPUE	N	CPUE	N	CPUE	N	CPUE	N
Chelon labrosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	11	0	0	21
Dicentrarchus labrax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1
Diplodus vulgaris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	3	0	0	6
Liza aurata	0	0	9	3	4	4	654	327	192	96	2099	2099	291	146	54	27	0	0	3303
Liza ramada	0	0	0	0	0	0	2253	1127	5240	2620	1332	1332	262	131	277	139	1	1	9365
Liza saliens	1	1	46	15	0	0	0	0	1	1	0	0	10	5	67	34	0	0	125
Mugil cephalus	0	0	1107	369	0	0	52	26	6	3	0	0	1	1	121	61	0	0	1287
Sparus aurata	0	0	0	0	0	0	1	1	0	0	9	9	61	31	39	20	0	0	110
Total	1	1	1162	387	4	4	2960	1480	5439	2720	3440	3440	625	313	586	293	1	1	14218

Table 4.4. Species composition, number of individuals (N) and catch per unit effort (CPUE) within Schiapparo Channel

Schiapparo	Sep		Oct		Nov		Dec		Jan		Feb		Mar		Apr		May		Total
	N	CPUE	N	CPUE	N	CPUE	N	CPUE	N	CPUE	N	CPUE	N	CPUE	N	CPUE	N	CPUE	
Anguilla anguilla	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1
Liza aurata	0	0	58	19	231	231	78	39	103	52	297	297	1	1	0	0	0	0	768
Liza ramada	0	0	0	0	8	8	48	24	6155	3078	463	463	0	0	2	1	1	1	6677
Liza saliens	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1
Mugil cephalus	4	4	716	239	1639	1639	15	8	0	0	0	0	0	0	1	1	0	0	2375
Sparus aurata	0	0	0	0	0	0	0	0	4	2	1	1	2	1	0	0	0	0	7
Total	4	4	774	258	1878	1878	142	71	6263	3132	761	761	3	1.5	3	1.5	1	0.5	9829

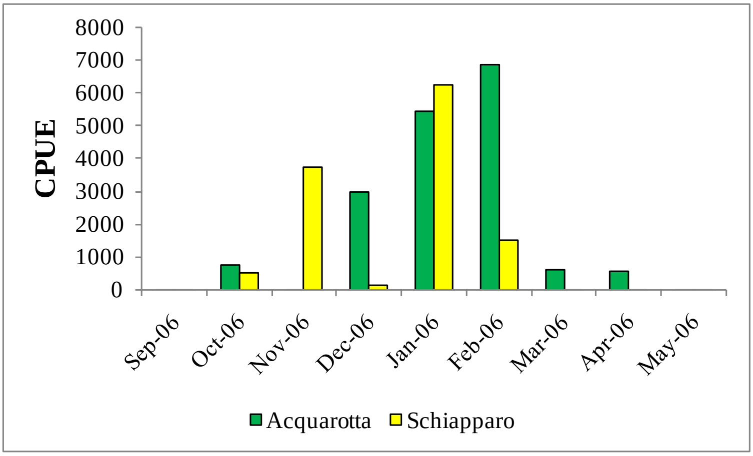

Figure 4.1. CPUE values of the young-of-the-year marine fish captured in the tidal channels of Lesina Lagoon.

4.1.3 Recruitment timing, size distributions and spatial abundance patterns

Liza ramada

L. ramada YOY fish were consistently collected from November 2006 to May 2007 at a size ranging from 12.5 to 24 mm SL. In both tidal channels, the abundance peak was recorded in January (Fig. 4.2). Small individuals (<15 mm) occurred in the catches twice, from November to December and in February. The length-frequency distributions showed the presence of two modes: a first one from December to January, a second one in February. Although the presence of two modes, the length-frequency distributions showed the progression of a single abundant cohort (Fig. 4.3).

Juveniles occurred in all stations sampled in the lagoon basin (Fig. 4.5). The highest juvenile catches occurred at station L5 (52.9%), situated near the mouth of Pilla Channel, and in much lower number at the stations L2 (16.7%) and L9 (11.2%), located near the tidal channels, and L1 (8.1%) and L7 (6.3%), located near the mouths of Cannelle Channel and Zannella Channel, respectively.

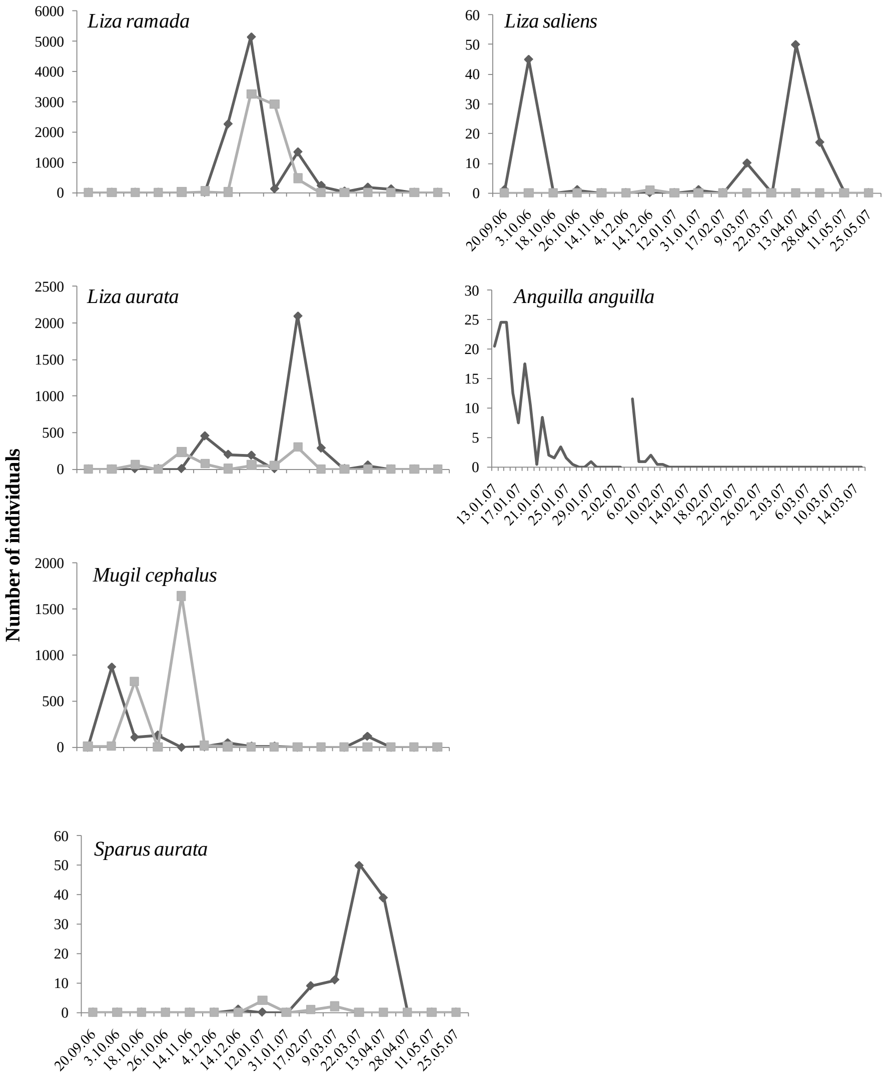

Figure 4.2. Abundances of the young-of-the-year marine fish captured in each sampling in each tidal channel. Acquarotta Channel, light grey; Schiapparo Channel, dark grey.

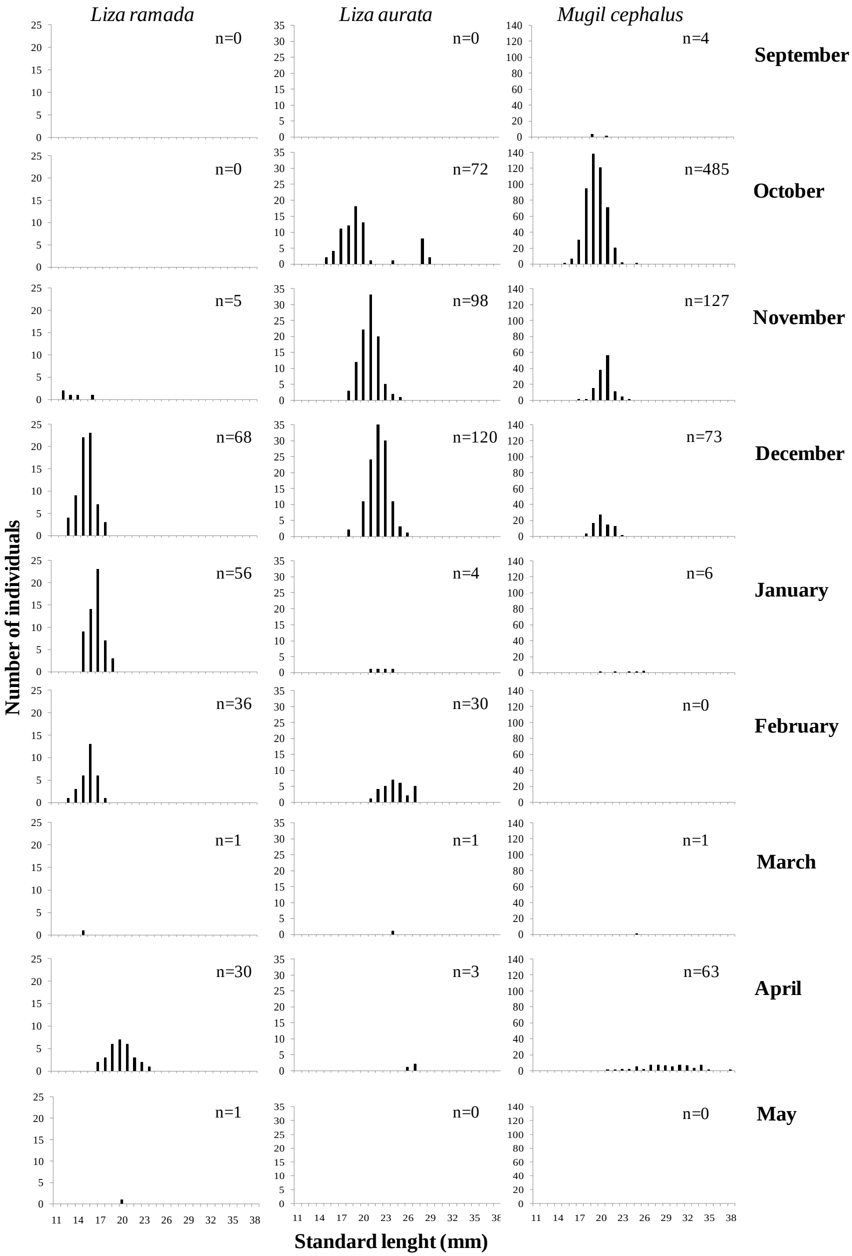

Figure 4.3. Monthly lenght-frequency distributions of *Liza ramada*, *Liza aurata* and *Mugil cephalus* juveniles collected in the tidal channels of Lesina Lagoon. The y-axes are scaled differently across species.

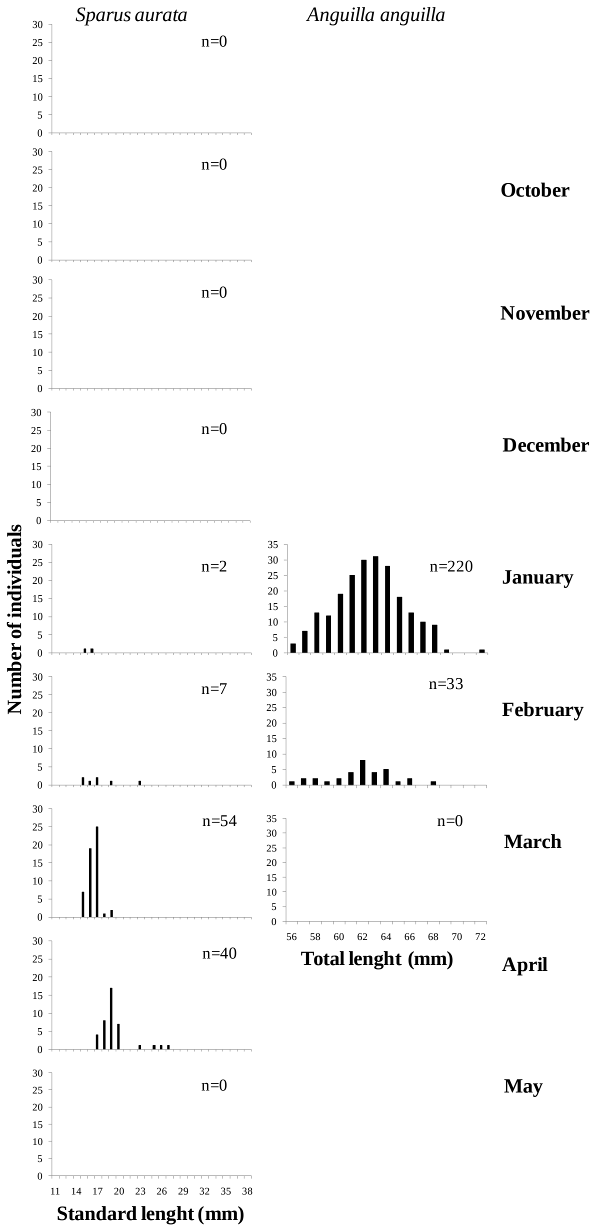

Figure 4.4. Monthly lenght-frequency distributions of *Sparus aurata* and *Anguilla anguilla* juveniles collected in the tidal channels of Lesina Lagoon. The y-axes are scaled differently across species.

Liza aurata

L. aurata YOY fish were collected from October 2006 to April 2007 at a size ranging from 15 to 27.9 mm SL. The recruitment of small individuals (<20 mm) occurred from October to December.

In each of the two tidal channels, two abundance peaks were recorded (Fig. 4.2). In the Acquarotta Channel, the first peak was observed in December, whereas a second peak, higher than the first one, was observed in February. In the Schiapparo Channel, the two peaks, of similar amplitude, were recorded in November and February. The length-frequency distributions showed the presence of two modes in October: a first one which progressed until February, a second one which disappeared in the following distributions, indicating the presence of two distinct cohorts (Fig. 4.3). The collection of a few larger individuals in October suggests that the recruitment of a second cohort might occur, but of low abundance.

In the lagoon, juveniles occurred in all stations investigated except in station L3 (Fig. 4.5). The highest juvenile catches occurred in station L5 (41.9%).

Mugil cephalus

M. cephalus YOY fish were collected from September 2006 to January 2007 and from March to April 2007 at a size ranging from 15.6 to 38.1 mm SL. The recruitment of small individuals (<20 mm) occurred from October to December. In each of the two tidal channels, the highest abundances were recorded in autumn: in October and December in the Acquarotta Channel, and from October to November in Schiapparo Channel (Fig. 4.2). Additionally, in the Acquarotta Channel, a peak of lower extent was observed in April. The length-frequency distributions showed the progression of a single abundant cohort (Fig. 4.3).

M. cephalus recruits were distributed in all stations in the lagoon (Fig. 4.5). The highest number of juveniles was captured at station L5 (43.5%) and, in lower extent, at stations L7 (33.2%) and L1 (15.5%).

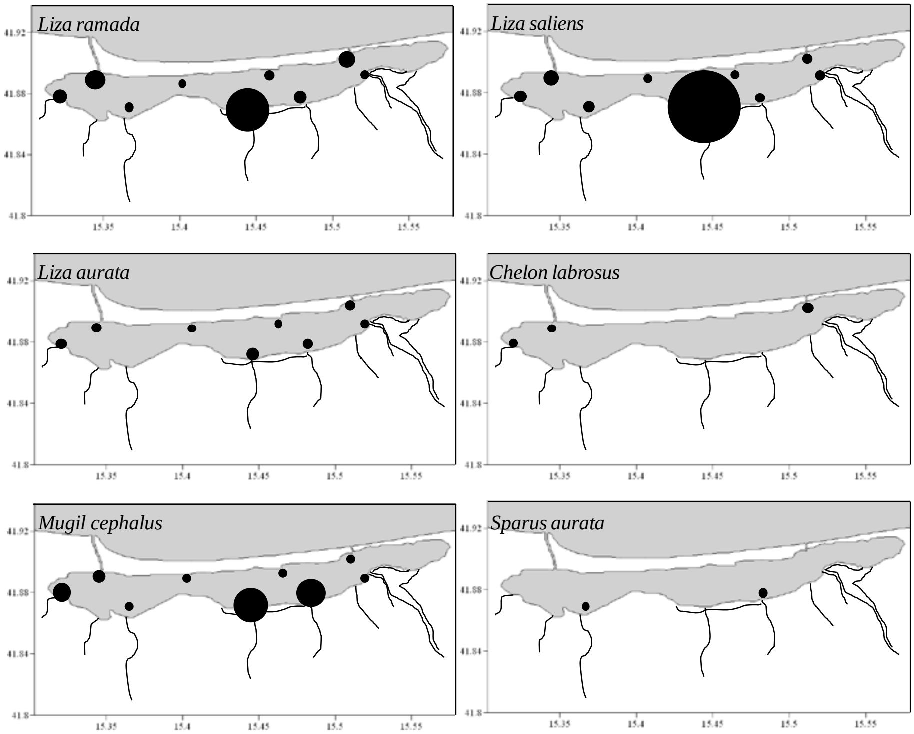

Figure 4.5. Spatial distribution of the juveniles of six species in Lesina Lagoon. Circle size is proportional to the abundance of the species in the station.

Liza saliens

Few YOY fish of *L. saliens* were intermittently collected all along the study period at a size ranging from 11.2 to 30.9 mm SL. The recruitment of *L. saliens* juveniles was very low at the Schiapparo Channel during in the course of the study period (Fig. 4.2). In the Acquarotta Channel, two main recruitment moments were recorded, a first in October and a second one in March and April. It was not possible to work out length-frequency distributions due to the small number of juveniles caught in the tidal channels. It's likely that the observations to the tidal channels started after the maximum recruitment period for this species.

In contrast, a large number of *L. saliens* Y-O-Y fish were captured within the lagoon basin. They were spread in all stations (Fig. 4.5). The highest number of juveniles was captured at station L5 (77.1%) and, in lower extent, at station L2 (8.7%).

Chelon labrosus

A low number of *C. labrosus* YOY fish was collected in April 2007 in the Acquarotta Channel at a size ranging between 18.0 and 22.0 mm SL (Fig. 4.2).

In the lagoon basin, *C. labrosus* recruits were distributed only in the stations L1, L2 and L9, with the highest abundance occurring in the latter one (88.0%) (Fig. 4.5).

Sparus aurata

S. aurata YOY fish were collected from December 2006 to April 2007 at a size ranging from 15 to 27.8 mm SL. The highest number of individuals was captured in the Acquarotta Channel in late March-early April (Fig. 2). Small individuals (<20 mm) occurred in the catches in all the recruitment period. The length-frequency distributions showed the progression of a single cohort (Fig. 4.4).

A small number of *S. aurata* recruits were captured in the lagoon basin at the stations L3 and L7 (Fig. 4.5).

Anguilla anguilla

Glass eels were collected from January to February 2007 at a size ranging from 56.2 to 72 mm TL in the Acquarotta Channel. The highest abundance was recorded in January (Fig. 4.2). In January, the length-frequency distribution showed the presence of a single mode (Fig. 4.4). In February, the length-frequency distribution was more homogeneous.

The pigmentation process, that takes place in the course of glass eel migration in continental waters, provides an indication of the timing of the migration. Figure 4.6 shows that in early January most glass eels were transparent, as shown by the high frequencies of the early pigment stages (VB late - VIA0 early). Pigmented stages (early and late VIA1) were progressively more abundant in the following samples. Toward the end of the month, a new migration event occurs, as shown by the fact that samples are again mostly, or completely, represented by unpigmented stages. In February, pigmented elvers are present in the samples, up to stage VI2, probably glass eels in a transition phase within the channel.

No glass eels were captured inside the lagoon.

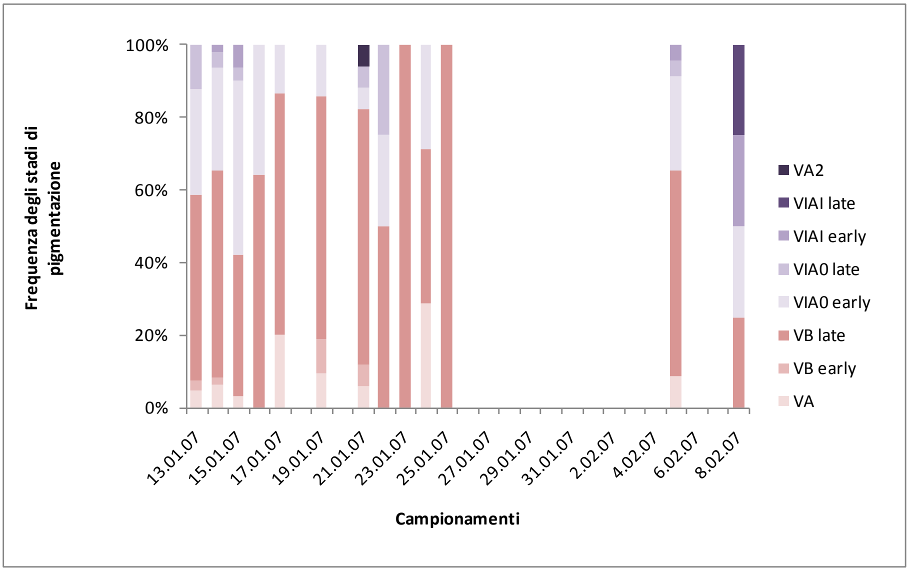

Figure 4.6. Frequency-distribution of the initial and final pigment stages in glass eels.

4.2 Discussion

The monitoring of recruitment to the Lesina Lagoon shows that the lagoon acts as a nursery mainly for the Mugilids, in agreement with what has already been observed in previous studies conducted in the area (Villani, 1998). No reduction in the number of YOY marine fish is observed with respect to previous studies (Villani et al., 1981-82; Priore et al., 1994; Villani, 1998). The pattern here observed is also similar to those recorded in the same region and in many other brackish areas of the Mediterranean, with *L. ramada*, *L. saliens*, and *L. aurata*, or in some cases *M. cephalus*, accounting for the largest number of recruits, together with smaller numbers of glass eels, sea-bass and sparids, especially *S. aurata* (Torricelli et al., 1981-82; Rossi and Franzoi, 1988; Iannibelli et al., 1989; Villani, 1998; Koutrakis, 2004). The prevalence of Mugilids among recruiting fish is in accordance with the catch of the artisanal fisheries in the lagoon, that yields mostly Mugilids (Rossi and Villani, 1980; Lumare and Villani, 1989).

The small number of juveniles of *D. labrax* and of family Sparidae found in Lesina Lagoon cannot be attributable to the lack of suitable reproduction grounds or to variations in geographical distributions of the species in the two sides of Italy. Sea bass, as well as many species of family Sparidae are well spread in Mediterranean Sea. They are more frequent along the western Mediterranean coasts than beside the eastern ones. In Italy, *D. labrax* recur mostly along the North Tyrrhenian and North Adriatic coasts, whilst *S. aurata* and species of genus *Diplodus* (i.e., *D. annularis*, *D. puntazzo*, *D. sargus* and *D. vulgaris*) are very common along the all Italian coastline (www.fishbase.org). Conversely, the amount of glass eels which migrate into TW systems is greater on the Tyrrhenian side than Adriatic one (Villani et al., 1981-82; Ciccotti et al., 2000). Migration of glass eels into the Lesina Lagoon was found to be quantitatively decreased, as along the entire Italian Adriatic coastline, according to the recent studies on the Adriatic region (Villani et al., 1981-82; Villani, 1998), also reflecting the marked decline in recruitment in Europe as a whole, not limited to the Mediterranean (Moriarty and Dekker, 1997; ICES, 2008).

In all probability the recruitment of euryhaline and valuable marine species of economic interest, generally assumed by some authors as modest to Lesina Lagoon (Villani et al., 1981-82; Priore et al., 1994; Villani, 1998), is affected by the low efficiency of the sea connections due to their morphology and consequent hydrodynamism. The modest flows of these channels and the limited tidal range of the marine waters off the lagoon (about 30 cm, Ficca et al., 1995), distinctive of most Mediterranean coastal lagoons, may limit the numbers of recruits entering the lagoon, reducing the “appeal” of the lagoon to YOY marine fish.

The study has enabled to confirm the migration calendar of the economically important marine species entering Lesina Lagoon (Fig. 4.7). Results are comparable to those already available for the same study area (Villani et al., 1981-82; Villani, 1998) and for other Mediterranean TW systems (Bograd, 1961; Cambrony, 1984; Rossi, 1986; Vidy and Franc, 1992), with most of the species recruiting with the highest number of specimens in winter. On the other hand, differences were observed with respect to brackish areas in the Italian coasts (Gandolfi et al., 1981; Torricelli et al., 1981-82; Rossi and Franzoi, 1988) and the coasts of Greece (Katselis et al., 1993; Koutrakis et al., 1994; Koutrakis, 2004), where the maximum recruitment of *L. aurata* and *L. ramada* occurs in spring. This discrepancy may be due to differences in the distance from the coast to the reproductive areas, as well as to local climatic factors (Rossi, 1986).

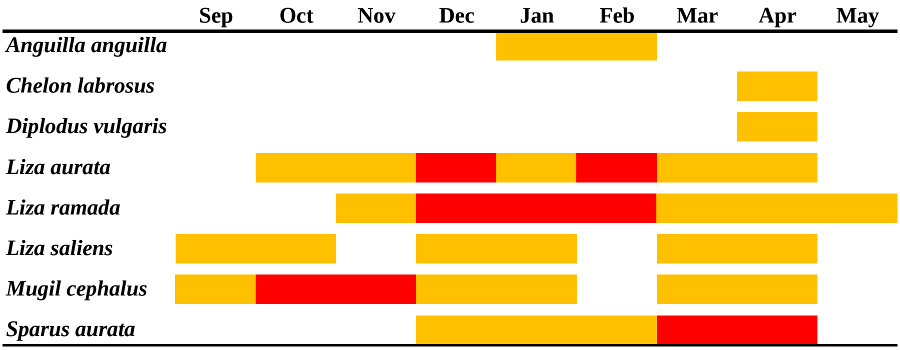

Figure 4.7. Recruitment calendar of the marine species captured in the tidal channels during the study period. Presence, yellow bars; abundant presence, red bars.

All species, except for *L. aurata*, showed one single cohort, which is the result of a specific spawning event (Breder and Rosen, 1966; Maitland and Campbell, 1992). In contrast, the two cohorts of *L. aurata*, likewise found in the estuarine systems of Strymonikos Gulf (Greece) by Koutrakis (2004), could be the result of two spawning events of different intensities or more likely of a single protracted spawning event.

Inside the lagoon, the dispersion of marine juveniles was not consistent among the stations. *L. aurata*, *L. ramada*, *L. saliens* and *M. cephalus* juveniles showed a clear preference for the area situated near the mouth of the Pilla Channel (station L5), where the largest number of individuals of each species was caught. Moderately high abundances of *L. ramada* and *M. cephalus* juveniles were found at stations L1 and L7, located near the mouths of the Cannelle Channel and Zannella River, where effluent is discharged from the buffalo and fish farms. These findings indicate that these areas function as nursery grounds for these two species. The high abundances of *L. ramada*, *L. saliens* and *M. cephalus* juveniles were found at stations L2 and L9, but they should be regarded as passing areas from tidal channels to nursery grounds.

Canonical Correspondence Analysis evidenced positively correlations between the occurrence of YOY fish of Mugilidae, and dissolved oxygen, chlorophyll *a* concentration and, in lower extent, soluble reactive silicate and dissolved inorganic nitrogen (see Chapter 3). These factors commonly show high values near the freshwater inputs (Roselli et al., 2009). Cardona (2006), studying the habitat selection by Mugilidae species in Mediterranean estuaries, indicated that *L*. *ramada* and *M*. *cephalus* seem prefer fresh or oligohaline waters, while *L*. *aurata* and *L*. *saliens* concentrate in polyhaline and euhaline sites. Different requirements of juvenile stages for most of the environmental factors with respect to the adults can explain the apparent discrepancy (Elliott and Hemingway, 2002). Most likely is the increased availability of food to drive the massive colonization of Mugilidae juveniles in the sites near the drainage channels in Lesina Lagoon as extensively explained in Chapter 3.

5. FISH ASSEMBLAGES IN TWO CIRCEO COASTAL LAKES: STRUCTURE, FUNCTIONING AND SPATIO-TEMPORAL DYNAMICS

5.1 Results

5.1.1 Environmental parameters

Water temperature ranged from 9.6 °C (January at station F1) to 27 °C (August at station F2) in Fogliano Lake and from 11.1 °C (January at stations C2 and C4) to 28.3 °C (August at station C3) in Caprolace Lake. A seasonal variation of mean values was observed, notwithstanding some missing data due to temporary inefficiency of the probe (Tables 5.1 and 5.2). Mean water temperature showed the lowest value at F1 and the highest value at F4 in Fogliano Lake (Table 5.3). In Caprolace Lake, the mean water temperature values were similar in all stations.

Salinity values ranged from 34 (April at station F2) to 53 (August at station F1) in Fogliano Lake and from 36 (July at stations C1 and C4; August at station C4) to 45 (November at stations C1, C2 and C3; January at stations C1 and C2) in Caprolace Lake. The lowest mean salinity values were recorded in the stations close to the tidal channels (F4 and C4) (Tables 5.1 and 5.2), and the highest values in the stations F1, F3 and C2 (Table 5.3).

Dissolved oxygen attained the minimum value in July (3.1 mg/l) and the maximum value in January (10.3 mg/l) at station F1. In Caprolace Lake, instead, the minimum value (3.6 mg/l) was reached in July in the station C2 and the maximum value in November (10.6 mg/l) in C1. Summer months had the lower mean values, while January the highest in both coastal lakes (Tables 5.1 and 5.2). Stations F2 and C2 showed the lowest mean values (Table 5.3).

pH ranged from 7.9 (January at station F2) to 10.0 (July at station F2) in Fogliano Lake, and from 7.8 (March at station C4) to 9.8 (May at station C1) in Caprolace Lake. In Fogliano Lake, the minimum mean value was in January and the maximum was reached in July (Table 5.1). In Caprolace Lake, the lowest mean value was shown in March and higher in the other months (Table 5.2). In each coastal lake, there were not relevant differences in pH mean values (Table 5.3).

Table 5.1. Mean hydrological parameters ± SD and chlorophyll *a* concentration ± SD at different months recorded in Fogliano Lake from March 2007 to February 2008. MS, missing data.

Station	Temperature (°C)	Salinity	Dissolved oxigen (mg l^{-1})	pH	Chlorophyll *a* (mg l-1)
Mar-07	16.5 ± 0.2	37.6 ± 0.6	7.3 ± 0.4	9.0 ± 0.1	3.4 ± 1.0
Apr-07	19.1 ± 1.0	36.3 ± 2.2	7.0 ± 1.9	9.0 ± 0.1	4.8 ± 5.6
May-07	16.5 ± 0.2	37.6 ± 0.6	7.3 ± 0.4	9.0 ± 0.1	3.4 ± 1.0
Jun-07	MS	MS	MS	MS	MS
Jul-07	25.4 ± 0.5	39.8 ± 0.5	4.0 ± 1.0	9.7 ± 0.2	2.9 ± 0.0
Aug-07	26.1 ± 1.3	51.0 ± 3.3	3.9 ± 0.8	9.5 ± 0.1	4.9 ± 1.2
Sep-07	21.7 ± 0.3	50.5 ± 3.4	MS	9.3 ± 0.1	3.7 ± 0.5
Oct-07	MS	MS	MS	MS	MS
Nov-07	13.0 ± 0.7	43.8 ± 3.9	6.2 ± 0.6	9.3 ± 0.0	MS
Jan-08	9.9 ± 0.5	36.6 ± 0.3	8.8 ± 1.6	8.1 ± 0.2	3.5 ± 0.4
Feb-08	14.5 ± 0.5	43.3 ± 3.3	7.2 ± 1.0	MS	MS

Table 5.2. Mean hydrological parameters ± SD and chlorophyll *a* concentration ± SD at different months recorded in Caprolace Lake from March 2007 to February 2008. MS, missing data.

Station	Temperature (°C)	Salinity	Dissolved oxigen (mg l^{-1})	pH	Chlorophyll *a* (mg l-1)
Mar-07	15.6 ± 0.1	38.5 ± 0.1	7.4 ± 1.1	8.5 ± 0.4	1.9 ± 0.4
Apr-07	21.1 ± 0.3	40.8 ± 0.5	7.7 ± 1.7	9.1 ± 0.2	2.6 ± 0.4
May-07	21.7 ± 0.4	40.4 ± 0.2	5.8 ± 0.3	9.5 ± 0.2	3.9 ± 0.2
Jun-07	MS	MS	MS	MS	MS
Jul-07	25.1 ± 0.4	37.3 ± 1.9	5.5 ± 1.3	9.6 ± 0.1	2.8 ± 0.6
Aug-07	27.3 ± 0.7	38.0 ± 1.6	5.4 ± 1.5	9.4 ± 0.1	3.2 ± 0.7
Sep-07	24.2 ± 0.3	40.0 ± 0.8	6.2 ± 1.0	9.5 ± 0.1	2.5 ± 0.3
Oct-07	MS	MS	MS	MS	MS
Nov-07	13.4 ± 0.3	44.0 ± 2.0	10.0 ± 0.8	9.3 ± 0.1	2.4 ± 0.6
Jan-08	11.2 ± 0.1	44.0 ± 1.4	8.8 ± 0.5	MS	MS
Feb-08	14.3 ± 1.2	39.0 ± 0.8	7.4 ± 0.7	MS	MS

Chlorophyll *a* ranged from a value nearer to 0 mg/l (April at stations F1 and F4) to 10.7 mg/l (April at station F3) in Fogliano Lake and from 1.5 mg/l (March at station C3) to 4.1 mg/l (May at station C2). Mean values were higher in April and August and in May and August than the other months, respectively in Fogliano and in Caprolace lakes (Tables 1 and 2). Chlorophyll *a* showed the lowest value in F4 and the highest in F3 in Fogliano Lake (Table 5.3). In Caprolace Lake, the mean values were lower in C3 and higher in C2 than in the other stations.

The highest ammonium concentrations were reached in May (0.08 mg/l) in both coastal lakes, while the lowest mean values were recorded in November (0.01 mg/l) in Fogliano Lake and in July and November (0.01 mg/l) in Caprolace Lake. On the other hand, stations F2 (0.04 mg/l) in Fogliano Lake and C2 and C3 (0.03 mg/l) in Caprolace Lake had the highest mean values (Fig. 5.1).

The highest concentrations of nitrite were recorded in April in both lakes (0.031 mg/l and 0.035 mg/l, respectively), while the lowest value were detected in July (0.007 mg/l) in Fogliano Lake and in February (0.011 mg/l) in Caprolace Lake. In both coastal lakes, the stations showed no considerable differences in mean nitrite concentrations among them (Fig. 5.1).

Table 5.3. Mean hydrological parameters ± SD and chlorophyll *a* concentration ± SD at different stations recorded in Fogliano and Caprolace coastal lakes from March 2007 to February 2008

Station	**Temperature (°C)**	**Salinity**	**Dissolved oxigen (mg l^{-1})**	**pH**	**Chlorophyll *a* (mg l-1)**
F1	17.6 ± 5.3	42.7 ± 7.2	6.6 ± 2.3	9.1 ± 0.4	3.1 ± 1.5
F2	18.2 ± 5.9	41.4 ± 6.5	5.9 ± 1.5	9.2 ± 0.6	4.4 ± 2.3
F3	18.4 ± 5.7	42.8 ± 6.5	6.6 ± 2.1	9.1 ± 0.4	5.2 ± 5.1
F4	18.0 ± 5.3	40.3 ± 3.2	6.7 ± 1.8	9.1 ± 0.5	2.8 ± 3.1
C1	19.6 ± 5.5	40.2 ± 3.0	7.0 ± 1.9	9.4 ± 0.3	2.7 ± 1.5
C2	19.1 ± 5.8	41.1 ± 2.3	6.4 ± 2.1	9.2 ± 0.4	3.1 ± 1.6
C3	19.5 ± 6.2	40.4 ± 2.7	7.4 ± 1.6	9.4 ± 0.3	2.3 ± 1.8
C4	19.2 ± 5.8	39.1 ± 2.2	7.3 ± 1.2	9.1 ± 0.6	2.8 ± 1.1

Nitrate concentrations were higher in March and in July (4.1 mg/l), respectively in Fogliano and in Caprolace lakes. On the contrary, the lowest values were seen in January (3.1 mg/l) in Fogliano Lake and in April (2.4 mg/l) in Caprolace Lake. There were no great differences in the mean nitrate values among stations in each lake (Fig. 5.1).

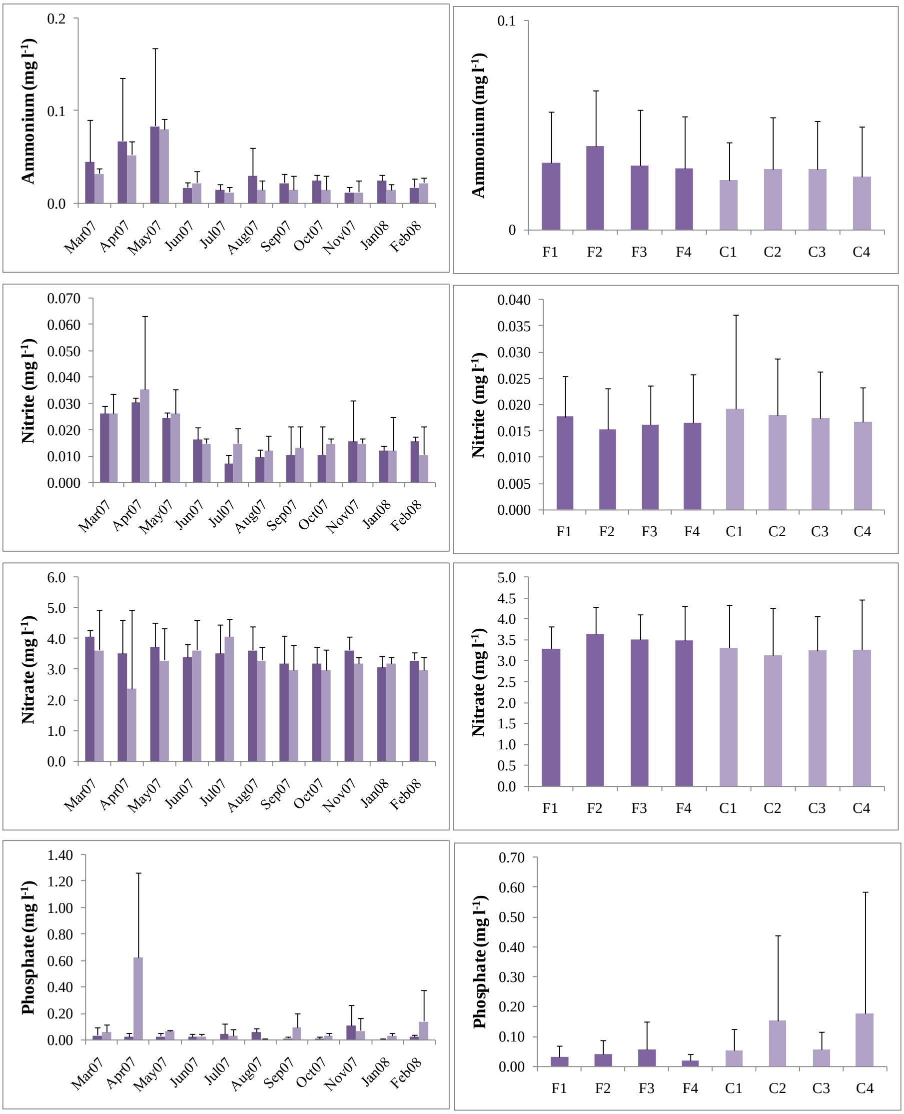

Figure 5.1. Temporal and spatial variations in mean (±SD) ammonium, nitrite, nitrate and phosphate in Fogliano and Caprolace coastal lakes. Dark violet bars, Fogliano Lake; light violet bars, Caprolace Lake.

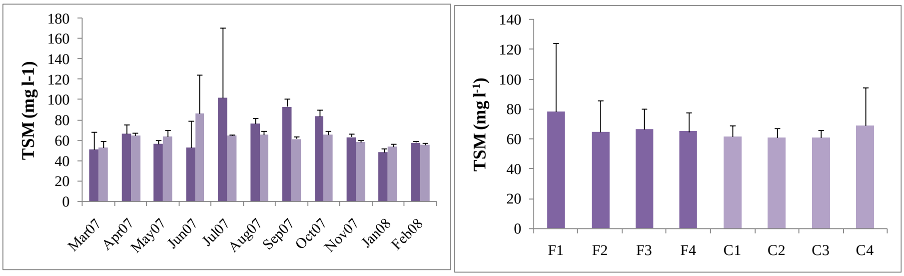

Figure 5.2. Temporal and spatial variations in mean (±SD) total suspended matter (TSM) in Fogliano and Caprolace coastal lakes. Dark violet bars, Fogliano Lake; light violet bars, Caprolace Lake.

The phosphate concentration reached the highest values in November (0.11 mg/l) in Fogliano Lake and in April (0.63 mg/l) in Caprolace Lake. In contrast, the lowest values were seen in October and January in Fogliano Lake (0.01 mg/l) and in August in Caprolace Lake (0.01 mg/l). In Fogliano Lake, the stations showed no strong differences in mean values among them, whereas C2 and C4 showed the highest mean phosphate concentrations in Caprolace Lake (Fig. 5.1).

TSM peaked in July (102 mg/l) in Fogliano Lake and in June (86 mg/l) in Caprolace Lake. The minimum values were measured in January (49 mg/l) in Fogliano Lake and in March (53 mg/l) in Caprolace Lake. TSM showed the highest mean values in F1 (79 mg/l) and in C4 (69 mg/l), respectively in Fogliano and Caprolace lakes (Fig. 5.2).

5.1.2 Fish assemblages of Circeo coastal lakes

A total of 7852 individuals were captured in Fogliano Lake, representing 21 species from 12 families (Table 5.4). Sparidae was the family more represented (6 species).

Five ecological guilds were found: resident species (R) (6 species), marine juvenile migrants (MJ) (12), marine seasonal species (MS) (2) and catadromous species (C) (1 species). In terms of abundance, R was the dominant ecological guild (7252 specimens, about 92% of the total catches). *Atherina boyeri* was the most abundant species (3641 specimens, 46% of the total catches), followed by *Aphanius fasciatus* (3144 specimens, 40% of the total catches) (fig. 5.3). The MJ guild accounted for about 7% of the total catches (539 specimens), and consisted mainly of *Liza aurata*, *Diplodus vulgaris* and *Diplodus sargus* (Fig. 5.4). The other guilds accounted for less than 1% together (61 specimens).

Among the feeding guilds, the most abundant group was that of invertebrate feeders (IS: 3793 individuals, 48% of the total catches; 7 species), followed by carnivorous feeders (CS: 3641 individuals, 46% of the total catches; 1 species), omnivorous fish (OV: 192 individuals, 2.4% of the total catches; 4 species) and herbivorous-carnivorous fish (HC: 180 individuals, 2.3% of the total catches; 5 species). Invertebrate fish feeders (3 species) and plankton feeders (1 species) together accounted for less than 1% of the total abundance.

Table 5.4. Total abundance (number of fish) of the species caught in each station of Fogliano Lake. EG, ecological guilds; FG, feeding guilds.

Family	Species	Code	EG	FG	F1	F2	F3	F4	*Total number*
Anguillidae	*Anguilla anguilla*	Aan	C	IF	0	2	5	0	7
Atherinidae	*Atherina boyeri*	Abo	R	CS	1153	675	630	1183	3641
Blennidae	*Salaria pavo*	Spa	R	IS	0	0	0	2	2
Clupeidae	*Sardina pilchardus*	Spi	MS	HC	0	0	0	33	33
Cyprinodontidae	*Aphanius fasciatus*	Afa	R	IS	1595	1391	104	54	3144
Engraulidae	*Engraulis encrasicolus*	Een	MS	PS	0	0	0	21	21
Gobiidae	*Gobius niger*	Gni	R	IF	2	0	0	0	2
	Knipowitschia panizzae	Kpa	R	IS	49	92	11	26	178
Moronidae	*Dicentrarchus labrax*	Dlaj	MJ	IF	3	6	3	4	16
Mugilidae	*Chelon labrosus*	Claj	MJ	OV	0	5	8	3	16
	Liza aurata	Lau - Lauj	MJ	HC	11	38	44	36	129
	Liza ramada	Lra - Lraj	MJ	OV	11	16	1	5	33
	Liza saliens	Lsaj	MJ	HC	5	0	0	0	5
Soleidae	*Solea solea*	Ssoj	MJ	IS	0	1	0	2	3
Sparidae	*Diplodus annularis*	Danj	MJ	IS	0	0	0	35	35
	Diplodus puntazzo	Dpuj	MJ	IS	0	0	0	20	20
	Diplodus sargus	Dsaj	MJ	OV	0	1	0	97	98
	Diplodus vulgaris	Dvuj	MJ	IS	0	0	0	126	126
	Sarpa salpa	Ssaj	MJ	HC	0	0	0	13	13
	Sparus aurata	Sauj	MJ	OV	10	7	11	17	45
Syngnathidae	*Syngnatus abaster*	Sab	R	IS	83	90	37	75	285
Total number					2922	2324	854	1752	7852

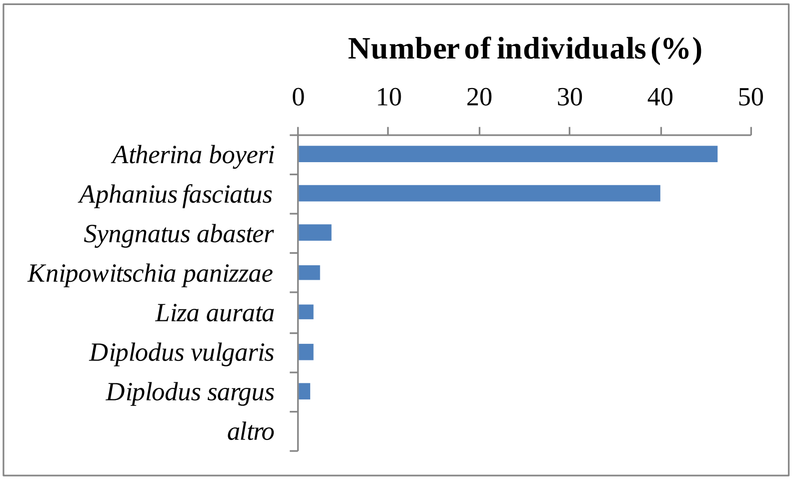

Figure 5.3. Number of specimens for each species captured in the Fogliano Lake.

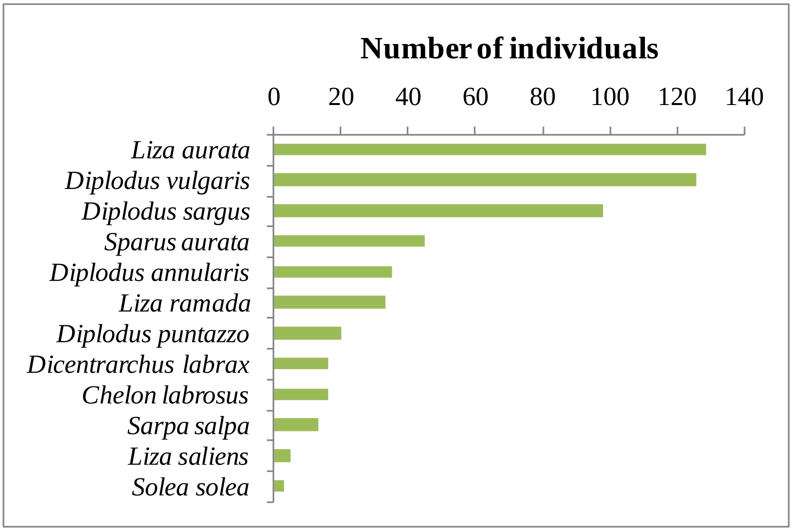

Figure 5.4. Number of specimens for MJ species captured in the Fogliano Lake.

In Caprolace Lake, a total of 5395 individuals were captured, belonging to 24 species and 12 families (Table 5.5). Sparidae was the family more represented (7 species).

Five ecological guilds were found: resident species (R) (6 species), marine juvenile migrants (MJ) (14), marine seasonal species (MS) (1 species), adventitious marine species (MA) (2 species) and catadromous species (C) (1 species). In terms of abundance, R was the dominant ecological guild (3888 specimens, about 72% of the total catches). *A. boyeri* was the most abundant species (2662 specimens, 49% of the total catches), followed by *A. fasciatus* (997 specimens, 18% of the total catches) (Fig. 5.5). The MJ guild accounted for about 27.7% of the total catches (1491 specimens), and was represented mostly by *L. aurata*, *Liza ramada*, *Sparus aurata* and *Dicentrarchus labrax* (Fig. 5.6). The other guilds accounted for 0.03% together (16 specimens).

Among the feeding guilds, the most abundant group was that of carnivorous feeders (CS: 2662 individuals, 49% of the total catches; 1 species), followed by invertebrate feeders (IS: 1363 individuals, 25% of the total catches; 11 species), omnivorous fish (OV: 665 individuals, 12% of the total catches; 5 species) and herbivorous-carnivorous fish (HC: 553 individuals, 10% of the total catches; 4 species). Finally, invertebrate fish feeders (2 species) accounted for 3% of the total catches (150 individuals) and plankton feeders was represented by only two individuals of *Engraulis encrasicolus* (Linnaeus).

5.1.3 Temporal and spatial variations in abundance and diversity

In Fogliano Lake, the highest values of species richness and total abundance were found in the station F4, located near the tidal channel (Fig. 5.7a and b). In contrast, the species richness showed the lowest mean values in F1 and F3, while the abundance in F2 and F3. Both species richness and total fish abundance varied over time, with the highest values reported in spring (March and April) (Fig. 5.7c and d). After April, the value for both ecological indices decreased reaching a minimum value in September, but showed an increase in the following period.

ANOVA indicated that the species richness varied significantly among seasons ($p < 0.001$) but not across stations (Table 5.6) with significant pairwise comparisons for spring with autumn and summer, and for winter with summer, as highlighted by Tukey’s test. In contrast, Dominance and Shannon indices showed no spatial and temporal variations. In terms of ecological guilds, the number of R species showed significant variation among seasons ($p < 0.001$) with a significant lower mean value in summer than in all other seasons. The number of MJ species showed significant variations among both seasons and stations ($p < 0.05$ and $p < 0.001$, respectively). Tukey's test detected a significant higher value in spring than summer. Finally, the number of MS species showed no significant temporal and spatial variations.

Table 5.5. Total abundance (number of fish) of the species caught in each station of Caprolace Lake. EG, ecological guilds; FG, feeding guilds.

Family	**Species**	**Code**	**EG**	**FG**	**C1**	**C2**	**C3**	**C4**	***Total number***
Anguillidae	*Anguilla anguilla*	Aan	D	IF	0	0	1	0	1
Atherinidae	*Atherina boyeri*	Abo	R	CS	824	387	596	855	2662
Blennidae	*Parablennius sanguinolentus*	Psa	MA	HC	0	0	0	1	1
	Salaria pavo	Spa	R	IS	1	1	0	2	4
Cyprinodontidae	*Aphanius fasciatus*	Afa	R	IS	595	275	85	42	997
Engraulidae	*Engraulis encrasicolus*	Een	MS	PS	0	2	0	0	2
Gobiidae	*Knipowitschia panizzae*	Kpa	R	IS	5	10	3	8	26
Labridae	*Symphodus tinca*	Sti	MA	IS	0	0	0	12	12
Moronidae	*Dicentrarchus labrax*	Dlaj	MJ	IF	49	10	3	87	149
Mugilidae	*Chelon labrosus*	Claj	MJ	OV	10	7	0	0	17
	Liza aurata	Lau - Lauj	MJ	HC	157	18	165	118	458
	Liza ramada	Lraj	MJ	OV	312	3	14	69	398
	Liza saliens	Lsaj	MJ	HC	23	34	16	15	88
	Mugil cephalus	Mcej	MJ	OV	18	0	2	0	20
Soleidae	*Solea solea*	Ssoj	MJ	IS	0	2	0	1	3
Sparidae	*Diplodus annularis*	Dan - Danj	MJ	IS	1	0	0	46	47
	Diplodus puntazzo	Dpuj	MJ	IS	3	0	3	21	27
	Diplodus sargus	Dsaj	MJ	OV	0	0	0	14	14
	Diplodus vulgaris	Dvuj	MJ	IS	0	1	0	46	47
	Lithognatus mormyrus	Lmoj	MJ	IS	0	1	0	0	1
	Sarpa salpa	Ssaj	MJ	HC	0	0	0	6	6
	Sparus aurata	Sauj	MJ	OV	52	119	14	31	216
Syngnathidae	*Nerophis ophidion*	Nop	R	IS	0	0	0	1	1
	Syngnatus abaster	Sab	R	IS	8	48	45	97	198
Total number					2058	918	947	1472	5395

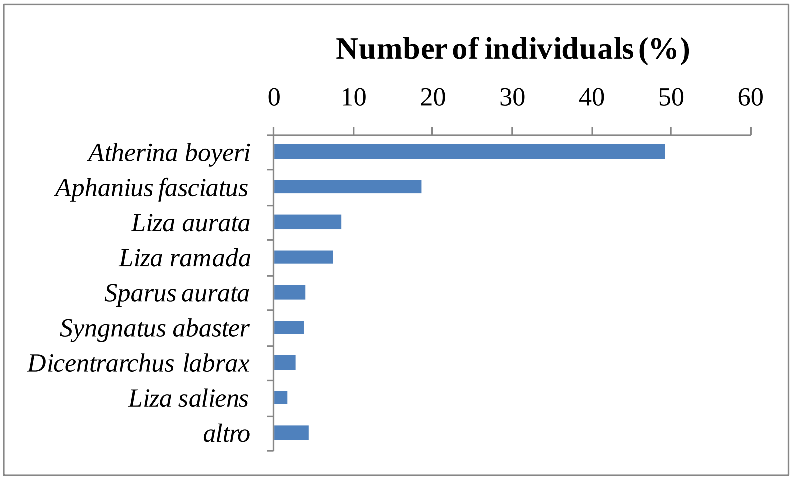

Figure 5.5. Number of specimens for each species captured in the Caprolace Lake.

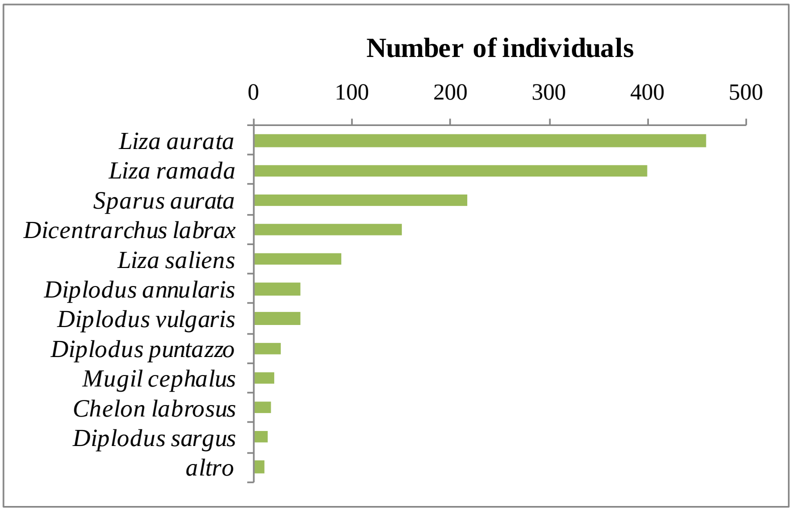

Figure 5.6. Number of specimens for MJ species captured in the Caprolace Lake.

Total fish abundance showed significant seasonal and spatial variations ($p < 0.05$; $p < 0.001$, respectively) (Table 5.6). Pairwise comparisons showed a significantly higher mean abundance in spring than in all other seasons. The number of R and MJ fish varied significantly among both seasons and stations ($p < 0.001$ and $p < 0.01$, respectively). Tukey's test showed significant higher ER and MJ abundances in spring than in the other periods. Finally, the number of MS fish showed no significant seasonal and spatial variations. The ecological guild C was not considered in the analysis as it was represented by just seven specimens belonging to one species, the European eel *Anguilla anguilla*, only sporadically found.

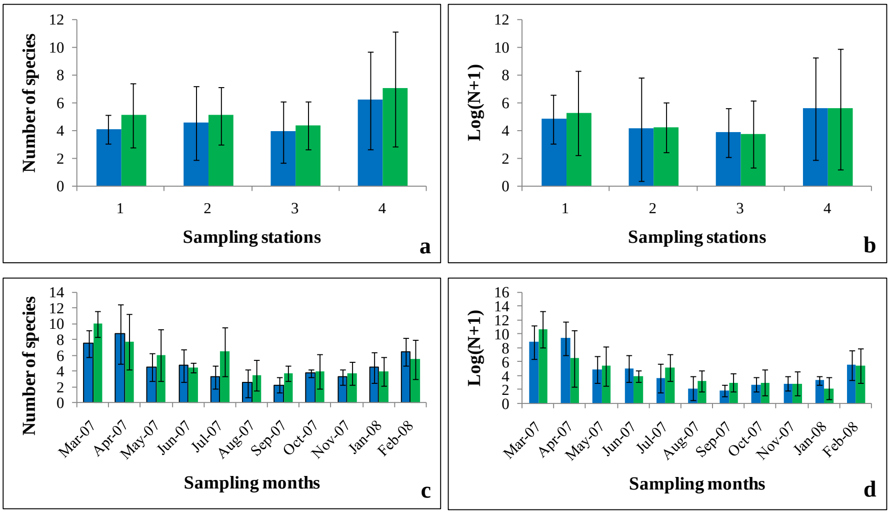

Figure 5.7. Differences in mean number of species and fish among months (a and c) and stations (b and d). Blue bars, Fogliano Lake; green bars, Caprolace Lake.

In Caprolace Lake, the highest species richness and total abundance values were found at the station C4, situated near the tidal channel (Fig. 5.7a and b). On the contrary, the lowest mean values of both indices were found in C3. Similarly to Fogliano, also in Caprolace both species richness and total number of fish showed temporal patterns of variations, with the highest values reported in March, followed by a decrease and a new rise in July (Fig. 5.7c and d). Minimum values were recorded in August for species richness and in January for total abundance.

ANOVA detected significant seasonal variations of species richness and number of R and MJ species ($p < 0.01$, $p < 0.05$ and $p < 0.05$, respectively) (Table 5.7), but Tukey's test showed only a significant higher species richness in spring than autumn. Furthermore, significant spatial variations in number of MA species were detected ($p < 0.05$).

Table 5.6. Results of 2-way ANOVA performed on species richness, diversity indices, total abundance (log (N+1) transformed) and number of species and individuals (log (N+1) transformed) in each ecological guild. Levels of significance: ns, not significant; *p < 0.5; **p < 0.01; ***p < 0.001.

		Fogliano Lake					
Source		**Station**		**Season**		**Station x season**	
df		3		3		9	
Species richness	**Mean square**	9.42		37.62		5.45	
	F Ratio	2.61	ns	10.43	***	1.51	ns
Dominance	**Mean square**	0.05		0.03		0.06	
	F Ratio	1.83	ns	1.16	ns	2.11	ns
Shannon	**Mean square**	0.27		0.29		0.23	
	F Ratio	2.57	ns	2.78	ns	2.17	ns
number of ER species	**Mean square**	0.20		5.03		0.54	
	F Ratio	0.33	ns	8.17	***	3.46	ns
number of MJ species	**Mean square**	7.36		18.56		0.47	
	F Ratio	4.30	*	10.82	***	2.41	ns
number of MS species	**Mean square**	0.20		0.06		0.06	
	F Ratio	1.68	ns	0.52	ns	0.52	ns
Total abundance	**Mean square**	0.74		2.64		0.51	
	F Ratio	4.45	*	15.96	***	3.06	ns
ER abundance	**Mean square**	0.81		2.40		0.54	
	F Ratio	5.13	*	15.28	***	3.46	ns
MJ abundance	**Mean square**	0.77		2.79		0.47	
	F Ratio	3.99	*	14.37	***	2.41	ns
MS abundance	**Mean square**	0.11		0.05		0.05	
	F Ratio	1.43	ns	0.66	ns	0.66	ns

ANOVA also detected significant variations in the mean total abundance value among seasons (p < 0.01). Pairwise comparisons showed a significantly higher mean value in spring than in autumn and winter. Finally, R fish abundance varied significantly among seasons (p < 0.01), with a significantly higher value in spring than in autumn and winter, as shown by Tukey’s test. The ecological guilds C and MS were not considered in the analysis as they was represented by only some individuals belonging to *A. anguilla* and *E. encrasicolus*, both caught only sporadically.

Table 5.7. Results of 2-way ANOVA performed on species richness, diversity indices, total abundance (log (N+1) transformed) and number of species and individuals (log (N+1) transformed) in each ecological guild. Levels of significance: ns, not significant; *p < 0.5; **p < 0.01; ***p < 0.001.

			Caprolace Lake	
Source		**Station**	**Season**	**Station x season**
df		3	3	9
Species richness	**Mean square**	13.17	25.73	6.34
	F Ratio	2.36 ns	4.62 **	1.14 ns
Dominance	**Mean square**	0.01	0.06	0.03
	F Ratio	0.28 ns	1.27 ns	0.72 ns
Shannon	**Mean square**	0.09	0.21	0.18
	F Ratio	0.46 ns	1.12 ns	0.95 ns
number of ER species	**Mean square**	1.11	2.19	1.52
	F Ratio	1.81 ns	3.55 *	2.46 *
number of MJ species	**Mean square**	7.42	14.70	3.19
	F Ratio	1.89 ns	3.74 *	0.81 ns
number of MA species		0.20	0.04	0.04
		3.44 *	0.72 ns	0.72 ns
Total abundance	**Mean square**	0.25	1.06	0.29
	F Ratio	1.10 ns	4.66 **	1.28 ns
ER abundance	**Mean square**	0.27	1.38	0.34
	F Ratio	1.70	8.55 ***	2.13
MJ abundance	**Mean square**	0.67	1.36	0.22
	F Ratio	1.06 ns	2.13 ns	0.12 ns
MA abundance	**Mean square**	0.09	0.02	0.02
	F Ratio	2.64 ns	0.51 ns	0.51 ns

5.1.4 Fish assemblage structure: temporal and spatial variations

nMDS analysis on fish assemblages of both coastal lakes was supported by cluster analysis performed on the same matrices. Figure 5.8 shows the nMDS ordination plots obtained by the temporal analysis performed on presence/absence (Fig. 5.8a) and abundance (Fig. 5.8b) for Fogliano Lake. The ordination plot shown in Figure 5.8a separated the samples into two main groups on a monthly basis except for three months that fell apart. The first group consisted of spring months (April, May and June) plus January, while the second group included the late summer and autumn months (August, September, October and November). March, July and February plotted separately from each other and from the others. ANOSIM indicated that the differences among the groups were significant (R = 0.98 and p < 0.001), with significant differences between spring and late summer/autumn groups, as shown by post-hoc pairwise comparisons. In the nMDS ordination plot obtained by the analysis performed on abundance (Fig. 5.8b), the largest group consisted of late summer and autumn months (August, September, October and November) plus January. March and April, and May and June were the other two groups. July and February plotted apart, in opposite regions of the ordination. ANOSIM showed that there were significant differences among all groups in terms of abundance (R = 1, p < 0.0001). Significant differences between the late summer/autumn and March-April groups, and between the late summer/autumn and May-June groups were detected by pairwise comparisons. SIMPER analysis indicated that the most (>50%) of the total dissimilarity was accounted for by the resident *A. fasciatus*, *A. boyeri*, *Syngnathus abaster* and *Knipowitschia panizzae* and by the YOY fish of *D. sargus* and *D. vulgaris* (Table 5.8).

In contrast, were results relative to the temporal analysis performed on presence/absence (Fig. 5.9a) and abundance (Fig. 5.9b) related to Caprolace Lake. The nMDS ordination plot shown in Figure 5.9a separated the samples into three monthly groups and two individual months (June and July). The first group consisted of late winter and spring months (February, March, April and May). The

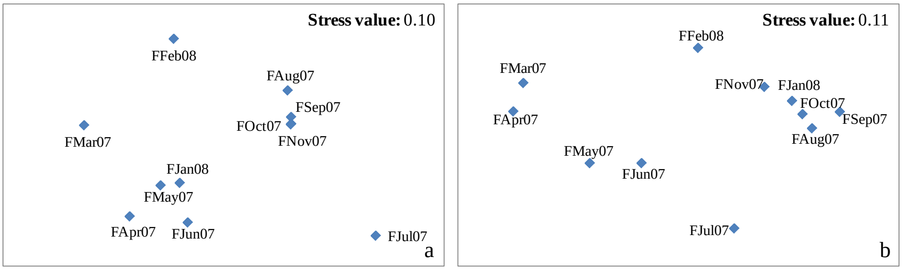

Figure 5.8. nMDS ordinations of months based on presence/absence (a) and abundance (b) of species collected in Fogliano Lake. Stress values are given in top right corner of each plot.

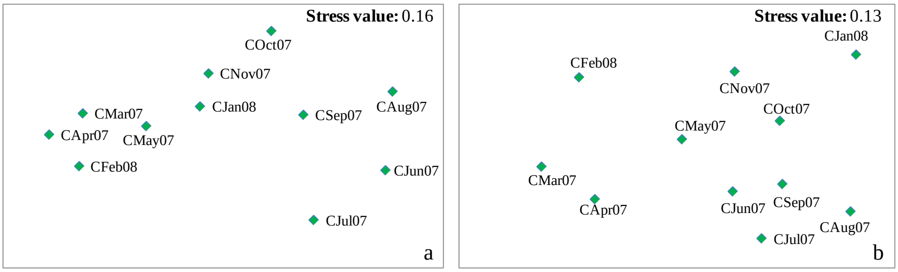

Figure 5.9. nMDS ordinations of months based on presence/absence (a) and abundance (b) of species collected in Caprolace Lake. Stress values are given in top right corner of each plot.

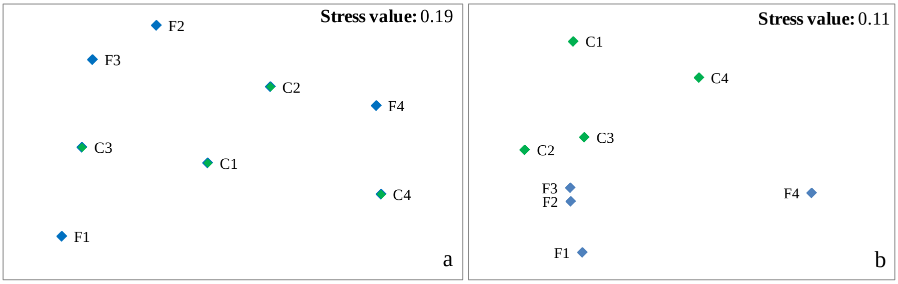

Figure 5.10. nMDS ordinations of sampling stations based on presence/absence (a) and abundance (b) of species collected in both Circeo coastal lakes. Stress values are given in top right corner of each plot.

second group included the late summer months (August and September), whereas the third group included the autumn months (October and November) plus January. ANOSIM showed that the differences among all groups were significant ($R = 0.92$ and $p < 0.0001$). Pairwise comparisons showed significant differences between late winter/spring and autumn groups. On the contrary, the nMDS ordination plot shown in Figure 5.9b separated the monthly samples in three groups except January and February. A first group consisted of March and April. A second group included the autumn months plus May, while a third group was formed by the summer months plus June. ANOSIM indicated that there were significant differences among all groups ($R = 0.88$, $p < 0.0001$) with a significant post-hoc pairwise comparison for summer months and autumn months groups. Further, SIMPER analysis showed that the majority (>50%) of total dissimilarity was accounted for by the resident *A.*

fasciatus and *A. boyeri*, and by the YOY fish of *L. aurata*, *L. ramada*, *S. aurata* and *D. labrax* (Table 5.9).

Figure 5.10 shows the nMDS plots yielded by the spatial analysis performed on presence/absence (Fig. 5.10a) and abundance (Fig. 5.10b) of the fish species in both coastal lakes. In the first nMDS ordination plot the stations were grouped in three pairs (C1-C3, F2-F3 and C4-F4) except for two stations (F1 and C2) (Fig. 5.10a). ANOSIM indicated no significant differences among groups ($R = 1$, $p = 0.002$). On the contrary, the nMDS ordination plot based on abundance data showed two larger groups of stations (F1-F2 and F3-C2-C3) and three stations (F4, C1 and C4) falling apart (Fig. 5.10b). ANOSIM showed no significant variations among groups ($R = 0.96$, $p = 0.002$). SIMPER was however performed and the species, which mostly contributed to the differences among groups, were listed in table 5.10. Stations F4 and C4 differed for the highest abundance of *D. sargus*, *D. vulgaris* and *Diplodus puntazzo* (Cetti) juveniles. In addition, the station C4 showed the highest abundance of *D. labrax*, *L. aurata* and *L. ramada* juveniles among stations of Caprolace Lake, like the station C1. Moreover, the station C1 evidenced the greatest number of *Liza saliens* and *S. aurata* juveniles, and of *A. fasciatus* specimens. Conversely, stations C2 and C3 showed a high abundance of *A. fasciatus* and *K. panizzae*, but the lowest abundance of many YOY marine juveniles, like F3. Finally, stations F1 and F2 differed in a larger number of *A. fasciatus*, *K. panizzae*, *S. abaster* and *L. ramada* juveniles, and for a lower abundance of the most marine species respect to F4.

Figure 5.11 shows the ordination plot obtained by CCA performed on environmental data and fish abundance results for Fogliano Lake. *K. panizzae*, *A. fasciatus* and *L. ramada* juv. were positively correlated with TSM and pH and, in lower extent, with salinity, Chla and phosphate. *A. boyeri*, *S. aurata* juv., *Chelon labrosus* juv., *L. aurata* juv. and *D. labrax* juv. were positively correlated with T and DO. *S. aurata* juv., *D. labrax* juv. and *A. boyeri* were additionally negatively correlated to pH and TSM. Finally, juveniles of all species collected belonging to the genus *Diplodus* were negatively correlated with salinity and positively with DO.

Table 5.8. Results of SIMPER analysis performed on fish abundance in Fogliano Lake. In the table are reported the species which accounted for most of the total dissimilarity among groups and their mean abundance in each monthly group.

Species	**FMar07-FApr07**	**FMay07-FJun07**	**FJul07**	**Summer-autumn months**	**FFeb08**
Aphanius fasciatus	2.34	1.75	1.82	0.62	0.81
Syngnathus abaster	1.25	0.50	0	0.65	1.12
Atherina boyeri	2.13	2.19	1.71	1.49	1.85
Diplodus sargus juv.	0.37	0.97	0	0	0
Diplodus vulgaris juv.	1.10	0.39	0	0.02	0
Knipowitschia panizzae	1.25	0.10	0.24	0.38	0.44

Table 5.9. Results of SIMPER analysis performed on fish abundance in Caprolace Lake. In the table, are reported the species which accounted for most of the total dissimilarity among groups and their mean abundance in each monthly group.

Species	**CMar07-CApr07**	**Summer months**	**Autumn months**	**CJan08**	**CFeb08**
Liza aurata juv.	0.93	0	0.76	0.54	1.48
Aphanius fasciatus	1.72	1.37	0.74	0.35	0.60
Atherina boyeri	2.07	1.33	1.57	0.70	1.66
Liza ramada juv.	1.61	0.11	0.08	0.44	0
Sparus aurata juv.	0.98	0	0	0	1.51
Dicentrarchus labrax juv.	0.75	0.02	0.21	0	1.31

The ordination plot obtained by CCA performed on environmental data and fish abundances for Caprolace Lake is shown in Figure 5.12. Most marine species, juveniles of *Diplodus*, *L. aurata* juv., and *D. labrax* juv. were positively correlated with DO and TSM and negatively with salinity and Chla. *A. fasciatus*, and the juveniles of *C. labrosus, S. aurata* and *L. saliens* were positively correlated with Chla and salinity and negatively with DO and TSM. Moreover, *L. saliens* juv. and *S. aurata* juv. were negatively correlated with nitrate, like *K. panizzae*. The latter was also negatively correlated with T. Finally, juveniles of *L. ramada* and *Mugil cephalus* showed a positive correlation with pH and T and a negative one with phosphate.

Table 5.10. Results of SIMPER analysis performed on fish abundance in both coastal lakes. In the table, are reported the species which accounted for most of the total dissimilarity among groups and their mean abundance in each group.

Species	F4	C4	F1-F2	F3-C3-C2	C1
Aphanius fasciatus	0.77	0.68	2.13	1.13	1.74
Dicentrarchus labrax juv.	0.14	0.95	0.15	0.16	0.73
Diplodus puntazzo juv.	0.45	0.46	0	0.03	0.11
Diplodus sargus juv.	0.99	0.36	0.02	0	0
Diplodus vulgaris juv.	1.10	0.71	0	0.01	0
Knipowitschia panizzae	0.53	0.24	0.85	0.23	0.16
Liza aurata juv.	0.55	1.06	0.42	0.78	1.1
Liza ramada juv.	0.04	0.86	0.19	0.17	1.47
Liza saliens juv.	0	0.37	0.08	0.33	0.49
Sparus aurata juv.	0.41	0.58	0.25	0.56	0.76
Syngnathus abaster	0.89	0.99	0.95	0.69	0.24

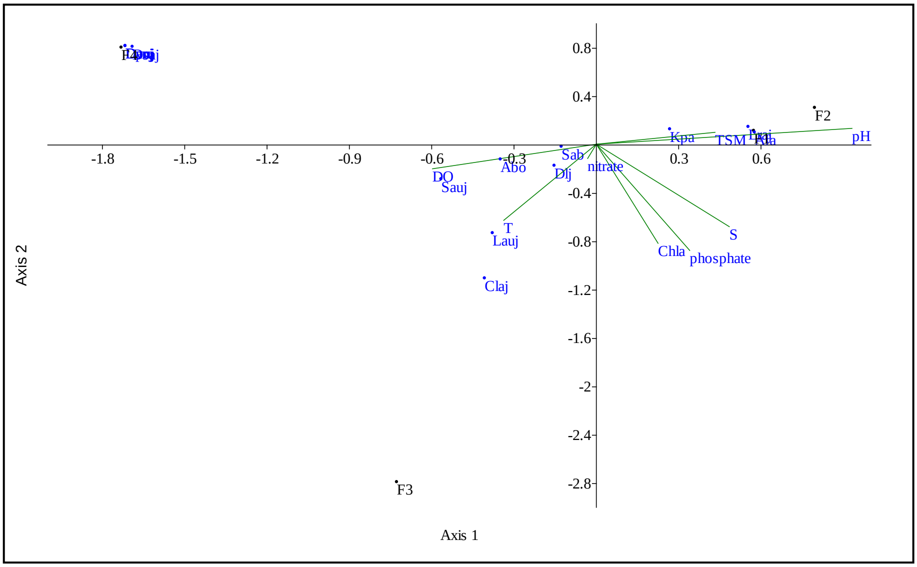

Figure 5.11. CCA plot of site and species sampled in Fogliano Lake with 8 environmental variables in the first two CCA axis. Axis 1, 83.9% of the total variance; axis 2, 12.7% of the total variance. Codes of fish species were reported in Table 5.1.

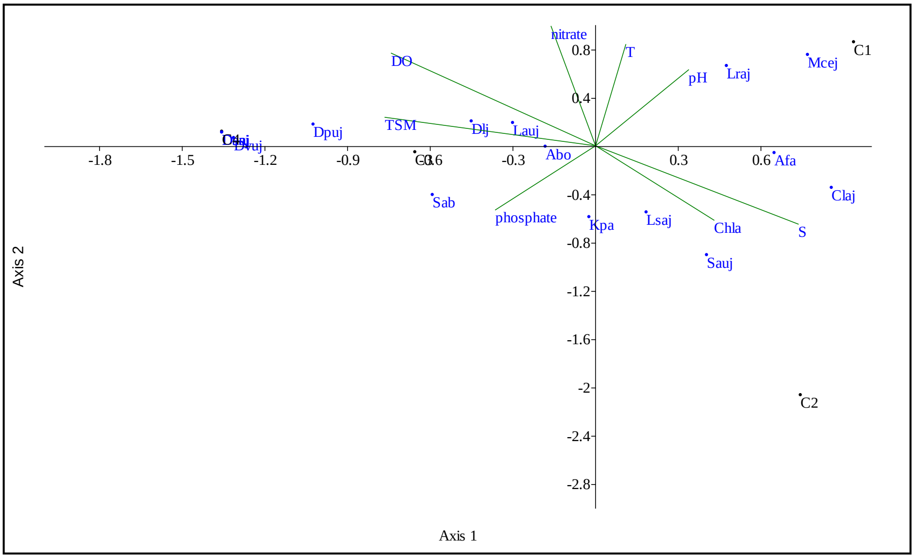

Figure 5.12. CCA plot of site and species sampled in Caprolace Lake with 8 environmental variables in the first two CCA axis. Axis 1, 57.6% of the total variance; Axis 2, 26.1% of the total variance. Codes of fish species were reported in Table 5.2.

5.2 Discussion

The fish assemblages of the two Circeo coastal lakes consist of a comparable number of species, most of which are frequent in Mediterranean coastal lagoons (Pérez-Ruzafa et al., 2007). *K. panizzae*, *Nerophis ophidion*, *Parablennius sanguinolentus* and *Symphodus tinca* are considered uncommon in Mediterranean coastal lagoons. Indeed, *P. sanguinolentus* and *S. tinca* are marine species which only occasionally perform feeding migrations to coastal lagoons with few individuals at the adult stage. On the other hand, *K. panizzae* and *N. ophidion* are resident species in Mediterranean coastal lagoons. *K. panizzae* is a gobiid relatively abundant in Fogliano Lake (Manzo et al., 2006b), with a restricted geographical distribution and a high conservation interest (see Chapter 3). *N. ophidion* is a pipefish distributed from the Norway to Morocco (except for the region between Denmark and Netherlands), and throughout the Mediterranean and the Black Sea. In the Mediterranean Sea, the species is principally spread in the western area and in

Italy it is very common along the North-Adriatic coasts (Malavasi et al., 2007). This pipefish species was already recorded in the Caprolace Lake, with few individuals distributed near the tidal channel (Zerunian, 1996; Manzo et al., 2006b).

The catadromous European eel, *A. anguilla*, occurs with a few specimens in Circeo lakes, while it was lacking in the samples from Lesina Lagoon. This result is due to the fishing method, inadequate to the capture of both adult stage and glass eels of *A. anguilla* (due to its morphology as well as benthic habits). In Lesina Lagoon, the presence of the European eel is indeed testified by the finding of the glass eels in the tidal channel recruiting to lagoon during this study. In all lagoons, adult eel is present among the catches of the professional fisheries, both fyke-net fishery and at the fish barrier. Coastal lagoons are indeed elective habitats for this euryhaline species, on which, in the past, lagoon fisheries strongly relied (Ciccotti, 2006). Today, eel catches have strongly reduced, in rivers as well as in lagoon systems, across the whole of its distribution area, and in the Mediterranean as well. In Lesina and in Circeo coastal lakes, this situation is also found (A.GE.I, 1997, 2004; Tancioni et al., 1998).

The European eel shares the fate of many diadromous species that because of the complexity of their life cycle, and of the fact that they use different environments in marine and continental waters, are particularly vulnerable to consequences of anthropogenic effects pressures, both direct and indirect. That is particularly true for eel, that lives across sea and land, and that is exploited by fisheries across the whole distribution area, targeted at all life stages. For this species, major problems exist, in relation to a continent-wide decline in recruitment observed in the course of the last decades, and to a contraction in adult eel capture fisheries (Moriarty and Dekker, 1997; ICES, 2004, 2008; Dekker, 2002). In relation to this, concern for the stock management and conservation has been growing. In September 2007 a Council Regulation (EC 1100/2007) established a new framework for the protection and sustainable use of the stock of European eel and in 2008 it was listed in 2008 as critically endangered in the IUCN Red List of Threatened Species (http://www. iucnredlist.org). Climatic changes, the diffusion of the parasitic nematod *Anguillicola crassus* and local impacts of anthropogenic origin are some important causes involved in the decline of the European eel stock (ICES, 2001; Knights, 2003). The human-induced impacts have surely played an important role on the status of local populations. The barriers along the freshwater courses, avoiding the migration towards the upper part of the rivers, the deterioration and loss of essential habitats, as coastal lagoons and wetlands, and the pollution of continental waters, have affected and affect negatively this species.

Fish assemblages of both coastal lakes are quantitatively dominated by the resident *A. boyeri*, a feature also common to Lesina Lagoon (see Chapter 3) and to other Mediterranean coastal lagoons (Andreu-Soler et al., 2003; Koutrakis et al., 2005; Franco et al., 2006b; Maci and Basset, 2009). In Fogliano Lake, the resident species *A. fasciatus* also showed a comparatively high abundance, representing the second most abundant species.

Despite the small sizes of the basins and their environmental homogeneity in terms of vegetation cover, the two coastal lakes support a moderately high species richness, even if lower than the Mediterranean average (Pérez-Ruzafa et al., 2007; Franco et al., 2008), with the family Sparidae well represented. Marine seasonal migrants, largely represented by juvenile stages, most contributed to the high species richness in both Fogliano and Caprolace lakes. The prevalence of the juvenile stages among the marine species is most likely due to the type of fishing method used in the samplings which may led to an underestimation of the marine species represented by adult individuals of large size (see Chapter 3).

As asserted by Mariani (2001), the relatively high number of marine species in Circeo coastal lagoons is substantially due to the relatively strong marine influence, also enhanced by the interruption of linkages with the freshwater streams. Moreover, the morphometric features of the tidal channels, which are short and wide in relation to the lagoon surfaces, may increase the influence of the sea on the general hydrology of the two lagoons (Perez-Ruzafa et al. 2007).

In both coastal lakes, a lower species richness has been found in the present study with respect to years 1996-1997 (Mariani, 2001). This may be explained by the different sampling effort, with a greater number of stations considered in the previous study, whereas the sampling method was the same in both researches.

The fish assemblage functional structure of both coastal lakes in terms of habitat use by fish reflects the typical structure of the Mediterranean lagoon fish assemblages with the dominance of marine species (migrants and stragglers) which accompany the resident species lower in number (Franco et al., 2008). By contrast, no freshwater species were found due to the absence of the connections with freshwaters channels. Marine euryhaline species were represented almost entirely by YOY fish which enter coastal lagoons in response to olfactory cues (Whitfield, 1999) or to the salinity gradient (Quinn et al., 1999) generated by lagoon water outflow. In particular, Caprolace Lake seems to provide an important nursery function. Notwithstanding the fact that resident species were quantitatively prevailing in fish assemblages of both lakes, marine juveniles showed a high proportion of individuals in Caprolace Lake. Moreover, some differences in the abundant YOY fish existed between two lagoons. Fogliano Lake showed higher proportions of *L. aurata*, *D. vulgaris* and *D. sargus* juveniles. On the contrary, *L. aurata*, *L. ramada*, *S. aurata* and *D. labrax* prevailed among marine juveniles in Caprolace Lake. The two TW bodies are far only 3–4 km from each other, hence is expected that natural factors controlling the recruitment processes of marine juveniles to coastal lagoons from the sea (i.e. presence of suitable spawning areas, local variations in the breeding time of each species, distance from the coast of the spawning grounds, reproductive success, meteoclimatic and hydrographic factors) (Rossi, 1986; Costa et al., 2002) did not originate the inconsistency in the entity and patterns of recruitment between two lagoons. On the contrary, the reason of this discrepancy may be a result of different degrees of confinement of the two ecosystems with a less-confined character of Caprolace Lake than Fogliano Lake (Gravina, 1986; Mariani, 2001). Hence, the higher attractiveness exerted by the Caprolace lagoon on the marine juveniles along the coast because of the higher efficiency of the sea-connection may have enhanced the nursery role of this lake. The lower efficiency of Fogliano tidal channel is additionally testified by the instability of its mouth verified during the study period, when it remained completely silted up from July to November 2007. It is possible that the inefficiency of the Fogliano tidal channel affected the incidence of *L. ramada*, *S. aurata* and *D. labrax* juveniles in the lake, very abundant in Caprolace Lake.

As regards the feeding mode, the invertebrate feeding, especially microbenthivory was the dominant mode in terms of number of species in both Circeo lagoons, followed by omnivory and partially herbivory and carnivory feeding, whilst the other categories were less represented, particularly planctivorous. The large number of invertebrate feeders in Fogliano and Caprolace coastal lakes is an attribute common with the Mediterranean and European TW fish assemblages, also formerly stated by Mariani et al. (2002) and Manzo et al. (2006b). In turn, the higher proportion of omnivores and herbivory-carnivory feeders and the lower proportion of piscivores and planctivores are distinct traits of the Mediterranean coastal lagoon fish assemblages (Franco et al., 2008). Some differences were however observed. The analysis on Fogliano Lake fish assemblage showed an almost equivalent number of invertebrate feeders and carnivores, while a quantitatively dominance of the carnivorous fish on the other feeding guilds, because of the less abundance of the invertebrate feeder *A. fasciatus*, was observed for Caprolace Lake fish assemblage.

Fish species richness, total abundance and assemblage structure evidently varied in time in both coastal lakes. The two ecological indices both showed characteristic seasonal patterns similar to those of other TW systems of the Southern Europe, with the highest values found in spring. The temporal variation in ecological indices was accompanied by changes in fish assemblage structure. Similarly to Lesina Lagoon and as found in other TWs of South Europe, in Circeo coastal lakes temporal changes in fish assemblage structure and ecological indices seem to be an effect of the temporal shift in the species number of residents and marine juveniles and in their abundances according to reproductive periods of the resident species and recruitment time of each marine fish to coastal lakes from the opposite open sea (Gordo and Cabral, 2001; Matic-Skoko et al., 2007; Ribeiro et al., 2006). In particular, higher abundances of the resident species *A. boyeri*, *A. fasciatus*, *K. panizzae* and *S. abaster*, and the YOY of *D. sargus* and *D. vulgaris* in spring were primarily responsible of the statistically significant temporal variation in the fish assemblages of Fogliano Lake in agreement with the spawning times of the resident species (Gandolfi et al., 1991) and the recruitment periods of the two sparid species in western Mediterranean (Bauchot and Hureau, 1986).

Rather, variations in occurrence and abundance of the dominant *A. boyeri* and *A. fasciatus*, and YOY of *L. aurata*, *L. ramada*, *S. aurata* and *D. labrax* played a key role in determining the temporal variations in fish assemblage structure of Caprolace Lake, according to the reproductive and recruitment periods of fish species (Bauchot and Hureau, 1986; Tortonese, 1986; Gandolfi et al., 1991; Kottelat and Freyhof, 2007).

Fish assemblages of both coastal lakes showed no statistically significant spatial variations. On the other hand, a pattern of distribution of the fish fauna in both coastal lakes was identified and seems to reflect a gradient of marine influence on the lagoons, in accordance with previous observations by Mariani (2001). Fish assemblages of the stations near the tidal channels of both lakes (F4 and C4) differed, in fact, due to the presence of the adventitious species (*S. tinca* and *P. sanguinolentus*) (only in Caprolace Lake), the most marine migrants (*Sardina pilchardus* and *E. encrasicolus*) and some YOY marine fish (such as *Sarpa salpa* and *Solea solea*) and by the highest abundances of many YOY marine fish, especially those belonging to the genus *Diplodus*. In opposition, inner stations (F1 and F2) appear to be less affected by the marine influence, and exhibit fish assemblages with high abundances of resident species (*A. fasciatus, A. boyeri*, *K. panizzae* and *S. abaster*) accompanied by YOY fish of marine euryhaline species which usually recur in Italian lagoons (*C. labrosus*, *L. aurata*, *L. ramada*, *L. saliens*, *D. labrax*, and *S. aurata*). The other stations may be considered a transition zone characterized by fish assemblages moderately influenced by the sea. In these stations, fish assemblages differed by the most confined stations F1 and F2 by a lower abundance of the resident species and a more abundance of the YOY fish of marine cyclic migrant species. Hence, Fogliano Lake maintains a higher confinement degree compared to Caprolace Lake, as found by Mariani (2001).

CCA analysis also showed that the species distributions mainly respond to a confinement gradient. This is particularly clear for Fogliano Lake, where the resident species *A. fasciatus*, *K. panizzae* and the *L. ramada* juveniles were found with higher mean values of salinity, pH, phosphate, total suspended matter and chlorophyll *a* concentration. These conditions generally are found in the more confined inner stations (F1 and F2). Indeed, only the resident fish and a few marine migrant species (such as some members of Mugilidae) which are able to withstand a wide range of environmental conditions (Thomson, 1966; McDowall, 1988; Akin et al., 2005), may take advantage of more confined but usually more productive areas of the lagoon systems. In Fogliano Lake, these species can access a larger amount of food resources, as indicated by the highest values of chlorophyll *a* concentration and total suspended matter in peripheral stations.

On the contrary, marine species whose tolerance towards fluctuations of environmental conditions is lower, such as many species of Sparidae (Akin et al., 2005), were abundantly found in the areas near the tidal channels of the two lakes, where the salinity was similar to that of the sea, dissolved oxygen was higher and the trophic parameters were lower (chlorophyll *a* concentration and phosphate concentration).

6. DISCUSSION

6.1 Fish assemblages and Mediterranean coastal lagoons typology

The assessment of the fish assemblage of three lagoons performed by a common methodology (same fishing method, sampling effort and timescale) gives the opportunity to make some considerations on a comparative basis, that in turn allow to draw some more general inferences, relative to lagoon fish assemblages in the Mediterranean region.

Results evidence that the fish assemblages of the three Italian lagoons have many common traits as well as differences. Furthermore, there is supporting evidence that the environmental complexity plays a primary role, as well as the marine influence extent, in structuring lagoon fish assemblages (Franco et al., 2006a).

In terms of taxonomical compositions, the fish assemblages of the three lagoons are alike by the occurrence of many common species, especially of marine origin but also lagoon residents, which are frequent in the most of Mediterranean coastal lagoons (Pérez-Ruzafa et al., 2007), also in relation to the wide spread geographical distribution in this region. The quantitative dominance of the two resident species *Atherina boyeri* and *Aphanius fasciatus* in all fish assemblages further reinforces the similarity.

Nevertheless, some different features also occur in the taxonomical composition and species richness, between the fish assemblages of Lesina Lagoon and those of the Circeo coastal lakes. The three Italian lagoons differ in size, morphology, origin and hydrological conditions (primarily salinity), and their fish assemblages clearly reflect this heterogeneity. In the Lesina Lagoon some species of freshwater origin (i.e. *Gasterosteus aculeatus* and the non-native *Oreochromis niloticus*), occurred, as opposed to the situation of the Circeo lagoons, where no freshwater species were found, and this is due probably to the lack of connections with surrounding streams.

On the other hand, the fish species richness appeared lower in Lesina Lagoon than in both the Circeo lakes. The number of fish species might be expected to be higher in Lesina Lagoon than in the two Tyrrhenian coastal lakes, as a consequence of a higher environmental heterogeneity, that could bring about a greater availability of niches suitable to fish, as commonly observed in larger lagoon systems compared to smaller ones (Pease, 1999; Pihl et al., 2002; Pérez-Ruzafa et al., 2006, 2007). The lower number of fish species in Lesina Lagoon was an effect of the high degree of confinement of the system, in turn due to the low efficiency of the tidal channels, long and narrow, in particular Acquarotta Channel, with respect to the total area of the basin, thus curtailing sea-lagoon water exchanges, and generally decreasing the availability of suitable habitat for colonization by marine species. The small size both of Fogliano and Caprolace lakes together with and the higher efficiency of their tidal channels, in particular of the latter, conversely endorsed the colonization by marine species, in spite of the lower environmental complexity if compared with Lesina Lagoon.

The high degree of confinement in Lesina Lagoon consequently affected also the functional structure of the fish assemblage, which was composed by comparable number of resident and marine species and by a unique freshwater species. In contrast, the fish assemblages of Circeo lagoons were dominated by marine species (especially YOY fish of marine migrants), a pattern common to the most of Mediterranean coastal lagoons (Pihl et al., 2002; Franco et al., 2008).

There are other examples of large Mediterranean coastal lagoons, Albufera (Blanco et al., 2003) in East Spain and Vaccarés in South France (Poizat et al., 2004), which have narrow connections with the sea and freshwater inputs. Nevertheless, for these, to a decrease of the availability of suitable habitat for marine species corresponded an increase of suitable habitats for freshwater species.

On the other hand, the functional structure of the three lagoons appeared more comparable in terms of feeding modes, except for a slight difference due to a quantitative dominance of carnivores in the fish assemblage of Caprolace Lake. On the contrary, invertivorous prevailed on the other feeding guilds both in Fogliano and in Lesina, similarly to most of European and Mediterranean lagoon fish assemblages (Elliott and Dewailly, 1995; Franco et al., 2008).

These findings point out how the different degree of interaction among sea, lagoon and freshwaters may deeply affect taxonomical composition, species richness and some functional features of the fish assemblages, even in lagoons located in the same geographical region. Circeo coastal lakes have higher exchanges degree with the sea, and no relations with freshwater systems. These have in fact been discontinued since because of the high nutrient inputs they brought to the lakes, that caused high eutrophication levels. Lesina Lagoon on the other hand has a quite noticeable continuity with the continental water system and a very low interface degree with the marine system. The outcome is a lower colonization by marine fish, not matched by a higher rate of colonization by freshwater species.

The investigation of spatial and temporal dynamics of fish assemblages evidenced marked temporal patterns and weak spatial ones in all case studies. Temporal patterns were found to be similar in the fish assemblages of the three lagoons, with the highest values of species richness and abundances recorded in spring. This is, the result of variations in abundances of the resident species in relation to their spawning period, combined to seasonal occurrences of YOY marine fish, recruiting to the lagoon in a period dependent by reproductive period of each species.

The spatial distribution of fish species in Fogliano and Caprolace lakes seemed to follow a gradient of marine influence from the sites near the tidal channels to the inner stations of both lakes. Furthermore, the fish assemblage of some peripheral stations of Fogliano Lake were typical of confined areas if compared to the inner stations of Caprolace Lake, evidencing a more confined character of Fogliano Lake than Caprolace Lake. By contrast, the spatial pattern of fish assemblage structure of Lesina Lagoon was representative of the higher environmental heterogeneity of the system, in which a single one-directional environmental gradient (confinement gradient) cannot be identified.

Pérez-Ruzafa et al. (2007), investigating the fish assemblages and the abiotic features of many Mediterranean coastal lagoons, have evidenced a positive correlation of fish species richness with the lagoon area and the openness parameter, which describes the potential influence of the sea on the lagoon hydrology and is related to the total transversal area of the tidal channels. Franco et al. (2008) found that latitude, lagoon area, habitat heterogeneity and average salinity extensively affect the fish species richness and the different use that fish make of the Mediterranean lagoon environments. On the other hand, they did not find any significant effect of the morphological characteristics of the lagoon connections with the sea on the fish assemblage structure.

The results obtained through this study confirm and highlight the role of morphometric features of lagoon tidal channels in structuring coastal lagoons fish assemblages (i.e. species richness and functional structure in terms of lagoon use by fish).

6.2 Quality status assessment of the of biological communities in coastal lagoons

In this research, the fish assemblage structure of the three coastal lagoons of the central-southern Italy was investigated by the classic approach in biological community studies, which relies on the taxonomical composition and the ecological indices (e.g., species richness, diversity indices and abundances), analyzing also the variations in space and time of fish assemblages in relation to some environmental parameters that can affect fish species occurrence and distribution in TW systems. The functional approach was also applied, categorizing fish species in functional guilds on the basis of the use they make of the lagoon environment of their feeding modes. The second approach is now considered to be reliable than the former in order to detect possible perturbations on TW biological communities consequent to human-induced impacts (de Jonge et al., 2006; Elliott and Quintino, 2007). Actually, some considerations on the status of the fish communities in the three lagoons can be made on the basis of functional guilds within the assemblage.

The fish assemblage of Lesina Lagoon showed a very low species richness with respect to fish assemblages of Circeo lagoons, and also to many others in Mediterranean region. However, its structure of dominance, as a consequence of the trophic status of the lagoon, and its functional structure, particularly in terms of feeding modes, are both comparable to those of most Mediterranean coastal lagoons. Additional insight for the assessment of the lagoon status is given by the evaluation of the recruitment patterns of the YOY marine fish: no changes in the nursery function of the lagoon with respect to the past were observed. Therefore, notwithstanding the low species richness, no significant disturbances in the Lesina Lagoon fish assemblages can be inferred.

On the other hand, it must be stressed that the use of diversity measures in the analysis of ecosystem structure in relation to human impacts, as recommended by the UE WFD, cannot be considered adequate, because this type of metric is not sufficient in discriminating between anthropogenic and natural stress in TW systems (The Estuarine Quality Paradox, *sensu* Elliott and Quintino, 2007).

Biological communities of TWs have many common features with marine areas subjected to anthropogenic stress, such as coastal areas with high eutrophication levels. The resulting feature displays high abundances of few species, r-strategists and with wide ecological amplitude, and generally low diversity and high biological productivity (Odum, 1969; 1985). In the case of TW systems, these features are the regular pattern that the biological communities display, and hence they must not be considered symptoms of anthropogenic stress. In contrast to marine and freshwater communities, where high diversity is required for successful ecosystem functioning and vice versa, TW systems successfully persist because of their low diversity. Organisms that are able to tolerate the changing environmental conditions in a TW system can take advantage of the lack of inter-specific competition and thus attain high population densities. Their fitness is not reduced in TWs, as in stressed marine areas, but is conversely enhanced. Therefore, the stress is only apparent in these ecosystems.

These considerations highlight the need of a specific methodology for the assessment of TW systems based on the quality status of biological communities in these systems. Specific methods shall have to consider both ecological indices and functional characteristics, the latter more robust in the assessment of quality status of TW biological communities.

6.3 Implications for the lagoon management

A crucial role of management in Mediterranean coastal lagoons has frequently been outlined (Crivelli and Ximenes, 1992; Peja et al., 1996; Quinn et al., 1999) to maintain the equilibrium of these transient environments, and to insure the stability of their biological communities. The results of the present research can therefore give a contribution to identify some key elements for the management of the three coastal lagoons taken into consideration.

The protection of the tidal channels from the silting up and the insurance of adequate lagoon-sea water exchanges are fundamental to a successful management strategy on coastal lagoons, by acting positively on the hydrology of the system and of the lagoon itself, and safeguarding the nursery function of the lagoon. This appears to be particularly true for Fogliano, where the position along the coastline of tidal channel easily brings about its silting up during sea storms. An active management of the structures placed in the tidal channels (sluices and *lavorieri*) could prove to be fundamental also in Lesina Lagoon, by allowing the recovery and improvement of the flow regime, this enhancing the attractiveness of the lagoon, that in turn could reflect on a higher number of recruits entering the lagoon.

Also, the identification and localization of the nursery areas for *Liza ramada*, *Liza saliens* and *Mugil cephalus* in the Lesina Lagoon, could represent a fundamental element and an important contribution in support the management choices for the lagoon fisheries. In the Lesina Lagoon, YOY fish of Mugilid species were mostly present in the sites near some freshwater inputs, especially close to the mouth of Pilla Channel. At the present moment, no processes associated with a quality deterioration of these areas, that could affect their nursery function, have been observed. On the other hand, it will be important to pursue the monitoring of these areas, because of their importance as essential fish habitats for economically valuable fish, in the perspective of a further decrease in environmental quality in these areas of the lagoon (Bruton, 1995; Schmitten, 1999).

The closure or limitation of the fishery in the same areas, with particular respect to some non-selective lagoon fishing techniques (i.e., fike-nets or other fishing gears with mesh size too small) could reduce the bycatch on these species (Whitfield, 1999). This option seems less necessary in the Circeo coastal lakes, where no definite spatial patterns were detected for YOY marine fish. The habitat conservation in combination with a precautionary fisheries management are important measures, that can lead to a sustainable exploitation of fish populations of these lagoon ecosystems in which a decrease in the yields was observed by long time (De Angelis, 1964; AGEI, 1997, 2004; Tancioni et al., 1998).

The conservation of threatened species also requires the conservation of their habitats, as recommended by the Habitat Directive. Some vulnerable resident species, such as *Syngnathus abaster* and *Knipowitschia panizzae*, were found in areas covered by seagrass beds in all three lagoons. Subtidal seagrass beds have indeed fundamental ecological functions in the lagoon environment, also as consequence of their three-dimensional structure. Some of these functions are the stabilization of the bottom and the providing of food and refuge to many benthic and nektonic species (Hemminga and Duarte, 2000). Indeed, many authors have found that seagrass beds support high fish abundance and biomass (Mainardi et al., 2002, 2005; Franco et al., 2006a, 2006b), and this seems related to the high structural complexity of these vegetation systems, which offer protection from the predators and food resources otherwise not available (Kikuchi and Peres, 1977; McRoy and Helfferich, 1980). Thus, the conservation of some species (e.g., *Syngnathus* spp. and *Hyppocampus* spp.), which also show specific morphological and behavioral adaptations to seagrass beds, is closely associated to the preservation of this habitat.

7. REFERENCES

A.GE.I. S.c.r.l., 1997. Studio delle interrelazioni esistenti tra le popolazioni ittiche e le componenti biotiche ed abiotiche degli ambienti lagunari. Technical Report, Ministero delle Politiche Agricole e Forestali, III Piano triennale della Pesca e dell'Acquacoltura nelle acque marine e salmastre (L. 41/82), 75 pp.

A.GE.I. S.c.r.l., 2004. Tecniche di acquacoltura responsabili in ambienti lagunari salmastri. Modelli produttivi integrati per la creazione di reddito aggiunto per i pescatori lagunari e le aziende di piscicoltura intensiva e l'avvio di programmi di ripopolamento attivo nella laguna di Lesina. Technical Report, Ministero delle Politiche Agricole e Forestali, V Piano triennale.

Akin, S., Buhan, E., Winemiller, K.O., Yilmaz, H., 2005. Fish assemblage structure of Koycezig Lagoon-Estuary, Turkey: spatial and temporal distribution patterns in relation to environmental variation. Estuarine, Coastal and Shelf Science 64, 671-684.

Andreu-Soler, A., Oliva-Paterna, F.J., Fernández-Delgado, C., Torralva. M., 2003. Age and growth of the sand smelt, *Atherina boyeri* (Risso 1810), in the Mar Menor coastal lagoon (SE Iberian Peninsula). Journal of Applied Ichthyology 19, 202-208.

Ardizzone, G.D., Cataudella, S., Rossi, R., 1988. Management of coastal lagoon fisheries and aquaculture in Italy. Vol. 293. FAO, Fisheries Technical Paper, Rome, 103 pp.

Bauchot, M.-L., Hureau, J.-C., 1986. Sparidae. In: Whitehead, P.J.P., Bauchot, M.-L., Hureau, J.-C., Nielsen, J., Tortonese, E. (Eds.), Fishes of the north-eastern Atlantic and the Mediterranean. Vol. 2. UNESCO, Paris, pp. 883-907.

Barnes, R.S.K., 1980. Coastal lagoons. The natural history of a neglected habitat. Cambridge University Press, Cambridge, 106 pp.

Beckley, L.E., 1985. Tidal exchange of ichthyoplankton in the Swartkops estuary mouth, South Africa. South African Journal of Zoology 20, 15–20.

Bianchi, C.N., 1988. Tipologia ecologica delle lagune costiere italiane. In: Carrada, G.C., Cicogna, F., Fresi E. (Eds.), Le lagune costiere: ricerca e gestione, CLEM, Massa Lubrense (Naples), Italy, pp. 57-66.

Bianchi, C.N., 2007. Biodiversity issues for the forthcoming tropical Mediterranean Sea. Hydrobiologia 580, 7-21.

Blaber, S.J.M., 1997. Fish and Fisheries of Tropical Estuaries. Chapman and Hall, London, 367 pp.

Blaber, S.J.M., Blaber, T.G., 1980. Factors affecting the distribution of juvenile estuarine and inshore fish. Journal of Fish Biology 17, 143-162.

Blanco, S., Romo, S., Villena, M.J., Martinez, S., 2003. Fish communities and food web interactions in some shallow Mediterranean lakes. Hydrobiologia 506-509, 473–480.

Boehlert, G.W., Mundy, B.C., 1988. Roles of behavioral and physical factors in larval and juvenile fish recruitment to estuarine nursery areas. American Fisheries Society Symposium 3, 51–67.

Bograd, I., 1961. Occurrence of Mugil in the rivers of Israel. Bulletin of the Research Council of Israel 9b, 169-191.

Bono, P., Ghiozzi, E., Malatesta, A., Zarlenga, F., 1985. Seminario informativo sui risultati del progetto "Laghi costieri". Terracina, 1985. Edizione Università degli Studi "la Sapienza" di Roma - provincia di Latina.

Brambati, A., 1988. Lagune e stagni costieri: due ambienti a confronto. In: Carrada, G.C., Cicogna, F., Fresi E. (Eds.), Le lagune costiere: ricerca e gestione, CLEM, Massa Lubrense (Naples), Italy, pp. 9-33.

Branco, P., Costa, J.L., de Almeida, P.R., 2008. Conservation Priority Index for Estuarine Index (COPIEF). Estuarine, Coastal and Shelf Science 80, 581-588.

Breber, P., 1994. Come si stima la produzione ittica potenziale di una laguna. Final Proceedings Conference "La laguna di Lesina quali prospettive quali soluzioni?", pp. 8-9.

Breder, C.M. Rosen, D.E., 1966. Modes of reproduction in fishes. T.F.H. Publications, Neptune City, New Jersey, 941 pp.

Breine, J.J., Maes, J., Quataert, P., Van der Bergh, E., Simoens, I., Van Thuyne, G., Belpaire, C., 2007. A fish-based assessment tool for the ecological quality of the brackish Schelde estuary in Flanders (Belgium). Hydrobiologia 575, 141-159.

Brugnano, C., D'Adamo, R., 2007. Spatio-temporal distribution and zooplankton assemblages in the Lesina Lagoon (Apulia, Adriatic Sea): relations to environmental conditions. Proceedings LaguNet 1st Conferences, Conservation and Management in Coastal Ecosystems, Naples, pp. 39.

Bruton, M.N., 1995. Have fishes had their chips? The dilemma of threatened fishes. Environmental Biology of Fishes 43, 1–27.

Bullo, G., 1902. La Laguna di Lesina. Editions Prosperini, Padova, 102 pp.

Cambrony, M., 1984. Identification et périodicité du recrutement des juvéniles de Mugilidae dans les étangs littoraux du Languedoc-Roussillon. Vie Milieu 34, 221-227.

Cardona, L., 2006. Habitat selection by grey mullets (Osteychthyes: Mugilidae) in Mediterranean estuaries: the role of salinity. Scientia Marina 70, 443-455.

Carrada, G.C., Fresi, E., 1988. Le lagune salmastre costiere. Alcune riflessioni sui problemi e sui metodi. In: Carrada, G.C., Cicogna, F., Fresi, E. (Eds.), Le lagune costiere: ricerca e gestione, CLEM, Massa Lubrense (Naples), Italy, pp. 35-56.

Ciccotti, E., 2006. Il caso dell'anguilla europea tra gestione e conservazione. In: Zerunian S. (Ed.), Pesci e pesca nei laghi costieri. Ufficio territoriale per la biodiversità di Fogliano – Parco Nazionale del Circeo, pp. 125-142.

Ciccotti, E., Busilacchi, S., Cataudella, S., 2000. Eel, *Anguilla anguilla* (L.), in Italy: recruitment, fisheries and aquaculture. Dana 12, 7-15.

Cilenti, L., Scirocco, T., Breber, P., Spada, A., 2002. Primi risultati sulla composizione della macrofauna bentonica della laguna di Lesina (FG). Biologia Marina Mediterranea 9, 605-608.

Coates, S., Waugh, S., Anwar, A., Robson, M., 2007. Efficacy of a multi-metric fish index as an analysis tool for the transitional fish component of the Water Framework Directive. Marine Pollution Bulletin 55, 225-240.

Cognetti, G., 1988. Colonizzazione delle acque salmastre. In: Carrada, G.C., Cicogna, F., Fresi, E. (Eds.), Le lagune costiere: ricerca e gestione, CLEM, Massa Lubrense (Naples), Italy, pp. 119-125.

Costa, M.J., Elliott, M. 1991. Fish usage and feeding in two industrialised estuaries – the Tagus, Portugal, and the Forth, Scotland. In: Elliott, M., Ducrotoy, J.P. (Eds.) Estuaries and coasts: Spatial and temporal intercomparisons. Olsen & Olsen, Fredensborg, Denmark, pp. 289-297.

Costa, M.J., Cabral, H.N., Drake, P., Economou, A.N., Fernandez-Delgado, C., Gordo, L., Marchand, J., Thiel, R., 2002. Recruitment and production of commercial species in estuaries. In: Elliott, M., Hemingway, K.L., (Eds.), Fishes in Estuaries. Blackwell Science, Oxford, pp. 54-123.

Cottiglia, M., 1980. Pesci lagunari. Guide per il riconoscimento delle specie animali delle acque lagunari e costiere italiane. AQ/1/90 Collana del progetto finalizzato "Promozione della qualità dell'ambiente" Consiglio Nazionale delle Ricerche, Italy, 140 pp.

Cozzolino, G.C., 1995. Macrofitobenthos della laguna di Lesina: cartografia estiva. Biologia Marina Mediterranea 2, 361-363.

Crisciani, F., 1994. L'idrodinamica della laguna di Lesina. Final Proceedings Conference "La laguna di Lesina quali prospettive quali soluzioni?, Lesina, Italy, pp. 22-23.

Crivelli, A.J., Ximenes, M.C., 1992. Alterations to the functioning of Mediterranean lagoons and their effects on fisheries and aquaculture. In: Finlayson, M., Hollis, M., Davis, T., (Eds.), Managing Mediterranean Wetlands and their Birds, vol. 20. IWRB Special Publication, Grado, Italy, pp. 134-140.

Crivelli, A.J., Ximenes, B., Gout, B., Lasserre, P., Freaon, P., Do Chi, T., 1995. Causes and effects of terrestrial runoff and riverine out flow on brackish/coastal marine fisheries ecosystems in the Northern Mediterranean region. In: Effects of riverine inputs on coastal ecosystems and fisheries resources. Vol. 349. FAO, Fisheries Technical Paper, pp. 59-88.

Cyrus, D.P., Blaber, S.J.M., 1992. Turbidity and salinity in a tropical northern Australian estuary and their influence on fish distribution. Estuarine, Coastal and Shelf Science 35, 545-563.

D'Adamo, R., Cecere, E., Fabbrocini, A., Petrocelli, A., Sfriso, A., 2009. The Lagoons of Lesina and Varano. In: Cecere, E., Petrocelli, A., Izzo, G., Sfriso, A. (Eds.), Flora and Vegetation of the Italian Transitional Water Systems. Corila, Lagunet, pp. 159-171.

D'Ancona, U., 1955. Raffronti economici fra stagnicoltura e vallicoltura. Bollettino della Pesca (Nuov. Ser. 10) 31, 9 pp.

De Angelis, R., 1964. Il lago di Lesina. Ministero della Marina Mercantile, Memorie 9.

de Jonge, V.N., Elliott, M., Brauer, V.S., 2006. Marine monitoring: its shortcomings and mismatch with the EU Water Framework Directive's objectives. Marine Pollution Bulletin 53, 5–19.

Dekker, W., 2002. Status of European eel stock and fisheries. Proceedings of the International Symposium "Advanced in Eel Biology", Tokyo, Japan, 28-30 September 2001.

Della Valle, C., 1961. La pesca nei laghi costieri del Lazio. Bollettino della Società Geografica Italiana 98, 48-97.

Elie, P., Lecomte-Finiger, R., Cantrelle, I., Charlon, N., 1982. Définition des limites des différents stades pigmentaires durant la phase civelle d'*Anguilla anguilla* L. Vie et Milieu 32, 149-157.

Elliott, M., 2002. The status, study and management of fishes in estuaries. In: Elliott, M., Hemingway, K.L., (Eds.), Fishes in Estuaries. Blackwell Science, Oxford, pp. 555-575.

Elliott, M., Dawailly, F., 1995. The structure and components of European estuarine fish assemblages. The Netherlands Journal of Aquatic Ecology 29, 397-417.

Elliott, M., Hemingway, K.L., 2002. Fishes in Estuaries. Blackwell Science, Oxford, 636 pp.

Elliott, M., Quintino, V., 2007. The Estuarine Quality Paradox, Environmental Homeostasis and the difficulty of detecting anthropogenic stress in naturally stressed areas. Marine Pollution Bulletin 54, 640–645.

Elliott, M., Griffiths, A.H., Taylor, C.J.L., 1988. The role of fish studies in estuarine pollution assessment. Journal of Fish Biology 33 (Suppl. A), 51-61.

Fabbrocini, A., Di Matteo, O., D'Adamo, R., 2008. *Abra segmentum* (Mollusca: Pelecypoda) of the Lesina Lagoon (Southern Adriatic coast, Italy): observations on variations in the population in relation to the main environmental parameters. Transitional Waters Bulletin 1, 39-44.

FAO, 1996. Integration of fisheries into coastal area management. FAO Technical Guidelines for Responsible Fisheries 3, 17 pp.

Ficca, G., Pierini, S., Purini, R., 1995. Numerical study of the dynamism of a lagoon. Proceedings of the Second International Conference on the Mediteraanean Coastal Environment, MEDCOAST 95, Tarragona, Spain, pp. 1607-1617.

Florio, M., Breber, P., Scirocco, T., Specchiulli A., Cilenti, L., Lumare, L., 2008. Exotic species in Lesina and Varano lakes new guests in Lesina and Varano lakes: Gargano National Park (Italy). Transitional Waters Bulletin 2, 69-79.

Fischer W., Bauchot M.L., Schneider M., 1987. Méditerranée et Mer Noire - Zone de Pêche 37. Volume 2: Vertébrés. Guide Fao d'Identification des Espèces pour les Besoins de la Pêche, FAO, Rome, 1529 pp.

Fortier, L., Leggett, W., 1982. Fickian transport and the dispersal of fish larvae in estuaries. Canadian Journal of Fisheries. and Aquatic Sciences 39, 1150–1163.

Franco, A., Elliott, m., Torricelli, P., 2007. Preface: Biodiversity and ecosystem functioning in coastal and transitional waters. Estuarine, coastal and shelf science 75, 1-3.

Franco, F., Franzoi, P., Malavasi, S., Riccato, F., Torricelli, P., Mainardi, D., 2006a. Use of shallow water habitats by fish assemblages in a Mediterranean coastal lagoon. Estuarine, Coastal and Shelf Science 66, 67-83.

Franco, A., Franzoi, P., Malavasi, S., Riccato, F., Torricelli, P., 2006b. Fish assemblages in different shallow water habitats of the Venice Lagoon. Hydrobiologia 555, 159-174.

Franco, A., Franzoi, P., Torricelli, P., 2008. Structure and functioning of Mediterranean lagoon fish assemblages: a key for the identification of water body types. Estuarine, Coastal and Shelf Science 79, 549-558.

Fumanti, B., Alfinito, S., Cavacini, P., 1996. Osservazioni preliminari sul fitoplancton dei Laghi di Fogliano, Monaci e Caprolace. Atti della Conferenza degli Studi e Ricerche sui Laghi costieri del Parco Nazionale del Circeo, pp. 81-91.

Fusari, A., Cecchetti, M., De Angelis, P., 2006. La pesca nei laghi costieri: aspetti storici e situazione attuale. In: Zerunian S. (Ed.), Pesci e pesca nei laghi costieri. Ufficio territoriale per la biodiversità di Fogliano – Parco Nazionale del Circeo, pp. 89-104.

GandoIfi, G., Rossi, R., Tongiorgi, P., 1981. Osservazioni sulla montata del pesce novello lungo le coste italiane. Quaderni del Laboratorio di Tecnologia della Pesca 3, 215-232.

Gandolfi, G., Pesaro, M., Tongiorgi, P., 1984. Environmental factors affecting the ascent of elvers, *Anguilla anguilla* (L.), into the Arno River. Oebalia 10, 17-35.

Gandolfi G., Zerunian S., Torricelli P., Marconato A., 1991. I pesci delle acque interne italiane. Istituto Poligrafico Zecca dello Stato, Roma, 616 pp.

Gisbert, E., Cardona, L., Castello, F., 1996. Resource partitioning among planktivorous fish larvae and fry in a Mediterranean coastal lagoon. Estuarine, Coastal and Shelf Science 43, 723-735.

Gordo, L.S., Cabral, H.N., 2001. The fish assemblage structure of a hydrologically altered coastal lagoon: the Óbidos lagoon (Portugal). Hydrobiologia 459, 125-133.

Gravina, M.F., 1986. Lo zoobenthos dei laghi pontini: un esempio di diagnosi ecologica di sistemi salmastri (1.) Atti Conv. Asp. Faun. Probl. Zool. P.N. Circeo, Sabaudia, pp. 117-131.

Guelorget ,O., Perthuisot, J.P., 1983. Le domain paralique. Trav. Lab. Géol., 16, École Norm. Sup., Paris, pp. 1-136.

Guelorget ,O., Perthuisot, J.P., 1992. Paralic Ecosystems. Biological organization and functioning. Vie Milieu 42, 215-251.

Haedrich, R.L., 1983. Estuarine fishes. In: Ketchum, B. (Ed.), Estuaries and enclosed seas. Elsevier, Amsterdam, pp. 183-207.

Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. PAST: Paleontological Statistics software package for education and data analysis. Palaeontologia Electronica 4.

Harrison, T.D., Whitfield, A.K., 2004. A multi-metric fish index to assess the environmental condition of estuaries. Journal of Fish Biology 65, 683-710.

Hemminga, M.A., Duarte, C.M., 2000. Fauna associated with seagrass systems. In: Hemminga, M.A., Duarte, C.M.(Eds.), Seagrass Ecology. Cambridge University Press, United Kingdom, pp. 199-247.

Hilmer, T., Bate, G.C., 1991. Vertical migration of a flagellate-dominated bloom in a shallow south African estuary. Botanica Marina 34, 113-121.

Howard, R.K., Koehn, J.D., 1985. Population dynamics and feeding ecology of pipefish (syngnathidae) associated with eelgrass beds of Western Port, Victoria. Australian Journal of Marine and Freshwater Research 36, 361-370.

Katselis, G., Minos, G., Marmagas, A., Hotos, G. Ondrias, I., 1994. Seasonal distribution of Mugilidae fry and juveniles in Mesolonghi coastal waters, Western Greece. Bios (Macedonia, Greece) 2, pp 101-108.

Kikuchi, T., Peres, J.M., 1977. Consumer ecology of seagrass beds. In: McRoy, C.P., Helfferich, C. (Eds.), Seagrass Ecosystems: A Scientific Perspective. Dekker, New York, pp. 147-193.

Kneib, R.T., 1997. Early life stages of resident nekton in intertidal marshes. Estuaries 20, 214-230.

Knight, B., 2003. A review of the possible impacts of long-term oceanic and climate changes and fishing mortality on recruitment of anguillid eels of the Northern Hemisphere. The Science of the Total Environment 310, 237-244.

Kottelat, M., Freyhof, J., 2007. Handbook of European freshwater fishes. Publications Kottelat, Cornol, Switzerland, 646 pp.

Koutrakis, E. T., 2004. Temporal occurrence and size distribution of grey mullet juveniles (Pisces, Mugilidae) in the estuarine systems of the Strymonikos Gulf (Greece). Journal of Applied Ichthyology 20, 76-78.

Koutrakis, E.T., Sinis, A.I., Economidis, P.S., 1994. Seasonal occurrence, abundance and size distribution of grey mullet fry (Pisces, Mugilidae) in the Porto-Lagos lagoon and Lake Vistonis (Aegean sea, Greece). Israeli Journal of Aquaculture/Bamidgeh 46, 182-196.

Koutrakis, E.T., Tsikliras, A.C., Sinis, A.I., 2005. Temporal variability of the ichthyofauna in a Northern Aegean coastal lagoon (Greece). Influence of environmental factors. Hydrobiologia 543, 245-257.

Iannibelli, M., Levi, D., Spezie, G., 1989. Osservazioni preliminari sulla rimonta del novellame nel lago Fusaro (Napoli). Oebalia XV, 803-805.

ICES, 2001. Report of the ICES/EIFAC Working Group on Eels. ICES CM 2002/ACFM:03.

ICES, 2004. Report of the ICES/EIFAC Working Group on Eels. ICES CM 2004/ACFM:09.

ICES, 2008. Report of the ICES/EIFAC Working Group on Eels. ICES CM 2008/ACOM 15, 208 pp.

Izzo, G., Signorini, A., Massini, G., 2005. L’uso dei sedimenti per la valutazione della qualità delle acque di transizione: correlazione tra test fisici, chimici e biologici. In: APAT (Ed.) Metodologie per il rilevamento e la classificazione dello stato di qualità ecologico e chimico delle acque, con particolare riferimento all’applicazione del decreto legislativo 152/99, pp. 45-377.

Legendre, P., Legendre, L, 1998. Numerical Ecology, 2nd English ed. Elsevier, 853 pp.

Lobry, J., Mourand, L., Rochard, E., Elie, P., 2003. Structure of the Gironde estuarine fish assemblages: a comparison of European estuaries perspective. Aquatic Living Resourse 16, 47-58.

Lumare, F., Palmegiano, G., 1980. Acclimatazione di *Paenaeus japonicus* (Bate) nella laguna di Lesina. Rivista Italiana di Acquacoltura 2, 53-58.

Lumare, F., Villani, P., 1989. Pesca e indirizzi di gestione produttiva del lago di Lesina (costa sud-est italiana). Oebalia 15, 683-691.

Maci, S., Basset, A., 2009. Composition, structural characteristics and temporal patterns of fish assemblages in non-tidal Mediterranean lagoons: a case study. Estuarine, Coastal and Shelf Science 83, 602-612.

Maes, J., Van Damme, P.A., Tallieu, A., Ollevier, F., 1998. Fish communities along an oxygen-poor salinity gradient (Zeeshelde Estuary, Belgium). Journal of Fish Biology 52, 534-546.

Mainardi, D., Fiorin, R., Franco, A., Franzoi, P., Giovanardi, O., Granzotto, A., Libertini, A., Malavasi, S., Pranovi, F., Riccato, F., Torricelli, P., 2002. Fish diversity in the Venice lagoon: preliminary report. In: Campostrini, P. (Ed.), Scientific research and safeguarding of Venice. Corila Research: Program 2001 results, La Garangola, Padova, pp. 583-594.

Mainardi, D., Fiorin, R., Franco, A., Franzoi, P., Malavasi, S., Pranovi, F., Riccato, F., Zucchetta, M., Torricelli, P., 2005. Composition and distribution of fish assemblages in the shallow waters of the Venice Lagoon. In: Campostrini, P. (Ed.), Scientific research and safeguarding of Venice, Corila Research: Program 2003 results. Multigraf, Venezia, pp. 405-419.

Maitland, P. S., Campbell, R.N., 1992. Freshwater fishes of the British Isles. HarperCollins Publishers, London, 368 pp.

Malavasi, S., Franco, A., Riccato, F., Valerio, C., Torricelli, P., Franzoi, P., 2007. Habitat selection and spatial segregation in three pipefish species.. Estuarine Coastal and Shelf Sciences 75: 143-150.

Manini, E., Breber, P., D'Adamo, R., Spagnoli, F., Danovaro, R., 2003. Lagoon of Lesina, Land-Ocean Interactions in the coastal zone (LOICZ). Nutrient fluxes in transitional zones of the Italian coast. A Report of the Lagunet Workshop. LOICZ Report & Studies, pp. 49-54.

Manzo, C., Lupini, G., Gravina, M.F., Ciccotti, E., 2006a. Relazioni trofiche tra le specie ittiche residenti in tre laghi costieri del Parco Nazionale del Circeo. In: Zerunian S. (Ed.), Pesci e pesca nei laghi costieri. Ufficio territoriale per la biodiversità di Fogliano – Parco Nazionale del Circeo, pp. 167-190.

Manzo, C., Scalchi, E., Fusari, A., Ciccotti, E., 2006b. Struttura e dinamiche spazio-temporali delle comunità ittiche di due laghi costieri del Parco Nazionale del Circeo. In: Zerunian S. (Ed.), Pesci e pesca nei laghi costieri. Ufficio territoriale per la biodiversità di Fogliano – Parco Nazionale del Circeo, pp. 143-165.

Marais, J.F.K., 1982. The effects of river flooding on the fish populations of two eastern Cape estuaries. South African Journal of Zoology 17, 96-104.

Marchand, J., 1988. Seasonal distribution, growth and ecological role of the juvenile sole population in the Loyre estuary (France). Journal of Fish Biology 33 (Suppl. A), 229-229.

Marchand, J., 1991. The influence of environmental conditions on the settlement, distribution and growth of 0-group sole (*Solea solea*) in a macrotidal estuary (Vilaine, France). Netherlands Journal of Sea Research 27, 307-316.

Mariani, S., 2001. Can spatial distribution of ichthyofauna describe marine influence on coastal lagoons? A central Mediterranean case study. Estuarine, Coastal and Shelf Science 52, 261-267.

Marshall, S., Elliott, M., 1998. Environmental influences on the fish assemblages of the Humber Estuary, U.K. Estuarine, Coastal and Shelf Science 46, 175-184.

Mathieson, S., Cattrijsse, A., Costa, M.J., Drake, P., Elliott, E., Gardner, J., Marchand, J., 2000. Fish assemblages of European tidal marshes: a comparison based on species, families and functional guilds. Marine Ecology Progress Series 204, 225-242.

Matić-Skoko, S., Peharda, M., Pallaoro, A., Curkrov, M., Baždarić, B., 2007. Infralittoral fish assemblages in the Zrmanjia estuary, Adriatic Sea. Acta Adriatica 48, 45-55.

McHugh, J.L., 1967. Estuarine nekton. In: Lauff, G.H. (Ed.), Estuaries, vol. 83. American Association for the Advancement of Science Special Publication, Washington, DC, pp. 581-619.

McRoy, C.P., Helfferich, C., 1980. Applied aspects of seagrasses. In: Phillips, R.C., McRoy C.P. (Eds), Handbook of Seagrass Biology: an Ecosystem Perspective, Garland STM Press, NewYork, pp. 297–343.

Miller, J.M., Burke, J.S., Fitzhugh, G.R., 1991. Early life history patterns of Atlantic North American flatfish: likely (and unlikely) factors controlling recruitment. Netherlands Journal of Sea Research 27, 261-275.

Moriarty, C., Dekker, W., 1997. Management of European eel fisheries. Fisheries Bulletin (Dublin) 15, 77-90.

Odum, E.P., 1969. The strategy of ecosystem development. Science 164, 262–270.

Odum, E.P., 1985. Trends expected in stressed ecosystems. Bioscience 35, 419–422.

Palmegiano, G.B., Deolo, A., Marolla, V., 1985. Rilevamenti dell'Istituto per lo Sfruttamento Biologico delle Lagune CNR di Lesina (FG). Dati meteorologici ed ambientali del 1984. Bollettino di Informazione Documenti dell'Istituto per lo Sfruttamento Biologico Lagune, CNR Lesina 2, pp. 1-54.

Pease, B.C., 1999. A spatially orientated analysis of estuaries and their associated commercial fisheries in New South Wales, Australia. Fishery Research 42, 67–86.

Peja, N., Vaso, A., Miho, A., Rakaj, N, Crivelli, A.J., 1996. Characteristics of Albanian lagoons and their fisheries. Fisheries Research 27, 215-225.

Pérez-Ruzafa, A., García-Charton, J.A., Barcala, E., Marcos, C., 2006. Changes in benthic fish assemblages as a consequence of coastal works in a coastal lagoon: the Mar Menor (Spain, Western Mediterranean). Marine Pollution Bulletin 53, 107-120.

Pérez-Ruzafa, A., Monpeán, MaC., Marcos, C., 2007. Hydrographic, geomorphologic and fish assemblage relationships in coastal lagoons. Hydrobiologia 577, 107-125.

Peterson, A. W., Whitfield, A. K., 2000. Do shallow-water habitats function as refugia for juvenile fishes? Estuarine, Coastal and Shelf Science 51, 359-364.

Pihl, L., Cattrijsse, A., Codling, I., Mathieson, S., McLusky, D.S., Roberts, C., 2002. Habitat use by fishes in Estuaries and other brackish areas. In: Elliott, M., Hemingway, K.L., (Eds.), Fishes in Estuaries. Blackwell Science, Oxford, pp. 10-53.

Poizat, G., Rosecchi, E., Chauvelon, P., Contournet, P., Crivelli, A.J., 2004. Long-term fish and macro-crustacean community variation in a Mediterranean lagoon. Estuarine, Coastal and Shelf Science 59, 615-624.

Pollard, D.A., Box, P.O., 1994. A comparison of fish assemblages and fisheries in intermittently open and permanently open coastal lagoons on the South coast on the New South Wales, South-Eastern Australia. Estuaries 17, 631-646.

Pombo, L., Elliott, M., Rebelo, J.E. 2005. Environmental influences on fish assemblage distribution of an estuarine coastal lagoon, Ria de Aveiro (Portugal). Scientia Marina 69, 143-159.

Potter, I.C., Claridge, P.N., Warwick, R.M. 1986. Consistency of seasonal changes in an estuarine fish assemblage. Marine Ecology Progress Series 32, 217-228.

Priore, G., La Salandra, G., Villani, P., 1994. The ascent of Sparidae and Soleidae fry in the Lesina Lagoon (Foggia-Italy). Bollettino della Società Adriatica di Scienze 75, 335-351.

Quinn, N.W., Breen, C.N., Whitfield, A.K., Hearne, J.W., 1999. An index for the management of South African estuaries for juvenile fish recruitment from marine environment. Fisheries Management and Ecology 6, 421-436.

Raynie, R.C., Shaw, R.F., 1994. Ichthyoplankton abundance along a recruitment corridor from offshore spawning to estuarine nursery ground. Estuarine, Coastal and Shelf Science, 39: 421-450.

Ribeiro, J., Bentes, L., Coehlo, R., Gonçalves, J.M.S., Lino, P.G., Monteiro, L.P., Erzini, K., 2006. Seasonal, tidal and diurnal changes in fish assemblages in the Ria Formosa lagoon (Portugal). Estuarine. Coastal and Shelf Science 67, 461-474.

Roper, D.S., 1986. Occurrence and recruitment of fish larvae in a northern New Zealand estuary. Estuarine Coastal and Shelf Science 22, 705–717.

Roselli, L., Fabbrocini, A., Manzo, C., D'Adamo, R., 2009. Hydrological heterogeneity, nutrient dynamics and water quality of a non-tidal lentic ecosystem (Lesina Lagoon, Italy). Estuarine. Coastal and Shelf Science 84, 539-552.

Rossi, R., 1986. Occurrence, abundance and growth of fish fry in Scardovary Bay, a nursery ground of the Po River delta (Italy). Archivio di Oceanografia e Limnologia 20, 259-280.

Rossi, R., Villani, P., 1980. A biological analysis of eel catches, *Anguilla anguilla*, from the lagoons of Lesina and Varano. Journal of Fish Biology 16, 413-423.

Rossi, R., Franzoi, P., 1988. Osservazioni sulla rimonta del novellame destinabile all'allevamento nell'area del delta del Po. In: Atti Seminari delle Unità Operative Responsabili dei Progetti di Ricerca promossi nell'Ambito dello Schema Preliminare di Piano per la Pesca e L'Acquacoltura, Ministero della Marina Mercantile, Consiglio Nazionale delle Ricerche vol. II, pp. 979-998.

Schmitten, R.A., 1999. Essential fish habitat: opportunities and challenges for the next millenium. American Fisheries Society Symposium, 22:3-10.

Sedberry, G.R., Carter, J., 1993. The fish community of a shallow tropical lagoon in Belize, Central America. Estuaries 16, 198-215.

Sfriso, A., Cecere, E., Petrocelli, A., Lenzi, M., 2006. Confronto della flora marina presente in alcuni ambienti di transizione italiani. Biologia Marina Mediterranea 13, 214-215.

Signorini, A., Massini, G., Migliore, G., Tosoni, M., Varrone, C., Izzo, G., 2008. Sediment biogeochemical differences in two pristine Mediterranean coastal lagoons (in Italy) characterized by different phanerogam dominance – A comparative approach. Aquatic Conservation: Marine and Freshwater Ecosystems 18, S27-S44.

Signorini A., Migliore, G., Varrone, C., Izzo, G., 2009a. The Fogliano Lagoon. In: Cecere, E., Petrocelli, A., Izzo, G., Sfriso, A. (Eds.), Flora and Vegetation of the Italian Transitional Water Systems. Corila, LaguNet, pp. 137-146.

Signorini A., Migliore, G., Varrone, C., Izzo, G., 2009b. The Lagoon of Caprolace. In: Cecere, E., Petrocelli, A., Izzo, G., Sfriso, A. (Eds.), Flora and Vegetation of the Italian Transitional Water Systems. Corila, LaguNet, pp. 147-158.

Sogard, S. M., 1994. Use of suboptimal foraging habitats by fishes: consequences to growth and survival. In: Stouder, D. J., Fresh, K. L., Feller, R. J. (Eds), Theory and application of Fish Feeding Ecology. University of South Carolina Press, Columbia, pp. 103-132.

Tancioni, L., Mamone, R., Mariani, A., Massa, F., Rampacci, M., Scardi, M., Maccaroni, A., D'Ambra, R., 1998. Lo studio del comportamento alimentare di pesci teleostei nel monitoraggio biologico delle lagune costiere: il caso dell'orata (*Sparus aurata* L.) nelle lagune di Fogliano e Caprolace (Parco Nazionale del Circeo, Italia Centrale). Biologia Marina Mediterranea, 5, 2133-2141.

Thomson, J.M., 1966. The grey mullets. Oceanography and Marine Biology. An Annual Review 4, 301-335.

Tongiorgi, P., Tosi, L., Balsamo, M., 1986. Thermal preferences in upstream migration glass-eels of *Anguilla anguilla* (L.). Journal of Fish Biology 28, 501-510.

Torricelli, P., Tongiorgi P., Almansi P., 1981-82. Migration of grey mullet fry into the Arno River: seasonal appearance, daily activity, and feeding rhythms. Fisheries Research 1, 219-234.

Tortonese, E., 1975. Fauna d'Italia. Osteichthyes. Calderini Editore (Bologna) vol. X and XI: 636 pp.

Tortonese, E., 1986. Moronidae. In:. Whitehead, P.J.P , Bauchot, M.-L., Hureau, J.-C., Nielsen J., Tortonese, E. (Eds.), Fishes of the north-eastern Atlantic and the Mediterranean. Vol. 2. UNESCO, Paris, pp. 793-796.

Uriarte, A., Borja, A., 2009. Assessing fish quality status in transitional waters, within the European Water Framework Directive : Setting boundary classes and responding to anthropogenic pressures. Estuarine, Coastal and Shelf Science 82, 214-224.

Vidy, G., Franc, J., 1992. Saisons de présence à la côte des alevins de muges (Mugilidae) en Tunisie. Cybium 16, 53-71.

Villani, P., 1987. The ascent of MugiIidae fry into a coastal lagoon of the southern Adriatic Sea. FAO Fisheries Report 394, 181-188.

Villani, P., 1998. Osservazioni sulla rimonta del pesce novella da semina nella laguna di Lesina (Foggia-Italia). Biologia Marina Mediterranea 5, 546-564.

Villani, P., Pesaro, M., Gandolfi, G., 1981-82. The ascent of elvers, *Anguilla anguilla* (L.), in two Italian localities of the Adriatic coast. Nova Thalassia 5, 125-139.

Walters, C. J., Juanes, F., 1993. Recruitment limitation as a consequence of natural selection for use of restricted feeding habitats and predation risk taking by juvenile fishes. Canadian Journal of Fisheries and Aquatic Science 50, 2058-2070.

Weinstein, M.P., Weiss, S.L., Hodson, R.G., Gerry, L.R., 1980. Retention of three taxa of postlarval fishes in an intensively flushed tidal estuary, Cape Fear River, North Carolina. Fisheries Bulletin U.S. 78, 419–436.

Whitfield, A.K., 1998. Biology and Ecology of Fishes in Southern African Estuaries. Ichthyological Monographs of the J.L.B. Smith Institute of Ichthyology 2, 223 pp.

Whitfield, A.K., 1999. Ichthyofaunal assemblages in estuaries: a South African case study. Reviews in Fish Biology and Fisheries 9, 151-186.

Whitfield, A.K., Wooldridge, T.H., 1994. Changes in freshwater supplies to southern African estuaries: Some theoretical and practical considerations. In: Dyer, K.R., Orth, R.J., (Eds.), Changes in fluxes in estuaries: Implications from Science to Management. Olsen & Olsen, Fredensborg, pp. 41-50.

Whitfield, A.K., Paterson, A.W., Bok, A.H., Kok, H.M., 1994. A comparison of the ichthyofaunas in two permanently open eastern Cape estuaries. South African Journal of Zoology 29, 175–185.

Wootton, R.J., 1990. Ecology of teleost fishes. (Fish and Fisheries Series 1.). Chapman & Hall, London, 404 pp.

Zerunian, S., 1996. Indagine faunistica sui Pesci del Parco Nazionale del Circeo (Osteichthyes, Teleostei). Atti Conforenza Studi e Ricerche sui Laghi costieri del Parco Nazionale del Circeo, Sabaudia, pp. 103-121.

Zerunian, S., 2006. I pesci dei laghi costieri italiani. In: Zerunian, S. (Ed.) Pesci e pesca nei laghi costieri. Ufficio territoriale per la biodiversità di Fogliano – Parco Nazionale del Circeo, pp. 7-87.

ACKNOWLEDGEMENTS

I am obliged to Prof. S. Cataudella, University of Rome ‘ Tor Vergata ’, for giving me the opportunity to perform my PhD work in the Laboratory of Experimental Ecology and Aquaculture, University of Rome ‘ Tor Vergata.

I kindly acknowledge Dr. Eleonora Ciccotti, who provided her scientific direction in my studies, for her valuable suggestions and critical reading of the manuscript.

I am grateful to Dr. Raffaele D’Adamo, Marine Science Institute (ISMAR) of Lesina, for give me the opportunity to do this experience and providing a precious support in all phases of my work.

I thank Dr. Zerunian and the staff of Circeo National Park (Sabaudia, Italy) for their hospitality. Circeo National Park also provided facilities and important support during sampling campaigns in the Fogliano and Caprolace lakes.

I would like also to thank the fishermen Mr Antonio D’Addetta and Mr Michele Giovanditti of *Società di Gestione della Laguna di Lesina* for their assistance in field collection during the sampling operations in Lesina Lagoon.

I thank Dr. Andrea Fusari, A.GE.I., Dr. Lea Roselli and Dr. Enrico Scalchi who assisted with both field and laboratory activities.

I thank Dr. Tommaso Russo for his advices in the data analysis.

A special *thank you* to all colleagues and friends who supported me during these years and who have shared this journey with me.

This research was partly supported by Regione Puglia, Area ”Policy for the rural development, Servizio “Hunting and Fishing” (POR 2000/06 - 4.13E) grant nr. 1939/P to R. D’Adamo. The study in the Circeo coastal lakes is a result of a collaboration between the Research Cooperative Institute (RCI) and the Biodiversity Territorial Department of Fogliano on the “Plan for the Research Applied to the Management and Conservation of the Water Environments in the Costal Lakes of Caprolace, Fogliano and Monaci”.