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Fatty acid profiles of migrating female silver eel from Mediterranean coastal lagoons as integrative descriptors of spawners biological quality

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ABSTRACT

The present study analyzed the lipid content and fatty acid profiles of European silver eels from Mediterranean lagoons, to interrogate the ecology and biology of eel, a panmictic species well represented in the region, with particular reference to breeder quality. Lagoons are coastal waterbodies included in transitional waters, sharing with these ecosystems, that include also brackish wetlands and river mouths, the characteristic of being influenced both by sea and continental waters. In the Mediterranean area these highly productive ecosystems, that also support a rich specific biodiversity, have a great relevance in relation to their great extent and the human and historical dimension, since they have long been exploited for their natural resources, especially for fishing. Eel collection was carried out in nine Italian lagoons typically representing these habitats, and two inland water habitats (a river and a lake) were added for comparison. Female silver eel muscle tissue revealed a mean lipid content significantly above the threshold considered necessary to provide the cue to trigger physiological reproductive changes for this species, in all the sampling sites irrespective of their typology. This emphasises the importance of Mediterranean coastal lagoons as habitats contributing to the eel oceanic migration, providing a significant share of spawning-stock biomass, both in terms of quality of the breeders and of their fitness to perform migration. Whereas the overall lipid content was similar among sites, the nine local populations differed in their fatty acid signatures. Thus, FA signatures might be proposed as integrative descriptors of eel spawner biological quality since they easily are able to differentiate among silver eel local stocks. Growth rates and body condition indices were strongly positively correlated to n-3:n-6 and DHA:EPA ratios in silver eels ready-to-migrate from the studied locations. This demonstrates that distinct PUFA, exclusively obtained through diet, are correlated with crucial biological features such as growth and condition of the silver eels that are going to undertake their journey to their oceanic reproduction sites. Overall, our results show the importance of additional tools for evaluating eel breeder quality that could also be integrated in the overall assessment of local stocks, a crucial step for ongoing and further management strategies of this endangered species.

1. Introduction

Among coastal and near-shore ecosystems, lagoons represent the habitats with the highest biological productivity in the Mediterranean region (Day et al., 1989; Pérez-Ruzafa and Marcos, 2012) as well as in other coastal areas over the world, playing a fundamental role in flood control, nutrient cycling and sediment dynamics (Airoldi and Beck, 2007). The composite structure and functioning of these highly resilient and productive environments, and their efficient trophic transfer, is the base on which their unique characteristic of accommodating human activities rely. In this respect, lagoons, as wetlands and transitional waters in general, provide a variety of goods, uses and values to mankind. Together, these environments offer an important set of ecosystem services, i.e. coastal protection, erosion control, water purification, preservation of cultural heritage and maintenance of economic activities such as fisheries, tourism and recreation (Barbier et al., 2011).

These general features apply to all 400 Mediterranean coastal lagoons, ranging from very large to extremely small in size and amounting to 580,000 ha in overall extension (Cataudella et al., 2015). Lagoons provide suitable habitats for many fish species that dwell in these transitional water bodies to feed and grow (Pihl et al., 2002; Franco et al., 2008) and therefore support the typical fish communities that sustain economic activities inside most Mediterranean lagoons (Cataudella et al., 2004; Pérez-Ruzafa et al., 2011). On the other hand, lagoons also support offshore stocks of some economically valuable species that are distinctive of Mediterranean fisheries.

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One feature of all types of coastal wetlands and transitional waterbodies is their role as nursery grounds for species which are considered important both ecologically and economically (Beck et al., 2001; Mumby and Hastings, 2008). Many fish species among those that inhabit lagoons in temperate systems (Anguillidae, Sparidae, Mugilidae, Serranidae, Sciaenidae, Pleuronectidae, Engraulidae) are in fact involved in some form of diadromy.

Lagoon habitats provide to fish protective conditions because they act as physical shelters and offer protection from predators, also ensuring growth through high productivity and robust food webs. This function of coastal lagoons is also enabled by the concurrent temporal patterns between fish recruitment to lagoons and prey availability, a coincidence that most migrating species have established. The web of connectivity linking lagoons and estuaries to coastal zones, similar to the connectivity of spatially distributed marine populations, relies then on the migratory patterns of fish, involving both the larval and juvenile stages as well as the out-migrating adults that enter and leave lagoons during their life cycles. Through the well-established ontogenetic migrations of lagoon-dwelling fish species, coastal wetlands contribute to many off-shore adult fish stocks, sustaining their renewability as well as their biomass, and this is an additional important role that lagoons play for many fish species in coastal areas (Able, 2015; Brehmer et al., 2013).

Among the many species composing the fish communities of Mediterranean coastal lagoons, the European eel (*Anguilla anguilla*, L. 1758) is one whose life history strongly relies on the connection between transitional waters, continental waters and sea. The oceanic larvae (*leptocephali*) are transported by currents across the Atlantic up to the European continental shelf where they metamorphose into glass eels. These recruit to continental waters of Europe and Northern Africa, where they remain until they attain a pre-reproductive stage (silver eels) after several years, ready to reach the Sargasso Sea, which is unambiguously recognized as the unique spawning ground for eel (Als et al., 2011). Eels are ubiquitous in coastal and continental habitats across Europe and in the Mediterranean region, because of its catadromous habits, as well as of its physiological and ecological endurance. This fish represents a unique example of panmictic species (Als et al., 2011), displaying an extreme plasticity in phenotypic traits. This, and the consequent adaptability to extremely different habitats, rely upon the common genetic pattern (Vøllestad, 1992; van Ginneken and Maes, 2005), even though interactions with biotic and abiotic factors of the continental habitats in which juvenile eel settle and grow play an additional role in this versatility (Aalto et al., 2015).

With specific reference to coastal lagoon habitats, Aalto et al. (2015), based on a preliminary assessment of past, present and potential escapement of breeders (silver eels) from these environments, have suggested that the Mediterranean sub-populations might provide a significant contribution to the global European eel stock. The role and relevance of Mediterranean lagoons as growing habitats for this species has also been highlighted by the study of habitat use that has shown how in transitional waters in this region growth rates and habits differ from the ones displayed in rivers and coastal habitats at more northern latitudes (Acou et al., 2003; Capoccioni et al., 2014). Residency, rather than nomadism, is the dominant habitat use behavior in Mediterranean transitional waters, since this attitude provides the most suitable conditions for growth (Capoccioni et al., 2014). However, definite settlement depends on catchment food availability and carrying capacity (Leone et al., 2016).

The issue of the habitat choice based on food availability, and the relationship between trophic habits, diet and growth, seem relevant related to the fitness and biological quality of eel spawners (Belpaire et al., 2009). This is the assumption of the present study, that aims at substantiate the hypothesis that eel spawners from different habitats, and in particular from diverse coastal lagoons, differ in quality, based on lipid content and FA composition. Some preliminary work for estimating the condition of escaping silver eels was carried out by ICES (2012, 2013) using parameters such as lipid level, eel size, cost of transport and distance to Sargasso Sea. Eels store lipids throughout the development from elver to silver stage and they fast during their reproductive migration, therefore the successful achievement of the life cycle relies on both the quantity (Verbiest et al., 2012) and quality of lipids accumulated, since FAs, and especially PUFA, are precursors of maturation regulators (Mazzeo et al., 2010).

Given the oceanic spawning migration, lipids play then a crucial role in both migration and reproductive success of all Anguillid species (Boëtius and Boëtius, 1985; Larsson et al., 1990; Svedäng and Wickström, 1997). The possibility to evaluate the reproductive potential of local stocks integrating information on quality of silver eels leaving single catchments appears of paramount importance related to the possible implications for stock management (ICES, 2012), by providing supporting knowledge for eel sub-populations, relevant to identify priority sites where management and/or conservation measures should be primarily addressed. A prolonged decline of recruitment and reduction of silver eel yields across the entire distribution area (ICES, 2016) aroused concern for the global stock, laying the ground for the implementation of a specific framework for its protection and recovery, through the issuing of a specific Regulation, EC 1100/2007 (Commission of the European Community, 2007).

Causes of eel decline are considered to be numerous and concurrent, attributable to natural as well to anthropogenic causes (van Ginneken and Maes, 2005). Among them, the risks associated to a reduced biological quality of silver eels has been put forward as significantly impacting the eel local stocks, and hence the entire population. The reduction of the fitness of potential spawners, as a consequence of specific contaminants and diseases, and the potential mobilization of high loads of reprotoxic chemicals during migration, are thought to be key factors that decrease the probability of successful migration and reproduction (Geeraerts and Belpaire, 2010). An increasing amount of evidence indicates that information about eel quality could be important not only for understanding the reasons for the decline of the species (Belpaire et al., 2016), but also for supporting any framework for protection and recovery of the eel stock (Robinet and Feunteun, 2002).

Against this background, the overall aim of this study was to assess the quality of migrating spawners through the evaluation of lipid content and FA profiles of white muscle of female silver eels from several local populations of European eel in Mediterranean coastal transitional waters and inland waters. Specific objective was to verify if FA composition differs in eel spawners from different habitats, with priority interest to coastal lagoon environments, since FA signatures might reflect differences in trophic conditions in turn due to ecological differences of habitats where the preceding growth period has been spent. In this respect, lipid content and FA signatures were evaluated as tools to provide insight into the ecology of eels over spatial and temporal ranges.

Since the 1990s, the use of fatty acids (FA) has given a remarkable acceleration to the investigations of food web interactions and ecosystem structures, given their usefulness as tools to understand ecological aspects such as trophic interactions, up to the quantitative assessment of predator diets (Iverson et al., 2004; Budge et al., 2006; Parrish, 2013). Changes in FAs composition can provide insight into the qualitative and quantitative aspects of animal diets in different environments. In the marine environment, they are used to elucidate aspects such as resource partitioning or habitat use within fish communities. The use of FAs as trophic biomarkers is based on the assumption that many FAs in the aquatic environment are characteristic of specific phytoplankton or invertebrate species but cannot be synthetized in appreciable amounts by higher trophic levels. Therefore, they retain the signature of the dietary origin when found in the consumer tissue (Stowasser et al., 2012).

Fish fatty acid composition and content are known to vary significantly, even between individuals of the same species. A number of environmental factors, such as the type and the availability of food, the