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Feeding strategies and ecological roles of three predatory pelagic fish in the western Mediterranean Sea

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ABSTRACT

Knowing the feeding ecology of marine predators is pivotal to developing an understanding of their ecological role in the ecosystem and determining the trophic relationships between them. Despite the ecological importance of predatory pelagic fish species, research on these species in the Mediterranean Sea is limited. Here, by combining analyses of stomach contents and stable isotope values, we examined the feeding strategies of swordfish, *Xiphias gladius*, little tunny, *Euthynnus alletteratus* and Atlantic bonito, *Sarda sarda,* in the western Mediterranean Sea. We also compared the trophic niche and trophic level of these species with published information of other sympatric pelagic predators present in the ecosystem. Results indicated that, although the diet of the three species was composed mainly by fin-fish species, a clear segregation in their main feeding strategies was found. Swordfish showed a generalist diet including demersal species such as blue whiting, *Micromesistius poutassou*, and European hake, *Merluccius merluccius,* and pelagic fin-fish such as barracudina species (*Arctozenus risso* and *Lestidiops jayakari*) or small pelagic fish species. Little tunny and Atlantic bonito were segregated isotopically between them and showed a diet basically composed of anchovy, *Engraulis encrasicolus,* and round sardinella, *Sardinella aurita,* and sardines, *Sardina pilchardus*, respectively. This trophic segregation, in addition to potential segregation by depth, is likely a mechanism that allows their potential coexistence within the same pelagic habitat. When the trophic position of these three predatory pelagic fish species is compared with other pelagic predators such as bluefin tuna, *Thunnus thynnus*, and dolphinfish, *Coryphaena hippurus*, present in the western Mediterranean Sea, we found that they show similar intermediate trophic position in the ecosystem. In conclusion, the combined stomach and isotopic results highlight, especially for little tunny and Atlantic bonito, the trophic importance of Clupeoid species in their diet. In addition, the importance of demersal resources for swordfish provides evidence for the pelagic-demersal coupling of the ecosystem and the need to manage marine resources in an integrated way.

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1. Introduction

Determining the feeding ecology of a particular organism is pivotal to understanding its ecological role in the ecosystem and to designing effective management programmes. Predatory pelagic fish species are often classified as top- and meso-predators within marine ecosystems, although there are important differences in the diets between species (Sibert et al., 2006; Stergiou and Karpouzi, 2002). Pelagic predators exert top-down influences on communities, and thus declines in their populations can have large impacts on marine ecosystems (Baum and Worm, 2009). However, the trophic role that individual species play within marine communities in many ecosystems is still often unclear, which precludes the prediction of the consequences of their removal or the reduction of their main trophic resources. To unravel this problem, more studies of species-specific trophic ecology are essential, as these can inform on the ecological role of species and thus on conservation strategies (Falautano et al., 2007; Potier et al., 2007; Romeo et al., 2009; Rosas-Luis et al., 2015).

In comparison to more abundant, ecologically and economically important small pelagic species (Palomera et al., 2007; Stergiou and Karpouzi, 2002), research focusing on predatory pelagic

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fish inhabiting the Mediterranean Sea is very limited (e.g. Falautano et al., 2007; Romeo et al., 2009; Stergiou and Karpouzi, 2002). This is true despite the fact that they play a potentially important ecological role for the functioning of the ecosystem and despite their economic importance. This is the case of swordfish, *Xiphias gladius*, little tunny, *Euthynnus alletteratus,* and Atlantic bonito, *Sarda sarda*, three migratory and predatory pelagic fish. Also, swordfish is considered a near threatened species by the IUCN Red List in the Mediterranean Sea (Di Natale et al., 2011). These species are found in open waters of tropical, subtropical and temperate oceans, including the Mediterranean Sea (Palko et al., 1981; Yoshida, 1980, 1979). Although several aspects related to their fishery, biology and genetics have been studied in the Mediterranean Sea (e.g. De Metrio et al., 1989; Tserpes and Tsimenides, 1995; Valeiras et al., 2008; Viñas et al., 2004), accurate data on their feeding habits are scarce (e.g. Campo et al., 2006; Falautano et al., 2007; Romeo et al., 2009), and are practically absent from some areas where these species are of high economic interest such as the western Mediterranean Sea. This lack of knowledge precluded their inclusion in ecosystem-based models aiming at assessing the impacts of fishing and climate variation and describing ecosystem functioning in this Mediterranean area (Coll et al., 2006; Corrales et al., 2015).

Previous information from other areas of the Mediterranean Sea and the Atlantic Ocean indicates that these three species are considered opportunistic and very voracious predators (Salman, 2004; Campo et al., 2006; Falautano et al., 2007; Romeo et al., 2009). In particular, little tunny and Atlantic bonito have an apparent preference for fin-fish, especially clupeoid species such as sardines *Sardina pilchardus*, and anchovies *Engraulis encrasicolus*, although their diet also includes other fin-fish species, crustaceans and cephalopods (e.g. Campo et al., 2006; Falautano et al., 2007). Although swordfish also prey on fin-fish, the importance of cephalopods in its diet appears to vary spatially and ontogenetically (e.g. Romeo et al., 2009; Salman, 2004).

The study of the feeding ecology of marine predators has traditionally relied on stomach content analysis (Stergiou and Karpouzi, 2002). Although these data permit high levels of taxonomic resolution, predatory pelagic fish often have empty stomachs and the prey that are recovered are often skewed toward those that are difficult to digest (Hyslop, 1980). Also, the method used to capture pelagic fish could affect the type of prey present in the stomachs. Stable isotopes of nitrogen (δ^{15}N) and carbon (δ^{13}C) have been used as a complementary tool to study different aspects of the feeding ecology of marine organisms (Layman et al., 2012). This approach is based on the fact that δ^{15}N and δ ^{13}C values are transformed from dietary sources to consumers in a predictable manner and integrate the diet of the consumer over a longer time period (muscle integrates information about feeding over several months; Madigan et al., 2012; Vander Zanden et al., 2015). δ^{15}N and δ^{13}C values are indicators of the consumers' trophic positions and dietary sources of carbon, respectively (Layman et al., 2012). In addition, by combining stable isotope values for consumers with those of their potential prey, isotopic mixing models can be applied to interpret the isotopic values by estimating the relative contribution of each prey item to the diet of the consumer (e.g. Stable Isotope Analysis in R [SIAR] isotopic mixing model; Parnell et al., 2010). Although outcomes of stomach content and isotopic analyses need to be interpreted with caution and may not be directly comparable, the combination of their results is highly useful to better understand the trophic ecology of marine predators (Albo-Puigserver et al., 2015; López et al., 2016; Olson et al., 2010; Young et al., 2015; Zudaire et al., 2015).

In the present study, we examined the feeding ecology of swordfish, little tunny and Atlantic bonito in the western Mediterranean Sea using a combined approach of stomach contents and stable isotopes (nitrogen and carbon isotopic values) in muscle tissue. We then compared their trophic niche and trophic level with published trophic information of other sympatric pelagic predators present in the ecosystem. Our study provides new insights into the ecological role of these three species within the pelagic community, obtaining new data on how these three important pelagic predators exploit available resources.

2. Materials and methods

2.1. Study area and sampling procedure

This study was conducted between May and September 2012 in the western Mediterranean Sea with individual samples provided by deep-water longline, surface longline, purse seine and gillnets fishing vessels working in the Balearic Sea (Table 1; Fig. 1). The depth and the period of the day varied between the gear type: deep-water longlines (depth=265–427 m; 2–8 h GMT), surface longline (depth=31–70 m; 2–8 h GMT), purse seine (depth=108–128 m; 0–6 h GMT) and gillnet (depth=27–87 m; 10–4 h GMT). This region is one of the most important fishing grounds in the Mediterranean Sea (Lleonart and Maynou, 2003; Navarro et al., 2016). The oceanographic features of the area are controlled by a southwestward current that follows the continental slope close to the coast in the northern part of the area where the continental shelf is narrow and influences the circulation features over the continental shelf in the southern part, which presents a wider continental shelf (Salat, 1996). Over these continental shelves, anticyclonic eddies may develop and local events like wind stress, vertical mixing, upwellings and inputs of freshwater, can have a major influence on the circulation patterns (Salat, 1996).

Individuals of swordfish (n=29, mean and standard deviation of body length=91.76 ± 7.71 cm), little tunny (n=18, body length=45.07 ± 23.19 cm), and Atlantic bonito (n=39, body length=27.05 ± 16.84 cm) were collected and stored in a fridge at 5–6 °C on board during spring and summer 2012 in the study area (Fig. 1). In the laboratory, from each collected individual, we measured the lower jaw fork length (in cm), and the stomach and a small portion of dorsal muscle (without skin and cartilage) were extracted from each specimen and stored at −20 °C until their analyses were conducted.

2.2. Stomach content analyses

At the laboratory, each stomach was weighed and its contents were extracted. Prey items found in each stomach were carefully separated and identified to the lowest taxonomic level possible. Individuals of each identified taxon were counted and weighed. Whenever fragments were found, the number of individuals was registered as the smallest number without overestimating the occurrence of prey items.

To assess the importance of different prey groups in the diet we calculate three trophic metrics for each species in relation to the total number of stomachs analysed: %FO (frequency of occurrence of each prey), %N (contribution by number of each prey) and %W (wet weight of each prey). All calculations were based on the number of non-empty stomachs. The vacuity index, %V = percentage of empty stomachs, was also calculated. We also estimated the %W at individual level (Chipps and Garvey, 2007).

2.3. Stable isotope analyses and isotopic mixing model

Muscle samples of swordfish (n=29), little tunny (n=18), and Atlantic bonito (n=23) were freeze-dried, powdered and 0.3–0.4 mg of each sample was packed into tin capsules. Isotopic

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