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Feeding ecology of two demersal opportunistic predators coexisting in the northwestern Mediterranean Sea

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ABSTRACT

The study of the feeding ecology of marine organisms is crucial to understanding their ecological roles and advancing our knowledge of marine ecosystem functioning. The aim of this study was to analyse the trophic ecology of two demersal predator species, black anglerfish (*Lophius budegassa*) and white anglerfish (*L. piscatorius*), in the northwestern Mediterranean Sea. Both species are important in the study area due to their high abundance and economic value, but information about their feeding behaviour is scarce. Here, we described the diet composition and ecological role of these two species, investigating whether trophic segregation exists between them and amongst fish of different sizes. In addition, by using experimental survey data we described the spatial distribution of both species to help us interpret trophic behaviour patterns. We gathered samples of two different sizes (small individuals of a total length <30 cm and large individuals ≥30 cm) of both species and combined stomach content analyses (SCA) and stable isotope analyses (SIA) of nitrogen and carbon with isotopic mixing models. Our results revealed that both anglerfish species are opportunistic predators, showing a diet composed mainly of fishes and, to a lesser extent, of crustaceans, with a small proportion of cephalopods, gastropods, bivalves and echinoderms. We found trophic segregation between the two species and the two sizes, indicating that they feed on different prey, in line with differences in their spatial distribution within the study area. This partial partition of food resources could also be explained by the differences in rhythms of activity that were reported in previous studies. In addition, although both species occupied a high position within the food web, our results showed that white anglerfish individuals and the large-sized fish of both species held higher trophic positions. This study demonstrates the usefulness of complementary approaches for trophic studies and confirms that both anglerfish species play an important role as predators in the northwestern Mediterranean Sea food web.

1. Introduction

Information about the feeding ecology of marine organisms is pivotal to understanding their ecological role in ecosystems. Diet information is also necessary to understand different ecological issues such as, for example, how ecological roles change with size, differences in prey selection between species or resource partitioning and the structure of marine communities (Macpherson, 1981; Stergiou and Fourtouni, 1991; Labropoulou and Eleftheriou, 1997). Moreover, diet information is also important to achieve the efficient management of commercial species, and to implement ecosystem-based approaches to understand and predict changes in the ecosystem due to human impacts and environmental change (Coll et al., 2009).

Although a large amount of information about the feeding ecology of marine species has been published, accurate information for some species is scarce (see review in Stergiou and Karpouzi, 2002). This is the case for two important demersal predators, the black anglerfish (*Lophius budegassa* Spinola, 1807) and the white

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anglerfish (*Lophius piscatorius* Linnaeus, 1758), in the Mediterranean Sea. Despite the limited information about these two species, they are highly exploited in the Mediterranean Basin due to their great economic value (Fariña et al., 2008; Colmenero et al., 2013). Both species are characterised by dorso-ventrally compressed morphology, a wide mouth, and the presence of an illicium, a modified first dorsal ray which serves as a lure (Fariña et al., 2008). Previous studies have shown that anglerfish species are non-selective feeders displaying a common feeding strategy characterised by hiding on the sea floor awaiting potential prey, luring them by moving the first ray and ambushing them (Laurenson and Priede, 2005; Fariña et al., 2008). Available data indicate that they mainly prey on fishes (Table 1). In addition, it was described that the diet of these species changes in relation to the size of the individuals (Crozier, 1985; Negzaoui-Garali et al., 2008; Stagioni et al., 2013).

The study of the diet of marine fish has commonly relied on stomach content analyses (Hyslop, 1980). However, anglerfish species show ambush behaviour within the trawling nets, the typical method of capture for these species. Thus, it is difficult to separate between their usual prey and the prey that was consumed in the trawl net. This limitation reinforces the importance of complementary analyses, such as the use of stable isotopes of nitrogen (δ^{15}N) and carbon (δ^{13}C). Stable isotope analyses (SIA) are based on the fact that δ^{15}N and δ^{13}C values are transformed from dietary sources to consumers in a predictable manner reflecting the food assimilated by the consumer in the tissue analysed (Layman et al., 2012). Particularly, nitrogen isotopes indicate the trophic position of individuals since they exhibit stepwise enrichment with higher trophic levels, whereas carbon isotopes vary among primary producers depending on the photosynthetic pathway providing information about the original sources of dietary carbon (Layman et al., 2012). Moreover, by combining stable isotope values of consumers with those from their potential prey, isotopic mixing models can be applied to obtain estimates of the relative contribution of each prey to the diet of the consumer (Parnell et al., 2010). Therefore, although outcomes of stomach content analyses and isotopic mixing models should be interpreted with caution, their combination allows for a better understanding of the feeding ecology of organisms (Navarro et al., 2014; Albo-Puigserver et al., 2015; Barría et al., 2015; Young et al., 2015).

Although some previous studies of the diet of these species were available (Table 1), the diet studies of black anglerfish mainly were conducted in the Atlantic Ocean and central Mediterranean Sea, with very few information from the feeding habits of this species in the Mediterranean Sea. Similarly, for white anglerfish, the few published diet studies were conducted in the Atlantic Ocean (Table 1). Also, studies including the direct comparison between the two species were lacking. Since black and white anglerfish tend to co-occur in the wild (Colmenero et al., 2015a), we expected some degree of trophic partitioning between the two species to reduce competition and allow coexistence (Schoener, 1974; Macpherson, 1981). In this study, our main objective was to examine the feeding habits of the black and white anglerfish in the northwestern Mediterranean Sea with the use of stomach content and stable isotopic methodologies. Specifically, the study aimed: (1) to quantify the diet composition and trophic position of both species; (2) to evaluate the effect of size on their feeding behaviour; and (3) to describe the species' spatial distribution to help us interpret trophic behaviour patterns.

2. Materials and methods

2.1. Study area and sampling procedure

The study was developed along the continental shelf and slope of the Catalan Sea associated with the Ebro River delta (northwestern Mediterranean Sea, Balearic Sea; Fig. 1). This area is particularly productive due to a combined effect of the Northern current and run-off from the Ebro River (Estrada, 1996). The study area is one of the most important fishing grounds in the Mediterranean Sea, with a high demersal biodiversity (Papaconstantinou and Farrugio, 2000; Navarro et al., 2015).

We collected 190 black anglerfish and 116 white anglerfish individuals from March 2012 until July 2013 from commercial bottom trawlers and during experimental fishing surveys conducted in February and July 2013 (ECOTRANS Project, Institut de Ciències del Mar ICM-CSIC). The depth of all catches ranged between 40–446 m and 40–775 m for the black anglerfish and white anglerfish, respectively. We recorded total length (TL, in cm) and weight (to the nearest 0.001 g) of all the individuals captured. Black anglerfish individuals ranged from 5 to 53.5 cm in total length (TL mean = 26.3 cm, SD = 11.2 cm), with a higher frequency (72.52%) for individuals from 15 to 37 cm in size. White anglerfish individuals ranged from 10.3 to 123 cm in TL (mean = 34.07 cm, SD = 21.20 cm), with a higher frequency (82.76%) of individuals <50 cm. The stomach and a small portion of muscle (without skin) of each individual were frozen at −20 °C until stomach content and isotopic analysis were carried out. In order to analyse possible differences in the feeding pattern amongst different sizes of the two species and to allow further comparisons with previous studies (Hislop et al., 2001; Maravelias and Papaconstantinou, 2003; Laurenson and Priede, 2005) we classified individuals into two size ranges (small size, TL < 30 cm; large size, TL ≥ 30 cm).

Results from the experimental fishing survey in July 2013 (ECOTRANS Project, Institut de Ciències del Mar ICM-CSIC) were used to describe the species' spatial distribution (Fig. 2). During this survey, 45 randomly distributed demersal trawl catches were made. Distribution maps of abundances (individuals·km^{-2}) were built with the Surfer v.11 software, using kriging as the interpolation method.

Table 1
Feeding studies and main prey species in the diet reported for black and white anglerfish. NW: northwestern, NE: northeastern, C: central.

Area	Main prey species	Reference
BLACK ANGLERFISH		
NE Atlantic	*Micromesistius poutassou, Capros aper* and *Citharus macrolepidotus*	Azevedo (1996)
C Mediterranean	*Merluccius merluccius, Trachurus mediterraneus* and *T. trachurus*	Negzaoui-Garali et al. (2008)
NE Atlantic	*Micromesistius poutassou, Phycis blennoides* and *Callionymus* sp.	Preciado et al. (2006)
C Mediterranean	*Merluccius merluccius, Gaidropsarus biscayensis* and *Mullus barbatus*	Stagioni et al. (2013)
C Mediterranean	*Merluccius merluccius, Gaidropsarus biscayensis* and *Callionymus maculatus*	Stagioni et al. (2007)
WHITE ANGLERFISH		
NE Atlantic	*Micromesistius poutassou, Capros aper* and *Citharus macrolepidotus*	Azevedo (1996)
NE Atlantic	*Trisopterus esmarkii, Merlangius merlangus* and *T. luscus*	Crozier (1985)
NE Atlantic	*Trisopterus esmarkii, Ammodytes marinus* and *Melanogrammus aeglefinus*	Laurenson and Priede (2005)