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Spatial and temporal patterns in the movement of adult two-banded sea bream *Diplodus vulgaris* (Saint-Hilaire, 1817)

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ABSTRACT

The patterns of spatial and temporal activity during the spawning season for an important recreational and commercial target species from the Mediterranean Sea and mid-east Atlantic, *Diplodus vulgaris*, were investigated using acoustic telemetry. No diel behavior was found in the detection pattern and the probability of detecting any tagged fish was independent of time. Individual fish spent 95% of their time in an area smaller than 1 km^2. The asymptotic value of home range (HR) was observed a few days after fish were tagged and released. There was high overlap in the areas used during the day and night, and individuals exhibited high site fidelity. The movements of *D. vulgaris* during the spawning season resembled random movement within a specific HR area (sedentary behavior) rather than directional movement (nomadic behavior) and daily migrations were discarded. The results provided here are useful for management and suggest that small protected areas can offer a promising approach to the sustainable development of this fishery.

1. Introduction

Diplodus vulgaris (Sparidae), the two-banded sea bream, is an important species targeted by the recreational and commercial fisheries in the Mediterranean (e.g., Coll et al., 2004; Lloret et al., 2008; Morales-Nin et al., 2005) and in some regions of the mid-east Atlantic (e.g., Veiga et al., 2010). This species is mainly observed over rocky bottoms and in *Posidonia oceanica* meadows at infralittoral habitats, and different aspects of this specie's life history (e.g., growth, reproduction and habitat preferences) are well known (La Mesa et al., 2010; Gonçalves et al., 2003; Gordoa and Moli, 1997; Sala and Ballesteros, 1997).

Owing to the intense exploitation of this species in the Mediterranean, a variety of management tools have been adopted to maintain the sustainability of the fishery. In addition to general rules (as in the case of the Balearic Islands, Morales-Nin et al., 2010), such as daily bag limitations or gear restrictions, a minimum legal size of 180 mm is stipulated in the Mediterranean area. Moreover, marine protected areas (MPAs) have become popular among managers as a tool for managing marine coastal resources in the Mediterranean (Francour et al., 2001). In fact, studies have shown that no-take areas perform well in achieving biomass recovery for this species (Di Franco et al., 2009; La Mesa et al., 2011).

In this context, the effectiveness of MPAs depends on the scale of fish movement in relation to the size of the MPA (Kramer and Chapman, 1999; Sale et al., 2005). To improve their performance, MPAs should be large enough to include appropriate habitats for containing the regular movements of adult fish (i.e., the home range of sedentary fish (Kramer and Chapman, 1999)). Thus, the spillover of early life stages (eggs and larvae), as well as the movement of adults into areas outside the MPA, can only be successful (in terms of sustainability) if a stable adult population is able to persist within the protected area (Kaplan et al., 2006).

Nevertheless, most spatial-management decisions have traditionally been based on population-dynamic models that incorporate fishing effort and a number of biological traits but assume fish populations to be spatially homogeneous (Botsford et al., 2003). Thus, space and time utilization become a key topic if population-dynamic models are used to establish a maximum sustainable yield level (Botsford et al., 2009). This element may be important in the case of *D. vulgaris* because the spatial use patterns of adults and potential spawners remain unknown. Spatial data have been obtained for subadults in nursery areas (Abecasis et al., 2009), as well as demonstrated using otolith microchemistry (Correia et al., 2011), however, information on the spatial behavior in habitats occupied by adults remains unavailable.

The main objective of this work was to provide information on the temporal and spatial use of habitats by adult *D. vulgaris* using acoustic telemetry. The use of acoustic telemetry has refined the study of the spatial and temporal structure of fish species over various scales of space and time (Parsons and Egli, 2005). Therefore, an

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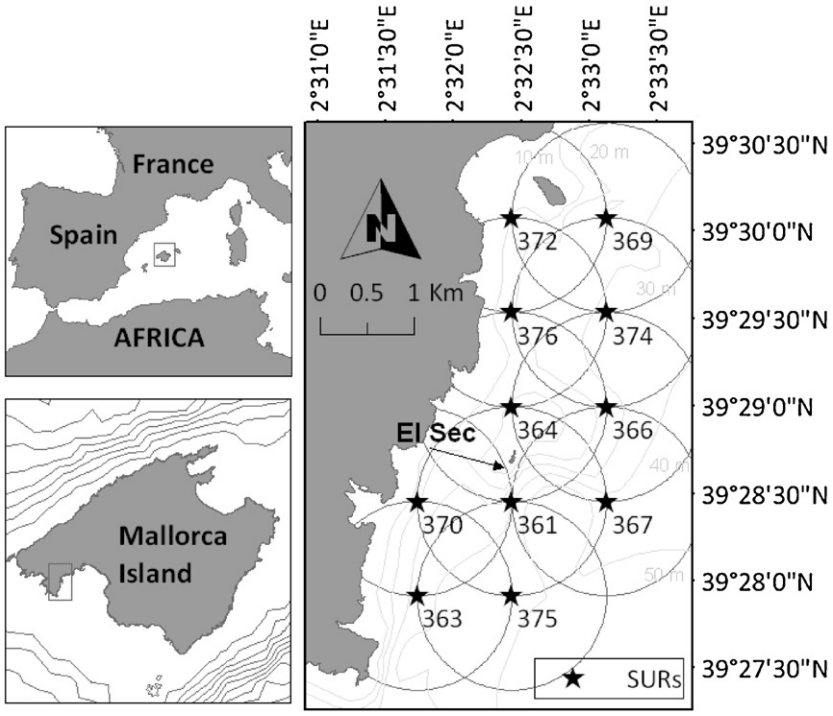

Fig. 1. Map showing the receiver array located in southwestern Palma Bay, Mallorca Island. The arrow shows the location of the experimental fishing for tagging. The figure also shows the position of each acoustic receiver (SUR-1) as a black star and the theoretical detection range provided by Sonotronics®.

acoustic receiver array was deployed to explore temporal patterns in *D. vulgaris* behavior, including short-term (e.g., diel) changes in activity. Home range and site fidelity were also investigated to determine the degree to which the adults are sedentary on a diel basis during the spawning season.

2. Materials and methods

2.1. Acoustic tracking experiment

An array of 11 acoustic omni-directional receivers (Sonotronics® model SUR-1) was deployed in southwestern Palma Bay in September 2010 (Mallorca Island, Fig. 1). The array design was based on a 1000 m × 1000 m grid (Fig. 1). This design incorporated the maximum detection range of the Sonotronics® acoustic tags used and allowed the detection range of the receivers to overlap (see Fig. 1). The array was also designed to address the trade-off between the unknown spatial range of this species in the Mediterranean (because no data exist on adult fish) and the number of receivers available. The array covered an area from the coast to the 30-m isobath and was composed of a mixture of *P. oceanica* meadows and rocky bottoms (D. March, personal observation) where *D. vulgaris* is likely to be observed (Sala and Ballesteros, 1997).

In October 2010, 10 *D. vulgaris* individuals were acoustically tagged using the acoustic tags model Sonotronics® CT-82-1-I. These tags are 38 mm × 16.5 mm in size, weigh 6 g in water and have a battery life of 60 days. At this time, *D. vulgaris* are in the reproductive spawning stage in the Mediterranean area (October to February, Tsikliras et al., 2010). *D. vulgaris* has been categorized as a rudimentary hermaphrodite, gonochoristic species with batch-spawning fecundity (Buxton and Garratt, 1990). The species is not sexually dimorphic, and sex-related differences could not be evaluated. The fish tagged (see Table 1) were greater than 180 mm in length, which is the size at maturity described for this species (Gonçalves et al., 2003). Thus, all individuals were spawners, as required by the main objectives of the present study.

D. vulgaris were individually caught and tagged near "El Sec" Island (Fig. 1) at night from a boat using conventional hook-and-line recreational gear. Large hooks (hook size 2) and large pieces of bait (pieces of shrimp, *Penaeus vannamei*) were used, along with the common best practices to improve survival of fish released (see (Bartholomew and Bohnsack, 2005). This method was adopted to reduce stress and hooking injuries (following the recommendations of Alós et al., 2009, 2008; Veiga et al., 2011). The fish were measured (to the nearest mm), weighed (to the nearest g) and placed in a 150-l onboard aerated fish-holding tank.

Individuals were anesthetized by immersion in 10 l of filtered and sterile seawater with 100 mg l^{-1} of tricaine methanesulfonate (MS222). Each acoustic tag was surgically implanted into the peritoneal cavity through a dorso-ventral incision and sutured using non-absorbable sutures (Mersilk, 4-0, Ethicon®) maximizing sterile conditions. The entire surgical process took less than 5 min. The fish was then placed in the onboard tank to recover until normal behavior was observed (i.e., the effects of the MS222 disappeared). The tagged individual was then released at the same position at which it was captured. The position, the depth (m), and the day and hour were recorded for each tagged fish.

The acoustic receivers array was retrieved in late December 2010, and the data were downloaded from each receiver. Each detection was individually recorded and labeled with a detection number, date (mm/dd/yyyy), hour (hh:mm:ss), frequency (kHz) and interval period (ms). To store and manage the data, a Microsoft Access data base was built following the criteria in March et al. (2010). Data from the U.S. Naval Observatory (http://aa.usno.navy.mil/) were used to categorize detections into diel phases (day vs. night) using the local sunrise and sunset data.