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Home range, movements and daily activity of the white seabream *Diplodus sargus* (Linnaeus, 1758) during the spawning season

Vincenzo Maximiliano GIACALONE[1], Carlo PIPITONE[1*], Fabio BADALAMENTI[1], Francesco SACCO[3], Arturo ZENONE[2], Rosalia FERRERI[1], Valeria MICALE[4], Gualtiero BASILONE[1] and Giovanni D'ANNA[2]
(1) *Consiglio Nazionale delle Ricerche, Istituto per l'Ambiente Marino Costiero (CNR – IAMC), via del Mare 3 91021 Campobello di Mazara; Italy*
(2) *Consiglio Nazionale delle Ricerche, Istituto per l'Ambiente Marino Costiero (CNR – IAMC), via G. da Verrazzano 17 91014 Castellammare del Golfo, Italy*
(3) *Università degli Studi di Palermo, Dipartimento di Scienze e Tecnologie Biologiche, Chimiche e Farmaceutiche, viale delle Scienze ed. 16 - 90128 Palermo, Italy*
(4) *Consiglio Nazionale delle Ricerche, Istituto per l'Ambiente Marino Costiero (CNR – IAMC), Spianata San Raineri 86 98122 Messina, Italy*
* *Corresponding author: carlo.pipitone@cnr.it*

Abstract: The knowledge of behavior of coastal fish during their reproductive season is an important information for the management of commercially important species and for the design of marine protected areas. This paper couples for the first time data on the movements, daily activity and home range of the white seabream, *Diplodus sargus* to data on its gonadal cycle. Five white seabreams caught along the Zingaro coast in the Gulf of Castellammare (NW Sicily, western Mediterranean) were tagged with miniaturized transmitters, released close to the fishing site and their movements monitored with an array of 13 receivers. The analysis of the acoustic detection data showed that (1) the tagged fishes had a smaller home range than previously known, possibly due to the seabed morphology in the study site, and (2) they moved to a deeper site in a very restricted and well identified time period. The spatial and temporal characteristics of such unusual downward movement suggest that it corresponded to spawning aggregation episodes.

Résumé : *Domaine vital, déplacements et activité journalière du sar commun* Diplodus sargus *(Linnaeus, 1758) lors de la saison de frai*. La connaissance du comportement des poissons côtiers pendant la saison de reproduction est importante pour la gestion des espèces d'intérêt commercial et pour la définition des aires marines protégées. Ce papier associe pour la première fois des données de déplacement, d'activité journalière et de domaine vital chez le sar commun *Diplodus sargus* à des données de développement gonadique. Cinq sars communs capturés le long de la côte Zingaro dans le Golfe de Castellammare (NW de la Sicile, Méditerranée occidentale) ont été équipés de transmetteurs miniaturisés, relâchés près de leur lieu de capture, et leurs déplacements ont été enregistrés en déployant 13 récepteurs. L'analyse des données de détection acoustique a montré que (1) les poissons marqués ont un domaine vital inférieur aux estimations précédentes, et (2) ils se déplacent vers une zone plus profonde à une période particulière et de courte durée. Les caractéristiques spatiales et temporelles de ces déplacements inhabituels en profondeur suggèrent qu'ils correspondent à des épisodes de concentration de frai.

Keywords: Reproductive movements ● Daily activity pattern ● Home range ● Gonad maturation cycle ● Acoustic telemetry

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Introduction

Acoustic telemetry techniques have been successfully used in the last decades to study the movements of marine fishes and invertebrates, providing detailed information on their spatial position useful to assess their home range, habitat use and activity pattern (Hussey et al., 2015). Recently, particular attention has been given to the study of reproductive movements towards spawning aggregation sites, whose knowledge and preservation is essential to the management of commercially important coastal species (Belo et al., 2016) and that can be incorporated in the design of marine protected areas (Garcia et al., 2014).

Among temperate reef fishes the white seabream *Diplodus sargus* (Linnaeus, 1758) is a common species targeted by artisanal and recreational fishermen in the Mediterranean Sea and eastern Atlantic Ocean, where it lives in rocky habitats down to about 50 m depth (Bauchot & Hureau, 2005). Due to its commercial value it has been the object of aquaculture initiatives and marine ranching experiments (D'Anna et al., 2004 & 2011).

The movement patterns of white seabream have been studied in natural and artificial habitats and knowledge has been gained on such ecological and behavioral aspects as site fidelity, activity pattern and home range (e.g., D'Anna et al., 2011; Abecasis et al., 2013; Di Lorenzo et al., 2014; Aspillaga et al., 2016). As regards to the activity pattern in general, white seabreams are diurnally active territorial fish (Harmelin-Vivien et al., 1995; Sala & Ballesteros, 1997; Figueiredo et al., 2005; Aspillaga et al., 2016), which display a behavioural plasticity that allows them to interpret environmental features and to adjust their activity accordingly (D'Anna et al., 2011; Di Lorenzo et al., 2016). As an example of such plasticity, D'Anna et al. (2011) found that white seabreams living in an artificial reef deployed over a sandy bottom area had a nocturnal feeding activity as opposed to the diurnal feeding known from the literature.

The reproductive biology of white seabream is relatively well known. This species is a rudimentary hermaphrodite with partial digynic protandry (Micale et al., 1987; Micale & Perdichizzi, 1994; Morato et al., 2003; Mouine et al., 2007). Its reproductive temporal pattern is strongly influenced by environmental conditions (especially seawater temperature) and varies according to the latitude (Morato et al., 2003). Spawning in the Mediterranean occurs between late winter and early spring with a peak in March and April (Mouine et al., 2007). Despite the acquired knowledge, information about its reproductive movements is still incomplete. According to Divanach (1985), Harmelin-Vivien et al. (1995) and Pastor (2008), in the northwestern Mediterranean this species descends to about 50 m depth to spawn. Di Lorenzo et al. (2014) and Abecasis et al. (2015) suggested that white seabreams make unusual long-distance movements and widen their home range during the reproductive season. More recently Aspillaga et al. (2016) concluded that white seabreams form resident spawning aggregations and perform a reproductive migration to deeper waters neighboring their usual home range, although no data on the sexual maturity of the surveyed population was provided.

To shed further light on the reproductive movements of white seabream the present study was conducted with the objective of assessing its home range, daily activity pattern and movements along the rocky coast of the Gulf of Castellammare during the reproductive season. To fulfill this objective acoustic telemetry data were coupled to gonadal cycle data collected from the same population. Based on the literature describing that white seabream move to deeper waters to spawn, fish position data were used to test the hypothesis that they modify their home range for short periods of time during the spawning phase.

Materials and Methods

Study area

The Gulf of Castellammare is located along the northwestern coast of Sicily, western Mediterranean (38°04'N-12°56'E). The western side of the gulf, known as Zingaro, is characterized by dolomitic cliffs alternating with small shallow bays. The bottom depth profile in the area is generally very steep with the 100 m isobath occasionally lying at less than 200 m from the coastline. The seabed is characterized by pebbles, gravel or coarse sand with patches of the seagrass *Posidonia oceanica* (L.) Delile, 1813 inside the bays, while rocky strips covered by photophilic algae precede walls covered by a coralligenous community on the cliffs.

All combined, these environmental features represent the perfect habitat for both adult and juvenile white seabream (Harmelin-Vivien et al., 1995).

Acoustic telemetry system

An array of 13 VEMCO VR2 omnidirectional receivers, labeled R00 to R12 according to their consecutive position, was deployed along the Zingaro coast from November 2009 to May 2010 (Fig. 1). A preliminary range test was performed *in situ* prior to the study deploying five receivers at different distances (100, 150, 200, 250, 300 m) from two pingers for two weeks. A detection range of 250 m was determined for the receivers as the longest distance before the number of acoustic detections started to decrease. Receivers were spaced 200 ± 31 m apart at 80 ± 23 m from the coastline over a 20-60 m depth range, allowing for a 2.6 km × 0.5 km (i.e. 1.3 km^2) monitored surface. Each

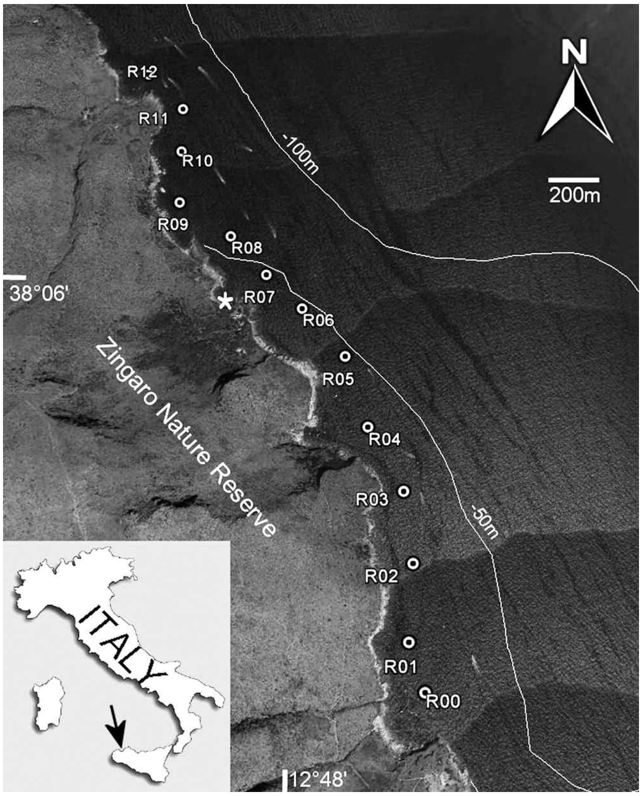


Figure 1. Map of the study area. R00-R12 indicate the positions of acoustic receivers. The asterisk indicates the release site of the tagged white seabreams.

receiver was suspended at 15 m below the surface on a 6 mm Ø rope moored to the seafloor with a 60 kg concrete block. A hard plastic trawl-net float was attached above each receiver to help maintaining a vertical orientation.

Fish tagging

A total of 23 white seabreams were caught between 23 and 27 November 2009 with longlines set on the rocky bottom between R03 and R06. After delicately removing the hook and punching their swim bladders to compensate embolism, the 12 largest individuals (190-260 mm total length, TL) were selected. Among them, 5 individuals (224 ± 23 mm TL) were sufficiently healthy to be surgically implanted with a miniaturized transmitter tag according to the methodology suggested by Thoreau & Baras (1996). The transmitting tags used in this study were VEMCO V9P-1L (size: 40 mm × 9 mm, weight in water: 5.2 g, random delay time: 60-180 s, transmission frequency: 69 kHz, estimated battery life: 251 days) equipped with a pressure sensor with a working depth range of 0-100 m and a precision of 0.4 m. Each fish was labeled according to its own tag code as follows: ## 229, 230, 231, 238 and 239. The tagged fish were released on 27 November 2009 close to R07 (Fig. 1) after a recovery period of 1-4 days spent in an underwater cage that was suspended at about 7 m depth. The release site was chosen close to the northernmost site of fish collection, within a small bay protected from wave action in order to allow a relatively safe and undisturbed post-surgery recovery.

Gonad maturation cycle

In order to assess gonad maturation in the white seabream population, an additional 111 white seabreams (165-380 mm TL, 65-1025 g total weight) were caught with longlines along the Zingaro coast from January to December 2010 (mean monthly catch number = 10 ± 8) and processed. Gonads were fixed in 4% buffered formalin, and then 5 µm sections were cut and stained following the Harris Hematoxylin and Eosin method (Hunter & Macewicz, 1985). Histological slides were mounted to determine the functional sex, according to the following categories: gonochoristic females (F), gonochoristic males (M), functional female hermaphrodites (mF), functional male hermaphrodites (Mf). Both sexes were microscopically staged for maturity as stage 1 (immature), 2 (developing), 3 (spawning capable), 4 (regressing), and 5 (regenerating) (Brown-Peterson et al., 2011).

Fish position and home range calculation

The receivers were collected in May 2010 and the detection data were downloaded and organized in a database using the VUE software provided by Vemco. Presence/absence data from each VR2 unit were used to assess the spatial distribution of the tagged fish based on the signals detected by each receiver over the whole study period. Residency index (I_R) was calculated as the ratio between the number of detection days of each fish and the total number of monitoring days (Afonso et al., 2008).

As the tags provided presence/absence data and depth information associated to actual date and hour, two different datasets were created for the horizontal and vertical components of movement. To assess the horizontal position, defined as Centre Of Horizontal Activity (COHA), firstly a distance value was attributed to each receiver starting from R00 = 0 m, R01 = 162 m, R02 = 364 m, …, to R12 = 2420 m. Successively a weighted arithmetic mean algorithm was applied to the distance value of each receiver and to its respective number of signals detected in each 30-minute interval (Simpfendorfer et al., 2002; Giacalone et al., 2005). Vertical position data were obtained directly from the dataset, and the maximum depth was selected for each 30-minute interval in order to represent the deepest positions reached by each fish in a GIS (Geographical Information System). Both horizontal (COHA) and vertical (maximum depth) positions from each fish were displayed in the GIS using the ArcMap 9.0 software. These parameters were used to estimate the home range as a Kernel Utilization Distribution at 95% and 50% (KUD95, KUD50) for the whole study period using the Hawth's analysis tools for ArcMap (Beyer, 2004). The KUD50 was defined as the home range core area (Worton, 1987).

Daily activity pattern

White seabreams are known to undergo vertical movements dictated by feeding and refuging needs along vertical rocky habitats (Sala & Ballesteros, 1997) according to a circadian activity rhythm (Figueiredo et al., 2005). In the present study, the daily activity pattern was estimated analyzing the depth variation of fish (ΔD) using vertical position data from the dataset described above. Horizontal movements were not utilized to this purpose due to the lower precision of receivers in the detection of horizontal positions (30-50 m: Giacalone et al., 2005). ΔD values were calculated as the difference between maximum and minimum depths recorded in each 30-minute interval.

Reproductive movements

Two variables were selected in order to detect and analyze the reproductive movements in detail: the maximum depth (MaxD) reached by the tagged fish in each 30-minute intervals for vertical movements, and the displacement (Dis) of fish position from the home range center calculated as the harmonic mean of all position data for horizontal movements. An exploratory analysis was performed by sorting all vertical detection data by depth and hour. Depth values exceeding the 95th percentile were isolated to identify types of vertical movements according to their duration, and the relative positions were visually inspected on the GIS.

Data analysis

The effect of the reproductive phase on daily activity and movement pattern was tested analyzing variations in ΔD, MaxD and Dis. The adopted experimental design included the following four factors: Period (fixed, with 2 levels: reproductive (R) and non-reproductive (NR)), Daily Phase (fixed, with 2 levels: Day and Night), Time (random, nested in the interaction Period × Daily Phase, with 2 levels 1 and 2), Days (random, nested in Time, with 5 levels). ΔD, MaxD and Dis values from each tagged fish were used as independent replicates.

The above design was used to perform a permutational univariate ANOVA (PERANOVA) on ΔD data and a permutational multivariate ANOVA (PERMANOVA) on MaxD and Dis data, both based on Euclidean distances. For both analyses, data were transformed (Ln(x+1)) and P (Monte Carlo) values were obtained using 9999 permutations of residuals under a reduced model variance. Significance was set at P = 0.05 and, when differences were detected, a pair-wise t-test was performed. All univariate and multivariate analyses were carried out using the PERMANOVA+ for PRIMER software package. The Levene's test was used to verify the homogeneity of variances for univariate data. A PERMDISP test was performed to verify the homogeneity of multivariate dispersions. The homogeneity of variances was satisfied for the univariate data (P = 0.27) but not for the multivariate dataset (P < 0.001).

Results

Home range

The total tracking time lasted 183 days from 27 November 2009 to 28 May 2010. Fish #238 was never detected by the receivers, so we assume that either the transmitter did not work properly or the fish died and went lost soon after its release, possibly because of its small size (190 mm TL) and consequent physical inadequacy to tolerate the consequences of tag implant. The remaining four tagged fish had a high I_R value that ranged from 75 to 94% across the total monitoring period (Table 1).

Each fish was detected predominantly by one single receiver (Fig. 2), with dominant detections ranging from 70% (R05, fish #231) to 90% (R04, fish #229). Receivers R00, R01, R02 and R12 did not detect any signal.

The home range extent of the tagged white seabreams ranged between 0.46 and 1.17 ha for KUD95 and between 0.02 and 0.05 ha for KUD50 (Table 1). Shape, size and extent of each home range and respective core areas are shown in figure 3.

Table 1. *Diplodus sargus*. Total length (TL), residency index (I_R) and home range (KUD50 and KUD95) of the tagged white seabreams.

fish ID	TL (mm)	I_R	KUD50 (ha)	KUD95 (ha)
#229	220	94%	0.02	0.46
#230	250	85%	0.05	1.17
#231	240	80%	0.05	1.04
#239	220	75%	0.03	0.67

Daily activity pattern

The interaction Period × Daily Phase for ΔD resulted significant (Table 2). Daytime values were higher in the reproductive period while night values were higher in the non-reproductive period (Table 2 & Fig. 4).

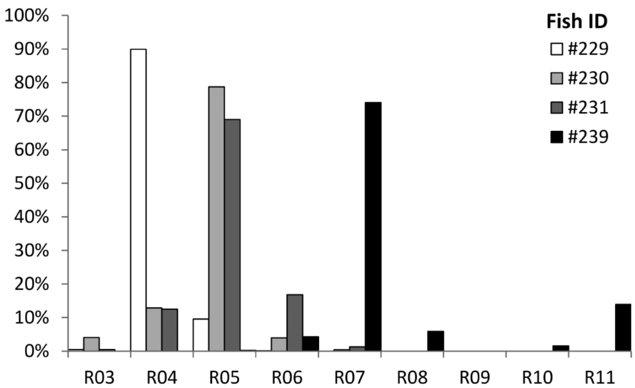


Figure 2. *Diplodus sargus.* Overall percent detections from each VR2 receiver (R03-R11) during the whole study period for the tagged white seabreams.

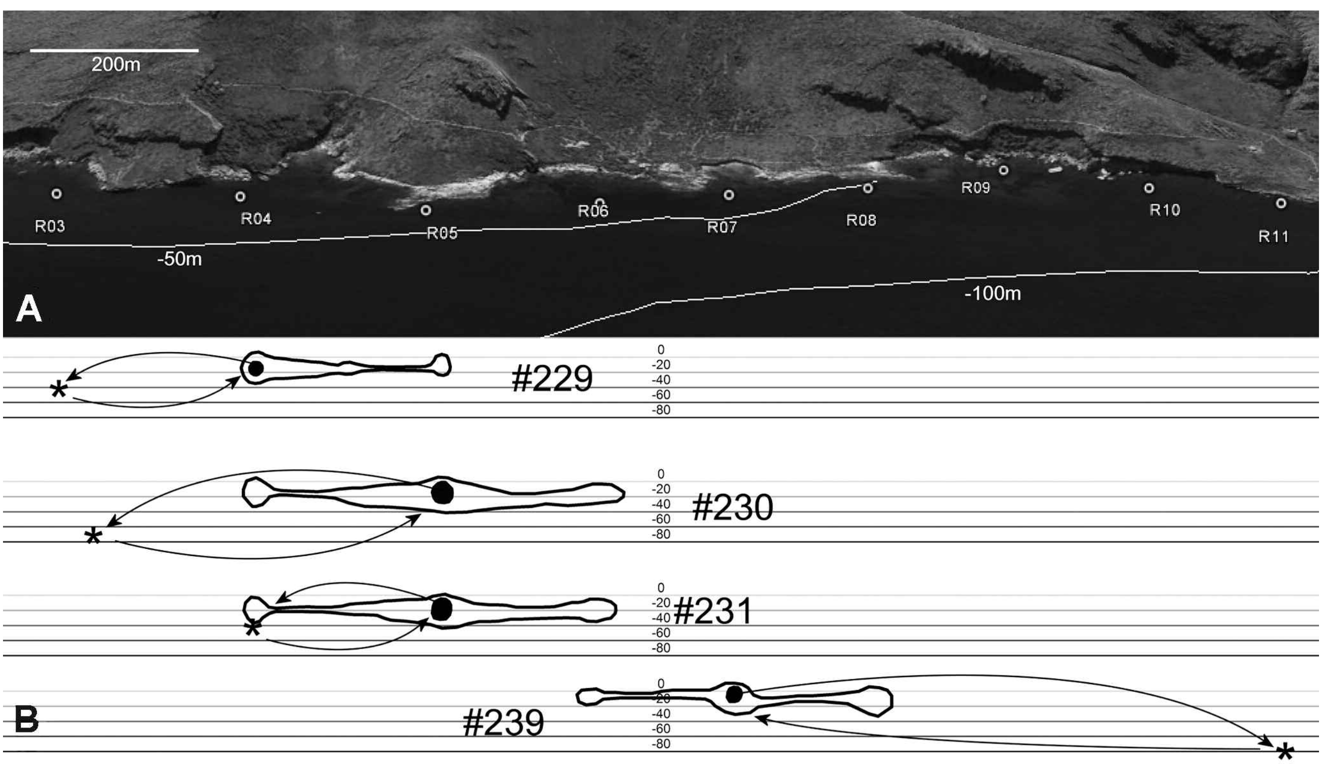
Reproductive movements

The depth data exceeding the 95th percentile allowed us to identify two types of movements: (1) one that included short trips (≤ 2 hours) within a maximum depth of 30 m, and (2) another that corresponded to the longest permanence at the maximum depth reached by each fish, when they visited a deep site on different dates. The corresponding movement patterns (Table 3) show that each fish moved to a deep site (marked with an asterisk in

Table 2. *Diplodus sargus*. Summary of PERANOVA and pair-wise tests on ΔD values calculated for the tagged white seabreams (R = reproductive period, NR = non-reproductive period).

Source of variation	DF	MS	Pseudo-F	P
Period (Pe)	1	2.37E-02	0.17164	0.682
Daily Phase (Ph)	1	26.358	191.22	**< 0.001**
Pe x Ph	1	2.9992	21.758	**< 0.001**
Time (Pe × Ph)	4	3.23E-02	7.75E-02	0.990
Days (Time(Pe × Ph))	32	0.41718	0.42482	0.997
Res	200	0.98201		
Pair-wise tests (Pe × Ph)				
● *Period*				
NR				day > night
R				day > night
● *Daily Phase*				
Day				R > NR
Night				R < NR

Figure 3. *Diplodus sargus.* Home range of the tagged white seabreams (#229, #230, #231, #239). **A.** Study area with the position (R03-R11) of VR2 receivers. **B.** Shapes of the reconstructed home ranges (KUD95, contour lines) and core areas (KUD50, black spots). The asterisks indicate the deepest site reached by each fish. The horizontal extent of section B corresponds to the actual extent of the coastline as represented in section A.



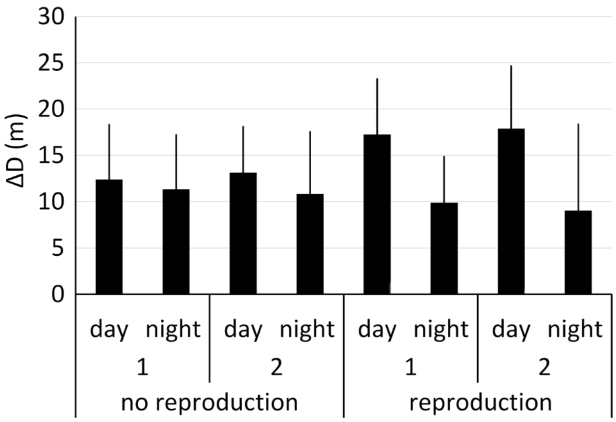


Figure 4. *Diplodus sargus.* Mean values of depth variation (ΔD, meters) for the tagged white seabreams during non-reproductive and reproductive periods in each daily phase and in two randomly chosen times (1, 2). Vertical bars: + standard deviation.

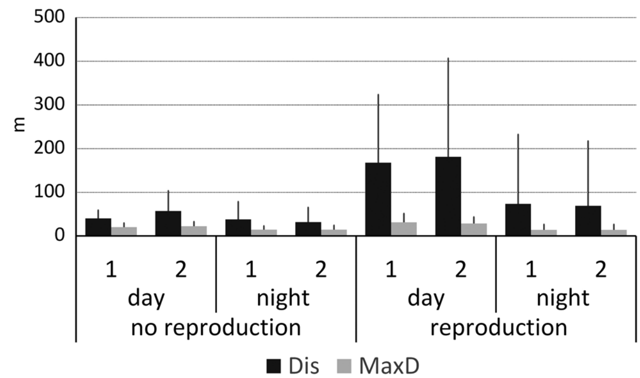


Figure 5. *Diplodus sargus.* Mean displacement (Dis) and maximum depth (MaxD) (meters) for the tagged white seabreams during non-reproductive and reproductive periods in each daily phase and in two randomly chosen times (1, 2). Vertical bars: + standard deviation.

Table 3. *Diplodus sargus*. Movement patterns of the tagged white seabreams identified through the analysis of the longest permanence at the deepest site.

Fish ID	Dates	Displacement between receivers (from - to)	Mean depth ± s.d. (from - to, m)	Hours (from - to)	Maximum depth (m)	Mean permanence at the deepest site ± s.d. (h)
#229	Apr 23-28, May 17	R4 - R3	14.13 ± 2.27-31.47 ± 2.22	05:00-13:00	41.8	6.3 ± 3.05
#230	Apr 4-17-23-28	R5 - R3	10.28 ± 0.63-47.94 ± 10.45	02:00-15:00	73.9	8 ± 2.94
#231	Mar 18, Apr 8	R5 - R4	13.42 ± 1.77-34.1 ± 3.17	05:00-15:00	38.7	8.5 ± 2.12
#239	Apr 7-17-21-25	R7 - R11	4.6 ± 2.3-33.93 ± 6.6	03:00-15:00	81.3	9.8 ± 0.96

Table 4. *Diplodus sargus*. Summary of PERMANOVA and pair-wise tests on MaxD and Dis values calculated for the tagged white seabreams (R = reproductive period, NR = non-reproductive period).

Source of variation	DF	MS	Pseudo-F	P
Period (Pe)	1	9.1543	11.022	**< 0.005**
Daily Phase (Ph)	1	157.89	190.11	**< 0.001**
Pe x Ph	1	13.342	16.065	**< 0.001**
Time (Pe × Ph)	4	0.52043	0.24716	0.942
Days (Ti(Pe × Ph))	32	2.1057	0.63591	0.956
Res	200	3.3113		
Pair-wise tests (Per × Ph)				
● *Period*				
NR			day ≠ night	
R			day ≠ night	
● *Daily Phase*				
day			R ≠ NR	
night			R = NR	

Fig. 3B) during a limited number of days in the time interval comprised between March 18 and May 17, spending on average 6.3 to 9.8 hours in that site. In those dates, which fall within the reproductive period as ascertained by gonad maturation analysis (see following text section), the horizontal displacements between each home range core area and the deepest site ranged from ca. 220 m for fish #231 to ca. 650 m for fish #239 (Fig. 3B). The mean vertical dimension of displacements ranged from ca. 17 m for fish #229 to ca. 38 m for fish #230, while the maximum depth reached ranged from 38.7 m for fish #231 to 81.3 m for fish #239 (Table 3).

The PERMANOVA found significant differences in the interaction Period × Daily Phase (Table 4). The pair-wise tests showed a significant difference between day and night in both periods and between periods during the day. The highest values were recorded during the day in the reproductive period, with a mean MaxD of 30.14 ± 17.28 m and a mean Dis of 174.38 ± 191.68 m in the two random times cumulated (Fig. 5).

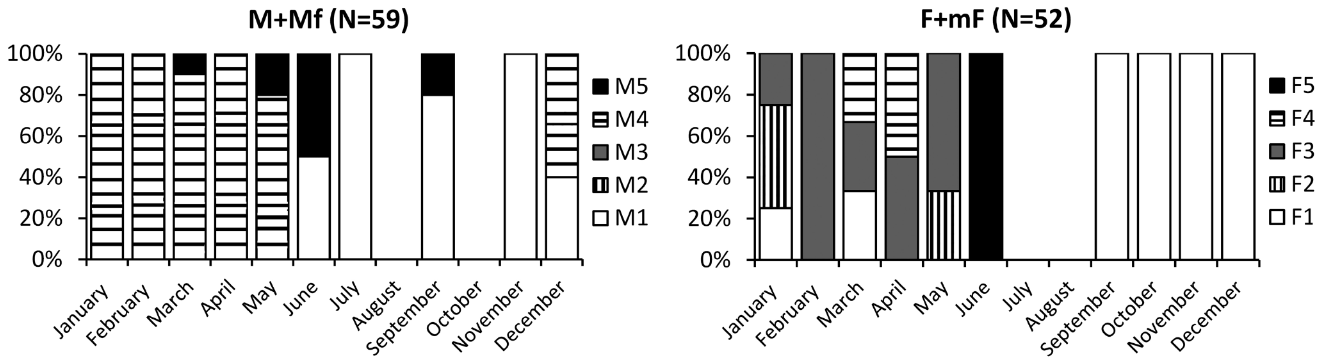


Figure 6. *Diplodus sargus*. Monthly percent distribution of maturity stages (M1-M5, F1-F5; see text) in fished white seabreams. M, males; Mf, functional male hermaphrodites; F, females; mF, functional female hermaphrodites.

Gonad maturation cycle

The histological analysis of ovaries and testes allowed us to assign sex and maturity stage to all specimens caught for the assessment of gonadal maturation. Males and females < 200 mm TL were found immature across all months. Figure 6 shows the monthly percent distribution of maturity stages in each sex. The analysis of gonads showed that males were ready to spawn from December to May while females were ready to spawn from March to May.

Discussion

This study provides some insight on the home range and movement patterns of white seabream during the spawning period along the coast of NW Sicily. The duration of the investigation and the collection of gonadal samples strengthen our findings and make for a sound comparison with other similar studies, despite the small number of tagged individuals.

The home range of the tagged fish ranged from 0.46 to 1.17 ha with very small core areas (0.02 to 0.05 ha). The fact that a high percentage of acoustic detections of each fish came from a single receiver suggests that tagged specimens made predominantly short-range horizontal movements during the whole monitoring period. The extent of these home ranges is narrow if compared to those estimated in previous studies. D'Anna et al. (2011) reported home range values between 1 and 17 ha from a sandy-bottom area that included artificial reefs in the Gulf of Castellammare, with a strong correlation between the home range extent and the distance between the refuge in the artificial reef and the feeding area on the surrounding sandy bottom. Abecasis et al. (2013), Di Lorenzo et al. (2014) and Aspillaga et al. (2016) found much wider and more variable home ranges for white seabream from different areas.

It is well known that home range shape and extension are influenced by body size, habitat structure, fish density, availability of resources (Kramer & Chapman, 1999) as well as duration and season of the monitoring period (Koeck et al., 2013; Abecasis et al., 2015). Season and fish size in most of the above studies are largely comparable with those in the present study. On the other hand bottom topography and depth profile are different, with an almost vertical seabed along the Zingaro coast as opposed to a flat seabed in other study areas. Belo et al. (2016) highlighted the role exerted by bottom topography on the movement pattern and home range of white seabream. In southern Portugal (Abecasis et al., 2009, 2013 & 2015), southern Adriatic (Di Lorenzo et al., 2014) and northwestern Sicily (D'Anna et al., 2011) white seabreams moved across relatively flat wide areas characterized by a gentle slope and a maximum depth of 20-30 m. Along the Zingaro coast the bottom topography is generally steep with only 150 m distance between the coast and the 50 m isobath. In these particular conditions fishes are likely to find all the needed habitats (i.e., refuge, feeding area and spawning ground) within a relatively small surface that encompasses a wide vertical range, which results in a smaller home range.

The choice of analyzing only vertical movements (i.e., ΔD data) to describe the daily activity proved to be a good decision considering that tagged fish tended to spend most of their time close to one single receiver, making short-range horizontal movements less accurately detectable. The analysis of ΔD data suggests that vertical movements were more intense during daytime hours, in agreement with the observation that white seabreams are diurnally active fish (Harmelin-Vivien et al., 1995; Sala & Ballesteros 1997; Figueiredo et al., 2005; Aspillaga et al., 2016). This pattern remained the same across the entire study period, suggesting that the daily activity is based on a circadian rhythm that does not change during the reproductive period. The higher value of ΔD during this reproductive period was actually determined by the movement to a deeper site in March-May.

The white seabreams monitored in the present study exhibited sporadic movements to deeper sites outside their home range. Di Lorenzo et al. (2014) noted similar unusual movements during the reproductive period, while Aspillaga et al. (2016) classified such displacements as “extraordinary movements” and attributed them to the search of a refuge during stormy events as well as to spawning aggregation episodes. The sporadic movements recorded in our study seemed to follow two different patterns. The first includes short trips lasting ≤ 2 hours and limited to a maximum depth of 30 m, probably related to feeding, refuging during bad sea conditions or escape from predators. The second is concentrated within the reproductive period (March-May), occurs between late night and mid-afternoon and is characterized by a mean duration of ~ 6 to ~ 10 hours and down to a maximum depth of 39 to 81 m, sometimes distant from their home range core area. Also, movement patterns during the reproductive period differ significantly from the rest of the study period as confirmed by the PERMANOVA results on maximum depth and displacement of fishes. In agreement with Aspillaga et al. (2016) and with further support derived from the analysis of the gonad maturity data, we interpret the deeper and longer downward movements as reproductive movements possibly leading to a resident spawning aggregation as described by Domeier & Colin (1997) for tropical reef fishes. Even though only two out of four tagged fish shared the site and time of descent while the remaining two chose different sites and times, the tagged fishes were fished in different spots and are not necessarily expected to aggregate all at the same place and time to spawn. The analysis of gonads indicates the presence of fully mature females from March to May and of fully mature males from December to May, which overlap with the dates of the observed movements to the deepest sites. Also, the size of the four tagged fishes suggests that no immature individuals were included in the lot. This observation is in agreement with the downward movements during the spawning period suggested by Divanach (1985), Harmelin-Vivien et al. (1995) and Pastor (2008).

The knowledge of home range and movement pattern of fishes is a crucial ecological information that can be integrated into marine resources management plans, especially at local scale. The coupling of such information to the knowledge of the reproductive cycle may provide a useful basis to the design of marine protected areas and to fisheries management initiatives, where the knowledge of spawning locations and their associated habitat may be of vital importance for their success. Nevertheless, our results should be taken with caution given the small amount of tagged fish. Further tagging campaigns along with a comparison of data collected inside and outside the reproductive season should be carried out in order to confirm the present results.

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