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Fitting the size of no-take zones to species movement patterns: a case study on a Mediterranean seabream

Manfredi Di Lorenzo[1], Giovanni D'Anna[2], Fabio Badalamenti[2], Vincenzo Maximiliano Giacalone[3], Richard M. Starr[4,5], Paolo Guidetti[1,6,*]

[1]Laboratory of Conservation and Management of Marine and Coastal Resources, DiSTeBA, University of Salento, 73100 Lecce, Italy

[2]CNR-IAMC, Sede di Castellammare del Golfo, Via G. da Verrazzano 17, 91014 Castellammare del Golfo (TP), Italy

[3]CNR-IAMC, U.O. Capo Granitola, Via del Mare 3, 91021 Torretta Granitola (TP), Italy

[4]Moss Landing Marine Laboratories, and [5]University of California Sea Grant Extension Program, 8272 Moss Landing Road, Moss Landing, California 95039, USA

[6]Université de Nice Sophia-Antipolis, Faculté des Sciences, EA 4228 ECOMERS, 06108 Nice cedex 2, France

ABSTRACT: No-take zones (NTZs) have been shown to be useful tools for marine conservation and fishery management, although the lack of information on species' movements often makes it difficult to properly establish NTZ size. Using acoustic telemetry techniques, we monitored the movements, home range (HR) and homing ability (to capture sites) of 22 adult white seabream *Diplodus sargus sargus* in a fully protected portion (138.60 ha) of the Torre Guaceto Marine Protected Area (SE Italy). After release at a different location than the site of capture, 85% of the tagged fish returned to the capture site within 3 d. Fish were monitored for 161 d. All tagged fish spent most of the time within the monitoring area (fish presence index = 92.8%) and showed a mean HR of 20.6 ha. These results indicate that the studied NTZ effectively protects seabream, as it entirely encompasses their HRs, which are on average far smaller than the reserve. Twelve individuals left the monitoring area during the period of the year that corresponds to their known time of spawning. This potential emigration during the spawning period indicates that the reserve alone does not fully protect white seabream and that other management options, such as a seasonal fishing closure during the reproductive period, may be needed. Estimates of movement patterns and HRs of fishes, therefore, represent useful information to better understand, refine and enhance the value of NTZs for protecting ecologically valuable species.

KEY WORDS: Marine reserve · Marine Protected Area · *Diplodus sargus sargus* · Acoustic telemetry · Fish Presence Index · FPI · Home range · Homing behavior · Wandering behavior

INTRODUCTION

The increased demand for seafood in the last few decades has caused a dramatic decline in fishery resources (FAO 2012). Additionally, fishing has the potential to negatively affect marine biodiversity and ecosystem health (Worm et al. 2006). To mitigate some of the impacts of fishing, Marine Protected Areas (MPAs) have been created worldwide to protect natural populations of marine species and their habitats, together with the related ecosystem functions and services. Among the various types of existing MPAs, marine reserves (hereinafter MRs; i.e. areas where extractive activities are forbidden) are considered to be effective tools for both conservation of marine biodiversity and fisheries enhancement

*Corresponding author: guidetti@unice.fr

(Halpern 2003, Micheli et al. 2005, Guidetti et al. 2008). MPAs often contain areas where some regulated human activities are permitted, and one or more 'no-take zones' (NTZs) which prohibit any extractive activities.

The effectiveness of MRs and NTZs for conservation of fishes depends on several socio-economic, cultural and bio-ecological factors (e.g. enforcement and compliance, habitat structure and variety, environmental conditions, life histories of fishes, etc.), as well as on MR design. For example, depending on a MRs' specific goals (e.g. providing benefits of spawning stock protection or benefits from spillover), the size of a MR should be determined by taking into account the scale of movements and home range of target species (Bartholomew et al. 2008, Gruss et al. 2011). Starr et al. (2007) showed that protection of spawning aggregations of Nassau grouper *Epinephelus striatus* in a Caribbean atoll was not sufficient for conservation of the species because fishing mortality during movements to and from a spawning area was high enough to cause significant population declines. In addition, protection benefits of MRs are likely to be more evident for residential species than for highly mobile species. Residential fish move little, so that both relatively small and large MRs may effectively protect substantial portions of local populations. Conversely, highly mobile species may move over large distances and spend more time outside the reserve boundaries (where they are exposed to fishing), thereby weakening or eliminating the protective effects of MRs/NTZs (Kramer & Chapman 1999, Russ 2002).

The white seabream *Diplodus sargus sargus* (Linneus, 1758) is one of the most important coastal fishes in the Mediterranean Sea for both commercial and recreational fisheries (FAO 2012). Several aspects of white seabream biology are quite well known (e.g. Harmelin-Vivien et al. 1995, Gordoa & Molí 1997, Leitão et al. 2007, Macpherson et al. 1997) as well as its important ecological role in rocky reef communities (Guidetti 2006, 2007). Reproductively, the white seabream is a rudimentary protandric hermaphrodite, with a spawning period during April and May (Morato et al. 2003), when the water temperature is between ~15 and 17°C (Mouine et al. 2007). Information about spawning locations is sparse: Harmelin-Vivien et al. (1995) reported that reproduction could take place in deep rocky seafloors, although no evidence is available regarding reproductive behavior. Migration of white seabream to specific spawning grounds has not been reported. Macpherson (1998) described ontogenetic shifts in habitat use of white seabream: newly settled juveniles (1.0 to 1.5 cm TL) showed a clear preference for shallow habitats between 0 and 2 m; a few months after settlement, recruits moved deeper to join adult conspecifics. Recently, Di Franco et al. (2012a) reported that post-settlement dispersal may occur at the scale of tens of kilometers, with about 30% of post-settlers recruiting to the fishery in the same sites where they settled. Little information about the movement patterns, residency and home range of adult white seabream is available, especially in the context of MRs.

The objectives of this study were to utilize acoustic telemetry techniques to assess: (1) residency and home range, (2) homing behavior (i.e. ability to return to capture sites), and (3) wandering behavior (i.e. movement outside the normal home ranges during the spawning period) of white seabream within the NTZ of Torre Guaceto, Italy MPA (hereafter TGMPA).

MATERIALS AND METHODS

Study area

This study was carried out between February and July 2011 in the TGMPA, which is situated in SE Italy (southern Adriatic Sea, near Brindisi, Italy) (Fig. 1). The entire MPA covers 2212.77 ha, and includes 2 NTZs (called 'Zones A' according to national law: the larger is ca. 138.60 ha, the smaller is 46.00 ha, in total 184.60 ha), a partial reserve (Zone B, 161.04 ha) and a general reserve (Zone C, 1867.13 ha) (Fig. 1). The TGMPA was designated in 1991, although effective enforcement did not begin until 2000–2001. Access to the 2 NTZs is restricted to scientists, MPA personnel and police authorities (e.g. coast guard). Regulated recreational fishing is allowed from the shore in Zone B. In Zone C, both commercial and recreational fishing are allowed with permission from the MPA management body. At present, a few (≤8) artisanal vessels have been authorized to fish once per week in Zone C (Guidetti et al. 2010). Spearfishing is banned in the entire MPA. Outside the MPA, fishing regulations are less restrictive (e.g. spearfishing is allowed) and are set by national laws. This study was conducted inside the larger NTZ, which contains rocky reefs from the coastline out to a depth of about 10 to 12 m, and harbors high densities of commercially and recreationally exploited fishes, including the white seabream (Guidetti 2007, Di Franco et al. 2012b).

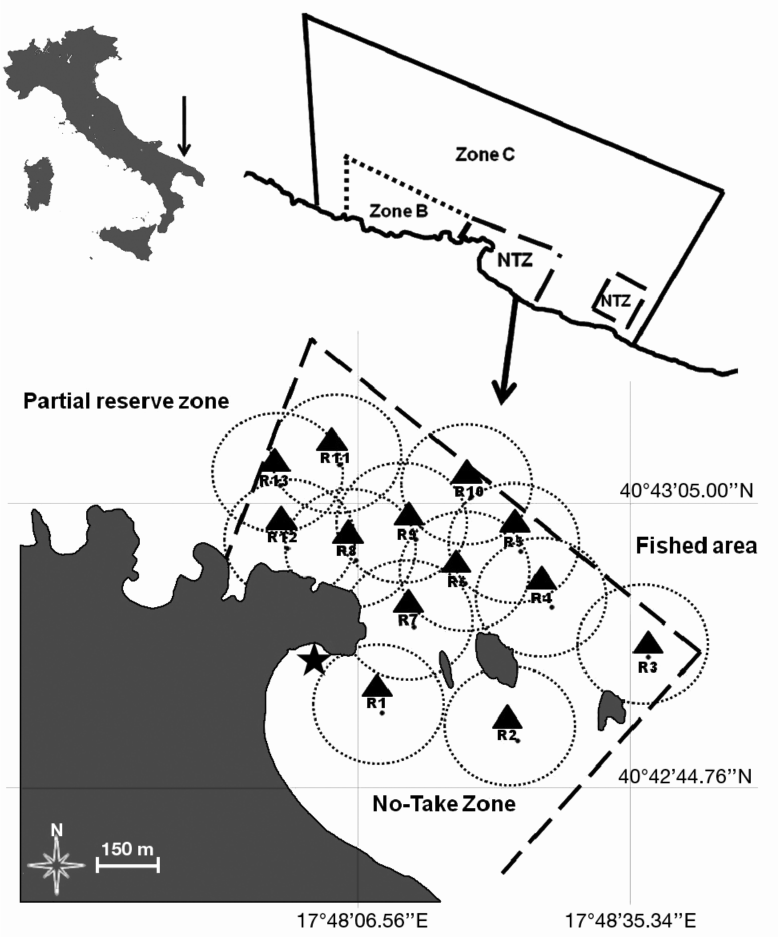

Fig. 1. Study area in SE Italy with map of the Torre Guaceto MPA showing the zoning (Zones A [No-Take Zone; NTZ], B, and C; see descriptions in 'Materials and methods') related to protection levels. Detail of the studied NTZ investigated and the array of remote acoustic receivers (black triangles) with their detection ranges (dotted circles); star indicates the release location of all tagged fish

Acoustic monitoring

An array of 13 VEMCO VR2 omnidirectional receivers was deployed inside the larger NTZ of the TGMPA from 14 February to 27 July 2011 (Fig. 1). A preliminary test to estimate the detection range of receivers was carried out *in situ* before VR2 deployment. Five acoustic receivers were spaced 100 m from each other along a horizontal line at depths of approx. 5 to 10 m. We then fixed 2 acoustic transmitters (VEMCO transmitter mod. V9-2L-A69-1303; min. and max. delay times: 30 to 90 s; nominal 60 s; estimated battery life 290 d) to a rope at a depth of about 8 m at the 2 ends of the line of receivers. Transmitters contained a random delay time to minimize code collision events. The receivers were thus at a distance of 100, 200, 300, 400 and 500 m, respectively, from the transmitters. Each receiver recorded the number of detections (ND) from the 2 transmitters in a 20 min period. We repeated the trial on 3 different days, then calculated the mean ND values (±SD) at different distances (Table 1). Based on these range tests, each receiver in the study was deployed at a distance of ~250 m from each other to ensure that the detection range of adjacent receivers would overlap (Giacalone et al. 2005). The receivers were suspended in the middle of the water column on lines that were anchored to the seafloor (depth range 5 to 12 m) using 60 kg concrete blocks. A hard plastic trawl-net float was attached above each receiver to help maintain a vertical orientation. The geometry of the receiver array was selected to maximize coverage in critical parts of the study area, and to provide information on the movements of animals entering, exiting, and moving across the NTZ boundaries. Receivers were labeled according to their position (Fig. 1; R1 through R13).

Fish tagging

Adult white seabream were caught using longline fishing gear set 50 to 170 m away from the shoreline, in the center of the NTZ, at a depth of about 5 to 7 m. The longline was assembled with 80 hooks (hook type: Mustad 2315/DT size 15) and it was soaked in water for about 40 min; hooks were baited with a sipunculid worm *Sipunculus nudus* (locally called bibi), which is a bait traditionally used by artisanal fishermen to target sparid fishes. Once a fish was caught, we recorded the GPS coordinates of the catch, removed the hook and if necessary, degassed the swim bladder with a hypodermic nee-

Table 1. Results of range tests carried out *in situ* before starting the telemetry experiment. Mean and standard deviation of the number of detections recorded by receivers at 5 different distances from transmitters (ID)

ID	Distance from transmitter (m)				
	100	200	300	400	500
1	20 ± 0.3	18 ± 0.4	17 ± 0.3	12 ± 0.8	6 ± 1.0
2	21 ± 0.5	16 ± 0.4	16 ± 0.2	10 ± 0.9	4 ± 0.7

dle (Alós 2008) to reduce symptoms of barotrauma. VEMCO transmitters were then surgically implanted into active fish that displayed normal swimming behavior, according to the methodology suggested by Thoreau & Baras (1996). As suggested by Winter (1996), the transmitter weight in air (3.6 g) was less than 2% of the weight of the smallest fish we tagged (ca. 250 g). Total length (TL) and weight of fish were measured using a measuring tape and balance, respectively. Once tagged, fish were held in a tank filled with aerated seawater to recover for a period of up to 1 h. During that time, fish were transferred to a release location that was different from the capture site, in order to assess homing behavior. All fish were released from the same location (red circle in Fig. 1), one that was 250 to 600 m away from the locations of capture.

Data analysis

An exploration of raw data recorded by the VR2 acoustic monitors was conducted as a first step in order to identify false detections (i.e. non-existing transmitter code or date/time errors) and to adjust detection times caused by time drifts of different receivers. Detections were used to calculate a fish presence index (FPI) of each tagged seabream within the study area (Abecasis & Erzini 2008) in order to evaluate the residency rate. For each individual, FPI was calculated as the percentage of the number of days spent in the study area (when at least 1 detection per day was recorded) over the entire monitoring period (from the day of release to the end of the study). FPI was also used to quantify the degree of fidelity to the study site. FPI values >80% were considered to be high (strong) levels of residency.

Signals recorded at several receivers within a 20 min period were used to calculate a center of activity (COA) of tagged fish for that 20 min period using the weighed-mean method described by Simpfendorfer et al. (2002). FiSAR, a custom-made software developed by Giacalone et al. (2006), provided the geographical XY location of the COA. The 20 min time interval was chosen in order to increase the accuracy of the COA estimates for each fish when using transmitters with a nominal delay of ca. 1 min and a 250 m receiver grid (Giacalone et al. 2005). The open-source QGis software and its spatial analysis routine was adopted to display COAs within the study area and to estimate home range and habitat utilization distribution (March et al. 2010, Abecasis et al. 2013). The minimum convex polygon (MCP95) method was used to measure the extent of the animal's range fitted to 95% of COA locations, excluding outlying points by the harmonic mean method. Kernel utilization distributions (KUDs) were chosen to estimate the probability of finding each tagged fish in a defined area within its home range at 95% and 50% (core area) levels.

In order to evaluate movements from the location a fish was released to its home site, we calculated the harmonic mean of all 20 min COAs for each fish. We then plotted the geographic location of each harmonic mean for each fish. We used a GIS to calculate the linear (direct line) distance each fish swam from point of release to the harmonic mean of its COA. By using the time of release and time of first calculated COA, we were able to calculate the time each tagged fish spent travelling to a home location. We considered these movements as proxies for homing, based on Wotton's (1990) definition of homing as 'an animal's ability to return to the territory or original capture site after displacement.'

Linear distances travelled by tagged fish during the spawning period were calculated to identify potential 'wandering behavior' of individuals. The 'spawning period' was deemed to occur in April and June based on biological data from the study site and elsewhere in the Mediterranean (Morato et al. 2003, Mouine et al. 2007, P. Guidetti unpubl. data), and on sea-surface water temperatures from the study area available at www.eurometeo.com/italian/meteomar. Within the spawning period, we considered 'wandering behavior' to be those movements that were larger than the maximum values of the distances moved before and after the spawning period (see Fig. 2).

We used linear regression analysis (using the Pearson correlation coefficient) to examine relationships between: (1) home range extent and fish length, (2) home range extent and days of detection/presence, and (3) homing time and distance travelled from release to capture sites. In order to detect differences among the movement patterns of fish showing wandering behavior, a 1-way ANOVA, with 'Period' as a fixed factor with 3 levels (before, during and after the spawning period), was performed. The homogeneity of variances was verified using Cochran's *C*-test. The response variable was the maximum distance recorded for each fish during the above-mentioned periods. STATISTICA software was used to perform the analyses at a 0.05 statistical significance level. All means are reported ±SD.

RESULTS

Residency

TLs of the 22 acoustically tagged white seabream ranged from 24.5 to 30 cm and averaged 26.9 ± 1.6 cm. Between 14 February and 27 July 2011, signals from 20 white seabream were successfully recorded within the receiver array for periods of 49 to 161 d (124.5 ± 27.1 d) (Table 2). Two out of 22 fish were detected for only 2 d. Data from these 2 individuals were deemed insufficient and excluded from the analysis. FPI in the monitored area varied from 48.5 to 100%, with an average value of 92.8 ± 13.6% (Table 2). Eighteen out of 20 tagged fish spent more than 75% of the total study period inside the studied NTZ.

Home range and homing

Home range sizes varied greatly among the tagged individuals; home ranges of 14 fish were estimated to be entirely within the monitoring area (Fig. 2). The 95% KUDs (KUD95) ranged from 2.9 to 40.1 ha and averaged 20.6 ± 10.0 ha. MCP95 ranged from 1.6 to 36.9 ha and averaged 17.3 ± 8.9 ha. KUD 50% (KUD50) estimates ranged from 0.2 to 9.5 ha and averaged 3.6 ± 2.7 ha (Table 2, Fig. 2). No significant correlation ($p < 0.05$) was detected between home range size and individual fish length (MCP95: $n = 20$, $r = 0.17$, $p = 0.46$; KUD95: $n = 20$, $r = 0.35$, $p = 0.13$; KUD50: $n = 20$, $r = 0.24$, $p = 0.29$), nor between home range size and days of detection/presence (MCP95: $n = 20$, $r = 0.24$, $p = 0.29$; KUD95: $n = 20$, $r = 0.07$, $p = 0.09$; KUD50: $n = 20$, $r = 0.09$, $p = 0.69$). Seventeen out of 20 white seabream moved from the release site to the capture sites within 3 d, with a mean homing time of 18.1 ± 16.8 h (Table 3). A positive correlation was found between homing distances and time required to get the capture site ($n = 17$, $r = 0.80$, $p < 0.001$). Although the remaining 3 fish did not show homing behavior, they were detected within the monitored area.

Wandering behavior

Spatial and temporal patterns of detections of white seabream movements indicated that 12 individuals displayed wandering behavior that took them far from the harmonic means of their COAs

Table 2. *Diplodus sargus sargus.* Detection data and estimates of fish presence index (FPI), 95% minimum convex polygon (MCP), 95 and 50% kernel utilization density (KUD) of 22 tagged white seabream within the Torre Guaceto No-Take Zone, monitored from 14 February to 27 July 2011 (161 d). TL: total length; ND: no. of detections; na: not applicable

Fish ID	TL (cm)	Release date (dd/mo/yyyy)	Total ND	Monitoring days	Presence days	FPI (%)	MCP95 (ha)	KUD95 (ha)	KUD50 (ha)
1	28	14/02/2011	15669	161	160	99.4	22.77	22.37	3.53
2	29	15/02/2011	15326	160	158	98.8	5.91	9.23	2.21
3	30	15/02/2011	23994	160	159	99.4	23.02	22.09	1.23
4	27	15/02/2011	14239	160	160	100.0	16.30	18.06	2.95
5	24.5	15/02/2011	47161	160	160	100.0	5.63	7.55	1.24
6	24.5	14/02/2011	9225	161	160	99.4	4.73	7.12	1.47
7	27.5	15/02/2011	33642	160	160	100.0	3.94	3.53	0.82
8	28	15/02/2011	7653	160	160	100.0	26.04	40.06	9.51
9	26	15/02/2011	15026	160	159	99.4	12.97	24.63	4.28
10	26	17/02/2011	33132	158	158	100.0	3.08	14.66	1.44
11	25	17/02/2011	10434	158	122	77.2	36.93	19.99	3.74
12	29	04/03/2011	19891	144	144	100.0	2.71	3.36	0.49
13	26	04/03/2011	18661	144	113	78.5	11.86	2.95	0.16
14	28	04/03/2011	8472	144	138	95.8	13.28	20.95	4.80
15	26	11/03/2011	16229	137	137	100.0	1.60	3.77	1.06
16	25	04/03/2011	5651	144	141	97.9	13.45	19.15	3.03
17	30	18/03/2011	16939	130	130	100.0	21.59	28.57	4.58
18	27	18/03/2011	6472	130	63	48.5	24.72	18.07	2.18
19	26	18/03/2011	9530	130	119	91.5	7.03	3.06	0.41
20	28	18/03/2011	516	130	94	72.3	9.69	33.95	8.54
21	26	11/03/2011	na	na	na	na	na	na	na
22	26.5	14/02/2011	na	na	na	na	na	na	na

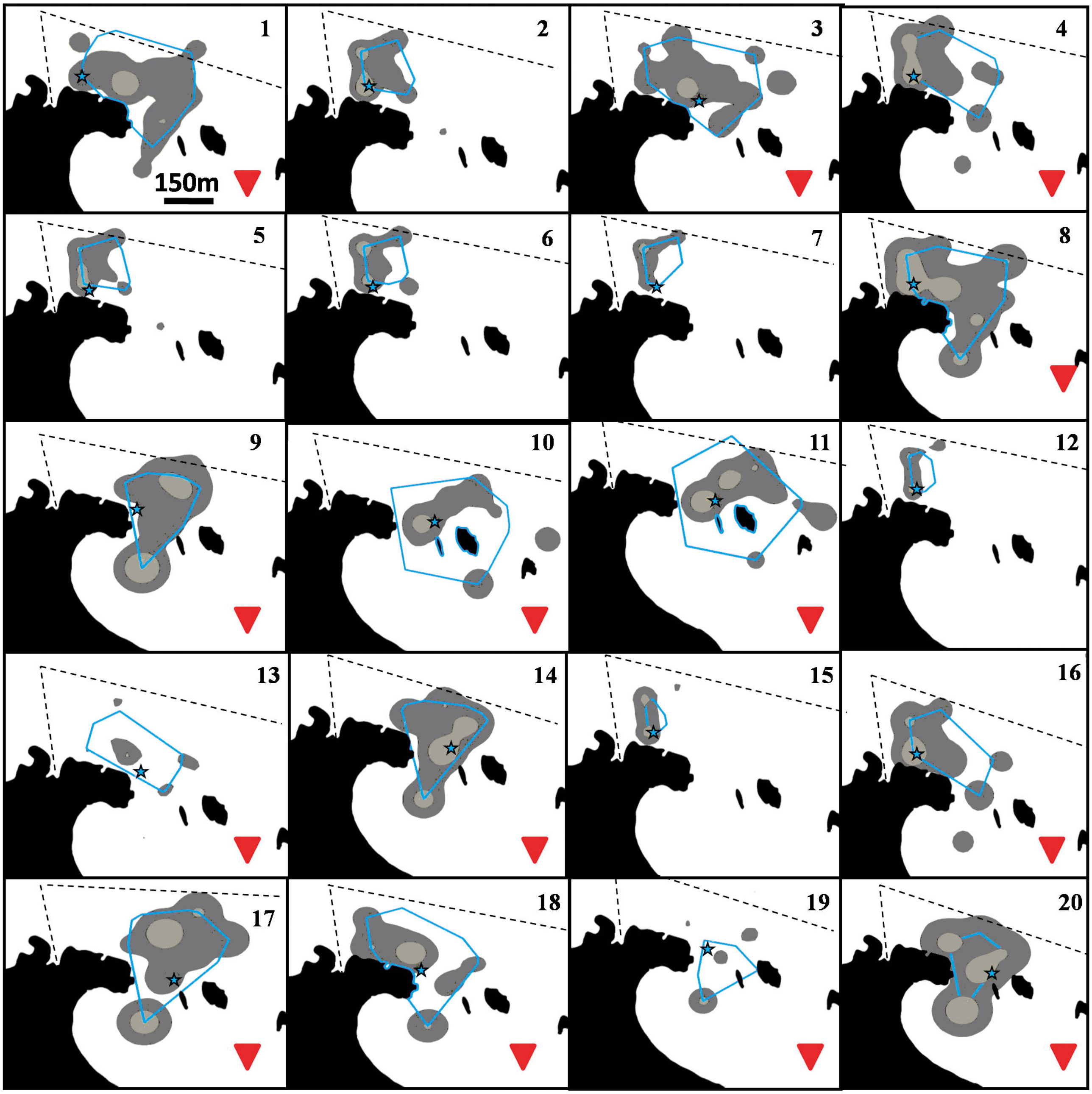

Fig. 2. *Diplodus sargus sargus.* Home range (HR) areas of 20 tagged white seabream. Dark grey area: 95% kernel utilization density (KUD); light grey area: 50% KUD; blue line: 95% minimum convex polygon (MCP). Stars: capture sites. Dotted lines indicate NTZ boundaries. The 14 fish labeled with a red triangle are those with a home range centered on the NTZ. These fish were used for the home range analysis

between 31 March and 17 May (Fig. 3). During this period, surface water temperature increased by approx. 5°C, from 13 to 18°C. The 12 individuals moved outside the study area from a northern part of the array in the evening/night (between 18:00 h and 23:30 h), and returned to the study area from the southernmost side of the NTZ in the afternoon of the following day (between 14:40 h and 17:40 h), thus spending ca. 10 ± 3 h outside the NTZ (Fig. 4). These 12 individuals were the only fish to show a wandering behavior, and this behavior occurred only between 31 March and 17 May. The other peaks shown in Fig. 3 are relative to movements within the NTZ. ANOVA results showed a significant ($F_{2,33}$ = 67.18, p = 0.001) effect of 'Period' on the maximum distance moved by the 12 individuals, with higher values

Table 3. *Diplodus sargus sargus.* Movement data of 17 tagged white seabream showing homing behavior. Release and homing date/time indicate the date and time each fish was released or was back at the catch site (dates are given as dd/m/yy). Distance travelled reflects linear distance from release site to the capture site. Homing time indicates the time each fish required to return to the catch site

Fish ID	TL (cm)	Release date and time (h)	Homing date and time (h)	Distance travelled (m)	Homing time (h)
1	28	14/2/11 20:20	15/2/11 13:40	3714.66	17.2
2	29	15/2/11 20:50	18/2/11 07:40	9543.00	58.5
3	30	15/2/11 20:50	17/2/11 06:00	5840.53	33.1
4	27	15/2/11 20:50	16/2/11 08:00	3388.73	11.1
5	24.5	15/2/11 20:50	18/2/11 18:00	8931.83	69.1
6	24.5	14/2/11 20:20	16/2/11 07:40	2732.07	35.2
7	27.5	15/2/11 20:50	16/2/11 06:20	1965.38	9.3
8	28	15/2/11 22:25	19/2/11 05:40	6336.00	79.15
10	26	17/2/11 21:25	18/2/11 16:40	2724.03	19.15
11	25	17/2/11 21:25	19/2/11 03:40	2211.53	30.15
12	29	4/3/11 22:00	5/3/11 01:20	1992.00	3.2
13	26	4/3/11 22:00	6/3/11 17:00	588.05	8.20
15	26	11/3/11 21:00	13/3/11 00:00	5728.00	27.00
16	25	4/3/11 22:00	5/3/11 11:00	2438.00	13.00
17	30	18/3/11 20:25	18/3/11 22:40	102.00	2.15
18	27	18/3/11 20:40	19/3/11 08:00	1121.00	11.2
20	28	18/3/11 20:40	20/3/11 07:40	305.00	35.00

occurring in correspondence with the spawning period. No significant differences were detected during the periods 'before' and 'after' the spawning period (Fig. 5). Further, during the tagging events in mid- to late March, we observed that the gonads of white seabream were mature.

DISCUSSION

Our work is the first to estimate long-term residency, home ranges and movement patterns of white seabream within a NTZ. During the monitoring period (161 d), tagged fish demonstrated high residency, homing ability, and most performed wandering behavior during the spawning period. Due to the lack of previous research regarding movements of white seabream in MRs, our results can only be compared with the few available studies conducted on relatively small-sized (22.5 and 20.5 cm) white seabream in other habitats, such as lagoons and artificial reefs (Abecasis et al. 2009, D'Anna et al. 2011). Despite the differences in mean lengths of fish, the high FPI values measured in our study compare favorably with these previous studies. Collectively, data from the 3 studies confirm that this species has a strong site fidelity. FPI values ranged from 83 to 94% in the Abecasis et al. (2009) study, and from 65.5 to 95.5% in the D'Anna et al. (2011) study. In our study, all but 2 tagged seabream (90% of the total number of fish tagged) displayed a high level of residency within the monitoring area. We discount the data from those 2 individuals because their transmitter signals disappeared 2 d after the tagging and release operation, indicating that either mortality (natural or induced by infection following the surgical insertion of the transmitter) or tag malfunction had occurred. It is possible, however, that those 2 fish could have home ranges just outside our zones of detection in the study area.

The size of white seabream home range showed a marked variability among individuals (between 3 and 40 ha). Such a variability may be explained by a number of factors, such as bottom topography, habitat type and distribution, food availability (Abecasis et al. 2009, Lino et al. 2009, D'Anna et al. 2011) and individual fish size (La Mesa et al. 2012, March et al. 2010 and references therein). A positive relationship between home range and individual size has been attributed to an ontogenetic shift in the use of space and habitats (Dahlgren & Eggleston 2000). Home ranges of white seabream at Torre Guaceto varied among individuals, but no relationship was found between home range size and individual fish size. This aspect, however, deserves further investigation, especially using a wider range of fish sizes.

Home range data show that tagged seabream spent most of their time within areas of a quite limited size (average KUD95 ≈20 ha and KUD50 ≈4 ha), far smaller than the extension of the NTZ we studied (≈140 ha). This implies that the NTZ of Torre Guaceto is large enough to successfully protect white seabream and other species with a relatively small HR. It has been reported that estimates of home range size can be affected by experimental conditions, such as the duration of the detection period and the specific position of receivers. Abecasis et al. (2013) reported a significant and positive relationship between home range size and duration of the experiment. The detection periods of fish in our study ranged between 49 and 161 d, but we observed no significant relationship between individual home range size and detection duration for any tagged seabream. The home range size estimated in our study was similar to that estimated by other authors across shorter monitoring periods (Abecasis et al. 2009, Lino et al. 2009, D'Anna et al. 2011). It is possible, however, that the positive relationship between study period and home range size described by Abecasis et al. (2013) would be apparent at Torre Guaceto if the study duration had been longer.

The positioning of receivers can also affect home range size estimation. If a fish occurs at the edge of a receiver's zone of reception, the estimated home range might be a partial estimate of that individual's actual home range. Six of the white seabream we tagged may have had larger home ranges than we estimated because they were located at the edge of the area covered by our receivers. We resolved this potential problem by using only the 14 white seabream whose COAs were entirely surrounded by receivers to calculate the average home range.

The bottom topography can affect home range estimates. The receiving range of acoustic monitors can be restricted by bottom relief and other structural features that impede the transmission of signals (e.g. whenever fish enter their refuges into the rocky habitat) and lead to an incomplete understanding of home range size. Finally, an ecological mechanism possibly contributing to reduced average home range size is population density, which may increase with NTZs (Eggleston & Parsons 2008, Gruss et al. 2011). The relationship between density and home range size deserves to be tested in future studies.

In our study, 17 of 20 (85%) tagged fish exhibited homing to capture sites following release. The positive correla-

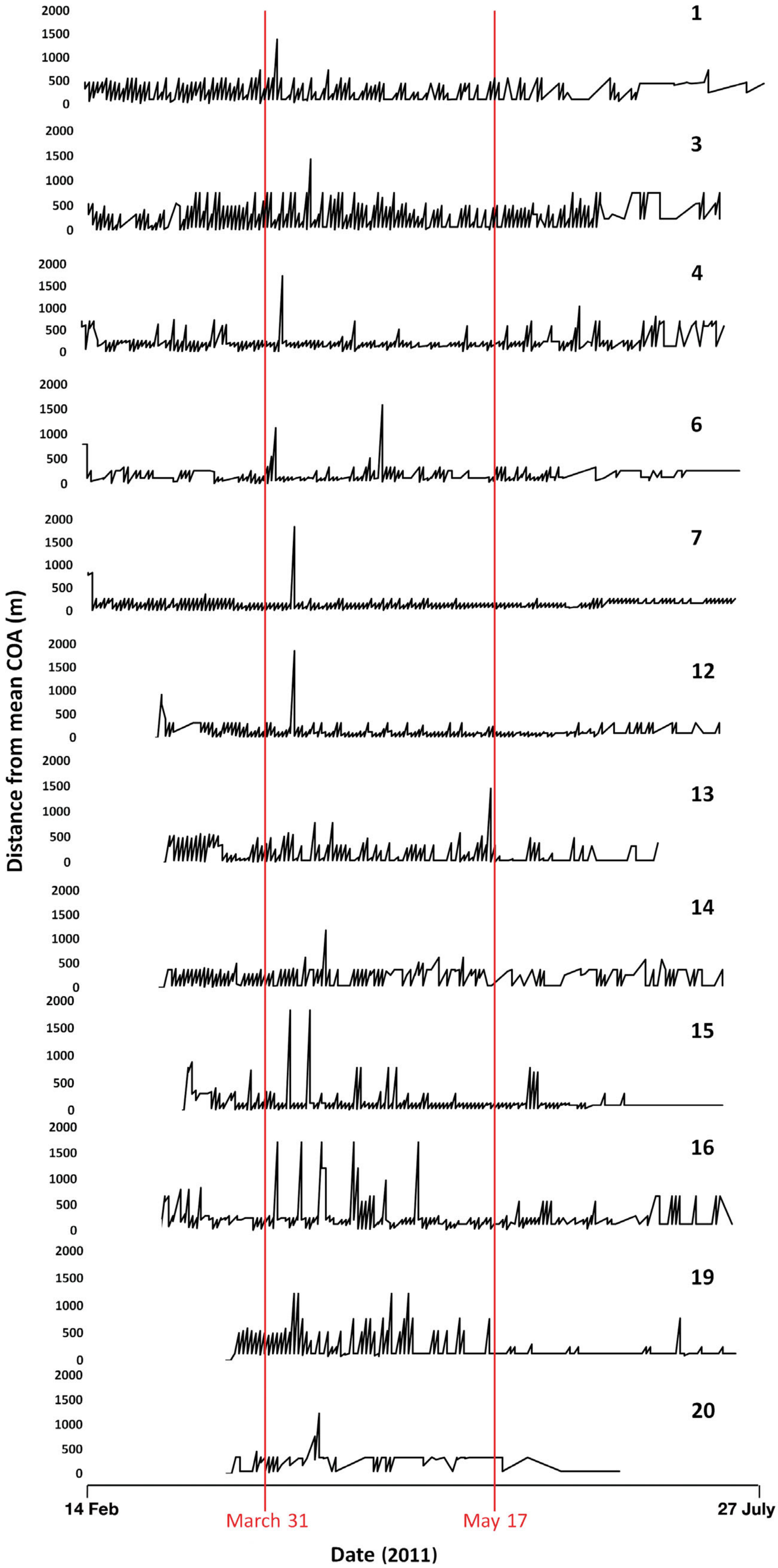

Fig. 3. *Diplodus sargus sargus.* Maximum distance of individual tag detections from the mean point of the centers of activity (COA) of the 12 tagged fish (fish ID on the right) that displayed wandering behavior. Red lines indicate the period of spawning (when most wandering behavior occurred)

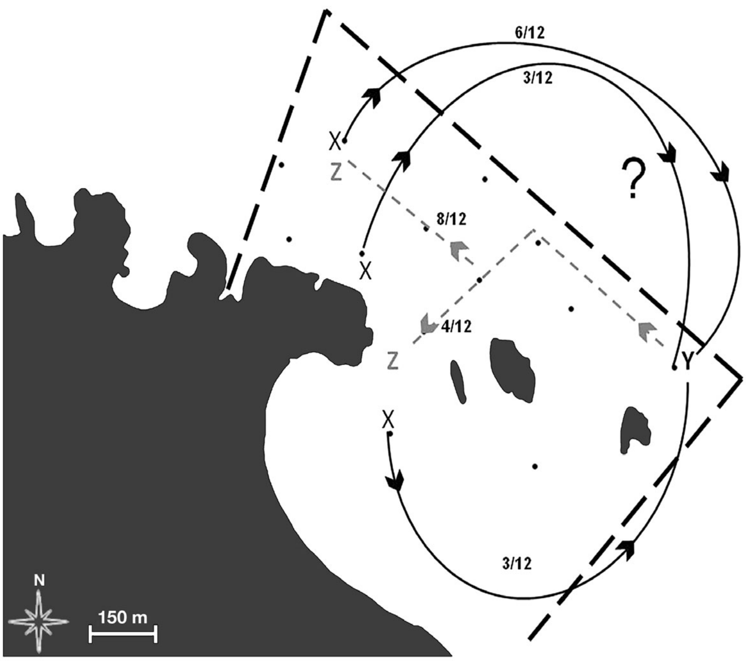

Fig. 4. *Diplodus sargus sargus.* Directions of movements of the 12 white seabream that left the study area during the spawning season (see Fig. 3). The black dashed line shows the boundaries of the No-Take Zone; X represents the location of the last signals detected before departure; black lines with arrows show the possible directions of movements to reach Y; Y indicates the location of the first signals received when tagged fish were returning to the study area; Z indicates return points (home); grey line shows the directions of movements to home; small black points show the positioning of receivers

tion between displacement distance travelled and the time to return to the site of capture suggests that fish return 'home' after being displaced. Other studies have reported a similar homing behavior for the white seabream (D'Anna et al. 2011), as well as other Mediterranean fish species (Jadot et al. 2006, Abecasis & Erzini 2008, La Mesa et al. 2012). Three of our tagged fishes, however, did not return to their respective capture sites, thus suggesting a possible home range relocation.

Although in this experiment tagged fish showed high site fidelity and spent most of the time close to their 'home' (i.e. core area), some (12 ind.) displayed a wandering behavior outside the monitoring area. This wandering behavior may have been related to spawning events triggered by surface water temperatures increasing from about 13 or 14°C to 17 or 18°C. Based on juvenile seabream otolith analyses, Di Franco & Guidetti (2011) estimated that the spawning period of white seabream in 2009 at the Torre Guaceto MPA likely occurs in May. All these converging observations about the white seabream spawning period suggest that it is very likely that this fish could start spawning in April. Hence, the wandering behavior shown by the 12 individuals in the period between April and May is likely related to spawning events taking place outside the studied NTZ. Further research is needed to better understand and explore such wandering behavior.

CONCLUSIONS

In this study, we report novel data regarding home range size and movement patterns of the white seabream within the Torre Guaceto NTZ on a relatively long-term time scale (161 d). During the monitoring period, tagged fish showed high site fidelity, marked homing behavior and individual variability in home range size. Most of the studied individuals also showed wandering behavior across larger distances than usual, but only during the spawning period. These wandering movements have not been previously reported, and they contribute to our understanding of seabream ecology — allowing the formulation of new hypotheses on several biological and ecological aspects of the white seabream (e.g. the possibility of spawning aggregations outside home ranges).

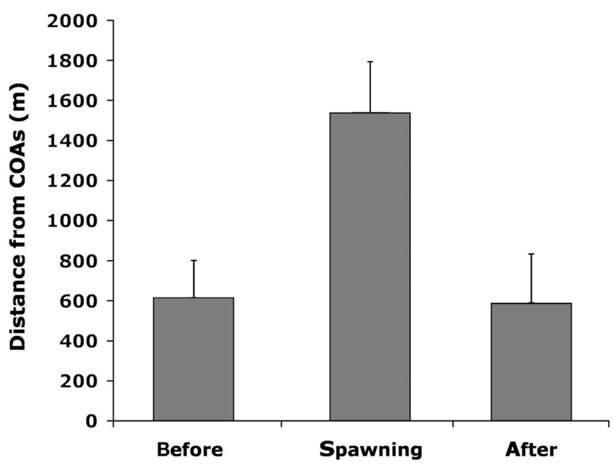

Fig. 5. *Diplodus sargus sargus.* Maximum distance (mean ± SD) from the harmonic mean of the centers of activity (COA) during, before, and after the spawning period traveled by the 12 white seabream displaying wandering behavior (see Fig. 3)

From a conservation perspective, the information obtained in this study is directly useful for improving management of MPAs. On the one hand, the fact that the home range of the white seabream is relatively small, and that this fish is quite site-attached suggests that this species could be effectively protected in relatively small MRs or NTZs (such as that of Torre Guaceto investigated here). We recommend, therefore, that MRs/NTZs should be larger than the average home range of the species targeted for protection. In our case, considering the relevant population densities of this fish in the study area (Guidetti 2007, Di Franco et al. 2012b), we can presume that a large number of white seabream were well protected within their home ranges (16.7 ha on average) within the larger NTZ (extending over 138.60 ha) of Torre Guaceto MPA. On the other hand, even though further studies are necessary to confirm our hypothesis, the wandering behavior taking place outside the NTZ during the reproductive period suggests that special measures should be implemented to protect white seabream during the spawning period (e.g. imposing fishing bans during the reproductive season). In conclusion, this study highlights the importance of determining movement patterns of species in need of protection, in order to refine and implement more appropriate management solutions.

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