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Site fidelity of farmed gilthead seabream *Sparus aurata* escapees in a coastal environment of the Adriatic Sea

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ABSTRACT: A small escape incident of gilthead seabream *Sparus aurata* tagged with acoustic transmitters (N = 25) from a commercial farm located in a coastal bay of the eastern Adriatic Sea was simulated to enable evaluation of recapture strategies and escapee management. Over a 3 mo monitoring period, tagged individuals showed spatial distribution closely related to fish farms, where 76 and 68% of tagged fish were present at the farm during the second and third weeks post-release respectively. Upon initial release, escaped seabream had a small total home range (0.142 km^2) that encompassed the farm site. Short-term residence differed among tagged fish. Few fish (28%) remained in the proximity of the fish farm for longer than 1 mo; most were likely angled or moved outside the acoustic array. Fish that moved elsewhere have the potential to cause substantial ecological and genetic impact, as they likely are able to quickly adapt to natural conditions. Considering the capture impact of the limited recreational fishery on this small-scale escape event, fish recapture by this type of fishery within 2 wk of escape could be feasible and is highly recommended.

KEY WORDS: Escapees · Telemetry · Residency · Home range · Diel activity · Coastal ecosystem · Management

INTRODUCTION

Aquaculture is responsible for impressive growth in the supply of fish for human consumption, with a current annual production of 73.8 million t or 44.1% of the total production from capture fisheries and aquaculture (FAO 2016). In line with global trends, growth perspectives of marine Mediterranean aquaculture suggest that production volumes will increase by a further 55% to 2030, and will focus on established production species, such as gilthead seabream *Sparus aurata* and European seabass *Dicentrarchus labrax* (Bostock et al. 2016). To retain the competitiveness and sustainable growth of aquaculture, research priorities are oriented toward minimizing environmental impacts. Despite the efforts, there are estimates that nearly 9 million fish have escaped from sea cages in 6 European countries over the past 3 yr, mainly due to structural or operational errors (Jackson et al. 2015). The contribution of escapees to natural populations can be substantial and can vary greatly among farmed species. It appears that net biting is a common behaviour of gilthead seabream and Atlantic cod *Gadus morhua*, enabling their more frequent escape through smaller holes in netting in contrast to other farmed species (Jackson et al. 2015).

Escaped fish may cause a range of genetic and ecological effects in native populations, including the risk of disease transfer (Arechavala-Lopez et al. 2013). The genetic introgression of farmed escapees into

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native populations (Glover et al. 2012) can lead to reduced overall fitness of wild populations (Fleming et al. 2000, Gilk et al. 2004, Tymchuk et al. 2007) and competition for food and habitat (Jonsson & Jonsson 2006, Šegvić-Bubić et al. 2011a). Post-escape behaviour of coldwater-aquaculture species, such as Atlantic salmon *Salmo salar* or Atlantic cod, has been extensively studied (Olsen & Skilbrei 2010, Skilbrei 2010, Uglem et al. 2010, Chittenden et al. 2011, Zimmermann et al. 2013). However, information on the ecological and genetic impacts of gilthead seabream and European seabass farming in the Mediterranean is still sparse. Recent studies have demonstrated that escaped European seabass and gilthead seabream are able to move away from their original farm to coastal fishing areas up to 20 km away, and that escapees may survive for relatively long periods (>6 mo) by feeding on natural resources (Arechavala-Lopez et al. 2011, 2012, Toledo-Guedes et al. 2014). The ability of escapees to exploit natural resources was evident in the relatively high proportion of gilthead seabream and European seabass escapees in wild populations in the Adriatic Sea and in the waters of Cyprus (13–15%) (Šegvić-Bubić et al. 2011b, 2017, Brown et al. 2015), and in the western Mediterranean (11–20%) (Izquierdo-Gómez et al. 2017). It seems that farmed escapees successfully introgressed and changed the genetic profile of certain wild populations, which were then characterized by decreased allelic diversity in comparison to unaffected wild populations (Šegvić-Bubić et al. 2017).

To date, there has been little effort to manage escapees in Mediterranean countries (Dempster et al. in press). Thus, regulations to minimize the risks associated with escapees by improving farming technology and implementing efficient recapture programmes are important for the future sustainable development of the Mediterranean fish-farming industry. Good examples of preventing escapes can be found in Norway and Scotland, where national legislation has introduced technical standards for sea-cage aquaculture equipment, coupled with an independent mechanism to enforce standards (Dempster et al. in press). The result was that the total number of escapees was cut in half, despite increasing production trends (Jensen et al. 2010).

Considering that the Adriatic Sea is relatively shallow, contains >1300 islands, and is the most indented Mediterranean coastline, marine finfish aquaculture in Croatia is carried out entirely in floating cages at inshore or semi-offshore sites. No information exists regarding the spatial dispersal of escapees in coastal environments that could enable evaluation of recapture strategies and escapee management in general. Thus, the objectives of the present study were to examine the spatial and temporal distribution of farmed gilthead seabream after a simulated escape incident at an inshore farm, and to increase the knowledge on the behaviour and movements of escapees in coastal ecosystems of the Adriatic Sea.

MATERIALS AND METHODS

Study area

The study was carried out in a coastal bay located in the eastern Adriatic Sea (Fig. 1). A shore net-cage fish farm is located in the southeastern part of the bay, 50 m from the coast, over a gravel-sand bottom at a depth of 15–20 m. Commercial farming was initiated in 1996 with an annual capacity of ca. 100 t of gilthead seabream and European seabass as the main production species. During the study, the farm concession area of 2520 m^2 consisted of 15 cages of varying volumes with a set net depth of 6 m. Water temperature at the sea surface gradually declined from 22°C (October) to 16°C (December) during the study period. In the bay, fish harvesting is permitted only by recreational fisheries, with total exclusion of the areas housing the commercial marina situated in the northern part of the bay, and within a 300 m radius of the fish farm, although these regulations are poorly enforced.

Tagging and release

To study the movements of escapees from cages and their site fidelity, 25 farmed gilthead seabream were tagged with acoustic transmitters and released from the cage on 9 October 2015 ('Farm' in Fig. 1), simulating a small-scale escape incident. Of these, 15 individuals were tagged with acoustic transmitters that included a depth sensor (model ADT-9-SHORT, Thelma Biotel; 28 mm × 9 mm, weight in air: 4.1 g, transmitting interval: 90 s, depth range: 51 m, depth accuracy: ±0.5 m). The remaining 10 individuals were tagged with acoustic transmitters without a depth sensor (model MP-9-SHORT, Thelma Biotel; 23 mm × 9 mm, weight in air: 3.7 g, transmitting interval: 90 s). The weight of tags in air did not exceed 2% of the fish body weight in air, as recommended by Jepsen et al. (2005). The minimum battery life for both transmitter types was 5.7 mo.

The tagged fish showed no external signs of disease or malformation. The average (±SD) total length was 29.8 ± 0.6 cm and average total weight was 502.8 ±

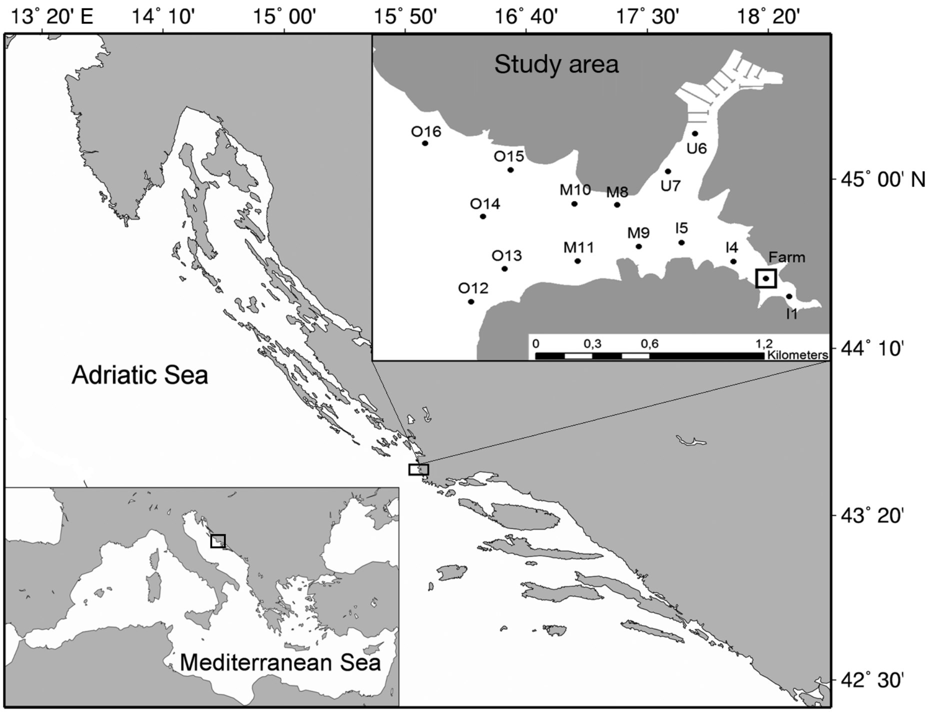

Fig. 1. Adriatic coast of Croatia. Lower left: Mediterranean. Upper right: study area in Peles Bay, with receiver locations (●) in the farm-impacted area (receivers: 'Farm', I1, I4, and I5), middle part of the bay (M8, M9, M10, M11, U6, and U7), and outer part of the bay (O12, O13, O14, O15, and O16). See also Table S1 in the Supplement at www.int-res.com/articles/suppl/q010p021_supp.pdf

32.2 g (see Table 1). Prior to tagging, fish were moved from the commercial cage to a holding pen (1 × 1 m) anchored in the vicinity of the operative coast. Fish were individually anaesthetized with 75 mg l^{-1} MS-222 in 40 l volume with an immersion period of 5 ± 1 min. For surgery, gilthead seabream were weighed and measured, and placed in a V-shape support where an incision (<1 cm) was made on the mid-ventral line between the pelvic fin and anus. After sterilization, the tag was gently inserted into the abdominal cavity and the incision closed with 2 stitches using silk sutures (2/0 Ethicon). Fish were also tagged on the side near the dorsal fin base with external T-bar anchor tags (Hallprint) to allow for fish identification in case of recapture. The handling time was approximately 2 min, followed by 3–4 min of recovery time in a 40 l tank. After recovery from anaesthesia, fish were transferred back to the holding pen for a further 24 h of observation. During that time, fish showed no stress reactions or mortality and began to feed.

The simulated small-scale escape incident was performed in close vicinity of the commercial cage of origin of the tagged fish. Two divers monitored the fish release and observed normal swimming behaviour. All handling and tagging was conducted in strict accordance with Croatian regulations on animal treatment and welfare (Ministry of Agriculture, Fisheries and Rural Development of Croatia, OG 135/06).

Acoustic receiver array

The spatiotemporal distribution of tagged fish was monitored by an array of 16 receivers (10 from Vemco, and 6 from Thelma Biotel) moored at 15 locations within the bay (Fig. 1; Table S1 in the Supplement at www.int-res.com/articles/suppl/q010p021_supp.pdf). Two receivers (Vemco and Thelma Biotel) were located directly at the release site (Farm) to ensure recordings at the farm. Three additional receivers were deployed at a distance of 150 m (I1 and I4) and 350 m (I5) from the farm, covering the farm-impacted area (inner area). The central part of the bay, including the entrance to the commercial marina, was covered by 6 receivers (M8, M9, M10, M11, U6, and U7; middle area), while the deepest parts of the bay were covered by 5 receivers (O12, O13, O14, O15, and O16; outer area). The distance between the site of release and the outermost receiver (O16) was 1.9 km. Both eastern portions of the bays (commercial marina and fish farm) are closed off, disabling the fish from leaving. Two detection range trials were performed prior to the tagging experiment during the daytime, with 2 fixed receivers next to the fish farm and 2 transmitters with the same characteristics as those used for the fish tagging. The receiver detection range varied between 300 and 350 m. Considering the distance between receivers (250–400 m) within the bay, the aim of the array design applied in the study was to provide a boundary within which released fish can be detected.

The main habitat observed in the outer area was *Posidonia oceanica* seagrass meadows, where depths varied between 25 and 45 m. The habitats within the central and inner areas of the bay were more heterogeneous, including seagrass meadows and rocky and sandy bottoms. The depth of the receiver sites varied from 12 to 46 m. All receivers were attached to anchored ropes at approximately 2–5 m from the seabed. The receiver array was removed on 31 December 2015.

Data analysis

Fish detections were analysed and filtered for potentially spurious detections, characterized as a single detection within a 30 min period (Arechavala-Lopez et al. 2011, 2012). To infer fish site fidelity, daily and weekly presence histories were plotted to visually inspect fish temporal mobility. The total periods between release and the last detection (D_t) and the number of days detected (D_d) were calculated for each fish. Following March et al. (2010), the residence index (I_R), defined as the quotient between D_d and D_t, was estimated for each individual fish, rather than for each receiver, and used as an alternative to determining the number of consecutive days of presence (Collins et al. 2007). I_R ranges from 0 (no residency) to 1 (absolute residency).

Two methods were used to estimate home range areas: minimum convex polygon (MCP) and bivariate kernel utilization distribution (KUD). MCP, as an indicator of fish dispersion within the monitored area, was calculated for each fish based on the location of the receivers using the Geospatial Modelling Environment (GME) (v. 0.7.4, www.spatialecology.com/gme) in conjunction with ArcGIS (v. 10.3) (Abecasis & Erzini 2008, Abecasis et al. 2013). To cope with multiple detections by the same individual at different receivers, the individual centre of activity (COA) position was calculated for each 30 min period following the method described by Simpfendorfer et al. (2002). This method is based on the fact that over a period of time (30 min period in this study), the number of receptions would be greater the closer the signal source is to the receiver. So, in the case where there are multiple receivers with overlapping detection ranges, and each receiver logs a signal, the shape of the probability surface for the signal's source location can also be approximated by a cone, but centred on a point equidistant from each receiver. Thus, over a period of time, the number of receptions at each receiver will be equal if the signal source is located equidistant from each receiver. In the same array of receivers, if the number of signal receptions is not equal, then it can be assumed that the signal source is closer to the receiver(s) that has the greatest number of receptions. In an *x*- and *y*-coordinate system (e.g. latitude and longitude), the best estimate of the position of the signal source is the mean of the receiver locations weighted by the number of receptions. One implication of this method is that the mean position estimated will always fall within the MCP described by the receiver locations.

COA positions were then used to calculate the core activity area (50% KUD) and the home range activity area (95% KUD), the parameters that provide information on the use of monitored space in a given time period (March et al. 2010). A smoothing factor (*h*) of 250 and 25 × 25 m cell grids were used to calculate KUDs in the GME (Abecasis et al. 2015). Using the Intersection tool in ArcGIS, obtained polygons of 50% and 95% KUD estimates were clipped to the bay polygon to exclude any portion of the calculated home range that occurred on land. To overcome potential underestimation of the area occupied by released fish in situations when they moved outside the receivers' array, home range area parameters were calculated for the initial period of the first 2 wk post-release for each fish and for the total period. To compare whether the area used by released fish changed over time (Mann-Whitney *U*-test), MCP and 95% and 50% KUD were additionally examined for the initial and subsequent periods of fish recorded within the study array for at least 1 mo. The subsequent period included the period following the second week till the end of detection for each fish.

The use of monitored space by time of day was assessed by binning all detections for each fish by hour and by receivers grouped with respect to distance from the farm (Farm: at the release site; 0.5 km: inner area; 1 km: middle area; 1.5 km: outer area). Only individuals (n = 21) detected for longer than 3 d were included in the analysis. The mean number of detections were plotted by hour and receiver group for each fish. The Mann-Whitney *U*-test was used to test for individual differences in the number of detections between day and night within each receiver group, and to test for differences in the total number of fish observed at the receiver situated at the fish farms in comparison to that observed at receivers in the middle and outer areas. To estimate variation in the vertical distribution of gilthead seabream at release (mean swimming depths and daily detections) in relation to the time of day or farm feeding schedule, 1-way repeated-measures ANOVA (Systat v. 13, SPSS) was applied to tagged individuals bearing the depth sensor. The diurnal cycle was divided into day, i.e. the period from sunrise to sunset (07:00–17:59 h), and night (the remaining period), while for the farm feeding schedule, each day was divided into the feeding period (07:00–14:59 h) and non-feeding period (15:00–17:59 h, daytime considered only). Only gilthead seabream (n = 13) observed for longer than 2 d following release from the farm were included in the calculation of vertical distributions by day or night. Before using ANOVA, normality and homogeneity of variance in the dataset were tested with the Shapiro-Wilk test and Levene's test, respectively. The data were log(x + 1)-transformed if normality and homogeneity were not assumed. A significance level of 5% was used for all tests.

RESULTS

Site fidelity

Throughout the 3 mo monitoring period, all tagged fish were detected by the acoustic receiver array. The highest numbers of detections were recorded by receivers at the release site and at neighbouring sites within the farm-impacted area (inner area: receivers I1 and I4). On average, gilthead seabream escapees were detected by 7 receivers over a period of 25 d (Table 1), and no fish were detected at all receivers. Short-term residence at the site of release differed among tagged fish. A high proportion of tagged fish were observed at the release site during the first 7 d (n = 23; 90%), and even 2 wk post-release (n = 19; 76%). However, at 4 wk after release, the number of detected fish decreased (n = 10; 40%), with the exception of several individuals (n = 7; 28%) that were continuously detected for >1 mo within the study bay (Fig. 2). According to the signal pattern observed at each receiver through the monitored period, it could be assumed that 40% were caught by local fishermen

Table 1. All *Sparus aurata* (N = 25) tagged with an acoustic transmitter, with (IDs 1–15) or without (IDs 340–349) a depth sensor. TL: total length; D_t: number of monitoring days; D_d: number of days with detections; I_R: residency index (D_d divided by D_t); MCP: minimum convex polygon based on 100% of the positions; 95% KUD and 50% KUD: kernel utilization distribution based on 95% and 50% of the positions respectively. Fish with only 1 detection day (IDs 6 and 340) are excluded from analysis. Fish losses due to angling/capture are assumed. See also Fig. S1 in the Supplement at www.int-res.com/articles/suppl/q010p021_supp.pdf

Tag ID	TL (cm)	Weight (g)	D_t (d)	D_d (d)	Total no. of detections	No. of receivers with detections	I_R	MCP (km^2)	95% KUD (km^2)	50% KUD (km^2)	Last fate
1	31	530	14	14	7084	6	1	0.12	0.068	0.037	Alive/moved away
2	30	528	44	41	29933	9	0.93	0.46	0.082	0.038	Alive/moved away
3	29	510	7	7	3188	9	1	0.47	0.071	0.035	Predated/dead
4	31	527	17	17	9947	9	1	0.48	0.272	0.042	Alive/moved away
5	30.5	499	15	15	6519	8	1	0.48	0.185	0.039	Alive/moved away
6	30	486	1	1	69	8	1	–	–	–	Alive/moved away
7	29	453	84	84	61169	7	1	0.35	0.067	0.036	Alive/farm
8	30	449	2	2	198	10	1	0.51	0.607	0.081	Alive/moved away
9	29	541	17	17	7666	9	1	0.36	0.136	0.037	Alive/moved away
10	29.5	467	19	19	9715	8	1	0.29	0.070	0.037	Captured
11	31.5	570	49	45	34035	11	0.91	0.64	0.069	0.036	Alive/moved away
12	29	474	23	17	5231	8	0.73	0.29	0.108	0.039	Captured
13	29	476	15	15	6903	9	1	0.33	0.072	0.037	Captured
14	30	558	3	3	730	3	1	0.01	0.069	0.037	Captured
15	29	448	45	45	19037	10	1	0.46	0.069	0.037	Alive/moved away
340	29.5	528	1	1	26	6		–	–	–	Alive/moved away
341	29.5	540	21	21	5289	6	1	0.15	0.068	0.038	Captured
342	31	535	10	10	1153	9	1	0.36	0.358	0.042	Captured
343	29.5	501	79	46	6369	6	0.58	0.09	0.068	0.038	Moved
344	30.5	533	45	45	9243	6	1	0.15	0.067	0.037	Captured
345	29	441	28	28	10178	6	1	0.15	0.068	0.036	Captured
346	29	458	37	21	2587	4	0.56	0.02	0.067	0.037	Unknown
347	31	537	21	21	2582	6	1	0.15	0.067	0.032	Captured
348	30	491	23	17	5160	3	0.73	0.006	0.068	0.037	Captured
349	29.5	491	7	7	1225	4	1	0.02	0.066	0.036	Unknown
Average	29.8	502.8	25.1	22.4	9809	7.2	0.94	0.283	0.124	0.041	

(last fate: 'captured', Table 1) without being reported and another 40% of the tagged fish moved out of the study area (last fate: 'moved away', Table 1) and were outside the detection range. Those individuals outside the detection range showed a final detection position in the outermost areas (receivers O13, O14, and O16), suggesting migration out of the bay. Individuals assumed to have been captured by the recreational fishery usually had a final record in the middle or inner areas of the bay and were characterized by a sudden loss of signal. For 2 fish (IDs 346 and 349), the loss of signal could not be defined, while an additional fish (ID 3) likely died during the acoustic survey, since it was continually recorded at the farm receiver until the end of the study. Overall, I_R scores showed high values (average: 0.94), suggesting that most fish were detected during their presence in the study area, although some individuals left the study area and returned again during the study period. Overall, I_R scores showed high values (average: 0.94), suggesting that most fish were detected during their presence in the study area, although some individuals left the study area and returned again during the study period ($D_t > D_d$ in Table 1; IDs 2, 11, 12, 343, 346, 348), resulting in relatively lower I_R scores (Table 1).

Spatial distribution

The total number of individuals detected by receiver stations away from the farm was significantly lower compared to the release site (Mann-Whitney

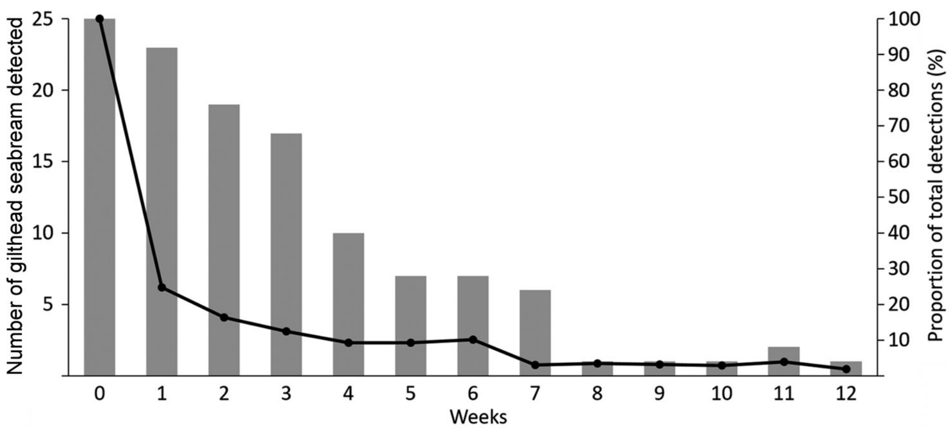

Fig. 2. Number of released *Sparus aurata* tagged with acoustic transmitters (N = 25) detected in close proximity to release farm over the total study period. Plotted line shows proportion of total fish detections per week at release farm. Week 0 represents date of release of fish from the farm

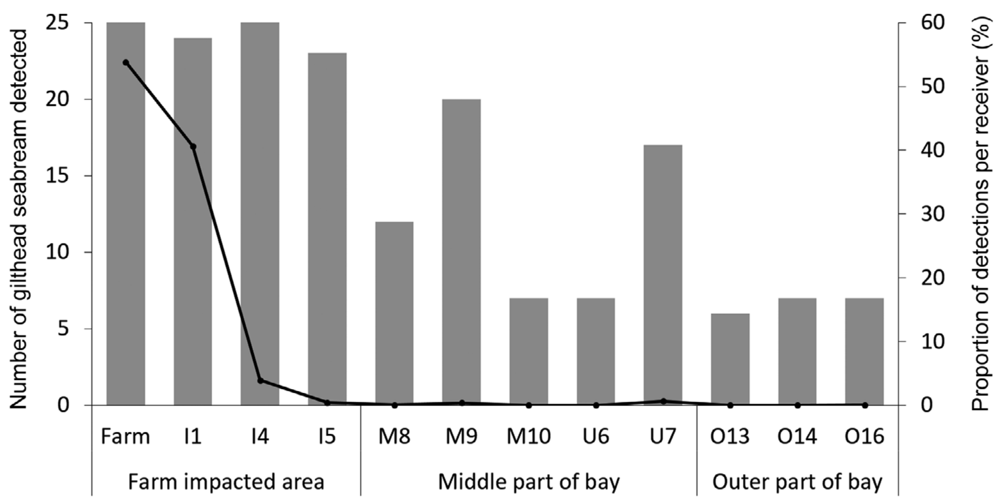

Fig. 3. Spatial distribution of acoustically tagged *Sparus aurata* within the bay during the total study period (12 wk). Plotted line shows proportion of overall detections for each receiver. No fish were detected at receivers M11, O12 and O15

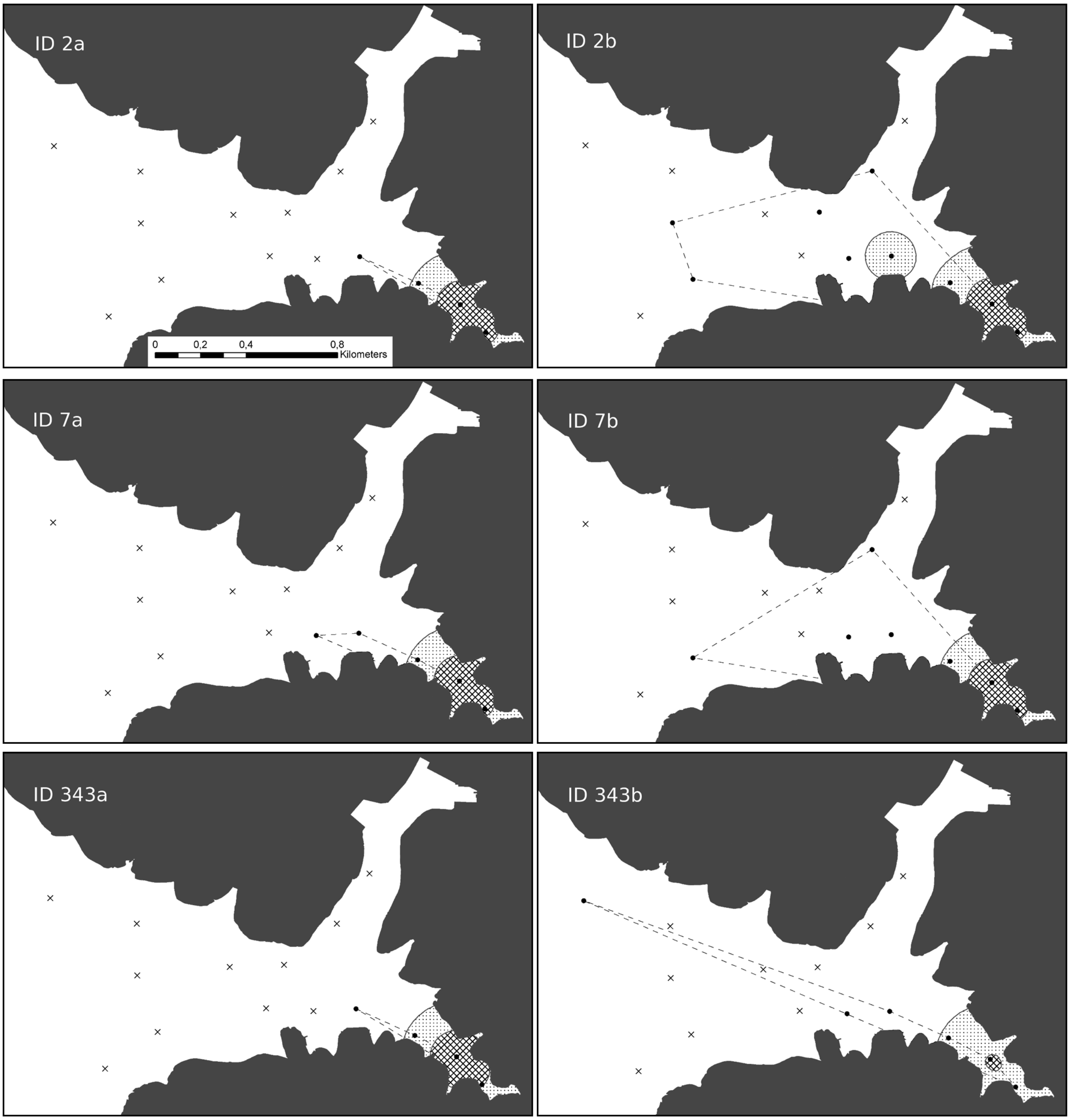

Fig. 4. Home range and core activity areas for acoustically tagged *Sparus aurata* (IDs 2, 7, and 343) in (a) initial period (first 2 wk after release) and (b) subsequent period (after the 2nd week until end of fish detection within the study area). Minimum convex polygon (MCP) (dashed line), 50% kernel utilization distribution (KUD) (cross-hatched area), and 95% KUD (dotted area). Receivers with (●) and without (×) fish detections. Selected individuals show patterns typical of fish recorded for >1 mo within the study array

U-test, $p < 0.05$), except for those locations in close vicinity of the farm (receivers I1, I4, and I5), which showed no significant differences in the total number of observed individuals compared to the release site (receiver 'Farm') (Fig. 3). These observations were supported by the home range area estimations. Namely, for the initial period (first 2 wk after fish release) and the total period, the core area (50% KUD) of all tagged fish was centred at the release site and at neighbouring sites within the farm-impacted area, i.e. inner area (receiver I1). In most cases, home range areas (95% KUD) included the inner and middle areas of the bay, both characterized by a heterogeneous seabed structure (Fig. S1 in the Supplement). For all 6 individuals with a prolonged stay of 30 d or more within the study array, the core areas (50% KUD) overlapped with the site of release during the initial and subsequent period (Fig. 4). Only 1 fish (ID 343) showed a reduction of core area size (by 90%) in the subsequent period in comparison to the initial period. In the subsequent period, fish left the study area and returned after 4 wk. Still, significant differences in home range area estimations between the initial and subsequent periods were observed only for MCP ($p < 0.01$), but not for 95% and 50% KUD (Mann-Whitney *U*-test). Tagged fish were always detected at a greater number of receivers during the subsequent period (Table 2, Fig. 4).

For the total study period (3 mo), the total home range area estimated with 95% KUD ranged between 0.066 and 0.61 km^2 (mean: 0.12 km^2), while the total home range area obtained with MCP ranged between 0.01 and 0.64 km^2 (mean: 0.28 km^2) (Table 1). The MCP home range area was significantly higher than that obtained by 95% KUD estimation (Mann–Whitney *U*-test, $p < 0.01$). The core area estimated with 50% KUD varied across different periods. For the total period, the core area ranged between 0.031 and 0.041 km^2 (mean: 0.039 km^2), while for the initial and subsequent periods, core area values ranged between 0.003 and 0.038 km^2 (mean for initial period: 0.013 km^2, mean for subsequent period: 0.020 km^2; Table 2).

Diel patterns

In terms of habitat use by time of day with respect to the diel detections of tagged fish, 16 of 21 fish showed no differences in diel patterns at the release area (farm), while in the farm-impacted area (receivers I1, I4, and I5), 20 fish showed significantly higher daytime detections (Fig. 5; Fig. S2 in the Supplement). A similar pattern of daytime activities was observed in the middle (5 fish) and outer areas (1 fish) of the bay, areas with a lower presence of released individuals and fewer number of detections (Fig. 3).

Diurnal variation in vertical movements of the tagged fish bearing a depth sensor (n = 13) was observed at the release farm, where swimming depth was marginally deeper during the night (7.5 ± 0.9 m) than during daytime (6.3 ± 0.8 m), especially in the early morning hours (04:00–05:00 h; Fig. 6). Significant differences were observed for swimming depths between the 24 h period ($F_{23,276} = 5.86$, $p < 0.01$) and the day–night period ($F_{1,12} = 18.9$, $p < 0.05$), but not between the feeding and non-feeding periods ($F_{1,12} = 2.1$, $p > 0.05$). With respect to day–night individual variability, only 2 fish (IDs 5 and 7) showed no significant depth variation.

Table 2. The 15 tagged *Sparus aurata* recorded within the study array for >2 wk. Initial period includes first 2 wk post-release for each fish detected, while subsequent period includes time after the 2nd week till end of detection for each fish recorded for >1 mo within the study array. D_t: number of monitoring days; MCP: minimum convex polygon based on 100% of the positions; 95% KUD and 50% KUD: kernel utilization distribution based on 95% and 50% of the positions respectively. For initial and subsequent periods, 50% KUD of all tagged fish overlapped with the farm area. See also Fig. 4

Tag ID	D_t (d)	Initial period				Subsequent period			
		No. of receivers with detections	MCP (km^2)	KUD 95% (km^2)	KUD 50% (km^2)	No. of receivers with detections	MCP (km^2)	KUD 95% (km^2)	KUD 50% (km^2)
2	41	4	0.02	0.067	0.037	9	0.46	0.110	0.038
4	17	7	0.18	0.175	0.027				
7	84	5	0.04	0.068	0.038	7	0.35	0.067	0.036
9	17	4	0.02	0.066	0.004				
10	19	8	0.29	0.072	0.005				
11	45	6	0.15	0.074	0.037	11	0.45	0.067	0.036
12	17	6	0.15	0.069	0.038				
15	45	6	0.15	0.069	0.004	10	0.46	0.069	0.003
341	21	3	0.01	0.067	0.004				
343	46	4	0.02	0.069	0.037	6	0.09	0.068	0.004
344	45	3	0.01	0.067	0.004	6	0.15	0.067	0.003
345	28	3	0.01	0.064	0.005				
346	21	4	0.02	0.066	0.003				
347	21	5	0.09	0.064	0.003				
348	17	3	0.01	0.068	0.003				
Average			0.07	0.076	0.013		0.36	0.075	0.020

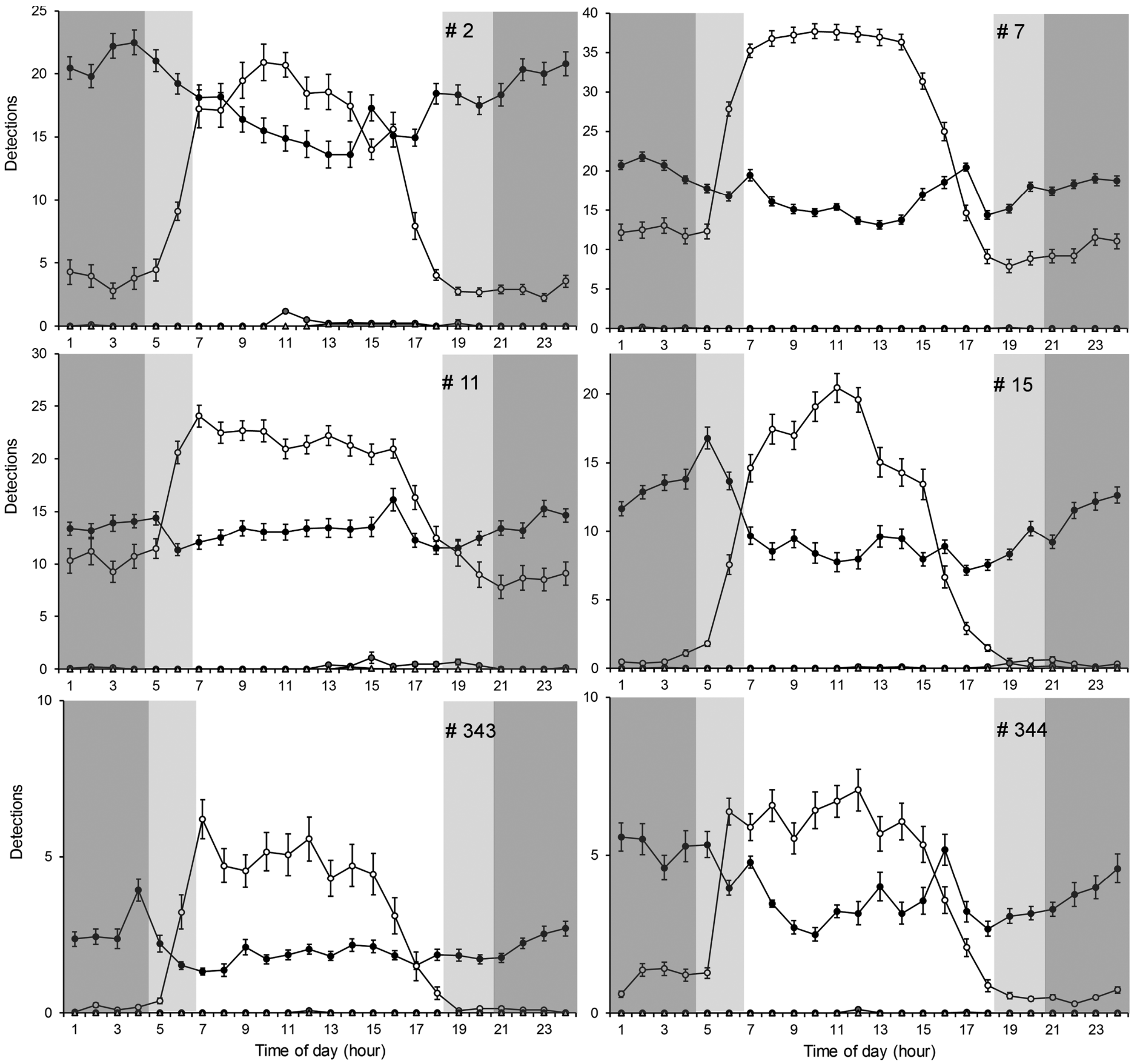

Fig. 5. Mean (±SE) number of detections per receiver group of released *Sparus aurata* tagged with acoustic transmitters (IDs 2, 7, 11, 15, 343, and 344) over the 24 h of the day. The receiver at the farm (●), receivers in the farm-impacted area (I1, I4, and I5) (○), the central area of the bay (M8, M9, M10, U6, and U7) (●), and the outer part of the bay (O12, O13, O14, O15, and O16) (▲). Dark grey plot areas represent nighttime, and light grey areas represent sunrise and sunset periods. Selected individuals recorded for >1 mo within the study array show typical daytime activity patterns in the farm-impacted area. See also Fig. S2 in the Supplement. Note different *y*-axis scales

Daily detections at the farm showed significant variation between the 24 h period ($F_{23,276}$ = 3.85, p < 0.01) and the day–night period ($F_{1,12}$ = 10.16, p < 0.01), although there was no difference between the feeding and non-feeding periods ($F_{1,12}$ = 0.49, p > 0.05). Interestingly, a positive correlation was observed between the number of detections and swimming depth (r = 0.67, p < 0.01), where fish movements closer to the surface were accompanied by a reduced number of detections.

DISCUSSION

Strong short-term farm fidelity

Acoustic telemetry surveying was carried out for the first time in the eastern Adriatic Sea to elucidate the post-escape behaviour and distribution patterns of gilthead seabream in a coastal ecosystem. Based on data obtained from 25 tagged fish over a 3 mo monitoring period, 3 main findings can be drawn from the present study.

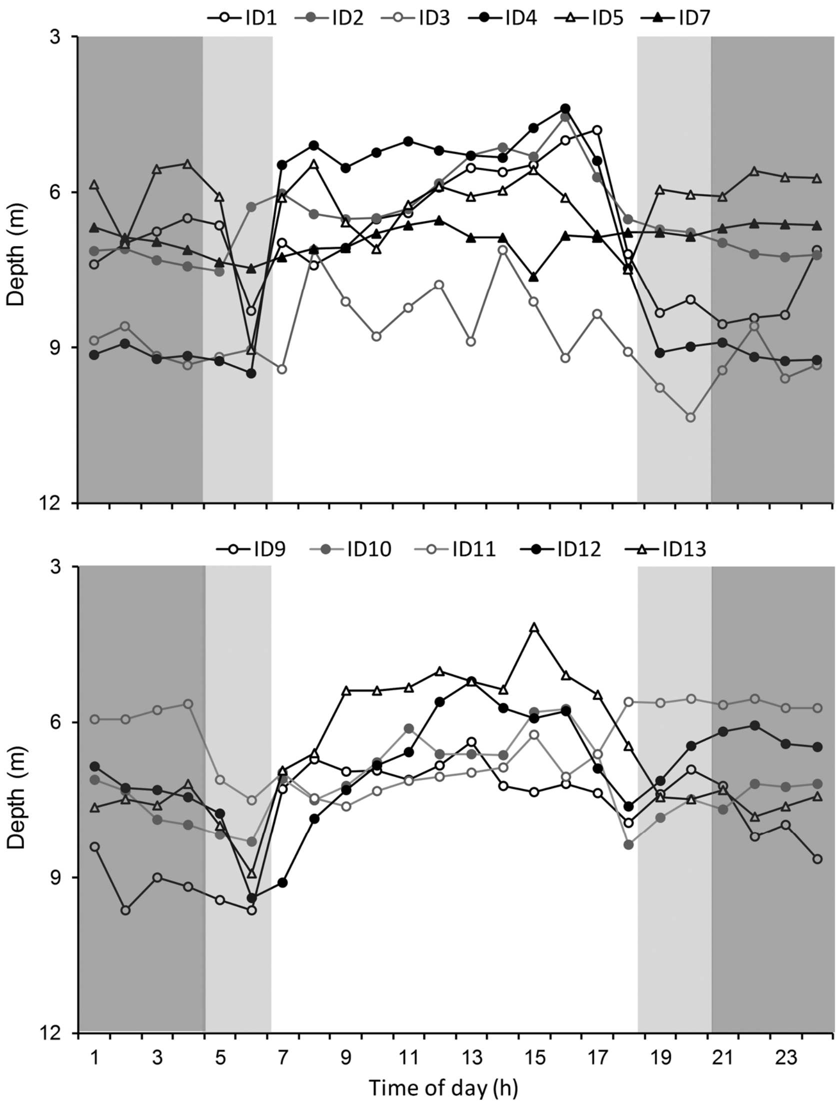

Fig. 6. Diurnal variation in vertical movements of the *Sparus aurata* tagged with depth sensors (upper panel: IDs 1–5 and 7; lower panel: IDs 9–13) around the farm during the 24 h of the day. Dark grey plot areas represent nighttime, and light grey areas represent sunrise and sunset periods. Fish cages with 6 m deep nets were moored at 12 m depth

Firstly, strong short-term farm fidelity of the tagged gilthead seabream was observed, with >70% of individuals recorded within the inner farm-impacted area even after 2 wk post-release. Secondly, spatial distribution was closely related to the fish farm, i.e. most fish showed a core activity area (50% KUD) centred in the farm concession area, which was accompanied by a generally small total home range (0.124 km^2) for the overall detection period. By comparing the total home range with the area covered by the receiver array (approx. 1.2 km^2), tagged fish occupied only 11% of total potential space. In addition, a high mortality rate (40%) within the bay was observed, likely due to fishing capture. Fishing pressures have previously been recognized as a significant driver of progressive decay in escapee abundance over time (Ramírez et al. 2015, and references therein). Thirdly, most fish showed diurnal variations in vertical movements within the farm area, preferring slightly deeper waters during night and shallower waters during the day. Such a diurnal pattern can be explained by the fact that gilthead seabream, as a daytime feeder in the natural environment (Pita et al. 2002) and with expressed daily locomotor activity rhythms (López-Olmeda et al. 2009), exploits waste feed from farms during daytime, occupying depths where the sea cage nets end (approx. 6 m).

Model-based analysis of escapee impact on the fitness of wild populations predicts that the long-term consequences of steady, low-level escapes are more detrimental than large-scale escapes at rare intervals (Baskett et al. 2013). In that sense, this simulation of small-scale escapes in the eastern Adriatic was set up to explore the impact of gilthead seabream on coastal systems and to examine possible management approaches to minimize unintended fitness consequences. Previous studies have shown that fish residence at a farm after release varies greatly in respect to farm location, fish life stage, and season (Skilbrei 2010, 2012, Uglem et al. 2010, 2013, Patterson & Blanchfield 2013, Arechavala-Lopez et al. 2017). In the present study, 76 and 68% of tagged fish were still present at the release farm during the second and third weeks, respectively. Similar fish proportions and residence times were observed in released Atlantic cod adults (Uglem et al. 2010). Strong site fidelity has also been noted for early life stages of salmon escapees released during autumn (Olsen & Skilbrei 2010), and Atlantic cod showed a preference for littoral areas in the areas surrounding the farm from which they were released (Serra-Llinares et al. 2013). In contrast, most studies have demonstrated rapid dispersion of escapees following release, especially in large fjords with salmonid aquaculture (Skilbrei 2010, Chittenden et al. 2011, Zimmermann et al. 2013) or in exposed localities with fish aquaculture in the western Mediterranean (Arechavala-Lopez et al. 2011, 2012, 2017). In the present study, rapid dispersion within 24 h was also detected, but for only 2 fish. Those individuals have the potential to cause the greatest ecological and genetic impact as they likely will be the quickest to adapt to natural conditions. Hybridizations between domesticated escaped farmed fish and wild conspecifics have already been recorded in the Adriatic Sea (Šegvić-Bubić et al. 2011b, 2017).

Relatively limited core and home activity areas of the tagged gilthead seabream were observed within the study bay. While use of the middle and outer areas of the bay was less frequent according to their home range areas (95% KUD), most fish showed a core activity area (50% KUD) centred in the farm-impacted area. For fish that had a prolonged stay of 30 d or more in the study array, a core activity area (50% KUD) of the initial period (first 2 wk) and subsequent period (after the second week till the end of study) overlapped with the farm-impacted area, demonstrating that fish farm fidelity did not change over time. On average, 2-fold greater values of MCP areas in comparison to the 95% KUD reflect outward movements during the study period and greater exploration of habitat over time. Six individuals (24%) left the study area and returned during the study period. The presence of other farms or hatcheries has been shown to influence patterns of movement by released fish (Patterson & Blanchfield 2013). Moreover, released steelhead trout *Oncorhynchus mykiss* dispersed gradually from the study site, by moving repeatedly from the release cages to other adjacent farms (Bridger et al. 2001). In the present study, the nearest fish-cage commercial operation to the farming site was 7 km away and potentially may explain the more widespread distribution of a few individuals.

Interestingly, farmed escapees from this study occupied home range areas very similar to those reported for wild gilthead seabream from a coastal lagoon (Abecasis & Erzini 2008) and for other sparids (Jadot et al. 2006, Abecasis et al. 2009). The coastal ecosystem can be beneficial in terms of providing shelter from large predators (Serra-Llinares et al. 2013) and for food availability (Stagličić et al. 2011), especially in areas with larger structural habitat complexity such as fish farms. Attraction of a variety of marine fish species to farms due to waste fish feed has been well documented (Sanchez-Jerez et al. 2011, Šegvić-Bubić et al. 2011c, Bacher et al. 2015). Thus, in the present study, initial attachment to farm installations during the initial 2 wk can be considered a period for fish adaptation to new environmental conditions.

Stomach content analysis was not conducted here, but according to Arechavala-Lopez et al. (2012), the initial diet of gilthead seabream upon escape was primarily based on macrophytes and food pellets, though very shortly thereafter (after 1 wk), gilthead seabream demonstrated the ability to feed on their most common natural prey. As an opportunistic feeder, gilthead seabream can adapt its diet to the available food in the habitat (Tancioni et al. 2003), preferring bivalves, arthropods, and gastropods as primary prey items (Pita et al. 2002, Šegvić-Bubić et al. 2011a, Hadj Taieb et al. 2013). Increased daily detections observed in the study area indicated higher fish mobility, likely related to feeding activity. Such a daily pattern was also recorded for other sparids (Santos et al. 2002, Abecasis et al. 2013) and labroids (Villegas-Ríos et al. 2013). Only the receiver deployed at the release site showed no daily pattern, rather it showed a continuous use of habitat over the 24 h period, due likely to the positive correlation between the number of detections and fish swimming depth. Namely, during the day, fish were significantly more present in the surroundings of cages at 6 m depth in comparison to nighttime, thus detection efficiency was reduced due to the shadowing effect from the cage nets and high biomass of farmed gilthead seabream. Otterå & Skilbrei (2016) observed a similar pattern at 5 m depth at a salmon farm in southwestern Norway, indicating that the detection rate of acoustic tags may vary with depth and time. In addition, the receiver located at the release site was enclosed from both sides of the bay by receivers from the farm-impacted area, and thus the increased daily detections recorded in the farm-impacted area was accompanied by a slight reduction in the number of daily detections at the farm.

No information was available from local fishermen regarding the escapee recapture rate. However, according to the observed detection pattern, more than a third of the released fish were captured between 3 and 6 wk after escape simulation. The majority of recaptures occurred in the middle areas of the bay (receivers M9 and M10) when fish moved away from the farm and became more vulnerable to fisheries. Despite a very modest local fishing effort in the bay, where harvest is only permitted for recreational fisheries, a recapture rate of 40% played a significant role in escapee removal. Still, a meta-analysis of simulated escape studies revealed a mean recapture success of 8% for overall farmed species, which was negatively correlated with both fish size and the number of fish escaped (Dempster et al. in press). Such low recapture success is shaped by the high dispersal fish capacity after release and delayed recapture efforts after large-scale escape events that typically occur during storms. Still, these conclusions cannot be transposed to coastal environments due to a relative lack of information.

Natural mortality was not as evident in this study as in the case of farmed European seabass and gilthead seabream escapees from the western Mediterranean, where >50% of tagged fish did not survive the initial weeks due to predation by piscivorous wild fish near the farm (Arechavala-Lopez et al. 2011, 2012). The bluefish *Pomatomus saltatrix*, the most common predator at Mediterranean farms (Sanchez-Jerez et al. 2008), is rarely observed near the inshore farms of the eastern Adriatic (T. Šegvić-Bubić pers. obs.). Thus, it could be argued that mortality by predation could be an effective mechanism for reducing escapee survival, since the occurrence of large predators such as greater amberjack *Seriola dumerili* or bluefin tuna *Thunnus thynnus* in the Mediterranean is greatly driven by seasonal migrations and reproductive behaviour (Fernandez-Jover et al. 2008, Šegvić Bubić et al. 2011c, Arechavala-Lopez et al. 2015).

Management considerations

The study results suggest that the organized recapture of escaped gilthead seabream would be a logical management option to prevent the impact of escapees on the fitness of wild populations. For inshore farms located in coastal systems, fish recapture by recreational fishery within 2 wk of escape could be feasible and is highly recommendable. Gillnets or beach seine nets could be additionally employed in case of large-scale escape events, though recapture efforts should be monitored in order to avoid unwanted bycatch that could affect other fish species. Still, within the framework of the marine fisheries national legislation, there is a lack of an action plan for the prevention and management of escapes. Escape reporting is still not mandatory for farmers, though the legislation stipulates the right of the farmer to recapture fish within the farming concession following a request to do so. In practice, permissions for fish recapture are rarely requested. Thus, additional regulations are required to preserve national aquaculture sustainability, such as technical standards for sea-cage equipment coupled with an independent mechanism to enforce the standard, legal requirements for monitoring and reporting, and codes of practice for the recapture of escapees (Dempster et al. in press). Since escapees may pose an environmental risk via the genetic erosion of wild counterparts, spread of disease, and/or trophic ecology disruption, a polluter-pays principle should be implemented in the national legislation. As suggested by Dempster et al. (in press), compensatory mitigation via market-based instruments including ecotaxes could provide the possibility for target recapture interventions in the areas of greatest conservation concern, or for other means to protect wild populations.

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