Spatial and temporal patterns in *Serranus cabrilla* habitat use in the NW Mediterranean revealed by acoustic telemetry

Josep Alós[1],*, David March[1], Miquel Palmer[1], Amalia Grau[2], Beatriz Morales-Nin[1]

[1]**Instituto Mediterráneo de Estudios Avanzados, IMEDEA (CSIC-UIB), C/ Miquel Marqués 21, 07190 Esporles, Illes Balears, Spain**

[2]**Laboratori d'Investigacions Marines i Aqüicultura (LIMIA), C/ Eng. Gabriel Roca 69, 07157 Port d'Andratx, Illes Baleares, Spain**

ABSTRACT: We used acoustic telemetry to describe the spatial and temporal patterns of habitat use of one of the species most targeted by recreational anglers in the NW Mediterranean, *Serranus cabrilla* (Linnaeus, 1758). Temporal patterns and fish position were determined using a fixed-receiver array located in a marine protected area (MPA) in Palma Bay (Balearic Islands). Fish position as centre of activity (COA, the centre of the area the fish uses during a specific time) and space utilisation preferences could be described due to a receiver array design with a high range detection overlap (more densely distributed near the COA). There were significantly more detections per time unit during the day, which was interpreted as increased activity possibly related to feeding habits and social behaviour. *S. cabrilla* spent 95 % of its time in an average area of 0.77 ± 0.17 km^2, with a core area (50 % of the time) of 0.10 ± 0.29 km^2. The home range size was not related to fish size or diel pattern (i.e. the size of the daytime home range was not significantly different from the night range). The linearity index and the index of reuse (proxies of site fidelity) also demonstrated that this species has high site fidelity, which suggests that it is sedentary with a limited adult dispersal capacity. Two main habitats were observed in the study area, and *S. cabrilla* spent on average much less time in seagrass meadows (*Posidonia oceanica* beds) compared to soft, gravel and detritus bottoms. A relatively small MPA would be a useful management tool for establishing sustainable exploitation levels of this species.

KEY WORDS: Spatial-temporal patterns · Marine protected area · MPA · Recreational fishing · Simultaneous hermaphroditism · Acoustic telemetry · *Serranus cabrilla*

INTRODUCTION

The use of space is often not considered when population dynamics of exploited fish stocks are studied (Botsford et al. 2009). Although there has been some improvement (e.g. Pecl et al. 2006, Semmens et al. 2010), management decisions are traditionally made based on population-dynamics models that incorporate fishing effort and a number of biological traits, but assume fish populations to be spatially homogeneous (Botsford et al. 2009). This assumption is often unrealistic and can have significant practical implica-

tions. Migration behaviour and movements of large migratory fish (e.g. bluefin tuna; Block et al. 2005) are very different from those of small reef species with a very limited home range (e.g. anemone fish; Fauntin 1991). These 2 examples represent extreme cases of space utilisation, and show that adequate knowledge of the spatial and temporal patterns of habitat use and fish movement would logically lead to a better understanding of fish population dynamics (Botsford et al. 2009).

One of the most obvious potential applications of information on spatial and temporal patterns of fish

movement is in the design of marine protected areas (MPAs) (Botsford et al. 2003). The usefulness of MPAs is in relation to spillover and depends on the scale of fish movement in relation to the size of the MPA (Kramer & Chapman 1999, Sale et al. 2005). To improve protection, MPAs must be large enough to enclose the appropriate habitats containing the regular movements of adult fish (i.e. their home range). Spillover of early life stages (usually with good dispersal capability) into areas outside the MPA can only happen if there is a sustainable adult population within the reserve (Kaplan et al. 2006). However, the extent of adult spillover also depends on cross-boundary movements (Kramer & Chapman 1999, Bartholomew et al. 2008).

Spatial and temporal patterns of habitat use are also relevant for justifying the usefulness of some fish species as bio-indicators of anthropogenic impacts. Bio-indicator species should be sedentary in order to reflect local exposure to human impacts (Burger & Gochfeld 2001). Moreover, fish abundance and behaviour can vary greatly at different temporal scales. The most obvious variations are those related to spawning aggregations (e.g. Begg & Marteinsdottir 2002, Rowe & Hutchings 2003, Berkeley et al. 2004, Lowerre-Barbieri et al. 2008, Walters et al. 2009, Semmens et al. 2010). However, more subtle variations operate over short time scales of hours to days (i.e. feeding or sheltering), and these can also affect fish abundance estimates and vulnerability to fishing pressure (Naylor 2005, Willis et al. 2006).

Fish acoustic telemetry is an alternative method to conventional tag-and-recapture studies of movement, and allows for understanding spatial and temporal scales but increases the cost and hence reduces the sample size that can be realised (e.g. Voegeli et al. 2001, Parsons & Egli 2005). This technology can be used for example to (1) quantify home ranges within MPAs (e.g. Lowe et al. 2003, Parsons & Egli 2005), (2) determine site fidelity (e.g. Collins et al. 2007, Abecasis & Erzini 2008, Abecasis et al. 2009, Semmens et al. 2010) and (3) describe temporal patterns (e.g. diel activity) of marine fishes (e.g. Jadot et al. 2002, Jorgensen et al. 2006, March et al. 2010).

Determining the spatial and temporal patterns of habitat use is especially important when the species exploited is sedentary because fishing could lead to local depletion. This may be the case for the comber *Serranus cabrilla* (Osteichthyes, Serranidae). *S. cabrilla* is a simultaneous hermaphrodite that has a short lifespan and is associated with beds of the Mediterranean endemic macrophyte *Posidonia oceanica* and with sandy and muddy bottoms along the coasts of the eastern Atlantic Ocean and the Mediterranean Sea (Bauchot 1987). There are data available on age and

growth (Tserpes & Tsimenides 2001, Torcu-Koc et al. 2004), reproduction (Garcia-Diaz et al. 1997), feeding habits (Labropoulou & Eleftheriou 1997) and also some behavioural aspects (Santos et al. 2002). However, spatial and temporal patterns of movement have not been previously reported.

This species is considered as by-catch and a low-value species by commercial fisheries in most regions of the NW Mediterranean. However, this species is one of those most frequently targeted by recreational fishing in this area (Morales-Nin et al. 2005, Lloret et al. 2008, Gordoa 2009). No specific management plan for *Serranus cabrilla* has ever been developed, probably due to its limited commercial interest. Additionally, this species has been shown to be vulnerable to the impact of recreational angling in terms of abundance and size (Ordines et al. 2005) and is considered to be an indicator of angling pressure (Harmelin 1987). The main purpose of the present study was to describe the spatial and temporal patterns of *S. cabrilla* movement using an omnidirectional receiver array. Specifically we described (1) temporal patterns and diel behaviour, (2) site fidelity, (3) home range area, and (4) habitat preferences in order to provide new biological information to facilitate future implementation of management plans to promote sustainable development of this fishery.

MATERIALS AND METHODS

Study site. The study was carried out in an MPA located in Palma Bay in the southern part of Mallorca Island (NW Mediterranean; Fig. 1) between May and October 2008. The Palma Bay MPA extends from the coastline to the 30 m isobath. Fishing activities have been regulated since 1982, albeit not enforced until the late 1990s (http://dgpesca.caib.es). There are 2 areas with different levels of protection: (1) the sanctuary area (~2 km^2), where only no-take activities are allowed, and (2) a buffer area where both artisanal and recreational fishing are regulated (Fig. 1). In the buffer area, temporal closures for some areas, minimum size and numbers of gears, bag and size limits and other management regulations are stipulated. A recent benthic cartography has been developed by the local government (Direcció General de Biodiversitat, Balearic Government) under the *Posidonia*-LIFE project framework, where 6 different habitat types were identified within the MPA boundaries (http://lifeposidonia. caib.es). The different habitat types in the area are: seagrass meadows (SM) dominated by the species *Posidonia oceanica*, photophyla algae (AL), sandy (FS) and gravel (GS) soft bottoms, a mixture of gravel and detritus (GD), and a mixture of algae and seagrasses
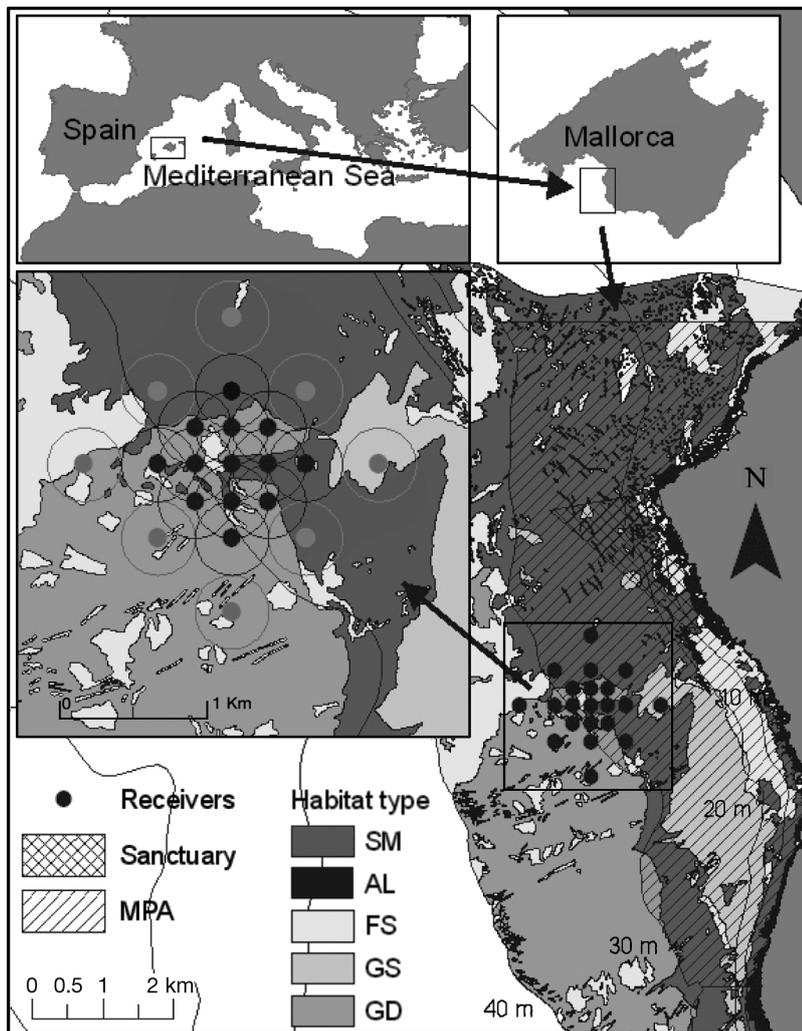
Fig. 1. Study site located in the marine protected area (MPA) of Palma Bay, Mallorca Island. Locations of the 2 fixed receiver arrays (●: central area in which receivers were more densely located; ●: peripheral area) and their buffer (~250 m) areas are shown. SM: seagrass meadow; AL: algae; FS: fine sand; GS: gravel sand; GD: gravel and detritus

(AS) (Fig. 1). The area also includes a number of small artificial reefs (~1 m^3) that were randomly placed in 1989.

Experimental design. A fixed array of omnidirectional acoustic receivers (Sonotronics© SUR-1) was deployed to monitor the spatial and temporal movements of *Serranus cabrilla* in the south of the MPA (Fig. 1). The array was designed so that there was (1) a central area in which receivers were more densely located, and (2) a peripheral area. In the central area of the receiver array, 13 receivers were deployed at a distance of 250 m from each other (Fig. 1). This design allowed the detection range of each receiver to overlap with others, improving the accuracy of fish position estimates (Fig. 1). In the peripheral area, 8 more

receivers were deployed, forming a 2 × 2 km diamond surrounding the central array (Fig. 1). Thus, a total of 21 receivers were deployed, covering an area of approximately 2 km^2 plus the detection range (~250 m) of the receivers located in the peripheral area (Fig. 1). Each receiver was oriented upwards at 1 to 2 m from the bottom to optimise detection and avoid thermocline effects (March et al. 2010). After the tagging experiment and the expected battery life of the acoustic tags had expired, we retrieved the receivers and downloaded the data.

Sampling and tagging method. A total of 15 *Serranus cabrilla* individuals were acoustically tagged and released in the study site between the end of July and the beginning of September 2008 (Fig. 1, Table 1). During that period, most individuals tagged were in the post-spawning stage (Garcia-Diaz et al. 1997). Most individuals (n = 13) were tagged using acoustic Pico-tags PT-3 (Sonotronics©). These electronic tags measured 19 mm in length and 7.8 mm in diameter, weighed 1 g in water and had an expected lifespan of 21 d when used continuously. However, they were customised to run intermittently to yield an active period of 12 h d^{-1}; thus, the lifespan was increased to approximately 35 d. In addition, one individual was tagged with the smallest version of Pico-tag (Sonotronics© PT-1; size: 16 × 7.1 mm; weight in water: 0.6 g; expected lifespan: 7 d) and another one with another type of acoustic tag (Sonotronics© IBT-96-1; size: 25 × 8 mm; weight in water: 1.5 g; expected lifespan: 21 d) (Table 1). These 2 additional acoustic tags were not customised.

The combination of a specific sequence of pulses at a specific frequency allowed fish to be identified (Table 1). Each time an omnidirectional acoustic receiver detected a signal (i.e. a specific pulse period range), it was recorded as a single detection, which was labelled with a detection number, date (mm/dd/yy), hour (hh:mm:ss), frequency (kHz) and interval period (ms). A tolerance interval of 5 ms was selected to remove false detections. Single detections made by a single transmitter over a period of 24 h were considered as spurious detections and also removed, following the decision criteria adopted by March et al. (2010).

Table 1. *Serranus cabrilla*. Characteristics of the tagged fish and the tags. TL: total length; TP$_i$: period between release date and last detection; DD$_i$: total number of days detected; RI$_i$: residence index

Fish code	TL (mm)	Weight (g)	Tag model	Tag frequency (kHz)	Tag interval (ms)	Release date (dd/mm/yy)	Total no. of detections	No. of receivers	TP$_i$ (d)	DD$_i$ (d)	RI$_i$
1	151	53.4	PT-3	69	870	18/07/08	2211	10	61	55	0.90
2	155	58.1	PT-3	70	860	08/09/08	9	1	2	2	1.00
4	154	57.3	PT-3	72	880	18/07/08	1850	7	25	25	1.00
5	164	57.4	PT-3	73	910	18/07/08	1885	6	24	24	1.00
6	140	49.2	PT-3	74	900	18/07/08	1650	7	16	16	1.00
7	141	54.3	PT-3	75	930	08/09/08	178	5	20	9	0.45
8	122	37.6	PT-1	76	920	09/07/08	808	7	4	4	1.00
9	154	57.6	PT-3	77	950	08/09/08	195	5	20	9	0.45
10	168	61.3	PT-3	78	940	21/08/08	270	7	4	4	1.00
17	154	57.9	PT-3	70	1040	18/07/08	775	8	11	11	1.00
19	174	67.8	PT-3	72	1060	21/08/08	21	4	18	4	0.22
20	168	60.7	PT-3	73	1070	21/08/08	218	4	38	20	0.53
21	166	60.7	PT-3	74	1080	21/08/08	84	7	27	16	0.59
80	163	60.4	PT-3	76	920	18/07/08	1150	4	12	12	1.00
220	152	56.3	IBT-96-1	78	1020	18/07/08	7139	8	39	39	1.00

Transmitters were activated a few minutes before being implanted in each individual.

All individuals were initially caught inside the fixed array by anglers. Large-sized hooks (size 4) and pieces of shrimp (*Penaeus vannamei*) were used as bait to reduce the incidence of deep-hooking (see details in Alós et al. 2008, 2009). Deep-hooking is one of the most important causes of post-release mortality in the genus *Serranus* (Alós 2008). *Serranus* species are prone to suffering barotraumas, which increases the mortality rate (Alós 2008). The effects of barotraumas were mitigated by using a 21-gauge hypodermic needle (length: 1.5 inches or 38 mm) to extract the excess gas from the swim bladder, formed during rapid decompression (Alós 2008). Deep-hooked fish and fish with bleeding injuries or severe barotraumas (e.g. exophthalmia) were not tagged and released.

After capture, fish were measured (to the nearest mm), weighed (to the nearest mg), tagged with a conventional (external) T-bar (Floy Tags$^©$) and placed into an 80 l onboard aerated fish-holding tank. Fish were anaesthetised by immersion in 10 l filtered and sterile seawater with 100 mg l^{-1} of tricaine methanesulphonate (MS222). Each acoustic tag was surgically implanted into the peritoneal cavity, maximising sterile conditions. Acoustic tags never exceeded 1.5 to 2% of the fish's body weight. Different kinds of sutures (absorbable [Vicryl Rapide 5-0, Ethicon$^®$] as well as non-absorbable [Mersilk 4-0, Ethicon$^®$]) and Dermabond, a topical skin adhesive (2-octyl cyanoacrilate, Ethicon$^®$), were first tested on dummy-tagged fish (n = 6) in a laboratory experiment to test the behaviour of the fish and the cicatrisation of the incision. The results revealed normal behaviour 10 min after surgery and

full cicatrisation in 2 wk using non-absorbable sutures (A. Grau & J. Alós unpubl. data). The entire surgical process took <5 min. After the tag was implanted, the fish was released into another aerated onboard tank to recover until normal behaviour was observed (approx. 10 to 15 min). Then fish were released at their capture sites within the fixed array of receivers following the protocol suggested by Jepsen et al. (2002). The GPS position, depth, day and hour of release were recorded for each tagged fish.

Data analysis. *Temporal patterns:* The number of days detected (DD$_i$) and the period between the release date and the last detection date (tracking period, TP$_i$) of a specific tagged Fish i were used to calculate a residence index (RI$_i$), defined as the quotient between DD$_i$ and TP$_i$ (Abecasis & Erzini 2008, Abecasis et al. 2009, Semmens et al. 2010). Unlike Abecasis & Erzini (2008), we estimated RI$_i$ for each fish rather than for each receiver (March et al. 2010), and used this to determine the number of days that the fish was present in the fixed array (Collins et al. 2007).

Temporal sequences of detections were plotted as the number of detections per hour for each individual. Then we used continuous wavelet transform (CWT) to identified periodicity patterns in these time series. CWT is considered to be a useful tool for decomposing a time series into time-frequency space (Percival & Walden 2000) and has been applied previously in acoustic tagging experiments (Subbey et al. 2008, March et al. 2010). The Morlet wavelet with the *sowas* package in R (version 2.11.0, R Foundation; www.r-project.org) was used to compute the 2-dimensional wavelet spectrum and calculate a point-wise test at a

95% significance level (Maraun et al. 2007). Wavelet coefficient values were normalised such that the highest spectral power equalled 1 (March et al. 2010).

Finally, we investigated diel patterns for each individual by pooling hourly detection data (i.e. number of detections per hour) into daily phases (day- vs. nighttime) and then comparing mean detections in each phase. Data from the US Naval Observatory (Astronomical Applications Department; http://aa.usno. navy.mil) was used to define each phase using sunrise and sunset to determine the day and night periods. Non-normal distribution of the data was detected and was not possible to transform adequately. Therefore we used a non-parametric Mann-Whitney U-test to test individually the hypothesis that the mean of number of detections was different between diel phases.

Spatial patterns: The Nadaraya-Watson kernel estimator (*sm* package in R; Bowman & Azzalini 1997) was used to calculate position estimates, or 'centre of activity' locations (COA$_{ij}$), for tracked fish i for every 60 min period j (see March et al. 2010. Thus, the estimation of the XY$_{ij}$ position for Fish i at Time j was based on the positions of the receivers that detected the fish during the Period j and weighted by the number of detections.

Two different methods were used to estimate the home range over the total period for each fish i: (1) minimum convex polygons based on 100% of the positions (MCP$_i$ 100); and (2) bivariate fixed-kernel utilisation distributions (95% and 50% KUD$_i$). MCP$_i$ 100 provided information on the extent of an animal's home range over a given period, while KUD provided information on the use of space within a range including the core area (50% KUD$_i$) and the home range (95% KUD$_i$). These home-range estimations based on the COAs estimated for each fish were calculated over a grid with a 50×50 m resolution using the *adehabitat* package in R (Calenge 2006). We selected a kernel bandwidth of 250 m, which corresponded to the detection range of the acoustic tags used (see March et al. 2010). Pearson's correlation coefficient was used to determine whether the home range size was correlated either to fish size or the duration of TP$_i$.

Changes in home range over time based on 95% KUD$_i$ were also investigated. The cumulative 95% KUD$_i$ was expected to increase over time and to eventually arrive at an asymptotic value when a fish had explored most of its true home range (March et al. 2010). Thus, temporal changes in daily cumulative home range size were visually examined using home range curves. It was assumed that asymptotic 95% KUD was reached when the difference in percentage between 2 consecutive days of the accumulated 95% KUD was <5% (Rechisky & Wetherbee 2003). For each Fish i, the change in percentage for each tracked day

was calculated as: % change = $([A_{in} - A_{in-1}]/A_{in}) \times 100$, where A_{in} is the 95% KUD area on Day n for Fish i, and A_{in-1} is the 95% KUD area on the previous day. Changes in the home range related to diel period were also investigated. Therefore, day and night KUD$_i$s were estimated on a daily basis for each fish. Non-normal distribution of the data was detected, and a non-parametric Mann-Whitney U-test was used to test individually the hypothesis that the mean size of the home range (50% and 95% KUD$_i$) was different between diel phases.

The linearity index (LI$_i$) and the index of reuse (IOR$_i$; Rechisky & Wetherbee 2003) were used as estimates of site fidelity and the direction of movements (random vs. directional movement; Danielson & Swihart 1987). LI$_i$ was calculated for each fish according to the formula LI$_i$ = $(F_n - F_1)_i / D_i$, where $F_n - F_1$ is the distance between the first and last COA$_i$ for Fish i, and D_i is the total distance travelled by that fish during the whole of TP$_i$. Fish with nomadic behaviour showing directed movement are expected to have LI$_i$ values close to 1, while fish with high site fidelity and random movements at sites should have an LI$_i$ value approaching 0 (Danielson & Swihart 1987). IOR was estimated as IOR$_{in}$ = $[OV(A_n, A_{n+1})_i]/[UN(A_n, A_{n+1})_i]$, where $OV(A_n, A_{n+1})_i$ is the area of overlap between 2 activity spaces (i.e. daily 50% or 95% KUD areas for Day n and Day $n + 1$), and $UN(A_n, A_{n+1})_i$ is the area of union between the 2 activity spaces during n days of the tracking period (TP$_i$) for Fish i. Values close to 1 for IOR$_i$ denote high overlap of the activity spaces showing high site fidelity and discrete values of home range, while values close to 0 indicate non-overlap of activity space and nomadic spatial behaviour.

Finally, due to the heterogeneity of the bottom type in the study area, habitat use was investigated to determine the habitat preferences of *Serranus cabrilla*. However, considering the error of the COA$_i$ estimations, we decided to only consider 2 main habitats: SM and soft and detritus bottoms (SDB). The habitat selection index (HSI$_i$) was used to estimate preference or avoidance of the available habitat type within the home range (Topping et al. 2005). HSI$_i$ was estimated as the quotient between habitat utilisation, defined as the percentage of estimated positions (COA$_i$) in a specific habitat for Fish i, and the habitat availability, as a percentage of each bottom type in the estimated MCP$_i$ 100 during the tracking period for each fish (Topping et al. 2005). Thus, preference or avoidance was estimated according to the degree of deviation in a positive or negative direction from a value of 1 (Topping et al. 2005). HSI$_i$ was also estimated for each habitat during the day and night for each tagged fish (i.e. HSI$_i$ values were estimated for each fish).
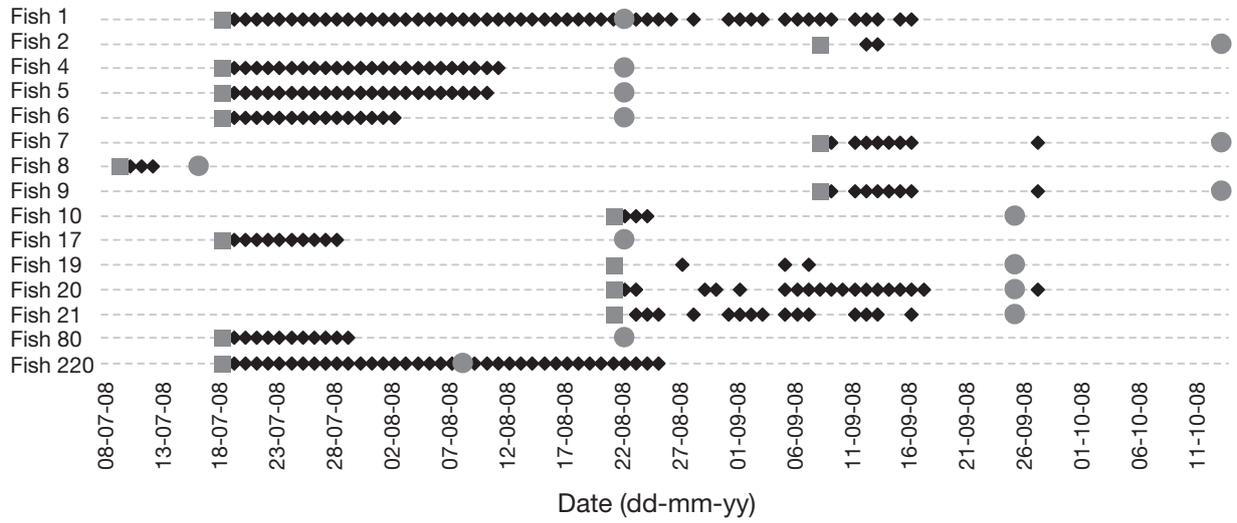
Fig. 2. *Serranus cabrilla*. Daily absence-presence plots of tagged fish within the monitored area between the first release date and the last expected transmission date. Days on which detections were made (◆), transmitter deployment dates (■) and expected transmitter death dates (●) are shown
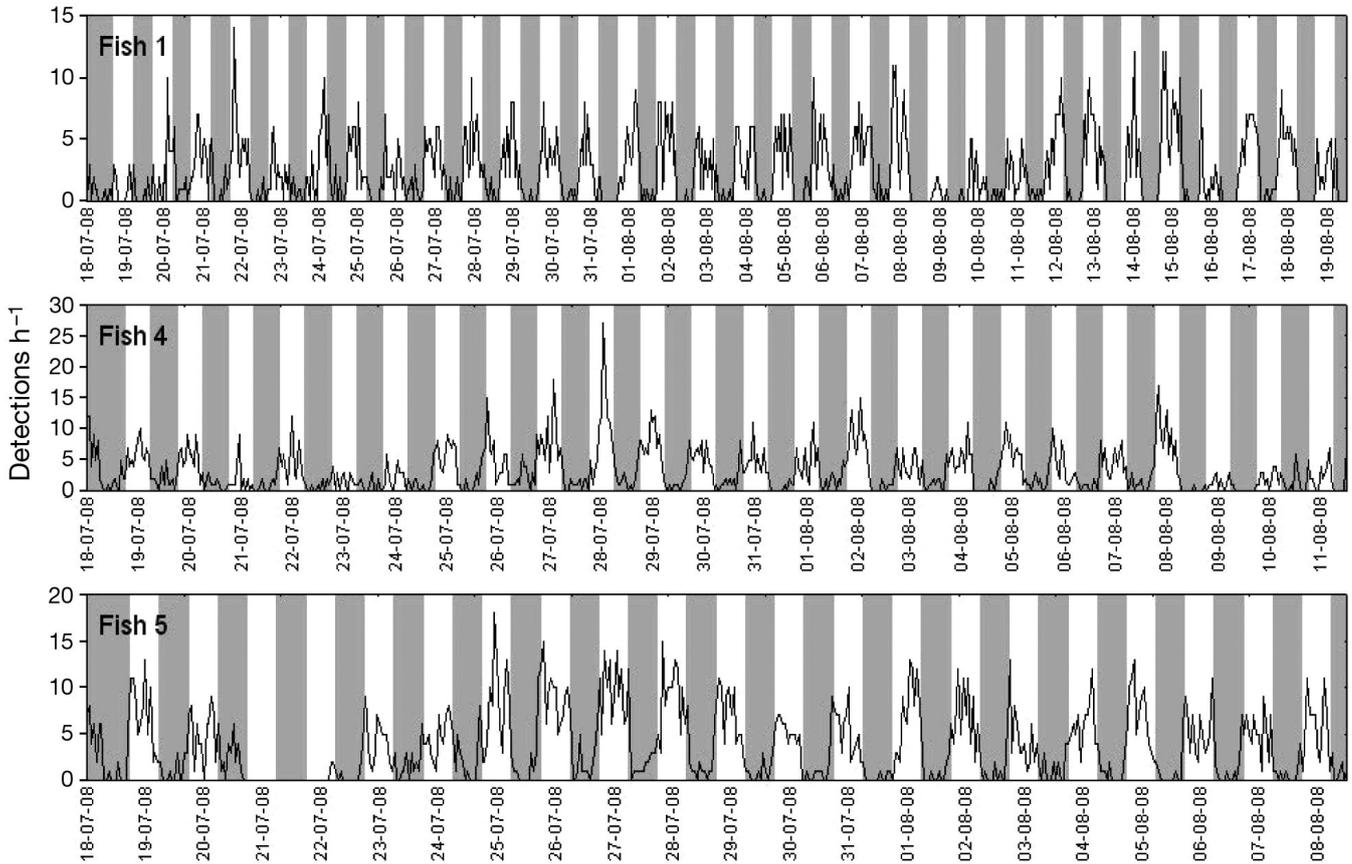

Fig. 3. *Serranus cabrilla*. Time series of the number of detections per hour per day of Fishes 1 (upper panel), 4 (middle panel) and 5 (lower panel). Vertical stripes represent day (white) and night (grey). Note the periodicity of the detection patterns related to day and night, with a higher number of detections during the day

RESULTS

The characteristics of the *Serranus cabrilla* individuals tagged and of the acoustic tags are summarised in Table 1. A total of 18 443 detections were downloaded from the array of receivers with a minimum of 9 detections (Fish 2) and a maximum of 7139 (Fish 220), and an average (±SD) of 1230 ± 1806 detections (Table 1). The number of receivers that detected a certain tagged fish varied from 1 (Fish 2) to a maximum of 10 (Fish 1), with an average of 6 ± 2.2 receivers (Table 1).

Three individuals (Fishes 2, 8 and 10) were monitored on <10 d and thus were not considered in our analysis of temporal and spatial patterns due the limited monitored period (i.e. sample size) (Table 1). For the other fish, TP_i varied from 11 d (Fish 17) to 61 d (Fish 1), with an average of 25.9 ± 14.2 d (Table 1). DD_i varied from 2 d (Fish 2) to 55 d (Fish 1), with an average of 16.7 ± 14.6 d (Table 1). RI_i ranged from 0.22 to 1, with an average of 0.79 ± 0.27. However, for more than half of the fish (n = 8), RI_i was 1, indicating that these

fish were in the monitored area on a daily basis. Most (80%) of the total tagged fish showed an RI_i value >0.5 (Table 1). Fig. 2 shows a time series of the daily absence-presence of tagged *Serranus cabrilla* in the monitored area.

Temporal patterns

Visual inspection of the hourly detections showed a clear temporal pattern characterised by a higher number of detections during the day than during the night (Fig. 3). The 24 h periodicity of these temporal patterns was also clearly observed by fitting CWT decomposition to the time series into time-frequency space. Fig. 4 shows the wavelet spectrograms of 8 individuals for which significant patches were observed in the 24 h scale, indicating a daily periodicity in the detections. These 24 h periodicities extended over several days for Fishes 1, 4, 5, 17, 80 and 220 (Fig. 4). In other cases, the periodicities were not as clear, but significant patches
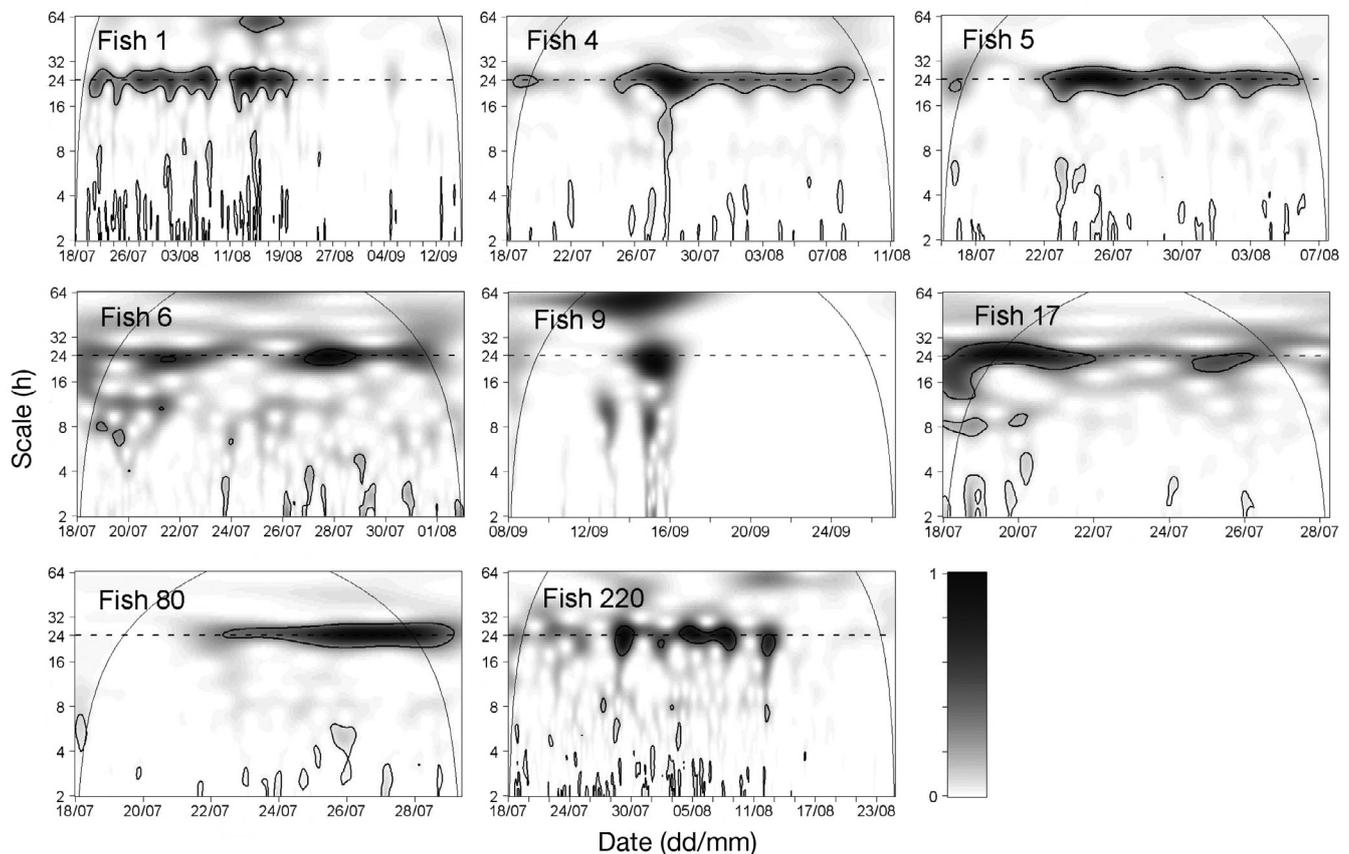

Fig. 4. *Serranus cabrilla*. Wavelet sample spectrums using a Morlet wavelet for 8 tagged fish (Fishes 1, 4, 5, 6, 9, 17, 80 and 220). Periodicities were detected in all cases on a 24 h scale (horizontal dashed line). Continuous thin lines represent the cone of influence (COI). Values outside the COI should not be interpreted due to edge effects. Thick contours represent the 95% confidence level and scale bar represents the intensity of the time-frequency space over time

for short periods were also observed in Fishes 6 and 9 (Fig. 4). All individuals showed a mean detection per hour that was significantly higher during the day compared to the night (Mann-Whitney U-test; Table 2). Differences between means were greater when the number of detections was larger (Table 2).

Table 2. *Serranus cabrilla*. Total and mean number of hourly detections in the day- and night-time obtained for each fish tagged. For all fish tagged, the mean difference between diel phases was significant (Mann Whitney U-test: $p < 0.001$)

Fish code	Diel phase	No. of detections	
		Total	Mean ± SD
1	Day	1893	2.44 ± 2.61
	Night	318	0.47 ± 1.12
4	Day	1564	4.55 ± 3.72
	Night	286	1.17 ± 1.54
5	Day	1620	4.91 ± 3.89
	Night	265	1.13 ± 1.76
6	Day	1163	5.33 ± 3.56
	Night	487	3.16 ± 2.7
7	Day	136	1.03 ± 1.93
	Night	42	0.33 ± 0.96
9	Day	153	1.22 ± 2.3
	Night	42	0.33 ± 0.93
17	Day	662	4.47 ± 3.77
	Night	113	1.09 ± 2.24
19	Day	18	0.08 ± 0.36
	Night	3	0.01 ± 0.15
20	Day	188	0.55 ± 1.16
	Night	30	0.09 ± 0.4
21	Day	76	0.22 ± 0.74
	Night	8	0.02 ± 0.15
80	Day	905	5.59 ± 3.99
	Night	245	2.15 ± 2.69
220	Day	4808	9.37 ± 6.11
	Night	2331	5.67 ± 4.58

Spatial patterns

The number of COA$_i$ locations varied from 29 (Fish 19) to 952 (Fish 1), with an average of 331.4 ± 294.3 COAs. MCP$_i$ 100 varied from 0.035 km^2 (Fish 220) to 0.438 km^2 (Fish 21) and had an average of 0.21 ± 0.12 km^2. Pearson's correlation index showed that MCP$_i$ 100 values were not correlated with TP$_i$ ($p = 0.70$) or fish size ($p = 0.84$).

Home range derived from 95% KUD$_i$s varied from 0.44 to 1.2 km^2, with an average of 0.77 ± 0.17 km^2 (Table 3). In the case of 50% KUD$_i$s (core area), areas ranged from 0.10 to 0.29 km^2, with an average of 0.18 ± 0.05 km^2 (Table 3). Estimated KUD$_i$s did not show a significant relationship with either TP$_i$ (95% KUD$_i$s: $p = 0.123$; 50% KUD$_i$s: $p = 0.121$) or fish size (95% KUD$_i$s: $p = 0.504$; 50% KUD$_i$s: $p = 0.935$). Fig. 5 shows the estimated MCP$_i$ 100, 95% KUD$_i$s and 50% KUD$_i$s for Fishes 1, 6, 7, 9, 20 and 220.

The plots of changes in the daily cumulative values of 95% KUD$_i$ for visual inspections of the temporal patterns of space utilisation are shown in Fig. 6. Based on the 95% KUD$_i$ values, we can see that most fish (n = 9) stabilised their home range during the tracking period (Fig. 6). The tracking days when the cumulative home range reached a constant value (i.e. percentage of daily change $<5\%$) are shown in Table 3. Fish 20 showed a step on tracking Day 22, but then the cumulative percentage remained constant (Fig. 6). However, Fishes 17, 19 and 80 increased their home ranges without reaching an asymptote (Fig. 6). In these cases, the daily cumulative area was characterised by a number of steps at different times. Fish 17 showed a large step on tracking Day 6, Fish 19 showed one on Day 7, and Fish 80 on Day 10 (Fig. 6).

Table 3. *Serranus cabrilla*. Asymptote (i.e. day on which the accumulated home range changed $<5\%$), minimum convex polygons based on 100% of the positions (MCP$_i$ 100) and bivariate normal fixed-kernel utilisation distributions (50% and 95% KUD$_i$) estimated for each fish. The p-value shown corresponds to the significance of the Mann-Whitney U test carried out to compare means in diel patterns and mean home ranges. nd: home range did not reach an asymptote; ns: not significant

| Fish code	Asymptote (d)	MCP$_i$ 100 (km^2)	50% KUD$_i$ (km^2)				95% KUD$_i$ (km^2)			
			Total	Day (mean ± SD)	Night (mean ± SD)	p	Total	Day (mean ± SD)	Night (mean ± SD)	p
1	2	0.375	0.13	0.12 ± 0.04	0.12 ± 0.03	ns	0.66	0.52 ± 0.13	0.51 ± 0.10	ns
4	3	0.237	0.18	0.13 ± 0.02	0.16 ± 0.04	<0.001	0.78	0.54 ± 0.06	0.68 ± 0.14	<0.001
5	9	0.188	0.15	0.11 ± 0.01	0.16 ± 0.04	<0.001	0.74	0.51 ± 0.07	0.65 ± 0.14	<0.001
6	7	0.206	0.22	0.11 ± 0.02	0.12 ± 0.04	ns	0.83	0.49 ± 0.09	0.52 ± 0.14	ns
7	3	0.188	0.14	0.13 ± 0.03	0.12 ± 0.02	ns	0.69	0.54 ± 0.08	0.51 ± 0.09	ns
9	8	0.188	0.15	0.12 ± 0.02	0.12 ± 0.03	ns	0.75	0.50 ± 0.06	0.50 ± 0.10	ns
17	nd	0.396	0.14	0.11 ± 0.01	0.15 ± 0.05	<0.05	0.81	0.48 ± 0.05	0.60 ± 0.16	ns
19	nd	0.125	0.21	0.11 ± 0.01	0.10 ± 0.00	ns	0.85	0.45 ± 0.06	0.44 ± 0.02	ns
20	23	0.062	0.15	0.10 ± 0.01	0.10 ± 0.00	ns	0.62	0.44 ± 0.04	0.43 ± 0.02	ns
21	9	0.438	0.29	0.11 ± 0.03	0.10 ± 0.00	ns	1.20	0.47 ± 0.09	0.42 ± 0.00	ns
80	nd	0.063	0.18	0.10 ± 0.00	0.11 ± 0.03	ns	0.77	0.43 ± 0.01	0.46 ± 0.09	ns
220	2	0.035	0.10	0.11 ± 0.01	0.09 ± 0.01	<0.001	0.44	0.44 ± 0.01	0.43 ± 0.01	<0.001
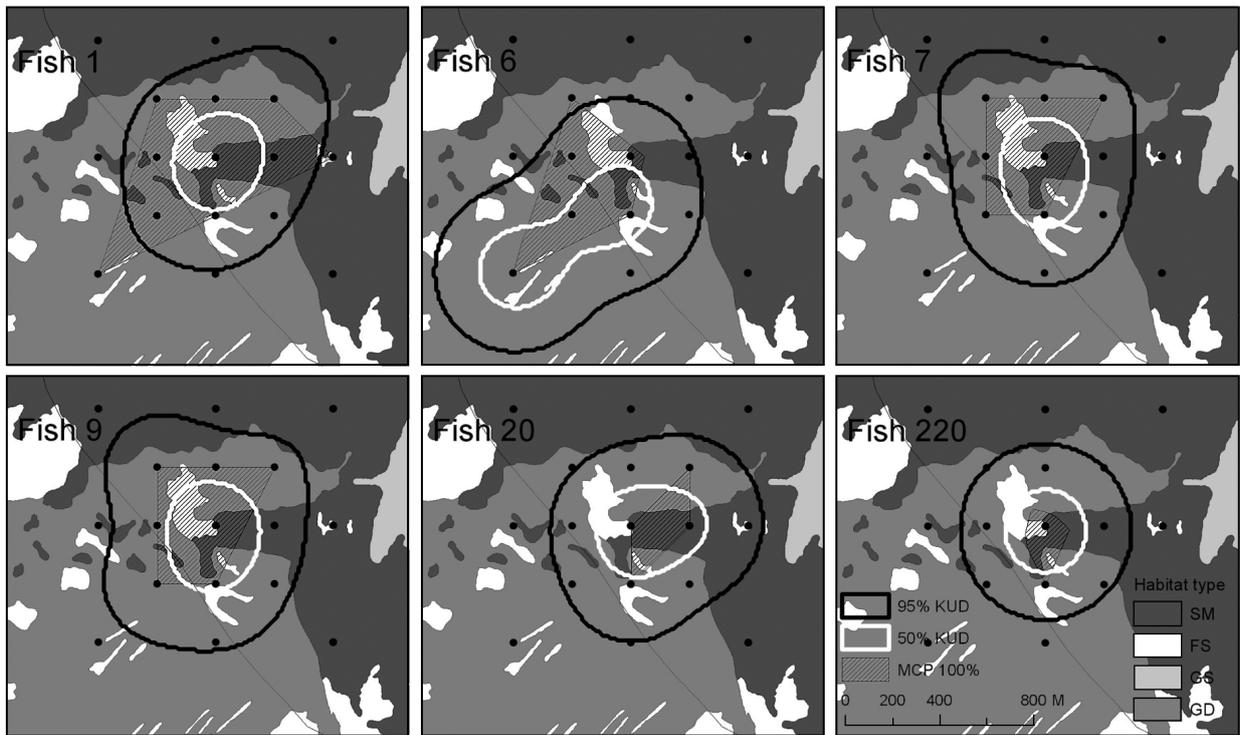
Fig. 5. *Serranus cabrilla*. Plots of space utilisation estimated for 6 tagged fish (Fishes 1, 6, 7, 9, 20 and 220). The graphical representation shows the minimum convex polygons based on 100% of the positions (MCP$_i$ 100) and the bivariate fixed-kernel utilisation distributions (50% and 95% KUD$_i$) estimated according to the information from the receiver array (●: fixed receivers). SM: seagrass meadow; FS: fine sand; GS: gravel sand; GD: gravel and detritus
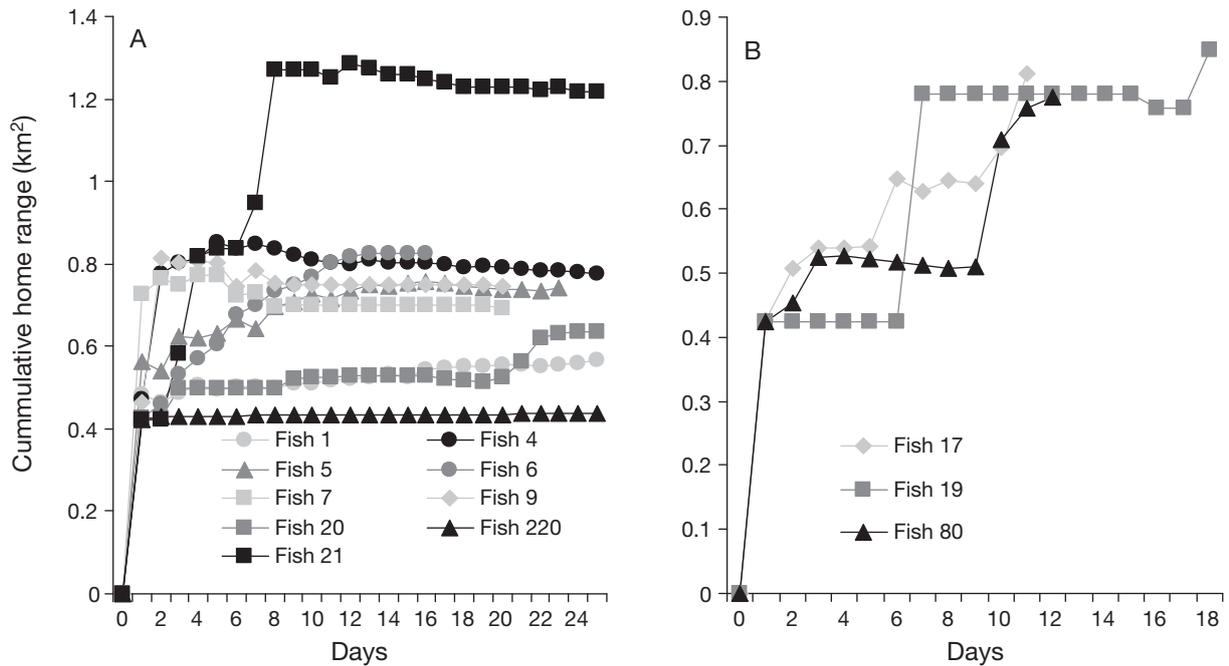

Fig. 6. *Serranus cabrilla*. Daily cumulative home range estimates (based on the bivariate fixed-kernel utilisation distribution for the home range [95% KUD$_i$]) for tagged fish. Individuals whose home range (A) eventually reached an asymptote, indicating that the activity space increased little with additional tracking time (the time series was limited to 25 d to improve visualisation), and (B) did not reach an asymptote

Most fish did not show significant differences in the mean daily home range estimated for day and night (Table 3). Fishes 4, 5 and 220 had significantly higher mean home range sizes during the night compared to

Table 4. *Serranus cabrilla*. Total time and total distance tracked for each tagged fish, as well as individual values of the linearity index (LI$_i$) and mean values of the index of reuse (IOR$_i$) based on the bivariate normal fixed-kernel utilisation distributions (50% and 95% KUD$_i$)

Fish code	Time$_i$ (h)	Distance$_i$ (m)	LI$_i$	IOR$_{50i}$ (mean ± SD)	IOR$_{95i}$ (mean ± SD)
1	1442	73189.51	0.001	0.53 ± 0.27	0.67 ± 0.21
4	581	67823.61	0.01	0.27 ± 0.23	0.60 ± 0.15
5	540	46475.74	0.01	0.44 ± 0.26	0.61 ± 0.15
6	361	25727.48	0.03	0.60 ± 0.26	0.75 ± 0.19
7	463	7310.83	0.04	0.48 ± 0.32	0.69 ± 0.22
9	460	5473.17	0.05	0.46 ± 0.34	0.66 ± 0.23
17	246	17515.72	0.03	0.47 ± 0.24	0.63 ± 0.17
19	411	1867.59	0.25	0.31 ± 0.44	0.51 ± 0.37
20	894	4685.48	0.01	0.65 ± 0.38	0.78 ± 0.23
21	1251	10421.82	0.03	0.23 ± 0.33	0.36 ± 0.33
80	273	5625.03	0.13	0.77 ± 0.23	0.87 ± 0.15
220	908	20775.49	0.001	0.82 ± 0.11	0.91 ± 0.06

Table 5. *Serranus cabrilla*. Percentage of available habitats (based on the minimum convex polygons that are based on 100% of the positions [MCP$_i$ 100]), percentages of estimated centres of activity (COA$_i$s) related to diel phase per habitat, and habitat selection index (HSI$_i$) related to diel phase for each tagged fish. SM: seagrass meadow; SDB: soft and detritus bottoms

Fish code	Habitat	Habitat area (%)	COA$_i$ (%) Day	COA$_i$ (%) Night	HSI$_i$ Day	HSI$_i$ Night
1	SDB	74.36	70.67	93.14	0.95	1.25
	SM	25.64	29.33	6.86	1.14	0.27
4	SDB	86.70	97.35	99.03	1.12	1.14
	SM	13.30	2.65	0.97	0.20	0.07
5	SDB	87.89	80.82	92.97	0.92	1.06
	SM	12.11	19.18	7.03	1.58	0.58
6	SDB	86.12	89.42	97.87	1.04	1.14
	SM	13.88	10.58	2.13	0.76	0.15
7	SDB	81.59	95.71	91.67	1.17	1.12
	SM	18.41	4.29	8.33	0.23	0.45
9	SDB	81.59	94.03	96.30	1.15	1.18
	SM	18.41	5.97	3.70	0.32	0.20
17	SDB	86.93	70.92	90.28	0.82	1.04
	SM	13.07	29.08	9.72	2.22	0.74
19	SDB	87.15	100.00	100.00	1.15	1.15
	SM	12.85	0.00	0.00	0.00	0.00
20	SDB	45.96	59.30	91.43	1.29	1.99
	SM	54.04	40.70	8.57	0.75	0.16
21	SDB	90.34	98.91	100.00	1.09	1.11
	SM	9.66	1.09	0.00	0.11	0.00
80	SDB	81.81	99.38	98.17	1.21	1.20
	SM	18.19	0.62	1.83	0.03	0.10
220	SDB	44.27	70.78	92.95	1.60	2.10
	SM	55.73	29.22	7.05	0.52	0.13

during the day, both in 50% KUD and 95% KUD (Table 3). Fish 17 also had significant higher mean home range sizes during the night compared to during the day (Table 3). However, the home range of this individual did not reach an asymptote (Fig. 6).

LI$_i$ and IOR$_i$ for all tagged fish are summarised in Table 4. The first index varied less and ranged from 0.001 (Fishes 1 and 220) to 0.25 (Fish 19), with an average of 0.05 ± 0.07 (Table 4). The highest values (0.25 and 0.13; Table 5) correspond to Fishes 19 and 80 respectively, which did not reach an asymptotic value for the cumulative home range (Fig. 6). The mean of IOR$_i$ estimated on a daily basis varied from 0.23 ± 0.33 (Fish 21) to 0.82 ± 0.11 (Fish 220) for the estimations based on 50% KUD, while values based on 95% KUD varied from 0.36 ± 0.33 (Fish 21) to 0.91 ± 0.06 (Fish 220) (Table 4).

Habitat use within the area defined by MCP$_i$ 100 varied between fish (Table 5). The 2 habitat categories SM and SDB were observed to have an average availability of 22.1 ± 15.9% and 77.9 ± 15.9%, respectively (Table 5). Both during the day and at night, the percentage of COA$_i$s that were on SDB habitat was higher than the percentage in SM habitat (Table 5, Fig. 7). Table 5 shows that day and night HSI$_i$ values varied among fish. The higher values correspond to SDB both during the day (1.13 ± 0.2) and at night (1.29 ± 0.36) (Table 5). The lower values, both during the day (0.66 ± 0.69) and at night (0.24 ± 0.0.23), were observed in SM (Table 5). Fig. 7 shows the mean and SD of the percentages of COA$_i$s and HSI$_i$ related to habitat type.

DISCUSSION

The usefulness of omnidirectional receiver arrays for monitoring fish behaviour has been extensively described (Heupel et al. 2006). In the present study, the combination of a receiver array and miniaturised acoustic tags provided new information on the spatial and temporal behaviour of *Serranus cabrilla*, one of the most important recreational target species in the NW Mediterranean Sea. A diel pattern has been clearly demonstrated in *S. cabrilla*. Santos et al. (2002) found that this species and another 2 similarly sized species from the same genus, *S. scriba* and *S. hepatus*, were more frequently observed in a visual census during the day than at night. A previ-
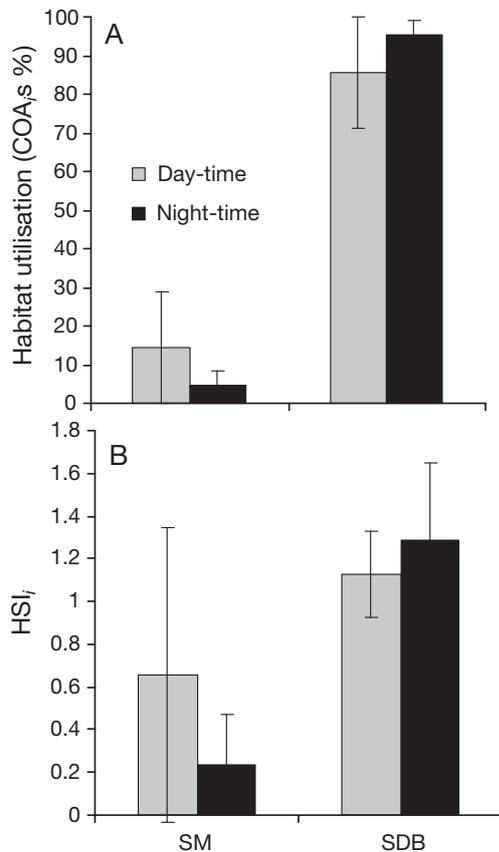
Fig. 7. *Serranus cabrilla*. (A) Mean percentage of centres of activity (COA$_i$s) and (B) mean values for habitat selection index (HSI$_i$) related to habitat type and diel phase. SM: seagrass meadow; SDB: soft and detritus bottoms. Error bars represent SD

ous study using passive telemetry showed diel patterns for *S. scriba*, which suggests a sheltering behaviour during the night within the seagrass meadow (March et al. 2010).

Although our results were clear (the chronogram of almost all the fish showed a clear increase in detections per hour during the day), the increase in detections in relation to activity patterns is a controversial issue. On the one hand, authors such as Topping et al. (2005) suggested that there is a negative relationship between detection frequency and movement rate, because the probability of being detected by a receiver is higher when fish are less mobile. On the other hand, Zeller (1997) and March et al. (2010) proposed that a higher number of detections during the day is due to the increased probability of fish being detected in their more active periods. In other cases, diel patterns were caused by changes in habitat use (e.g. Jadot et al. 2002, 2006, Verweij & Nagelkerken 2007) or were due to tidal variations (e.g. Humston et al. 2005).

In the case of *Serranus cabrilla* in the present study, there was no relationship between diel pattern and home-range size. Thus, the observed diel patterns appeared to be caused by the decrease in activity and mobility during the night. During the day, *S. cabrilla* was more active, and the probability of a fish being detected increased, probably due to feeding habits and social behaviour. During the night, fish were less mobile, less visible and remained hidden, which decreased the probability of being detected. This kind of diel behaviour has been reported for other temperate-reef fish and attributed to predation avoidance during the night (e.g. Chateau & Wantiez 2007, March et al. 2010).

The position estimation obtained by acoustic-receiver arrays can be improved using an array design in which the detection ranges of more than one receiver overlap (Simpfendorfer et al. 2002, 2008, Hedger et al. 2008). In the present study, the array design used allowed us to estimate a large number of COAs for most of the fish and then estimate home-range areas and habitat preferences. To estimate COAs, we obtained MCP$_i$ 100 for each tagged fish, which averaged 0.21 ± 0.12 km^2. MCP$_i$ 100 tends to be inaccurate due to the large weight of a few extreme COA estimates (March et al. 2010). However, even taking this into account, the MCP$_i$ 100 results gave evidence to support the sedentary nature and high site fidelity of *Serranus cabrilla*.

Bivariate fixed-kernel utilisation distributions seem to be more robust against outlier COAs (March et al. 2010). The present study results showed that *Serranus cabrilla* spends 95% of its time within an average area of 0.77 ± 0.17 km^2, and its core area (50% of the time) is 0.10 ± 0.29 km^2. These results agree with observations previously reported that describe this species as sedentary with a limited adult dispersal capability (Harmelin 1987). Other smaller-sized serranids of the same genus also have small home-range sizes (*S. scriba*: 95% KUD: 0.76 to 1.3 km^2; core area: 0.17 to 0.29 km^2; March et al. 2010). However, larger-sized serranids seem to have smaller home ranges: e.g. *Plectropomus leopardus* (0.1 to 0.2 km^2; Zeller 1997), *Epinephelus guttatus* (112 to 5636 m^2; Shapiro et al. 1994), *Paralabrax clathratus* (33 m^2 to 0.01 km^2; Lowe et al. 2003) and *E. tauvina* (0.07 to 0.73 km^2; Kaunda-Arara & Rose 2004). The relationship with bottom features on a microhabitat scale in small-sized serranids is not as clear as in large-sized species (La Mesa et al. 2002). It is interesting to note that the large serranids with small home ranges mentioned just above are all protogynous hermaphrodites, and in most cases they are socially structured in harems where the largest male protects a group of females from other males. In contrast, the 2 small-sized species of genus *Serranus* (*S. cabrilla* and *S. scriba*) are simultaneous hermaphrodites, and the

social and reproductive behaviour of this strategy is often complex and unknown in most cases (Petersen 2006).

The present results showed that the home-range size was uncorrelated with fish size. This disagrees with the results obtained for larger-sized serranids, which are protogynous hermaphrodites and sex-changing fish (Kaunda-Arara & Rose 2004). For example, in *Epinephelus tauvina*, the larger individuals (males) show smaller home ranges than the smaller individuals (immature fish, females and young/smaller males; Kaunda-Arara & Rose 2004). However, our results agree with those reported for *Serranus scriba*, which are also simultaneous hermaphrodites (March et al. 2010).

For the relationship between space utilisation and diel patterns, our results showed that most of the fish had home-range areas that did not significantly change between day and night. *Serranus scriba* shows the same pattern (March et al. 2010). However, other species show different space use during day and night (e.g. Lowry & Suthers 1998, Jadot et al. 2002, 2006, Verweij & Nagelkerken 2007). In *S. cabrilla*, although fish were detected less frequently by the receivers, fish used the same-sized space and the same location. The results agree with the conclusion mentioned above, that the observed diel patterns appeared to be caused by the decrease in activity and mobility during the night.

Our results demonstrate that *Serranus cabrilla* has high site fidelity. On the one hand, LI_i values were usually close to 0 (mean ± SD: 0.05 ± 0.07), which suggests that LI_i values are more related to random movements at the site than directed movement (Danielson & Swihart 1987). On the other hand, IOR_i mean values on a daily basis showed high overlap in activity spaces on 2 consecutive days. In fact, 91.6% of the tagged fish showed a mean IOR_i value >0.5 (i.e. tagged fish used >50% of the same activity spaces on 2 consecutive days). Another small serranid (*S. scriba*) also shows high site fidelity (March et al. 2010). Thus, all results reported here support the conclusion that *S. cabrilla* is a sedentary species with a limited adult dispersal capability and higher activity during the day than at night.

Our results confirmed that the habitat of *Serranus cabrilla* begins at the edge of the seagrass meadow (*Posidonia oceanica* beds). Therefore, this species does not have the same habitat preferences as *S. scriba*, which predominantly inhabits seagrass meadows (Moranta et al. 2006, Deudero et al. 2008, March et al. 2010). In the present study, *S. cabrilla* was found to inhabit soft bottoms with rocks and detrital habitats more frequently. However, it is interesting to note that seagrass meadows could play a role in the life history of *S. cabrilla*, either as adult individuals or in early life stages, and this opens up new paradigms for further research.

The movement patterns of *Serranus cabrilla* (one of the main targets of the recreational fishery in the western Mediterranean) need to be taken into account in MPA design. Temporal and spatial distribution of fish movement patterns needs to be incorporated into models of protected fish populations (Botsford et al. 2009). To achieve conservation and fisheries management goals, MPAs have to be of sufficient size to protect the target species (Kramer & Chapman 1999). *S. cabrilla* is sedentary, with a home-range size frequently <1 km². Thus, a relatively small MPA could significantly reduce fishing mortality of fish located within the protected area. This has 2 main implications to the whole of the fishery. First, if the population is allowed to increase in density inside the MPA, more adult individuals are likely to be closer to the boundary and exposed to fishing mortality beyond the protected area (Kramer & Chapman 1999). Second, a relatively small MPA could maintain a number of old and large fish which are known to have higher fecundity. This pool of high-fecundity fish could be the key to maintaining sustainable population levels in exploited surrounding areas via spillover of eggs and larvae (i.e. because these early life stages are pelagic). This species has been catalogued as a bio-indicator of fishing pressure (Harmelin 1987) and it is vulnerable to angling and overexploitation (Ordines et al. 2005); therefore, it is expected that it would respond well to protection.

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