Assessing the size adequacy of a small no-take marine protected area (MPA) for Mediterranean moray and European conger

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ABSTRACT: In 2011, several type I marine protected areas (no-take MPAs) were established inside the Sudoeste Alentejano and Costa Vicentina Marine Park, located along the southwestern coast of Portugal. This study quantified the home range, movement patterns and activity levels of 19 moray *Muraena helena* and 6 conger *Conger conger* eels to assess if the size of one of these MPAs (Pessegueiro Island) is adequate to protect these heavily fished species. Individuals were captured inside and outside of the no-take MPA, tagged with acoustic transmitters and monitored for 2 mo during the summer of 2013. Morays and congers showed a mean residency index of 0.48 and home ranges of 19.4 and 34.4 ha, respectively, corresponding to 4 and 8 % of the MPA. Morays and congers were active for 3.3 and 12.0 % of the time, respectively, mainly at night and during quarter lunar phases. Morays moved <1 km d^{-1} around reefs near the island, while congers roamed more widely. Results highlight the importance of this no-take MPA as a refuge and feeding area for both species, at least during the summer period, and suggest that its size is adequate for protecting these species against fishing activity. Ultimately, the present study provides evidence that small no-take MPAs can be adequate for protecting species with small home ranges.

KEY WORDS: Activity patterns · Acoustic telemetry · *Conger conger* · Home range · *Muraena helena* · PNSACV Marine Park

INTRODUCTION

Human population growth is leading to an increase in fish consumption and a decrease in the abundance of commercially fished species (FAO 2014), with associated problems regarding fisheries sustainability (Pauly et al. 2002). In face of this, management plans for marine resources based on scientific evidence are essential. Given the limited success of traditional management tools such as fishing effort control, the implementation of marine protected areas (MPAs) has been highly advocated in promoting fisheries sustainability and biodiversity preservation (Allison et al. 1998, Pauly et al. 2002). These protected areas are generally accepted as being effective and contributing to increases in the number, biomass, abundance and size of individuals of multiple key species (e.g. García-Rubies & Zabala 1990, Roberts 1995, Russ 2002). An MPA can be defined as any intertidal or subtidal area that is protected by law to preserve biodiversity and assure a sustainable use of its resources (Kelleher & Kenchington 1992). In 1995, a 2 km wide coastal stretch was designated as an extension of the Sudoeste Alentejano and Costa Vicentina Natural Park (PNSACV), southwest Portugal. At the time, no fishing restrictions were implemented. How-

ever, in 2011 this area was designated as a marine park, and type 1 (no-take) partial protection areas were implemented. In these areas, commonly referred to as no-take MPAs, almost all fishing activities are now forbidden.

The efficiency of an MPA depends on its location and size (e.g. Claudet et al. 2008) together with an appropriate management plan and adequate monitoring and surveillance (Allison et al. 1998, Claudet & Pelletier 2004, García-Charton et al. 2008). Furthermore, knowledge of fish species biology and ecology is a key factor when designating an MPA or a network of MPAs (Allison et al. 1998, Claudet & Pelletier 2004). Thus, knowledge on fish movements, activity patterns and habitat use throughout MPAs and adjacent areas is paramount (e.g. Kramer & Chapman 1999, Claudet & Pelletier 2004, Topping et al. 2005). Furthermore, to be efficient, a no-take MPA should encompass at least most of the home ranges of the species of interest to reduce the probability of their capture by commercial or recreational fisheries (Kramer & Chapman 1999, Pauly et al. 2002); here, home range is defined as the relatively circumscribed area over which an organism moves to acquire vital resources for survival and reproduction (Dingle 1996).

Home range estimation can be based on presence indicators (Powell 2000), and acoustic telemetry is a widely used method to study the movement of marine organisms (Zeller 1999, Heupel et al. 2006) and help plan and manage several MPAs (e.g. Abecasis & Erzini 2008, Abecasis et al. 2009, Alós et al. 2012). Although acoustic telemetry is often used to study the spatial ecology of many marine fish (e.g. Finn et al. 2014, Farris et al. 2016, Lédée et al. 2016), this technique has not been used to date on several commercially important species, such as the Mediterranean moray *Muraena helena* (Linnaeus, 1758) and the European conger *Conger conger* (Linnaeus, 1758) (Pita & Freire 2011, Matić-Skoko et al. 2014).

The Mediterranean moray (Muraenidae) is a territorial fish, which lives in crevices on rocky reefs (La Mesa et al. 2008) and forages mainly during the nighttime on crustaceans, cephalopods and fish (e.g. Bauchot & Saldanha 1986a, Matić-Skoko et al. 2014). Moray eels inhabit shallow waters near the coast to up 800 m in depth (Jiménez et al. 2007). Nearshore, where fisheries targeting *M. helena* generally occur, individuals are mostly females and juveniles (Matić-Skoko et al. 2014).

The European conger (Congridae) inhabits coastal areas from a few meters to over 1000 m in depth (Mytilineou et al. 2005). Juveniles are demersal and display cryptic behavior and high site fidelity (Correia et al. 2012) typically within rocky reefs associated with sandy bottoms (Day 1880, Bauchot & Saldanha 1986b, La Mesa et al. 2008). Individuals seem to be more active during sunset and nighttime (Day 1880, Morato et al. 1999, Pita & Freire 2011), feeding mostly on crustaceans, cephalopods (octopus) and fish (Morato et al. 1999, O'Sullivan et al. 2004, Matić-Skoko et al. 2012). Due to their semelparity, congers are particularly vulnerable to intense targeted fishing (Morato et al. 1999).

Both species are common inside the Pessegueiro Island no-take MPA, where, unlike in adjacent areas, individuals are supposedly protected from fishing activities. No previous study has examined whether the size of the no-take MPA around Pessegueiro Island encompasses most of the home range of conger and moray eels. Previous studies indicated that this small, no-take MPA was adequate to protect white seabream *Diplodus sargus* (Linnaeus, 1758), a species which is also highly targeted by fishers and displays a small home range and high site fidelity (e.g. Belo et al. 2016). Nevertheless, it is important to test an MPA's suitability for a broad array of commercially exploited fish species in order to further confirm the effectiveness of this management tool.

Regardless of their wide distribution and commercial importance, most studies on conger and moray have focused on diet (e.g. Morato et al. 1999, O'Sullivan et al. 2004, Matić-Skoko et al. 2014), age and growth (e.g. Matić-Skoko et al. 2011, 2012), reproduction (e.g. Cau & Manconi 1984, Sbaihi et al. 2001, Matić-Skoko et al. 2011) and population structure (e.g. Correia et al. 2012). Very few studies have examined the home range, movement patterns, space use and site fidelity of moray and conger eels. To our knowledge, only 1 study (Pita & Freire 2011) has provided preliminary information on these aspects of the ecology of conger eel. This lack of knowledge makes it challenging to promote management measures for the sustainable exploitation of both species.

The main objective of this study was to assess whether the size of the Pessegueiro Island no-take MPA is adequate for the protection of Mediterranean moray and European conger. Activity patterns and habitat use of both species were studied by means of acoustic telemetry, and the influence of environmental factors on the behavior of both species was also evaluated. The results from this study provide important and useful information on the adequacy of small no-take MPAs to protect fish species, whilst delivering valuable information on moray and conger ecology and behavior.

MATERIALS AND METHODS

Study area

The study was carried out in the Pessegueiro Island type I MPA (fishing activities forbidden with the exception of commercial harvest of stalked barnacle *Pollicipes pollicipes* [Gmelin, 1790]), the northernmost protected area within the PNSACV Marine Park (Fig. 1). This protected area belongs to a network of several type I protected areas, implemented within the PNSACV Marine Park in 2011. This no-take MPA has an area of approximately 450 ha surrounding a small rocky island. Maximum depth is ca. 18 m, and the seabed is mainly composed of rocky reefs delimited by sandy bottom. Several islets surround the island. On the northern and western sides, a rocky platform extends over 400 m, after which sandy bottoms abound. These areas are exposed to the dominant north-western wind and swell. The fish community of this region is diverse, with 149 fish species described, some with high commercial value, including morays and congers (ICNB 2008).

Field work

In July 2013, an array of 20 underwater acoustic receivers (VEMCO VR2W 69 Hz) was deployed inside the no-take MPA, covering most of its area (Fig. 1). Receivers were attached to a removable cable secured with stainless steel snap hooks on each end and connected to the main cable fixed to a 100 kg cement block. A rigid plastic buoy maintained the receiver in a vertical position. The entire mooring apparatus measured ca. 2 m in height and was permanently submersed. Mooring geographical coordinates were recorded by GPS.

Detection range of most receivers depends on environmental conditions and habitat type, from 600 m in deep water and low turbulence conditions to 30 m in the shallow waters of tidal creeks (e.g. Finstad et al. 2005, O'Toole et al. 2011, Welsh et al. 2012). Range testing was not conducted, since detection range would greatly vary among receivers due to the no-take MPA geography and sea conditions. However, it was assumed that individuals would be detected within at least 100 m away from a receiver, as previously observed in this area with an almost identical receiver array (e.g. Belo et al. 2016). Sentinel tags would be the most adequate method of continuously measuring home range (e.g. Payne et al. 2010, Currey et al. 2014), but this method was discarded as both studied species potentially display high site fidelity (e.g. Pita & Freire 2011, Correia et al. 2012), and this would increase the chance of code transmission collision. To optimize signal coverage near the island, 10 receivers were deployed less than 200 m from each other. Remaining receivers located farther from the island were positioned farther apart (ca. 400 m), since bottom characteristics in those areas enable higher detection range.
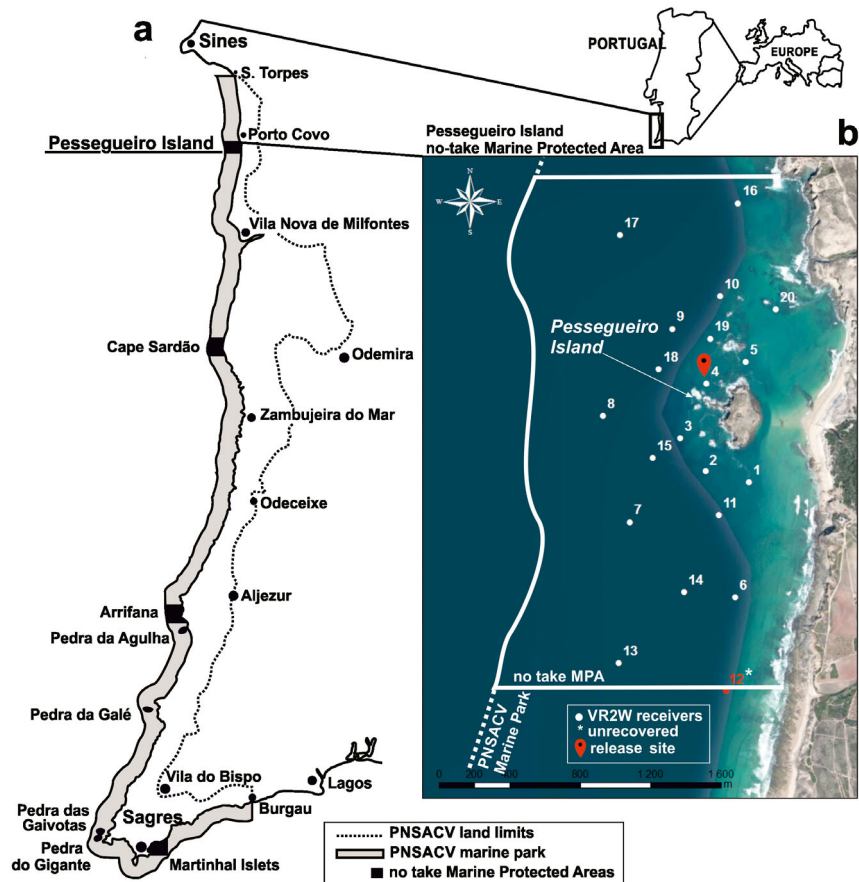

Fig. 1. (a) Sudoeste Alentejano and Costa Vicentina Marine Park (PNSACV), Portugal (grey), with its network of no-take marine protected areas (MPAs; black). (b) Detail of the Pessegueiro type I protection area (i.e. no-take MPA) and location of acoustic receivers (dots). Receiver 12 (red) was not recovered

Individuals were caught in early August 2013 inside the Pessegueiro Island no-take MPA using overnight fishing with baited traps. In total, 16 morays and 5 congers were captured. Three additional morays and 1 conger captured southwest outside the protected area were also tagged. Individuals were placed inside a 600 l oxygenated renewed sea water tank and individually anesthetized with a 2-phenoxyethanol (0.4 ml dm^{-3}) solution. After measuring for length (mm) and weight (g), a 9 mm diameter coded acoustic transmitter (Vemco V9-2H, 69 kHz) was implanted in the intraperitoneal cavity. Each transmitter measured 29 mm in length and weighed 2.9 g (in water). Power output was 151 dB, with a 99 d expected battery life and transmission rate of 60 s (30–90 s) nominal delay. After surgery, individuals were placed in a recovery tank for a minimum of 2 h before being released inside the MPA (Fig. 1). Tagged fish were monitored until receivers were collected in early October 2013 to avoid the winter storm season. Data from the first 2 d after release — when tagged individuals were presumably recovering from surgery and eventually relocating to the capture sites — and from the period when receivers were being retrieved, were discarded resulting in a 60 d study period. Adverse sea conditions, typical of the region during most of the year, restricted this study to summer.

Data analysis

After removing false detections and assessing the noise quotient, each individual detection was assigned location, date, time, lunar cycle and swell height at the time of detection (see Section 1.1 in Supplement 1 at www.int-res.com/articles/suppl/m584p213_supp.pdf).

Residency, activity and covered distance

The residency index (I_r) was calculated for each individual as the ratio between the number of days on which the fish was detected and the total number of days of monitoring (Afonso et al. 2008). Individuals were considered active when intervals between consecutive detections were <10 min. The activity time (T_a, %) was calculated as the ratio between individual activity time and total time of monitoring. The individual covered distance index (I_{cd}) was calculated as the sum of the minimum distances covered between consecutive detections (Lino 2012). Average daily distance covered (for days with recorded activ-

ity) and final displacement vectors ($\bar{d}$) were also calculated to assess the displacement tendency of tagged individuals (see Section 1.2 in Supplement 1).

Kernel density estimation (KDE) analysis

KDE was computed to determine home and core ranges of morays and congers. This tool estimates a bivariate density probability function, 'utilization distribution,' corresponding to the spatial distribution of a certain individual, thereby providing information on habitat use (Jacoby et al. 2012). Home and core range areas and contours were obtained using the ESRI software package ArcGIS 9.3® with Hawth's Analysis© extension (Beyer 2004), applying an h_{ref} value (Worton 1989) of 90 for morays and 135 for congers. The percentage of the MPA used by each individual was calculated (see Section 1.3 in Supplement 1).

Network analysis

Network analysis evaluates the type and degree of interactions between activity centers (Jacoby et al. 2012) and has been used as a complement to KDE (e.g. Espinoza et al. 2015, Lédée et al. 2015, Belo et al. 2016). Spatial networks are complex systems of nodes, representing acoustic receivers, connected by edges, i.e. fish movements. Centrality, a node-type metric, was calculated as both degree centrality (C_d) and betweenness centrality (C_b), measuring the affluence to the focal node (C_d) and its importance as a middle location between several paths (C_b) (Jacoby et al. 2012, Makagon et al. 2012). Network analysis was performed using the UCINET software package (Borgatti et al. 2002) after testing each network for nonrandom patterns using the igraph R package (Csardi & Nepusz 2006), through an edge rearrangement and bootstrap approach (Croft et al. 2011). By crossing this information with KDE analysis, it is possible to determine the type of area use of each individual (Lédée et al. 2015). Areas with high C_d indicate evident space fidelity (Jacoby et al. 2012). Areas with high C_d overlapping core range correspond to refuge areas. Conversely, areas with high C_b may represent ecological paths or access areas to valuable resources (Jacoby et al. 2012), such as feeding areas. Regarding individual fish, high individual C_d values indicate movements centered in a particular area, concordant with refuging behavior. High individual C_b indicates broader movements, consistent with

roaming behavior (Jacoby et al. 2012) (see Section 1.4 in Supplement 1).

Environmental parameters

Influence of circadian cycle, lunar cycle, tidal cycle and swell on tagged fish behavior was also analyzed through multivariate PERMANOVA (Anderson et al. 2008) performed in PRIMER 6 & PERMANOVA+© and Mantel tests using the ade4 R package (Chessel et al. 2004, Dray & Dufour 2007, Dray et al. 2007). Given the low sample size for congers, these analyses were only performed for morays (see Section 1.5 in Supplement 1).

RESULTS

The mean noise quotient was −222.22, a value concurrent with reduced environmental noise and occurrence of code collision. This suggests that individuals

could be within receiver range, even when they are not being detected.

I_r, I_{cd} and T_a

In total, 69 936 single and individual codes were detected and recorded by the VR2W array, with detections varying considerably amongst individuals of both species, i.e. standard deviation of 3467 detections for morays and 13 902 detections for congers.

Both morays and congers had high mean I_r (morays: 0.48; congers: 0.48; Table 1), and most of the tagged individuals were detected throughout the study period (Fig. 2). Congers were generally more active than morays (morays 3.25 %; congers 12.02 %) (Table 1). Morays covered (I_{cd}) around 11.0 km during the 60 d study period, with a median daily covered distance (DCD) of 0.8 km, while congers covered about 334.9 km (DCD = 8.7 km; Table 1). Displacement vectors confirm that morays moved mainly around their release location (near receiver R4), presenting final

Table 1. Summary table of moray (M) and conger (C) individual total length (TL), residency index (I_r), total activity time (AT), activity time (T_a), core range (CR), home range (HR), percentage of marine protected area (MPA) corresponding to the home range (%MPA), covered distance index (I_{cd}) and daily distance covered (DCD, on days with registered activity). Dashes represent assessment not possible

Fish ID	TL (cm)	I_r (%)	AT (h:min)	T_a (%)	CR (ha)	HR (ha)	% MPA	I_{cd} (km)	DCD (km)
M1	74.0	0.39	1:55	0.13	4.3	23.8	5.32	10.48	0.40
M2	72.0	0.54	10:06	0.70	3.7	20.5	4.59	13.17	0.42
M3	96.0	0.15	0:55	0.06	4.4	31.9	7.15	4.97	0.87
M4	105.0	0.16	0:38	0.04	4.0	24.7	5.53	2.81	0.82
M5	76.0	0.97	338:21	23.50	1.9	12.6	2.83	267.98	4.32
M6	79.5	0.84	104:04	7.23	3.1	21.9	4.90	228.86	4.30
M7[a]	88.0	0.03	2:23	0.17	9.2	44.0	9.86	11.55	5.78
M8	81.5	0.69	46:19	3.22	2.4	14.4	3.22	76.49	1.98
M9	85.5	0.57	9:26	0.66	2.7	13.7	3.08	4.40	0.16
M10	84.0	0.67	19:56	1.38	2.3	17.0	3.81	16.67	0.40
M11[a]	76.5	0.72	48:10	3.35	3.5	32.2	7.20	93.21	2.25
M12	83.5	0.06	0:00	0.00	3.2	14.8	3.31	0.69	–
M13	97.0	0.87	158:49	11.03	2.7	18.6	4.17	188.27	7.82
M14	86.0	0.60	13:44	0.95	1.8	8.20	1.84	4.57	0.14
M15	98.0	0.18	0:14	0.02	2.9	14.4	3.21	1.37	0.34
M16[a]	73.0	0.52	19:30	1.35	7.5	58.4	13.07	67.83	2.40
M17	78.0	0.49	19:36	1.36	3.0	21.5	4.82	116.53	4.65
M18	97.0	0.08	0:04	0.01	4.4	19.9	4.46	0.42	0.25
M19	87.5	0.89	92:51	6.45	2.6	24.4	5.46	129.62	2.47
Mean	85.2	0.48	46:28	3.25	3.4	19.4	4.23	11.02[b]	0.82[b]
C1	82.0	0.89	673:09	47.14	3.9	15.4	3.46	0.00	–
C2	87.5	0.80	112:45	7.83	12.3	45.0	10.07	447.08	9.11
C3[a]	78.5	0.05	5:13	0.36	29.7	133.8	29.94	24.33	9.93
C4	85.0	0.67	70:42	4.91	9.7	42.7	9.57	334.88	8.28
C5	98.0	0.01	00:00	0.00	–	–	–	–	–
C6	96.0	0.02	1:57	0.14	–	–	–	–	–
Mean	87.8	0.48	171:42	12.02	8.6	34.4	7.70	334.88[b]	88.69[b]

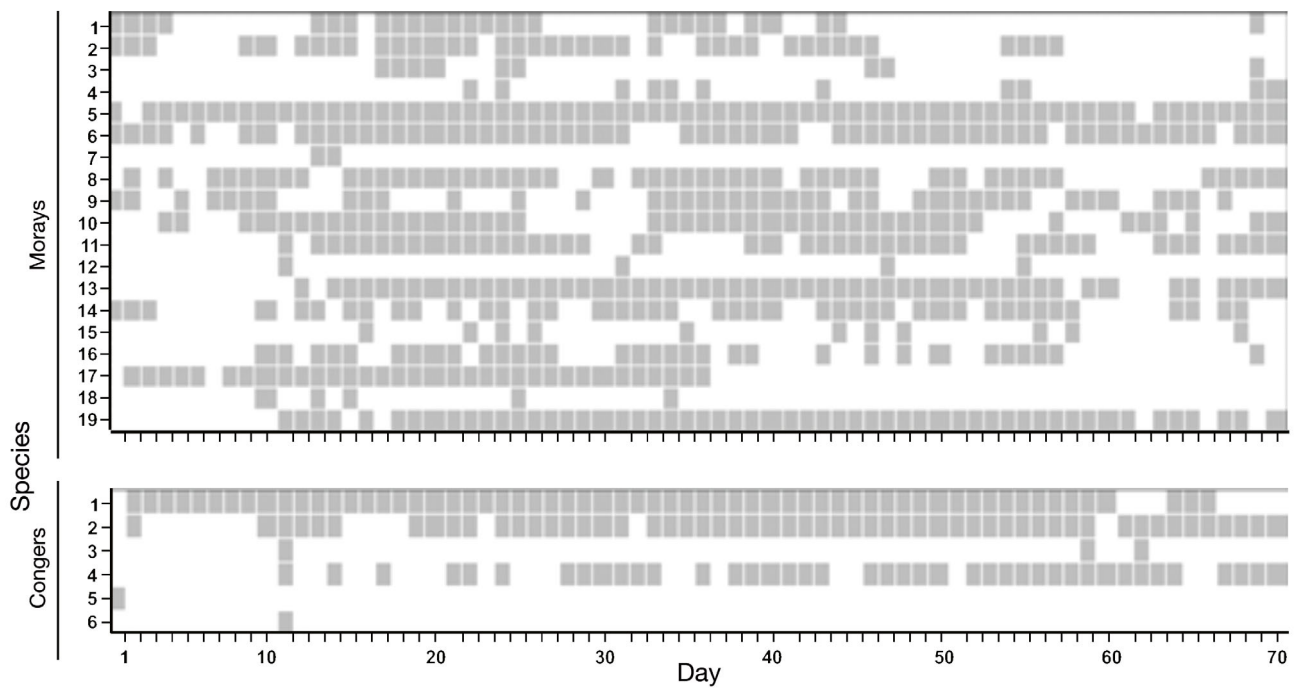[a]Individuals captured outside the no-take MPA; [b]Median

Fig. 2. Daily presence/absence map of tagged morays and congers throughout the monitoring period. Grey squares indicate presence
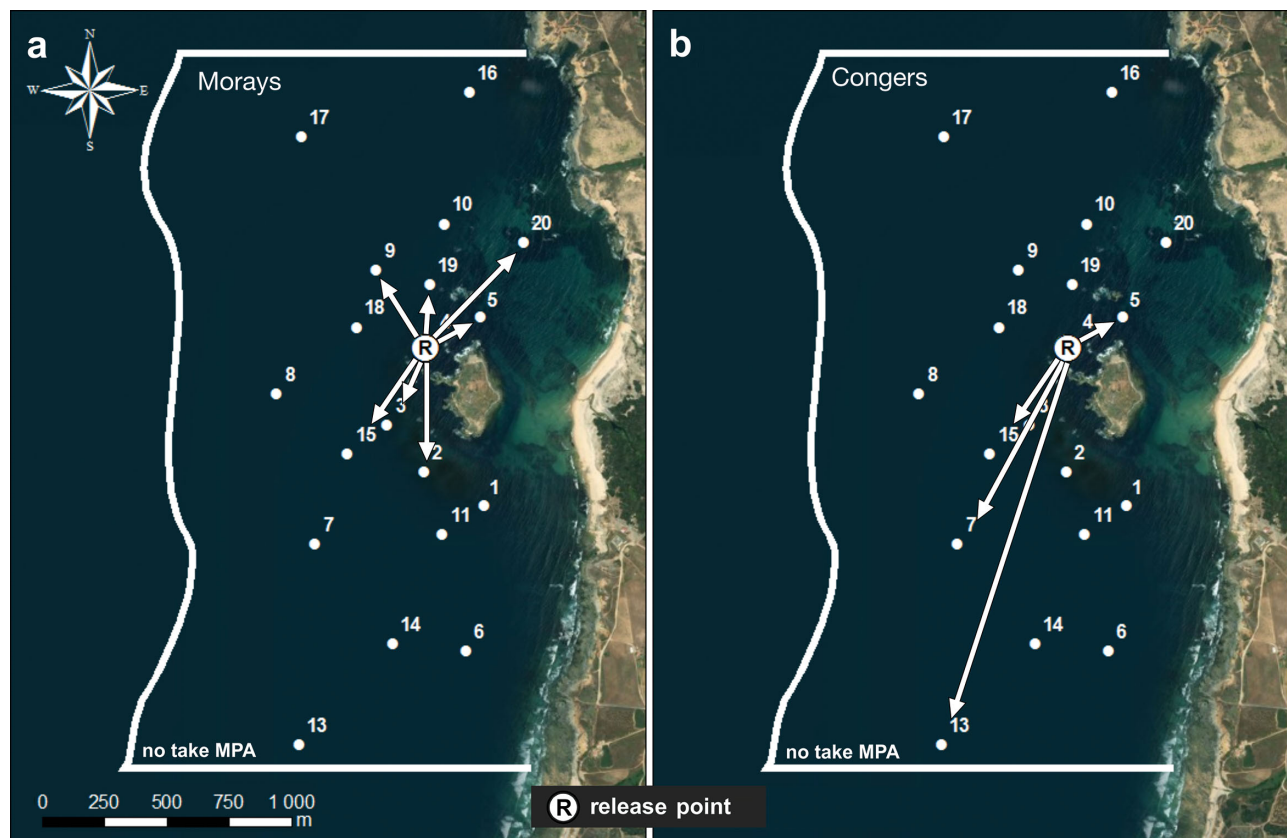

Fig. 3. Final displacement vectors of tagged (a) morays and (b) congers captured inside the no-take MPA in relation to their release point. Numbered dots indicate the positions of receivers

displacement vectors directed towards nearby re-
ceivers (Fig. 3). Congers had less uniform behavior,
with congers C1, C2 and C4 staying and/or moving
mainly around their release location, whereas C5 and
C6 moved to receivers R7 and R13 (the last receiver
near the southern limit of the study area; Fig. 3).
Overall, these 2 individuals were detected only
during the first 150 min after their release (Fig. 2).

KDE analysis

Morays presented an average home range of
19.4 ha (4% of the no-take MPA) and a core range of

3.4 ha. Congers had mean home ranges of 34.4 ha
(8% of the no-take MPA) and core ranges of 8.6 ha.
KDE analysis showed that morays were generally
confined to a specific and restricted area near the
island (Fig. 4a,b) while congers showed wider areas
of coverage, although some also had home and core
ranges centered around few locations (Fig. 5a,b).

Network analysis

Network analysis confirmed that morays moved
over smaller areas, occasionally moving between
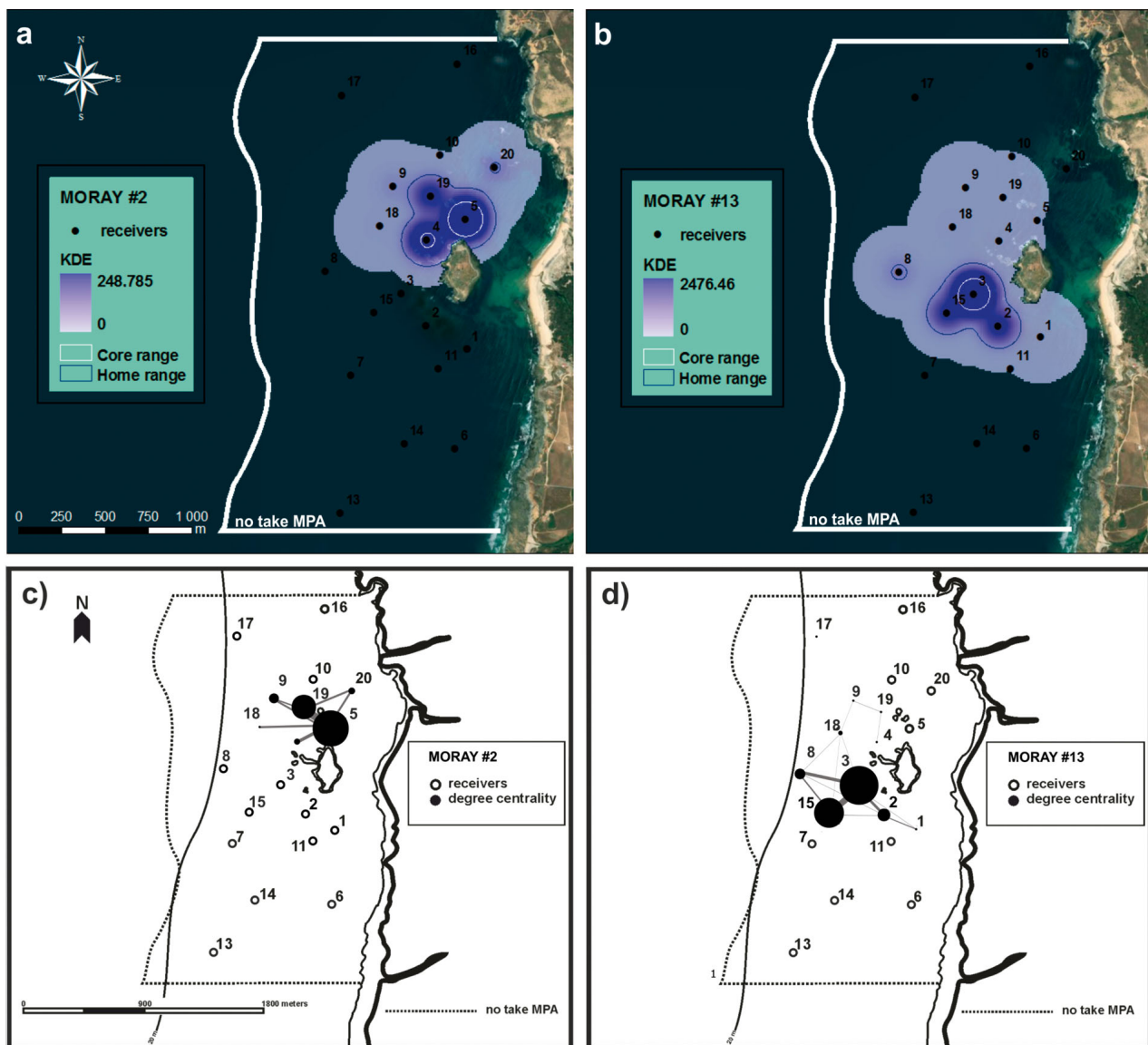zones (Fig. 4c,d) while congers displayed wider-

Fig. 4. Examples of (a,b) kernel density estimation analysis and (c,d) movement patterns (refuge areas) determined through
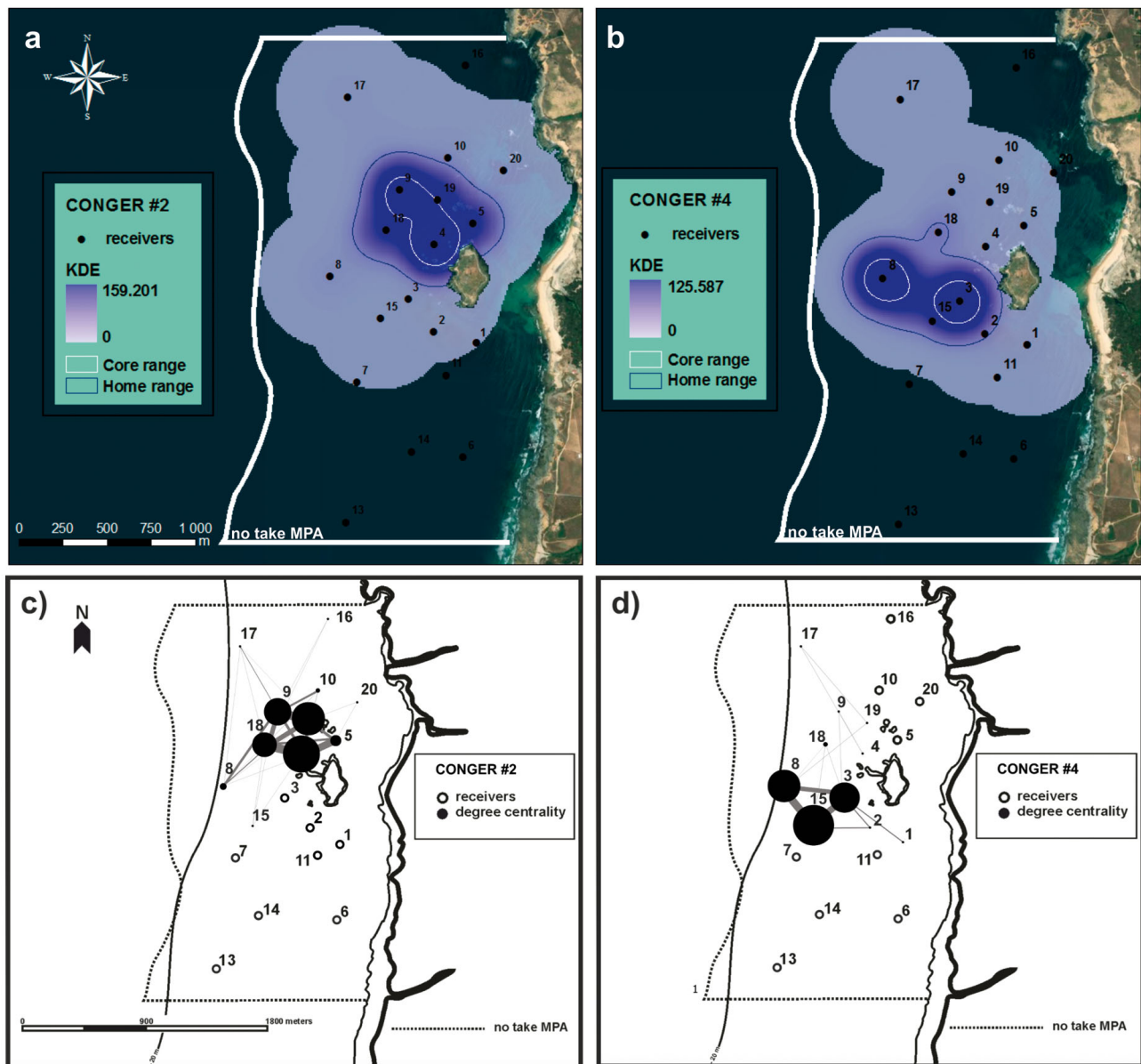network analysis for morays. Larger circles: higher degree centrality; thicker lines: higher number of connections

Fig. 5. Examples of (a,b) kernel density estimation analysis and (c,d) movement patterns (refuge areas) determined through network analysis for congers. Circles and lines as in Fig. 4

ranging movements (Fig. 5c,d). Centrality values indicate the area around receiver R4 as the most used by morays (Fig. 6). C_d values showed that the area around receiver R19 was highly frequented as well, while C_b values for areas around R5, R1, R2 and R8 emphasized their importance as passageways (Table S1 in Supplement 2 at www.int-res.com/articles/suppl/m584p213_supp.pdf; Fig. 6). Overall, refuge areas and crossing and/or feeding areas were mostly located in rocky reefs near the island in the northeast quadrant (Fig. 6).

Environmental parameters

Moray T_a was significantly influenced by environmental parameters, since tagged individuals were significantly more active during nocturnal, first quarter lunar phase and low swell periods (Table 2, Fig. 7a–d). PERMANOVA revealed interactions between lunar phase and circadian cycle and swell (Table 2), with significantly higher T_a in first quarter lunar phases during both day and night (Table S2 in Supplement 2, Fig. 7e,f) and in third quarter lunar
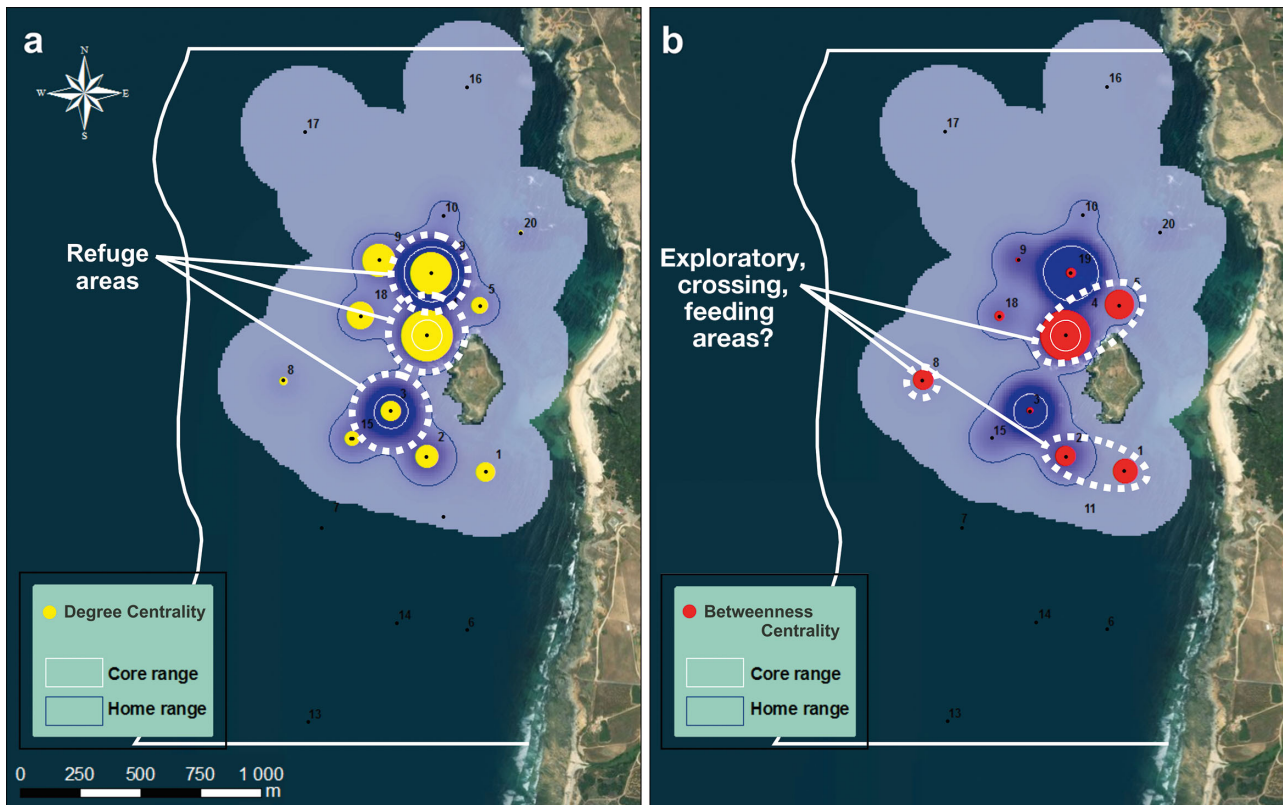
Fig. 6. (a) Refuge areas and (b) passageways/feeding areas of morays according to kernel density estimation and network analyses

phase with low swell (Table S2, Fig. 7g). Graphical analyses show congers with higher median T_a during nighttime, third quarter lunar phase, ebbing tide and high swell (Fig. 7h–k).

Regarding C_b values, Mantel tests showed that moray movement patterns varied with environmental variables (r < 0.4, p > 0.05). The C_b values indicate that morays preferred to use areas near the island as

Table 2. Results of PERMANOVA regarding activity time (T_a) variation according to environmental parameters. p: calculated probability to significance level $\alpha = 0.05$; perm: number of permutations

| Factors	df	SS	MS	Pseudo-F	p	Perm
Circadian cycle	1	18550.0	18550.0	21.96	0.00	999
Lunar cycle	3	13138.0	4379.4	5.19	0.00	998
Tidal cycle	1	797.3	797.3	0.94	0.37	999
Swell	1	5959.8	5959.8	7.06	0.01	998
Circadian cycle × Lunar cycle	3	7358.6	2452.9	2.90	0.02	999
Circadian cycle × Tidal cycle	1	1112.0	1112.0	1.32	0.24	997
Circadian cycle × Swell	1	520.5	520.5	0.62	0.52	999
Lunar cycle × Tidal cycle	3	834.4	278.1	0.33	0.91	999
Lunar cycle × Swell	3	6833.0	2277.7	2.70	0.03	997
Tidal cycle × Swell	1	762.2	762.2	0.90	0.38	999
Circadian cycle × Lunar cycle × Tidal cycle	3	1168.8	389.6	0.46	0.83	998
Circadian cycle × Lunar cycle × Swell	3	5030.1	1676.7	2.00	0.09	999
Circadian cycle × Tidal cycle × Swell	1	469.96	470.0	0.56	0.53	998
Lunar cycle × Tidal cycle × Swell	3	2332.6	777.5	0.92	0.46	999
Circadian cycle × Lunar cycle × Tidal cycle × Swell	3	1015.3	338.4	0.40	0.85	997
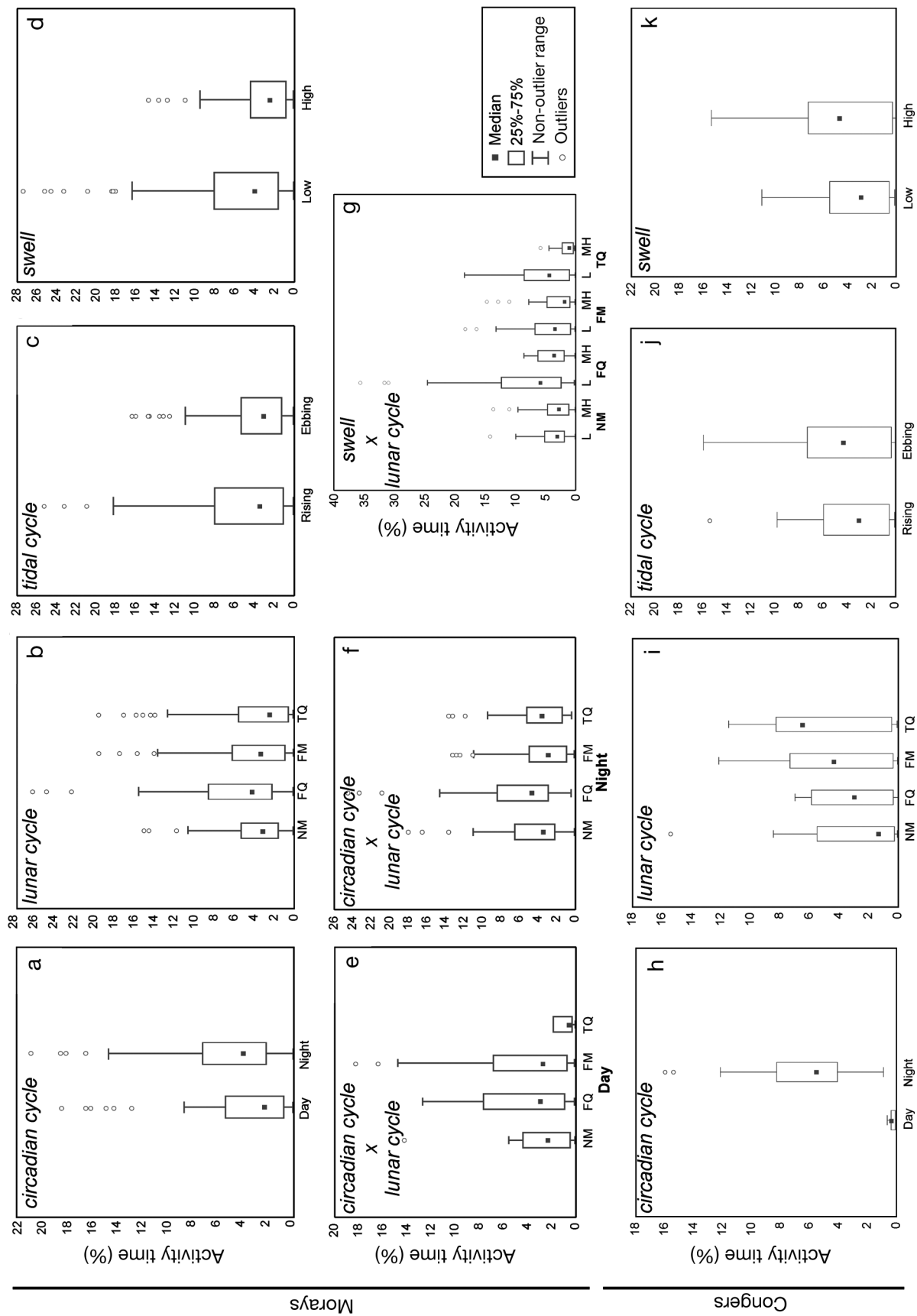
Fig. 7. Moray and conger activity time for each environmental variable tested. For morays: (a) circadian cycle, (b) lunar cycle, (c) tidal cycle, (d) swell, (e,f) interaction between lunar and circadian cycle, and (g) interaction between swell and lunar cycle. For congers: (h) circadian cycle, (i) lunar cycle, (j) tidal cycle and (k) swell
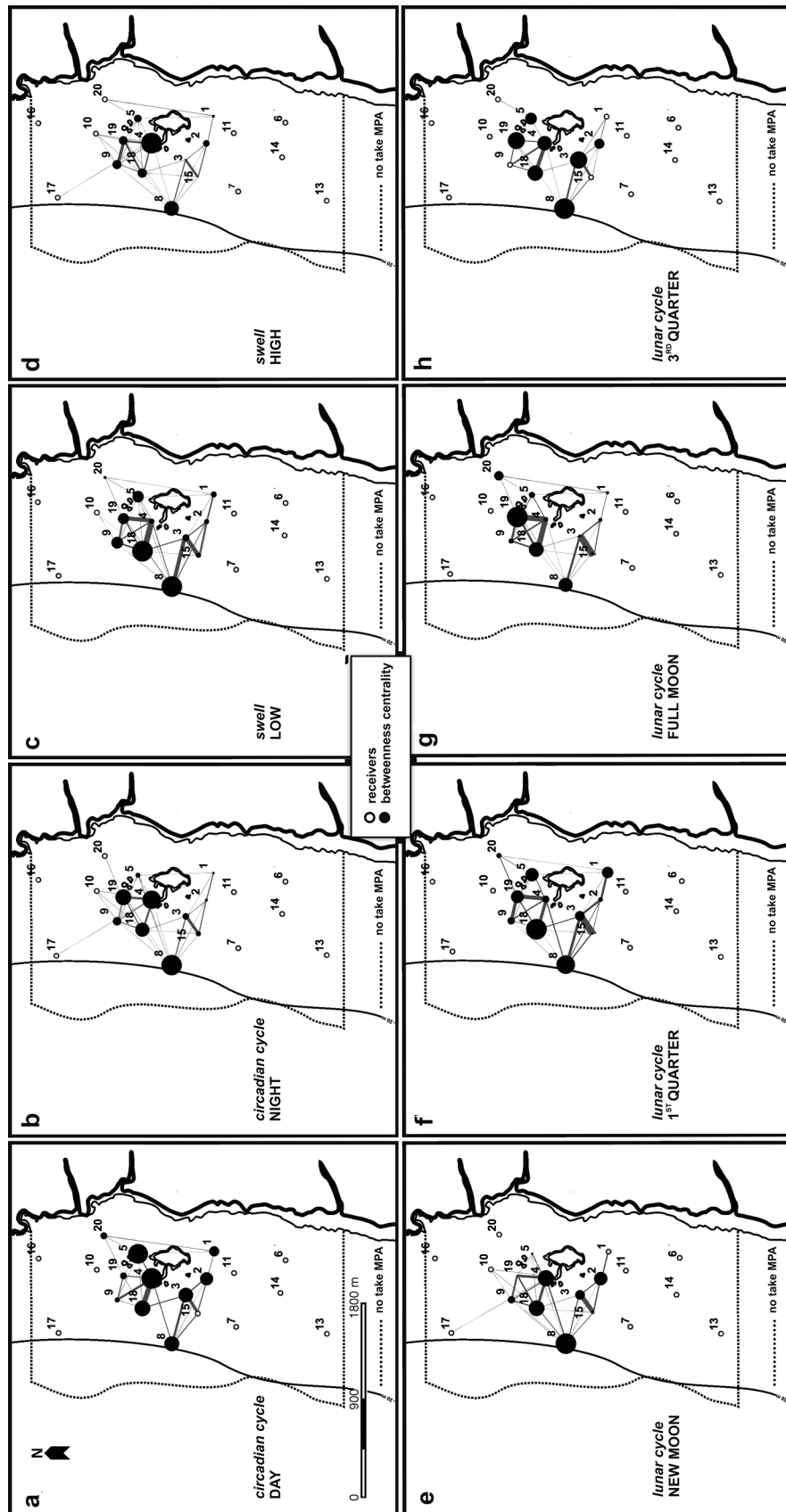
Fig. 8. Moray movement patterns determined by network analysis (betweenness centrality; see Materials and Methods) according to (a,b) circadian cycle, (c,d) swell and (e–h) lunar cycle. Larger circles: higher betweenness centrality; thicker lines: higher number of connections

passageways and/or feeding areas during daytime (Fig. 8a) with high swell (Fig. 8d) in full moon periods (Fig. 8g). During night, low swell and other lunar periods, morays tended to explore farther.

DISCUSSION

Pessegueiro Island no-take MPA proved to be an important refuge and foraging area for both morays and congers. The size and location of this small protected area seem adequate to protect these species during the summer, when fishing pressure is highest. These results, together with previous findings (e.g. Belo et al. 2016), suggest that Pessegueiro Island no-take MPA, and other small no-take MPAs in general, can provide effective protection against fishing activities for highly targeted species with small home range and high site fidelity. Our results highlight the appropriateness of MPAs as management tools for these species. Our measurements also corroborated and complemented previous findings (e.g. Cau & Manconi 1984, Morato et al. 1999, O'Sullivan et al. 2004, Correia et al. 2012, Matić-Skoko et al. 2012, 2014).

The cryptic behavior of morays and congers, which use rocky reefs as shelters, can disturb sign transmission, reducing the detection range of receivers (Lino 2012, Welsh et al. 2012) and likely contributed to some of the interference in code transmission observed in this study. Noise quotient values suggested that using sentinel tags would not have solved this issue but, rather, likely would have increased code collision. Although a range test was not performed to assess how habitat complexity and variable ocean conditions influenced the efficiency of signal detection, the deployment design of the array of receivers used here was based on a reference detection range of 100 m to provide an optimal coverage of the MPA, following previous studies in this area (Belo et al. 2016). Despite a low level of detections, I_r of both congers and morays was high (ca. 50%), while the latter were about 4 times more active than the former (12 vs. 3%). Both species have well defined home ranges which were restricted to <8% of the MPA's area.

In this study, the mean home range of morays (19 ha) was about 50% that (34 ha) of congers. Pita & Freire (2011) previously reported a very small (0.6 ha) home range for a single conger tracked manually for 48 h. Despite a larger number of individuals tagged in this study, conclusions regarding the activity and home range of congers should be addressed

with some caution. Furthermore, conger C1 was registered on only 1 receiver, although detection cycles were concordant with a living individual. On the other hand, centrality measures for morays were high, revealing a more pronounced territorial and a less pronounced roaming behavior compared to congers. Both species centered their movements closer to the island, frequently on the northwestern side, where shelter is afforded by complex rocky habitats (J. Parrinha unpubl. data). Moray refuge areas overlapped with 3 well known complex rocky reefs, whereas crossing and other areas which may be foraging habitats were somewhat to the east. The southernmost of these areas is dominated by sandy habitats with a few flat rock platforms.

Inside this no-take MPA, morays and congers displayed similar habits. Both presented low activity levels and nocturnal behavior, corroborating previous research (Pita & Freire 2011). However, differences in their patterns of activity and size of their home range suggest that these species have adopted distinct behaviors, probably related to differences in foraging. Morays were significantly more active during the night and first quarter lunar phase with low swell conditions. Indeed, centrality values indicated that morays were more active during the night in offshore areas, with broader, more long-distance movements. Despite being more active in offshore areas during low swell and quarter lunar phase periods, in these periods morays movements were spatially restricted. During the day, high swell and full moon periods, morays centered their activities around their refuge reefs. During nighttime, morays may successfully forage using olfaction (Santos & Castro 2003) which may allow these fish to forage in darkness and remain inactive to avoid predators during nights with a full moon. Digestive tract contents from morays captured around the no-take MPA indicated that these species mostly feed on octopus and bony fish, including seabreams (Silva 2015). The nocturnal activity of morays may be related to the similar activity pattern of cephalopods (Altman 1966, Kayes 1973) and predator–prey interactions between these species (Meisel et al. 2013). Additionally, during daytime, in high swell and full moon periods, morays centered their activities near the island around known feeding areas of seabreams (Belo et al. 2016). This suggests that morays may maximize their predatory success via prey switching (e.g. Matić-Skoko et al. 2014). Although far fewer individuals were monitored, congers tended to be active for longer periods during the night, as also described by Pita & Freire (2011), and during the third quarter and full moon.

Conger possess relatively large eyes, they are known to avoid capture during full moon periods (Day 1880), and low activity levels in new moon periods indicate that they may be essentially visual predators. Since octopus are also the preferred prey of conger (Xavier et al. 2010, Matić-Skoko et al. 2012, Silva 2015), higher activity by conger during nocturnal full moon may also reflect trophic interactions between these 2 species.

In contrast to individuals captured within the MPA, morays and congers captured outside the MPA appeared to have larger home ranges which, in some cases, extended towards the southern limit of the no-take zone, an area intensively used as a passageway. All morays captured outside the MPA were ultimately recaptured by fishermen and, unlike morays captured inside the MPA, which were detected most frequently within 800 m of their release location, 2 of these 3 individuals moved south by the end of the monitoring period. These non-resident individuals may have been moving towards their original home range (Fig. S1 in Supplement 3 at www.int-res.com/articles/suppl/m584p213_supp.pdf) and were subsequently captured by fishermen 2 nautical miles west-southwest from the no-take MPA near their original capture location (Fig. S2 in Supplement 3). Similar patterns cannot be confirmed for congers as no individuals were recaptured, although congers displayed a similar displacement during the monitoring period. Ultimately, these observations support site fidelity behavior, typical of life strategies of cryptic and sedentary species.

A network of small MPAs is commonly accepted as an effective tool for protecting species with movement patterns similar to those found for the Mediterranean moray and European conger (Moffitt et al. 2009). Monitoring a larger number of individuals over longer periods would help define the environmental factors influencing patterns of movement. Especially important will be documenting any intrinsic, seasonal changes in activity patterns which may influence the effectiveness of the no-take MPA. Comprehensive bathymetric and geomorphological mapping of the area will underpin future investigations on the habitat use of these and other rocky reef species (e.g. Topping et al. 2005, Friedlander & Monaco 2007). In addition, combining passive and active telemetry techniques (e.g. Afonso et al. 2009, Pita & Freire 2011, Lino 2012) and sensor tags such as the AccelTag (de Almeida et al. 2013) will further advance knowledge on the movement and activity patterns of these fish and the effective design of small no-take MPAs.

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