

Movement patterns of the spiny lobster *Palinurus elephas* (Fabricius, 1787) from a central western Mediterranean protected area

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SUMMARY: Movement patterns of the spiny lobster *Palinurus elephas* were determined from 389 individuals (total tagged 5666) tag-recaptured inside a no-take area of the central western Mediterranean and its surrounding zone. High site association and limited movements in tagged lobsters was observed; 60.4% of lobsters moved less than 2 km from the centre of the area (site of release). No clear relationship between lobster movement pattern and sex or size was observed; however, it seemed that the largest males and females tended to be more resident, thus contributing to the rebuilding of the biomass of local lobsters. Most lobsters undertook migrations in the southwest direction. The increased availability of shelters and food towards the southwest could have contributed to the lobsters' movement. The results of our research indicate that the small size of the protected area and the scale of the movement exhibited by tagged lobsters allows a proportion of the lobster population to move out of the protected area and become susceptible to capture in the adjacent fishery.

Keywords: lobster, *Palinurus elephas*, protected area, spillover, movement.

RESUMEN: PAUTAS DE MOVIMIENTO DE LA LANGOSTA *PALINURUS ELEPHAS* (FABRICIUS, 1787) DESDE UN ÁREA PROTEGIDA EN EL MEDITERRÁNEO OCCIDENTAL CENTRAL. – Se determinaron las pautas de movimiento de 389 individuos de la langosta *Palinurus elephas* (total marcados 5666) marcados y recapturados en el interior de un área protegida (sin captura) así como de su área circundante. En las langostas marcadas se observó una elevada asociación al lugar de liberación, así como movimientos limitados: el 60.4% de las langostas se movieron menos de 2 km desde el centro del área de liberación. No se observó ninguna clara relación entre las pautas de movimiento de las langostas y su sexo y talla; no obstante, hay una tendencia a que los machos y hembras grandes muestren un comportamiento más residente, contribuyendo así al aumento de la biomasa local. La mayor parte de langostas mostró migraciones en dirección sudoeste. La mayor disponibilidad de refugios y alimento hacia el sudoeste pudo haber contribuido al movimiento de las langostas. Los resultados de este estudio indican que el pequeño tamaño del área protegida y la escala de movimientos mostrados por las langostas marcadas permite a una porción de la población su salida del área protegida y su susceptibilidad a la captura en la pesquería adyacente.

Palabras clave: langosta, *Palinurus elephas*, área protegida, excedente, movimiento.

INTRODUCTION

The effect of a reduction in fishing effort on the density and biomass of lobster populations has been thoroughly investigated in the Mediterranean Sea and in other marine regions (Sanchez Lizaso *et al.*, 2000). Most studies conclude that fishery reserves

can increase lobster stocks in neighbouring areas, particularly through the migration of adults (Dugan and Davis, 1993; Roberts and Polunin, 1993; Rakin and Kramer, 1996; Rowe, 2001; Guenette *et al.*, 1998; Kelly *et al.*, 2002; McGarvey, 2004; Follesa *et al.*, 2007). However, there are few studies detailing lobster emigration from protected areas. General

aspects of ecology and behaviour, such as type of movement, site fidelity and habitat selection, have been poorly investigated even though there has been a considerable increase in research on spiny lobsters in the last two decades (Phillips and Kittaka, 2000; Goñi and Latrouite, 2005).

Movement patterns of lobsters play an important role in determining a population's response to marine reserves (Polacheck, 1990; DeMartini, 1993; Attwood and Bennett, 1995; Guenette and Pitcher, 1999). Patterns of lobster movement can be divided into three general categories (Herrnkind, 1980): migrations, wherein an individual or population moves a considerable distance, often but not always returning to the original area; nomadism, the wandering of individuals without any clear start and end points; and homing, the periodic, often daily, excursions from a shelter to some nearby area, with subsequent return to that shelter or others nearby. Each of these patterns is thought to be developed from some biological need such as food, shelter, reproduction or recruitment, and different lobster species may exhibit any, or all, of these patterns during their life histories (Stewart and Kennelly, 1998).

Movement patterns have been studied in many migratory spiny lobsters, including *Panulirus argus* (Latreille, 1804), *P. cygnus*, George, 1962, *P. ornatus* (Fabricius, 1798), *P. guttatus* (Latreille, 1804) and *Jasus edwardsii* (Hutton, 1875) (review in Herrnkind, 1983). All these species exhibit nomadic movements spanning several kilometres, as well as seasonal mass migrations of up to 500 km (Herrnkind, 1983). The neurohormonal mechanisms and environmental factors orienting these movements remain unknown. Although several aspects of the biology of *P. elephas* (Fabricius, 1787) have been investigated, knowledge of the movements of this species is still very poor. Most previous studies have been on observations of individuals in situ or held in captivity (Mercer, 1973; Hunter *et al.*, 1996; Díaz *et al.*, 2001) and have highlighted nocturnal habits and movements related to foraging, reproduction and shelter use (Goñi and Latrouite, 2005; Giacalone *et al.*, 2006).

The aim of this paper is to further investigate the movement patterns of *P. elephas* in a protected area and the surrounding commercial zones in the central-western Mediterranean by means of a tag-recapture programme carried out from 1997 to 2007. Movement was analyzed in relation to the lobster's size and sex.

MATERIALS AND METHODS

The study was carried out in a protected area (called the "Su pallosu area") of central-western Sardinia in the central-western Mediterranean Sea, at 50-100 m depth and in the surrounding fishery zone (the zone around the protected area, mainly within a radius of <5 km from the centre of the area).

The protected area, first identified in 1997, was chosen as a point of release on account of its geomorphological and bionomic characteristics. When investigated by scuba divers, it proved to be characterised by formations comparable to coastal precoralligenous and coralligenous detritus (Pérès and Picard, 1964). Since 1998, fishing has been prohibited in the ca. 4 km² area (Regional Law No. 776 of 6-5-1998) (Secci *et al.*, 1999). From 1998 to 2007 (except for 2002 and 2003), a total of 5666 individuals [mean Carapace Length (CL) of 45.59 mm ± 6.68 SD for females (N = 3141) and 46.01 ± 8.45 SD for male (N = 2525)], from samples taken from the "Su pallosu area" (N = 1898) and commercial captures made by local fishermen (N = 3768), were tagged and released inside the protected area. The plastic T-bar-type tags were inserted dorso-laterally between the first and second abdominal segments using a tagging gun (Campillo *et al.*, 1979). After about three days in tanks in order to assess tagging stress (estimated mortality of ca. 3%, Secci *et al.*, 1999), the tagged individuals were released mainly in the centre of the protected area. Data recorded upon initial tagging and subsequent recaptures included tag number location. When a lobster was recaptured, the identification number of the tag was recorded. Samples were recaptured during experimental samplings inside the area and commercial fishing in the surrounding fishery zone. Commercial captures in the zone surrounding the protected area were made primarily by the fishermen involved in experimental samplings within the no-take area. These fishermen all belonged to the Su Pallosu fishing cooperative. The fishing effort outside the protected area, made generally by fishermen of the cooperative, was evenly distributed around the area. The few fishermen not belonging to the Su pallosu cooperative were encouraged to return the tagged lobsters to the cooperative fishermen. In this way the lobsters could be released again in the centre of the protected area. This allowed longer-term movement information to be collected at subsequent recaptures.

During the recapture programme, experimental sampling inside the “Su pallosu area” was conducted following a specific programme. Each year, in the period from May to September (when commercial fishing is allowed), an average of 10 experimental samplings were carried out (except for 2004, when there were only four). Sampling was conducted using trammel nets of 1000 m length (nominal mesh size from 50 to 73 mm) following a sampling plan with transects set up in such a way as to survey the whole protected area. The first transect was placed from west to east in the centre of the area, with the remaining nine parallel to it at a distance of *ca.* 250 m from each other. The nets were put down in the middle of the day and hauled up in the morning of the following day.

Because the lobsters were captured during commercial or experimental sampling with nets, it was more difficult to know the exact point of the original site of capture prior to being tagged. Only for 8 individuals was it possible to know the initial capture location and then to estimate the homing ability.

Distance moved by lobsters was calculated as the straight line between the point of the release (centre of the protected area) and the point of recapture. The recapture point was always considered the middle point of the sample net.

To determine whether lobster movement varied with size, lobsters were subdivided into three size categories (small, CL<80 mm; medium, 80<CL<110 mm and large, CL>110 mm). The analysis was performed by sex for all individuals and for each size category.

The circular distribution of the lobsters’ heading was analysed with the Rayleigh test (Zar, 1996). The hypotheses are as follows:

H_0 = the sampled population is uniformly distributed around a circle.

H_1 = the population is not uniformly distributed.

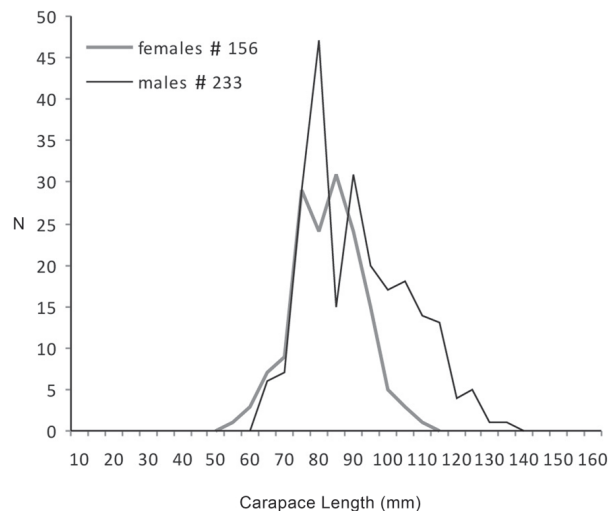


FIG. 1. – Size distribution (CL, mm) of tag-recaptured lobsters in the protected area and its surrounding zone.

If H_0 is rejected we may conclude that there is a mean population direction, identified by a specified mean angle (Zar, 1996). The probability level of significant difference was set at $P=0.05$.

RESULTS

From 5666 tagged lobsters, a total of 389 (233 males, CL from 60.10 to 130.7 mm and 156 females, CL from 54.6 to 107.7 mm) were recaptured both inside the protected area and in its surrounding fishery zone (Fig. 1). Of the total number, 323 lobsters were recaptured one time, 58 two, 7 three and 1 four times.

Although very few data of the initial capture location were available (only for 8 lobsters), no particular ability to orientate homeward was recorded. Only two female lobsters (respectively # 4 and 7) were recaptured in the proximity of the initial point of capture (C, Fig. 2). Lobster # 5 was recaptured in the opposite direction with respect to point C,

TABLE 1. – Length increments, sex, days at liberty and movements [distance (km) and direction] of eight lobsters tagged and release during the experimentation. M, tagging; RC, recapture; C, point of initial site of capture; RE, point of release; RC, point of recapture.

N°	Carapace length (mm)		sex	Day at liberty	C- RC		C-RE		RE-RC	
	M	RC			distance	direction	distance	direction	distance	direction
1	75.00	83.60	m	203	4.700	148°	0.160	118°	4.800	327°
2	65.90	86.70	m	942	0.521	164°	0.160	118°	0.642	334°
3	54.00	61.00	f	262	4.400	44°	0.160	118°	4.500	226°
4	89.00	91.90	f	399	0.102	335°	0.325	66°	0.339	229°
5	99.30	99.00	m	69	1.200	341°	0.727	153°	0.486	173°
6	52.10	70.30	f	782	17.200	33°	0.453	349°	17.600	212°
7	51.50	61.20	f	426	0.179	252°	0.574	14°	0.502	177°
8	80.00	86.40	f	320	0.463	56°	0.459	324°	0.641	190°

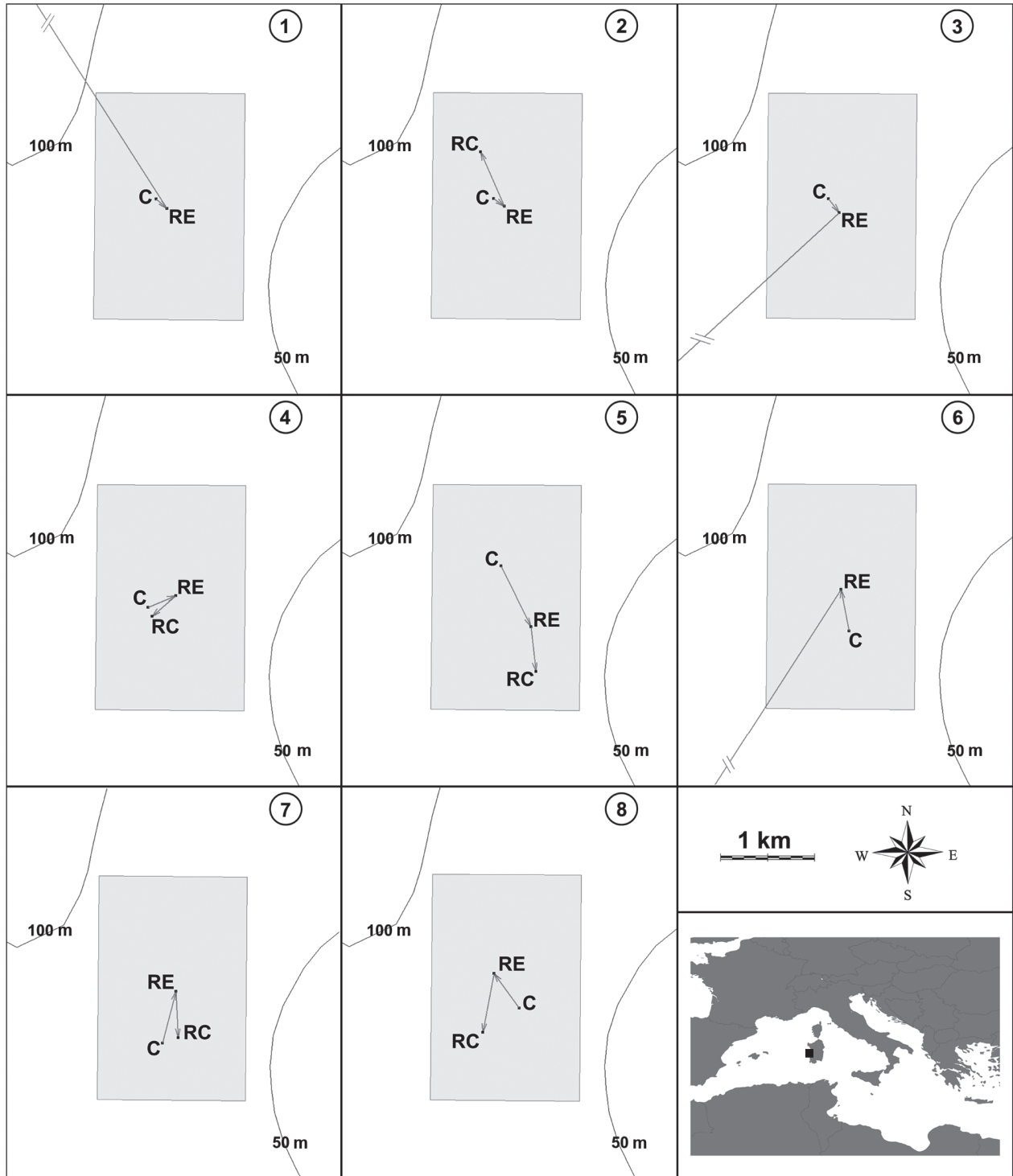


FIG. 2. – Movement patterns of the eight tagged lobsters inside and around the protected area (rectangular area). Legend: inside the circle the number of the tagged lobster; C, point of initial site of capture; RE, point of release; RC, point of recapture.

and lobsters (respectively # 1-3-6) many kilometres away were found. No correlation was found between homing ability and sex or size (Table 1).

On the whole, strong site fidelity was evident in tagged *P. elephas*. As many as 60.4% of lobsters

moved less than 2 km from the centre of the protected area (site of release). Moreover, 79.9% of lobsters were found at a distance of <5 km from the centre; only 2.3% of the lobsters moved further than 20 km. The greatest recorded movement was made

TABLE 2. – Range of carapace length (mm), mean distance travelled (km) and mean of days at liberty of tagged and recaptured lobsters for different sex and size groups.

	Range CL (mm)	Distance travelled (km)		Days at liberty mean
		mean	mean/year	
total females	54.6-107.7	4.12 ± 11.6	2.62	573.2 ± 465.7
total males	60.1-130.7	3.15 ± 5.89	2.39	481.0 ± 359.0
size groups				
total small	54.6-79.9	2.18 ± 3.28	2.26	350.7 ± 255.0
small females	57.0-79.9	2.69 ± 4.04	2.58	380.3 ± 272.7
small males	60.1-79.5	1.91 ± 2.56	2.12	327.6 ± 230.1
total medium	80.0-109.8	3.94 ± 6.14	2.31	622.0 ± 430.3
medium females	80.0-107.7	3.66 ± 5.30	1.81	737.3 ± 529.1
medium males	80.0-109.8	4.12 ± 6.69	2.81	535.0 ± 318.0
large (only males)	110.0-130.7	1.30 ± 2.44	0.64	741.0 ± 576.0

by an 80 mm CL female, which covered a distance of 134 km (in southeasterly direction) over a period of 712 days. The greatest distance moved by a male was 45.9 km southwest over 1546 days. On average, males apparently moved less than females (3.15 ± 5.89 km in a mean period of 481.0 ± 359.0 days versus 4.12 ± 11.6 km in a mean period of 573.2 ± 465.7 days, respectively), although no statistical difference was observed between the two mean values (*t* test = 1.08646, *P* = 0.278) (Table 2). There was no significant relationship between time at large and distance moved (Table 2, Fig. 3). Linear regression analysis of the log-transformed data confirmed this statement (for females $y = 0.0002x - 0.0065$, $r^2 = 0.017$; for males $y = 0.000x - 0.008$, $r^2 = 0.040$).

Both males and females showed a low dispersion of the angles (*r* value of 0.134 and 0.176 respectively) which were not uniformly distributed around the circle (for males Rayleigh’s test $z = 4.2168$, $N = 233$, $0.02 < P < 0.01$ and, for females $z = 4.8451$, $N = 156$, $0.01 < P < 0.005$) (Table 2). Direction of travel for males was $224.58^\circ \pm 75.36$ and for females $207.71^\circ \pm 73.54$. Movement of both sexes tended to be mainly in a south-west direction (Fig. 4).

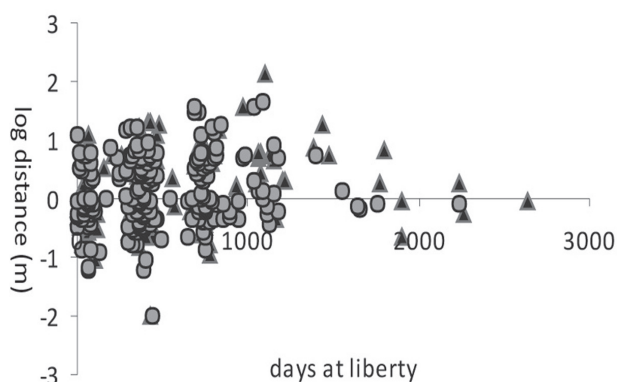


Fig. 3. – Relationship between days at liberty and distance travelled by males (circles) and females (triangles).

Of the three size groups, we observed males and females in the small and medium size groups. The largest females (CL 80.0- 107.7 mm) observed were in the medium size group. In the large size group (110.0-130.7 mm), only males were observed (Table 2).

From the analysis of the mean distance moved by various size groups, individuals of the large size group (males) travelled the lowest mean distance (1.33 ± 2.44 km) (Table 2), highlighting a high site fidelity to the reserve in comparison with the other size groups. Significant differences in the mean distance travelled were found between the large and medium groups (*t* test = - 3.2346, *P* = 0.0013) and large and small groups (*t* test = -2.0993 *P* = 0.037). From the Rayleigh’s test, the large group size highlighted a uniform distribution of the angles ($z = 2.020$, $N = 25$, $P > 0.1$). The same pattern of distribution was also observed for female lobsters of the medium size group (the largest ones) ($z = 0.9879$, $N = 81$, $P > 0.2$) (Table 3). Small females and males showed no uniform circular distribution and instead, a movement preferentially towards a southwest direction ($197.72^\circ \pm 69.73$ and $267.68^\circ \pm 70.76$, respectively). Medium-size males moved mostly in a south-east direction ($169.07^\circ \pm 73.29$) (Table 3).

TABLE 3. – Results of Rayleigh’s test and mean angle taken by lobsters recaptured presented by sex and size categories (in bold significant *P* value).

	r	Z	P	Mean angle
total females	0.1762	4.8451	<0.01	207.71 ± 73.54
total males	0.1348	4.2168	<0.02	224.58 ± 75.36
size groups				
total small	0.2592	6.408	<0.002	235.04 ± 72.35
small females	0.2592	4.7037	<0.05	197.72 ± 69.73
small males	0.2372	4.8405	<0.01	267.68 ± 70.76
total medium	0.1324	3.4572	<0.05	187.25 ± 75.47
medium females	0.1104	0.9879	>0.2	-
medium males	0.1817	3.8329	<0.05	169.07 ± 73.29
total large (males)	0.2843	2.020	>0.1	-

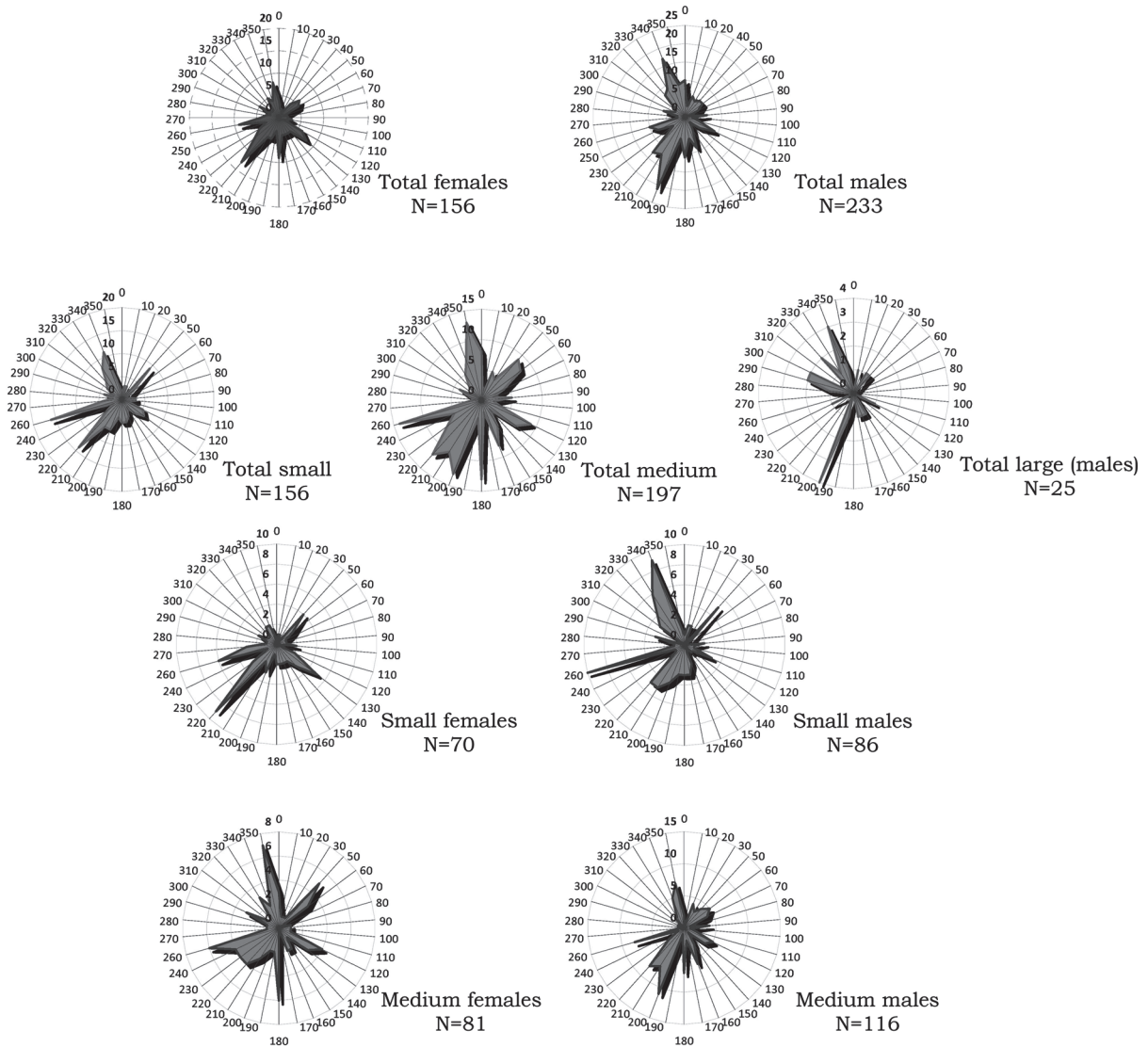


FIG. 4. – Circular distribution for lobsters recaptured presented by sex and size categories.

DISCUSSION

This study showed a high site fidelity and limited movements in tagged *P. elephas*. Of the lobsters, 60.4% moved a distance of less than 2 km from the centre of the protected area (site of release), a distance shorter than the arbitrary value of 5 km chosen by Booth (1997) to define large-scale movement. Movement patterns of lobsters resulted in the exchange of individuals between the protected area and nearby harvested areas even in the first year of experimentation (Follesa *et al.*, 2007). Considering that the mean distance moved by lobsters in a year was *ca.* 2 km/yr and that the maximum distance a lobster would have to cover in order to move outside

the area would be between 1.4 and 1.6 km (straight line), it appears clear that a spillover of individuals outside the area would be possible after the first year of tagging.

In general, there did not seem to be a clear relationship between lobster movement pattern and lobster sex or size. However, a more uniform circular distribution was noted in the largest individuals: males in the large size group and females in the medium size group. Longer distances were travelled by sexually immature males (CL 54.6-79.9) and females (CL 57-79.9). Similar size-related characteristics of movement by immature individuals have also been reported for other spiny lobster species, including *P. cygnus* (Phillips, 1983), *P. argus* (Davis

and Dodrill, 1989), *P. gilchristi* (Groeneveld and Branch, 2002), *P. delagoae* (Cockcroft *et al.* 1995, Groeneveld, 2002), and *Jasus edwardsii* (McKoy, 1983; Annala and Bycroft, 1993). The progressive percentage increase of *P. elephas* biomass values recorded from 1997 to 2007 inside the protected area (Follesa *et al.*, 2008) could be caused by a greater movement of immature individuals from inside the protected area to outside, whereas the males in the large size group and the females in the medium size group may be more sedentary. The results for size-related movements were somewhat difficult to interpret, but it could be hypothesised that mature and/or adult lobsters tended to be more resident, contributing to the rebuilding of the biomass of local lobsters. Males with CL >110 mm showed the highest site association; female site fidelity tended to increase as individuals reached mature size (size at onset maturity = 76.5 CL mm; Goñi *et al.*, 2003). If we consider that in an unfished population the size of breeding females of *P. elephas* that contributes most to egg production is CL 105-110 mm (Goñi *et al.*, 2003), the high fidelity by the largest females that we observed could support a greater egg production within the protected area.

It is unclear why most lobsters moved specifically in the southwest direction. Broadly speaking, the highest proportion of recaptures may occur where fishing effort is greatest even if the animals disperse randomly, resulting in an apparent directionality of dispersion that does not actually exist (Annala and Bycroft, 1993). This did not seem to happen in our study. The fishing effort was relatively evenly spread around the protected area and its distribution would probably not bias the location of the tag returns. It is likelier that the increased availability of shelters and food observed by ROV images contributed to the preferential southwest movement of juveniles and adults.

Generally, very little is known about the specific cause of directional migrations taken by spiny lobsters. Lobsters mainly wander to forage for food or to seek new individual shelters as their life styles change with growth, particularly in the juvenile phase (Norman *et al.*, 1994). Following each moult and growth increment, the progressively larger juvenile searches for and finds larger, suitably-sized holes or crevices for protection during foraging (George, 2005). Hernkind (1980) stated that adults sometimes move seasonally for moulting and reproductive purposes or episodically to avoid short-term adverse envi-

ronmental conditions, but they often return to their original area. Although very few data of the initial capture location were available, no particular ability of lobsters to find the way back to their home patch and no correlation between homing ability and sex or size were found during our study. It did not seem that the greatest sedentary behaviour of the largest males and females could be explained by a particular ability to orientate to their patch within the reserve.

As in some other lobster studies (Kelly and MacDiarmid, 2003), we found no evidence for a relationship between days at liberty and distance moved.

Our findings on the movement patterns of lobsters demonstrate the potential importance of no-take areas in fisheries management. The evaluation of the impact of no-take areas on a fished stock is a complex process involving factors such as the displacement of fishing effort from no-take areas to open areas, the dynamics of fishing fleets, and biological parameters influencing productivity (Stockhausen *et al.*, 2000). Movement of lobsters in and out of the no-take areas can be considered to be another important factor because of its influence on stock rebuilding inside the no-take area and the spillover of individuals (Gardner *et al.*, 2003). Our results highlight a high level of movement between the protected area and the surrounding zone, which may contribute to the increased lobster biomass at the no-take boundaries (Follesa *et al.* 2007, 2008). Similar patterns were found in another Mediterranean reserve. Goñi *et al.*, 2006 found that lobster spillover from the Columbretes Marine Reserve in Spain enhanced fishery CPUE up to 4 km from the MPA boundary. Results from northeast New Zealand (Kelly, 2001) suggest that with *J. edwardsii* occasional spillover can occur.

Our study provides further insight into the potential effects of introducing protected areas into managed commercial spiny lobster fisheries. Although our results cannot be generalised to all protected areas, there is no doubt that in some circumstances stock moved into managed areas may not necessarily be sedentary, thus providing further benefits to the neighbouring commercial areas.

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Scient. ed.: P. Abelló.

Received July 7, 2008. Accepted November 26, 2008.

Published online April 14, 2009.