HABITAT, MOVEMENTS AND MIGRATION OF THE SPIDER CRAB *MAJA SQUINADO* IN THE RIA DE AROUSA (NW SPAIN). PRELIMINARY DATA USING ULTRASONIC TELEMETRY

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ABSTRACT. Ultrasonic telemetry techniques were used to analyze the movement patterns of juveniles and adults of *Maja squinado* (Decapoda, Majidae) in the outer part of the Ría de Arousa (Galicia, NW Spain). Juveniles (N = 8, 80-130 mm carapace length) were characterized by slow movements (9.7 m/day in summer and 4.5 m/day in winter) and were limited to shallow zones (1-10 m, average depth for the different animals was 4.5 m) with rocky kelp beds. After the pubertal moult in summer, adults (N = 7) carried out non-directional movements similar to juveniles, but with a speed of 22.1 m/day and a greater depths (7.3 m). In 1-3 months after the pubertal moult, there was a second phase of movements, corresponding to the beginning of the autumn migration. At this stage, adults carried out large scale movements (average speed 75.8 m/day, the maximum distance observed between sucessive locations was 2.5 km in 7 days), which were highly directional (NE-N) towards the central channel (mean individual depth from 9 to 23 m; maximum depth recorded was 39 m) and outer area of the Ría. The beginning of these wide-ranging movements coincided in time with meteorological (variations in the direction of the predominant winds and an increase in rainfall) and oceanographic changes (decline in shallow water salinity and temperature). These movements determine recruitment in the tanglenet fishery, which relies on animals that have reached maturity in the same year.

INTRODUCTION

The spider crab *Maja squinado* (Decapoda, Majidae) is a species that lives in the Northeast Atlantic Ocean and Mediterranean Sea, at depths ranging from the subtidal level to 90 m (Kergariou, 1984). There is strong evidence that spatial segregation exists by sex, between juveniles and adults, and reproductive stage; these habitat differences are variable according to the season (Kergariou, 1971, 1984; Kergariou & Veron, 1981; Rodhouse, 1984; Le Foll, 1993; Meyer, 1993). In the Ría de Arousa (Galicia, NW Spain), this species is more abundant in the outer area and adjacent coastal area. Juveniles, having a carapace length (CL) of < 120-140 mm are found predominantly in shallow waters characterized by mixed hard-and-soft bottoms. The adults, on the other hand, are present in the deeper zones where they are the target of a tanglenet fishery (González-Gurriarán et al., 1993, 1994; unpublished data).

Mark-recapture studies have been carried out with *M. squinado* in the English Channel (Edwards, 1979, 1980), south of Brittany (Camus, 1983), north of Brittany and the Gulf Normano-Breton (Kergariou, 1976; Latrouite & Le Foll, 1989; Le Foll, 1993), and in the Adriatic Sea (Stevcic, 1967, 1973; Bussani & Zuder, 1977). These authors point to the existence of long distance, directional migrations affecting adults. Sufficient information is not available to be able to determine the timing of the beginning of the migration, nor to identify the triggering mechanisms; although there has been some speculation on the existence of internal cues and on the influence of environmental factors (Stevcic, 1971a; Latrouite & Le Foll, 1989). Conventional tags do not give any insight into the animals' activity during the life stages when they do not carry out large movements; the only data

available are from experiments with animals in captivity (Stevcic, 1971b; Le Foll, 1993). However, there is no information on juvenile activity.

The purpose of this paper is to study the activity, movements and habitat utilization of juveniles approaching maturity and adults of *M. squinado*, by means of ultrasonic telemetry techniques (Hawkins & Urquhart, 1983; Maynard & Webber, 1987; Wolcott & Hines, 1989, 1990; Kasello *et al.*, 1992). This study is part of a project whose aim is to analyze the activity, movement and migration patterns of this species and identify their causal mechanisms. Knowledge of these aspects is highly important for the fishery of this species, given that catches are directly related to the activity arhythms nd migrations.

MATERIAL AND METHODS

Study area. This research was carried out in the Ría de Arousa, in the northern area of the O Grove Peninsula. The outer and middle part of this Ría as well as the adjacent coast constitute the areas where the spider crab fishery takes place, for the most part with tanglenets and to a lesser extent using the glass box, and occasionally, traps. The areas selected to start the experiments consist of rocky kelp beds, alternating with sandy bottoms, with tidal ranges of 3 m, and <10 m depth. This type of area constitutes the typical habitat of juveniles and adults which have recently undergone the pubertal moult (Fig. 1).
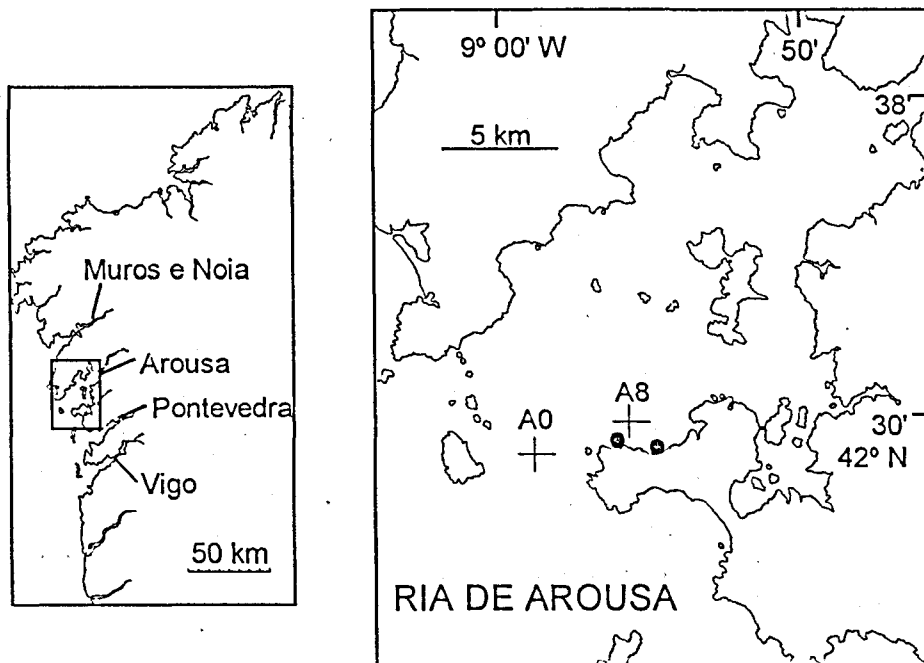

Figure 1. *Maja squinado*. Galician coast (NW Spain) and Ría de Arousa. Location of the areas where the animals tagged with transmitters were released (dots), and sampling stations of oceanographic data (A0 and A8).

Telemetry methods. We used VEMCO Ltd. (Halifax, Canada) ultrasonic telemetry equipment. Four types of transmitters were employed. The V2B-2L tags are 38 mm long, 8.5 mm in diameter, weighing 5.3 g in the air. This type of miniature transmitter with short life batteries (20-25 days) allowed tracking of juveniles in summer during the period between consecutive moults. In winter and spring V2B-2LR tags were used for juveniles; they are similar to the former but have a double, longer life exterior battery (these batteries are 10 mm longer, and tracking was carried out during 50-60 days). The V3-4LO-R tags are 65 mm long, 16 mm in diameter and weigh 12.9 g in the air; the lithium battery that attaches to the transmitter is the same diameter, 34 mm long, and weighs 13 g in the air. The V3's allowed to track adults for up to 141 days. Two V3T-4LO-R temperature transmitters were also used, measuring 80 mm in length and weighing 16.6 g in the air, with the same diameter and battery type as the V3. The

average life was 48 days. In all cases the weight of the transmitter was less than 2% of the body weight of the animal. Previous observations in the laboratory indicate that the tags do not affect their behaviour. To locate tagged crabs, a V-10 directional hydrophone and VR-60 receiver with an internal decoder for telemetry were used.

The animals used in this study (8 juveniles, with CL between 90 and 131 mm and 7 adults, 124-171 mm, which had recently undergone the pubertal moult) were caught using the glass box in the study area. Transmitters were attached with quick epoxy, after the dorsal part of the carapace was scrubbed with a brush to remove seaweeds, and was dried with alcohol, acetone and dry air. Animals were released and tracked from small boats equiped with a depth sonar and a satellite global positioning system (GPS). In the experiment which began in summer, 3 juveniles and 2 adults were released on 24/07/93, 2 adults on 02/08/93 and another 2 adults on 08/10/93, at depths of between 1.3 and 4.5 m in the same area where they had been caught. The time between locations varied initially between 0.4 and 3.1 days (24/07/93 to 13/08/93) and later, from 5 to 11 days until the end of the experiment (22/12/93). In the experiment started in winter (10/03/94), when the adults are not present in the shallow area, 5 juveniles were released at depths of 3.2-6.5 m, and the time elapsed between observations was 2.9-6.1 days (except in one ocasion in which 11 days elapsed between locations). The positioning of the animal location was carried out using the GPS. Owing to the error inherent in the GPS system, which may be greater than the small scale movements of the animals, in summer juveniles were also located with respect to coastal landmarks (tracking took place in the shallow zone with an abundance of rocks and landmarks). In the experiment started in the winter, buoys were used to mark the locations, thus supplementing the GPS data; the distance between buoys was estimated and movement direction was measured with a compass. Complementarily, depth, surface and bottom water temperature, and temperature data transmitted by the V3T tags were recorded at the time of observation.

Oceanographic data. Weekly data on temperature, salinity and oxygen dissolved on the surface and bottom were provided from two sampling stations in the Ría de Arousa (Fig. 1), by the Centro de Control da Calidade do Medio Mariño of the Consellería de Pesca, Marisqueo e Aquicultura of the Xunta de Galicia. Daily meteorological data (wind speed and direction, and rainfall) were provided by the Centro Meteorológico Zonal de A Coruña.

Data analysis. The distance between consecutive locations and movement direction in relation to the north was estimated from GPS locations. The same estimate was made for juveniles based on data from coastal landmarks and buoys. The distance between locations was assumed to be the minimum distance travelled by the animal between observations. The mean depth was calculated for each animal, omitting the release observation, and each location was weighted by the interval between observations (it was considered that the time period that elapsed at a particular depth extended from the middle of the time interval elapsed from the previous location to the middle of the interval elapsed up to the next location). The average movement orientation was calculated for each animal, based on the direction of the movements between consecutive locations weighted by the distance moved from the previous location. The statistic R was computed, which is equal to the mean vector length and represents a measurement of concentration of the different movement angles. Tests of Rayleigh were carried out to determine if the movement of each animal presented a significant directional orientation (null hypothesis: $R = 0$) (Batschelet, 1981).

RESULTS

Similar movement patterns were observed in juveniles of *M. squinado* during the summer and winter-spring experiments. In the summer the 3 tagged animals were tracked between 20 and 25 days; they carried out small scale movements within a restricted area. The maximum distance between locations was 103 m, with a mean speed for the different crabs ranging from 4.9 to 13.7 m/day (Table 1, Fig. 2). These movements were carried out in small areas, mostly with rocky bottoms, where the animals were located at mean depths ranging for the different specimens from 2.6 to 5.8 m (Table 1, Fig. 3). The temperature in this area during the study period fluctuated between 15 and 18°C (Fig. 3). At this time of year, in the shallow zones inhabited by the juveniles, temperatures may change as much as 2°C during the course of the day or between areas that are only tens of meters apart.

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Table 1. *Maja squinado*. Average distance, speed of movement and direction for juveniles (using landmark and buoy data) and adults (using GPS locations). Average juvenile bearings were not calculated due to the lack of directionality of individual tracks. For adults, two phases of movement are differenciated (see text for details).

	JUVENILES			ADULTS		
	Summer	Winter	Total	1st phase	2nd phase	Total
Number of crabs	3	5	8	5	6	7
Carapace length (mm)	123	98	107	--	--	151
Tracking time (days)	23.3	55.7	43.5	52.9	27.6	61.4
Number of observations (1)	16.7	12.8	14.3	14.8	5.0	14.9
Distance (m)	235	250	244	919	1805	2203
Speed (m/day)	9.7	4.5	6.5	22.1	75.8	51.4
Depth (m) (1,2)	4.1	4.8	4.5	7.3	14.0	10.2
Bearing respect to north (R) (3)	--	--	--	300.9	318.3	310.6
				(0.540)	(0.901)	(0.674)
Average R - GPS	0.190	0.266	0.237	0.353	0.805	0.584
Average R - Buoys	--	0.104	--	--	--	--

(1) Excluding observation corresponding to release.

(2) Mean depth for each animal calculated weighting by time each location.

(3) Average bearing calculated from individual angles weighted by parameter R of each animal (in parenthesis, the statistic R obtained for this average angle).
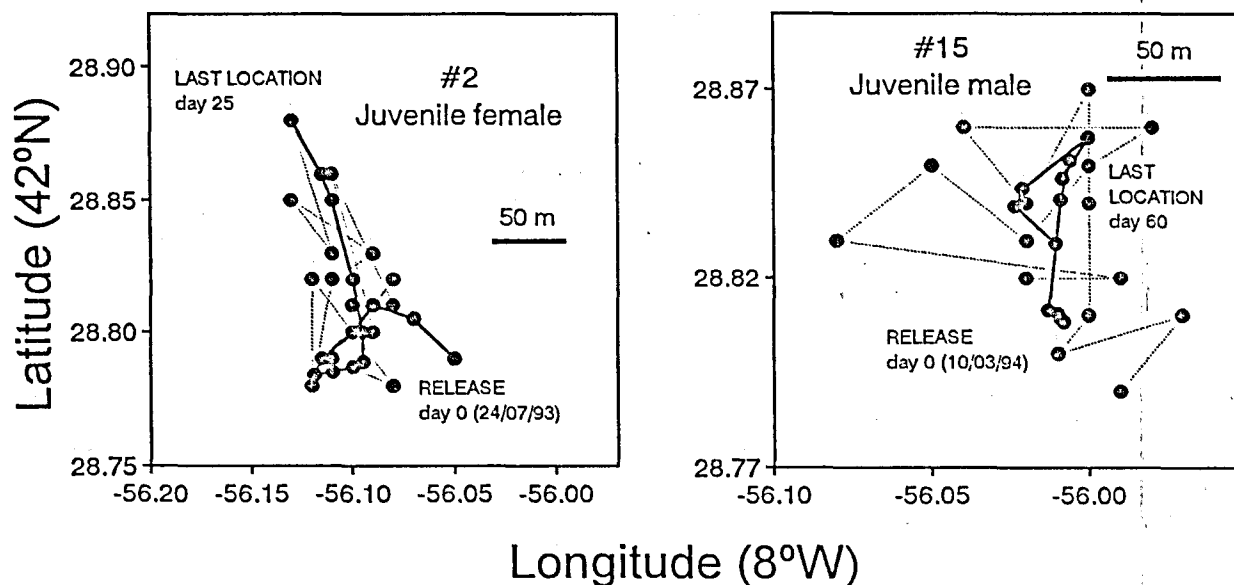

Figure 2. *Maja squinado*. Examples of movements of juveniles in experiments in summer (#2) and winter (#15). Locations corresponding to GPS, coastal landmarks (summer), and buoys (winter) are shown.

Five juveniles were tracked in winter-spring during a period of 50-60 days; the mean speed, between 3.5 and 6.1 m/day for different animals, was lower than in the summer experiment, although the differences were not significant (t-test, $P > 0.05$). Distances of up to 250 m between consecutive locations were recorded, which were higher than the summer values as there was a longer time interval between locations. The animals were located on rocky bottoms except in one observation, and at a mean depth ranging from 3.0 to 6.6 m (t-test, $P > 0.05$, comparing both experiments) (Fig. 3). The mean temperature during this experiment ranged between 12 and 15.5°C. An increase of 2°C was observed during the final stage,

which coincided with the beginning of spring (Fig. 3). The spatial variability of the temperature was lower than in the summer.
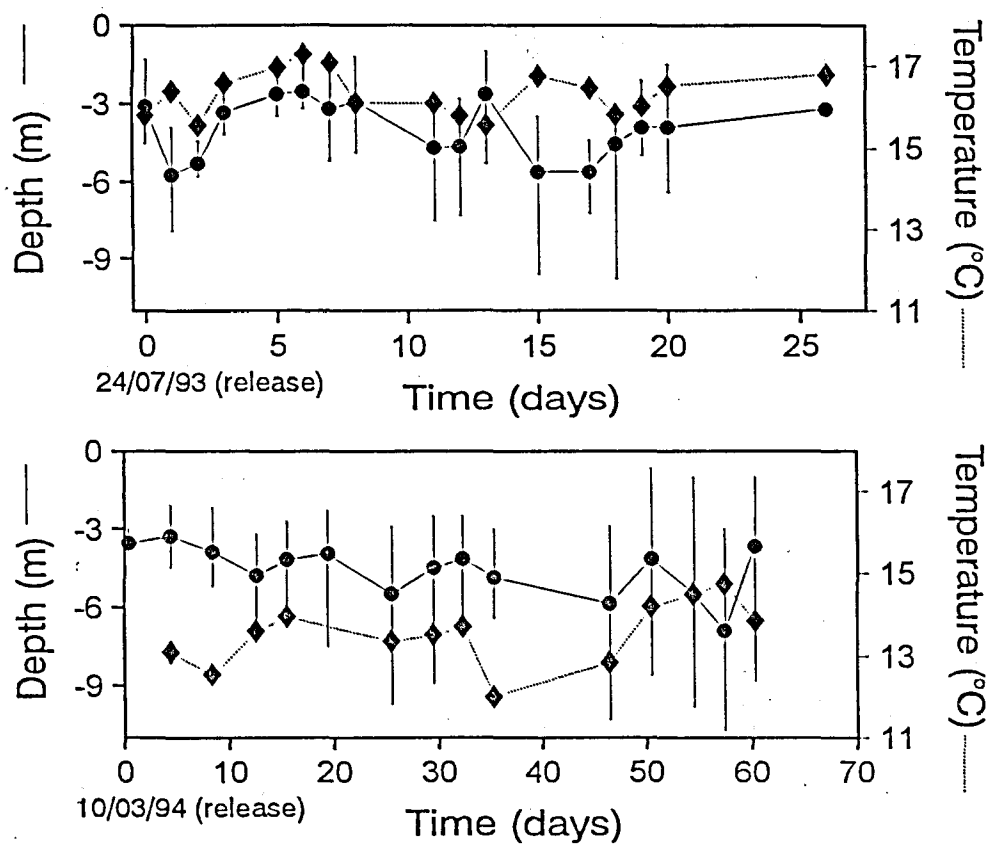

Figure 3. *Maja squinado*. Mean depth and bottom temperature corresponding to the locations of juveniles tracked in summer and winter. Maximum and minimum individual depths are also shown.

Juveniles did not show significant directionality in their movements in either experiment (Table 1; tests of Rayleigh, $P > 0.05$). The R statistic had a value that ranged from 0.086 to 0.268 for the animals tagged during the summer experiment (GPS data), while in the winter-spring experiment, R had values from 0.175 to 0.365 based on GPS and from 0.063 to 0.205 using compass measurements (t-test, $P > 0.05$, comparing values based on GPS for both experiments).

The tracking period for adults oscillated between 23 and 142 days (Table 1). The duration of the tracking period was determined by battery life in 4 crabs, and by the impossibility of locating 3 animals in periods of inclement weather conditions coinciding with large scale movements. Two movement phases were defined for adults in terms of speed, distance covered, and directionality. During the first phase of tracking, after their release in shallow areas where the animals undergo the pubertal moult, the movement patterns were similar to those of juveniles (Table 1, Fig. 4). The average speed ranged from 13.4 to 18.7 m/day (excluding one specimen which was located daily) (t-test, $P < 0.05$ comparing juveniles and first phase of adults). During this first phase, adults were observed in shallow zones with predominantly rocky bottoms, although at slightly greater depths than in the case of juveniles (t-test, $P < 0.05$). The depth of the locations ranged from 3.5 to 11.6 m, with an average value for the different animals of 4.8 to 9.4 m (Table 1; Fig. 5).

The beginning of the second phase was characterized by movements on a larger scale (over 500 m between consecutive locations 5-7 days apart) and the animals moved towards deeper areas (Table 1, Figs. 4 and 5). The mean speed of movement in this second stage ranged

between 34 and 138 m/day (t-test, P<0.05, comparing the first and second adult phases), and movements of up to 2627 m in a period of 7 days between locations were observed. In this second phase animals frequently presented periods of small scale, non-directional movements, in between times when large distances are covered. During the time we were able to continue tracking the animals in the second phase, locations were recorded at depths of 4 to 38 m, with a mean value of 8.7 to 23.3 m for the different crabs, significantly higher than in the first phase (t-test, P<0.05). These movements indicated a transition often from rocky to soft substrates, as depth increases, although the animals occasionally passed through rocky areas. Adults began the phase of large scale movements in late summer and autumn, and only one crab did not started the second phase of movement during the experiment.
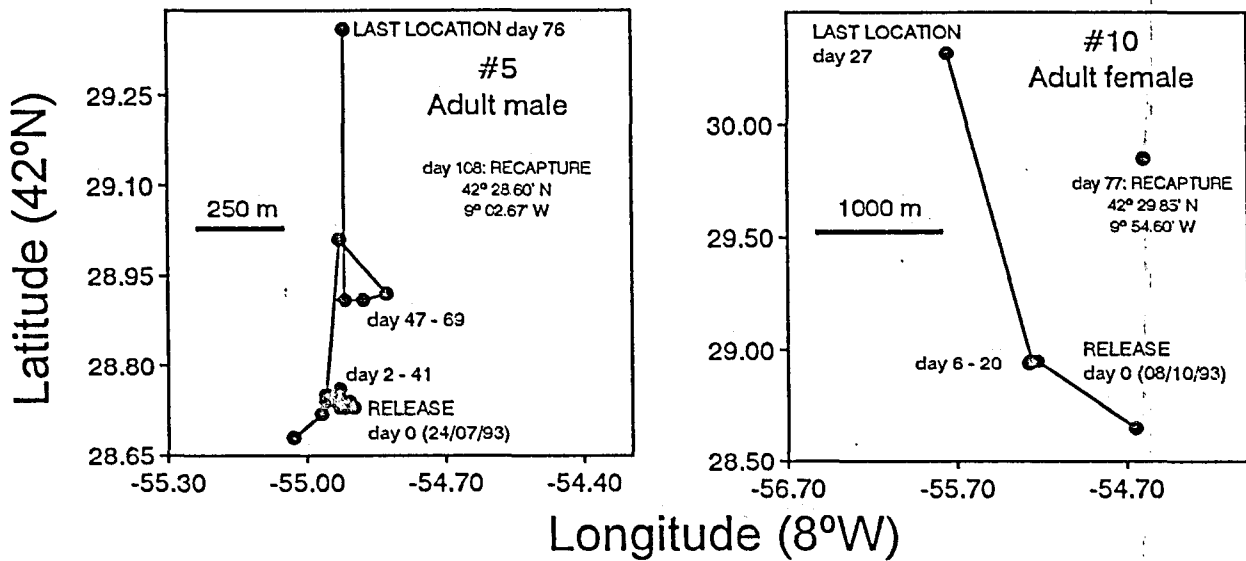

Figure 4. *Maja squinado*. Examples of movements of adults determined by GPS location.
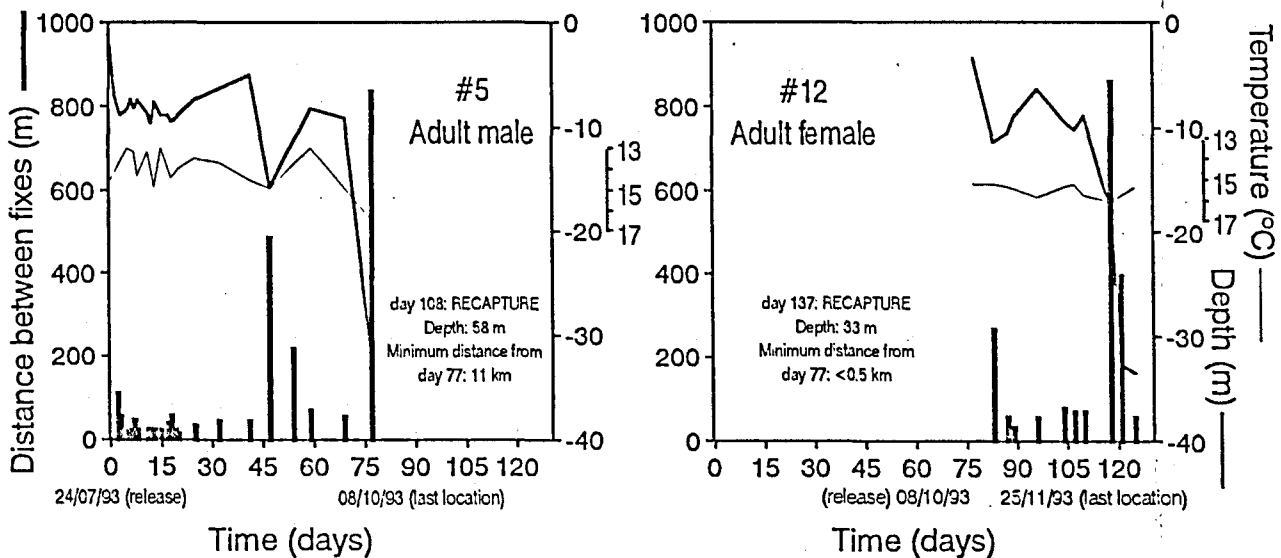

Figure 5. *Maja squinado*. Depth, bottom temperature and distance between consecutive locations for two of the tracked adults. Animal #12 was tagged with a temperature transmitter, whereas temperature data for the crab #5 was recorded at the location point. Day 0 = 24/07/93.

Adults showed no directionality in their movements during the first phase (tests of Rayleigh, P>0.05 for all animals except one) and the value of the statistic R (range = 0.099-0.698) was not significantly different to juveniles (t-test, P>0.05). During the second phase there

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was a higher directionality of movement (t-test, P<0.01, comparing the statistic R between the first and second phase of adults), with values of R always greater than 0.62, although given the small number of locations for each animal, it was possible to test for significance only in in one case (P<0.05). If the two tracking phases are analyzed together, a significant directionality can be observed (P<0.05) in all the animals except one. The mean angle of movement orientation in the second phase varied between 286 and 3° in the different animals. These movements correspond to a bathymetric gradient, and the crabs moved in the direction of the central channel and the outer area of the Ría (Fig. 6).
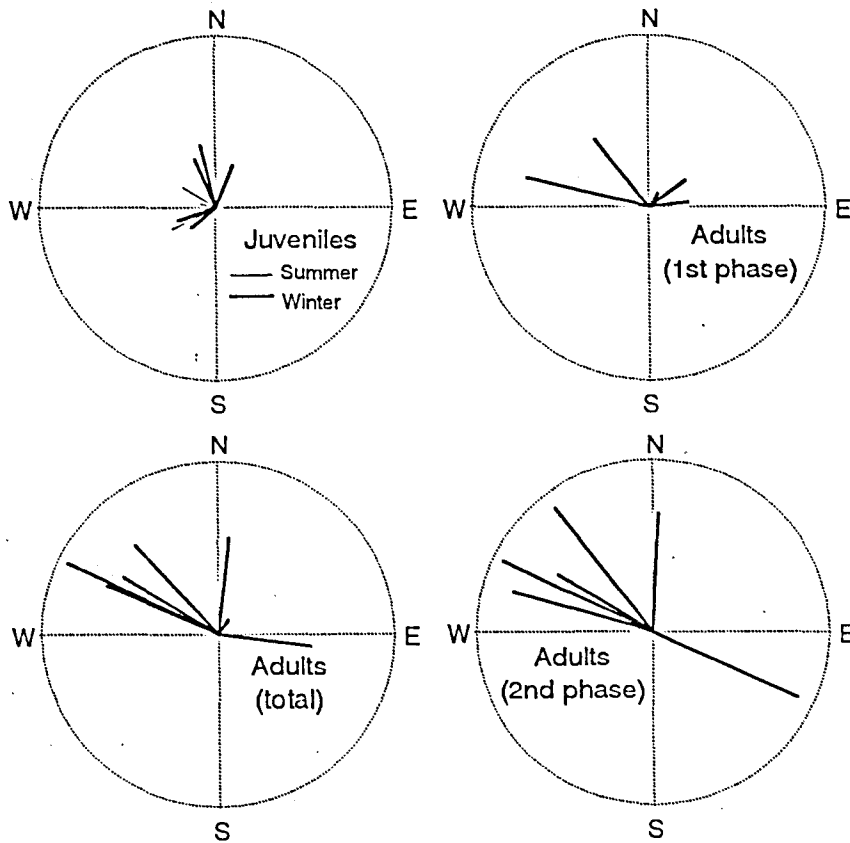

Figure 6. *Maja squinado*. Average angles of movement in juveniles (corresponding to summer and winter experiments) and adults (1st and 2nd phase and for the whole tracking period). Vector length is proportionate to directionality of movement (statistic R; radius of the circunference R = 1).

The first phase of tracking of adults coincided with the summer experiment for juveniles, and was carried out in the same area, with similar temperature values. At beginning of autumn, temperatures decreased in the shallow zones by around 2°C, and from October on, they did not go above 15°C. There were no major thermal changes when adults moved from the shallow areas to the deeper zone. In fact the animals occasionally moved to areas where the temperatures were initially higher than those in the areas where they have come from (Fig. 5).

DISCUSSION

The spider crab *M. squinado* shows seasonal differences in the activity and distribution of juveniles and adults. For this reason, the fishery in Galician waters, essentially carried out with tanglenets, targets adults during periods of high activity while they are carrying out large scale movements. Also there is a marginal, artisanal glass-box fishery in shallow waters to catch juveniles (González-Gurriarán et al., 1993, 1994, unpublished data). In other geographical areas, habitat differences (substrate and depth) between juveniles and adults and between

sexes have been mentioned (Bourdon, 1965; Kergariou, 1971, 1984; Kergariou & Veron, 1981; Stevcic, 1973; Edwards, 1980).

The activity patterns of juveniles in the Ría de Arousa both in summer and winter are characterized by slow speed movements (<10 m/day), which are not directional. Each animal moves in a restricted area within the available habitat, and were located at mean depths <7 m (Fig. 7). Although it is feasible to catch juveniles both from rocky bottoms and soft substrates, in the telemetry experiments all the animals were caught and released in rocky kelp beds. On no occasion were they found in sandy zones during the tracking period; however some of the animals probably moved across this type of bottom between locations. Our results show that no movement occurs between isolated favourable habitat zones, although we do not rule out the possibility that this may occur if tracking were carried out for longer periods of time. Different authors point to the juvenile distribution in delimited coastal zones, characterized by seagrass beds in spring (Kergariou, 1971, 1984) and soft substrates, in general, at depths of under 15 m from spring to autumn (Le Foll, 1993), or throughout the yearly cycle (Meyer, 1993). Distribution and habitat utilization patterns of juveniles may be related to predator avoidance and to the search of areas of high temperature to optimize growth in summer.
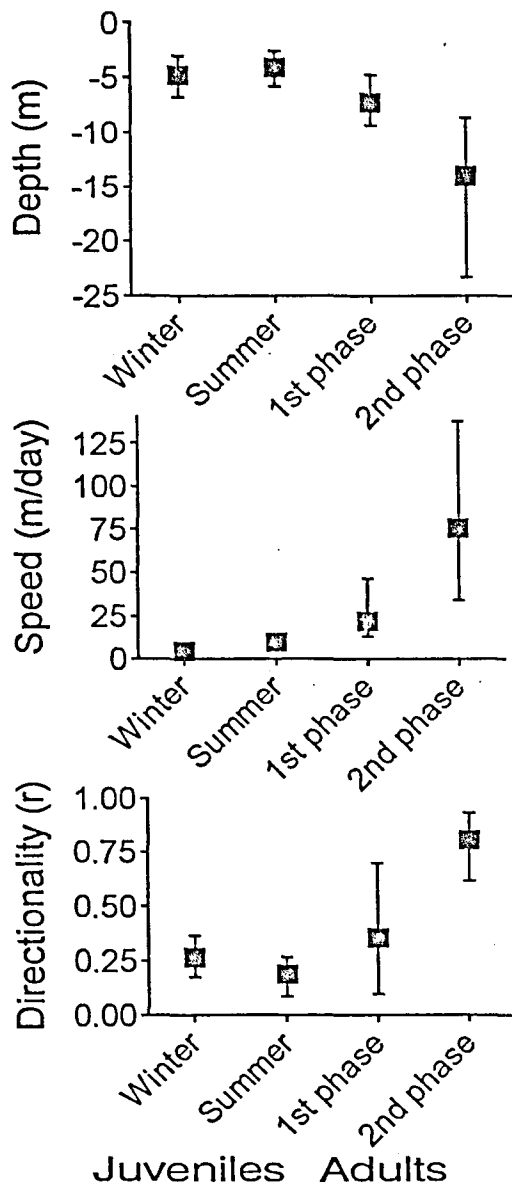

Figure 7. *Maja squinado.* Depth, movement speed and directionality (*R*) in juveniles during summer and winter experiments and adults during the 1st and 2nd phase. The mean value for the different animals tagged and range (maximum and minimum individual mean value) are shown.

Previous information on the activity rhythms of *M. squinado* is based on mark-recapture studies with conventional tags, which analyze large scale movements in adults (Stevcic, 1973; Kergariou, 1976; Bussani & Zuder, 1977; Edwards, 1979, 1980; Camus, 1983; Latrouite & Le Foll, 1989; Le Foll, 1993). The adult migrations described take place in autumn and are directed towards deep zones, perpendicular to the bathymetric slope or with another specific orientation. In spring animals migrate in the opposite direction. From the mark-recapture data available, it is not possible to give a detailed description of adult movement patterns (speed, depth and orientation, during the migration period or when they remain stationary), and to identify the causal mechanisms of the activity changes. Our results show that there are no major differences between the activity of juveniles and adults immediately following the terminal moult; however, among adults two clearly defined behavioural phases can be distinguished over time. After the pubertal moult, *M. squinado* carries out non-directional movements, similar to those of juveniles, but the average speed is greater. During this first pahse, they tend to move to slightly deeper zones within the same habitat, although mean depth is less than 10 m (Fig. 7).
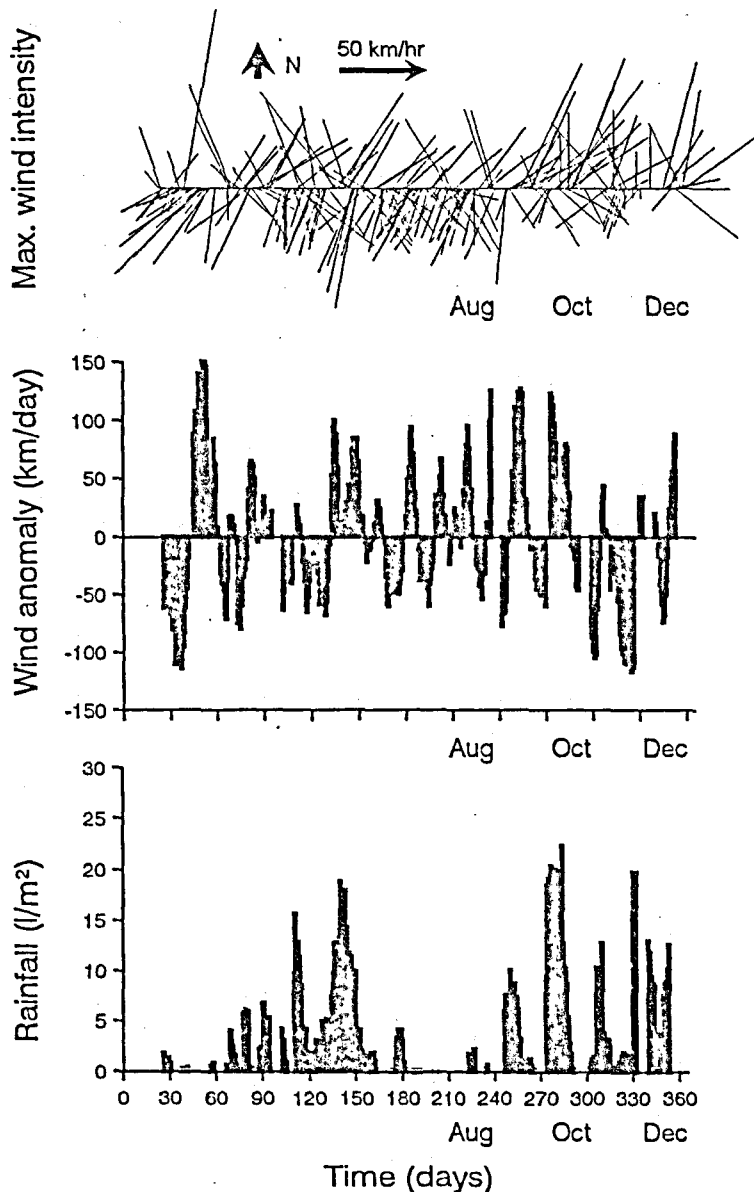

Figure 8. Daily time series of meteorological data in the Ría de Arousa during 1993. Maximum wind speed and direction, anomaly of the daily wind displacement with respect to the annual mean, and rainfall are shown. Anomaly of wind displacement and rainfall correspond to a moving average of 5 days. Data provided by the Centro Meteorológico Zonal de A Coruña for the station at Vilagarcía de Arousa.

After a period of 1-3 months has elapsed from the time when most animals undergo the pubertal moult (July-August, González-Gurriarán *et al.*, 1994, unpublished data), a second phase of movements begins, representing the start of the autumn migration cited by other

authors (reviewed by Le Foll, 1993). During this phase adults carry out long-range movements of up to 2 km in one week, with an average speed an order of magnitude greater than in the first phase (Fig. 7). During this phase, there are intermediate stationary periods, which means that the speed at the time of maximum activity could be much greater. In the hours following the release of the animals, speeds as high as 77 m/hour were recorded. The mean speeds quoted by other authors for the autumn migration, based on mark-recapture data, ranges between 9.6 km/month (Latrouite & Le Foll, 1989; Le Foll, 1993) and 20.5 km/month (Camus, 1983). In our study 5 of the 7 adults tagged were caught by the local fishery, during the 7 month period following the start of the experiment, with the greatest distance covered between the point of the last location to the place where it was recaught being 10.7 km in 31 days. The large scale movements are clearly oriented to the the central channel and the mouth of the ría. In the same way, the autumn migrations in the Gulf Normano-Breton and on the French Atlantic coast are oriented towards bottoms having depths of 50-70 m, where the animals remain relatively stationary for the winter (Le Foll, 1993). Some authors have hypothesized that the variability of movement orientation between different geographical areas depends on the coastal topography and dominant currents in the zone (Kergariou, 1976; Edwards, 1980; Camus, 1983; Latrouite & Le Foll, 1989), with the animals seeking out higher temperatures, or in some cases, a bathymetric slope (Latrouite & Le Foll, 1989) or they may be determined by the residual currents in order to compensate for larval drift (Camus, 1983; Le Foll, 1993).
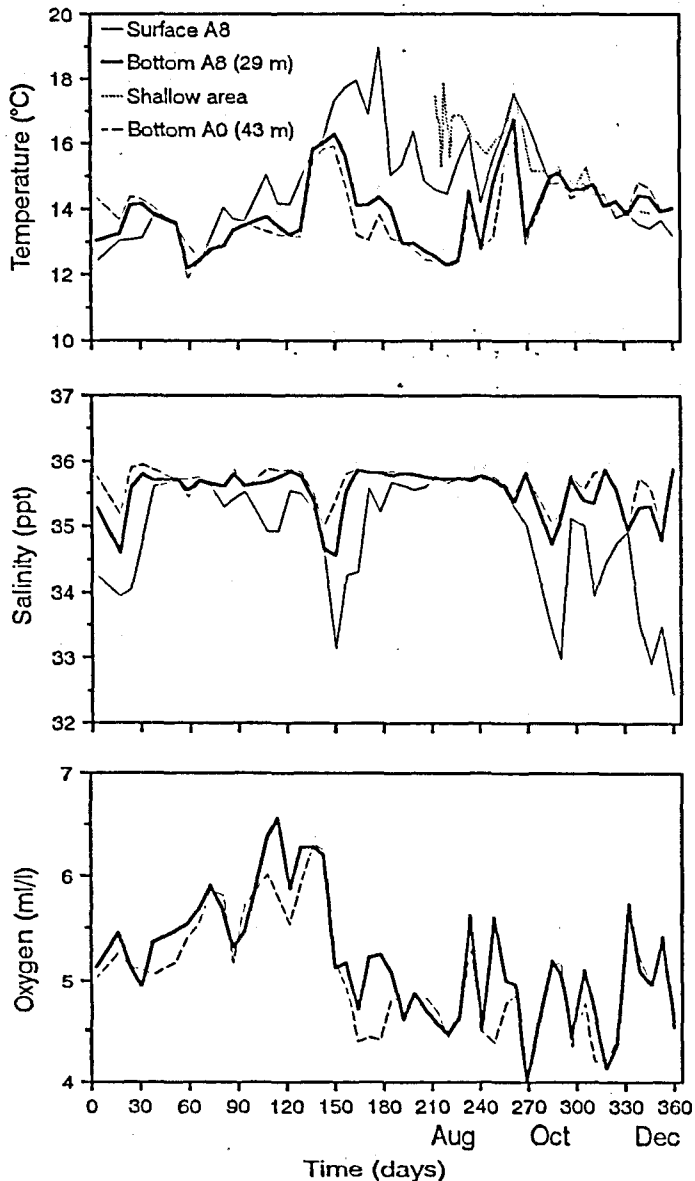

Figure 9. Weekly time series of temperature, salinity and dissolved oxygen on the surface and bottom waters in stations A0 and A8 during 1993. Temperature throughout the study period is shown in one of the shallow zones where the experiment started. Data provided by the Centro Galego para o Control da Calidade do Medio Mariño (Consellería de Pesca, Marisqueo e Acuicultura of the Xunta de Galicia).

According to our results, in the Ría de Arousa, the movement of the animals towards deeper areas coincided in time with a complex change in environmental conditions: variation in the prevailing winds (and probably the dominant currents), the start of a season with heavy rainfall and a decline in salinity, and a sharp drop in the shallow water temperature (Figs. 8 and 9). In September the prevailing winds, which during the summer were NE-N, shift and became predominantly SW; rainfall increased as well. In waters near the areas where the animals were released, the salinity on the surface layer decreased from 35.6 ppt in summer to 33.0 ppt, while the bottoms show smaller fluctuations and salinity never fell lower than 34.6 ppt. For the duration of the study there were no major changes in dissolved oxygen on the bottom.

The summer temperatures were high and variable in the shallow zones and surface layer of the deeper waters (the highest values recorded were over 18°C), whereas at depths of 30-40 m, they were more stable and around 2°C lower. The beginning of the second phase of movement in adults coincided with a temperature decrease in the area they occupy, with temperatures of approximately 15°C in October, reaching 12-13°C in winter. In contrast, the deeper zones which are closer, coinciding with the direction of the migration, had slightly higher temperatures in winter than the bottoms where the animals had come from (Fig. 3, 5 and 9). The beginning of gonad maturation in females in the Ría de Arousa (González-Gurriarán et al., 1993) coincides with the start of the second phase. This process is temperature-dependent (Stevcic, 1971a; González-Gurriarán et al., 1993, unpublished data) and may be favoured by avoiding the temperature drop in shallow waters in autumn-winter. The existence of directionality may be related to the fact that both sexes must coincide in space during or after the autumn migration, as mating takes place outside the shallow zones where the pubertal moult occurs (González-Gurriarán et al., 1993). The return of adults to shallow zones in spring has been related to the search for warmer temperatures that will favour egg incubation and hatching (Stevcic. 1971a, 1973, 1975) and assure recruitment in favourable zones (Le Foll, 1993).

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