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Migratory patterns in the spider crab *Maja squinado* using telemetry and electronic tags

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Abstract

Migrations play a key role in the life history of the spider crab *Maja squinado* and determine fishery catches. These movements involve an important bathymetric gradient and a change in the oceanographic environment. Ultrasonic telemetry has a number of drawbacks in the study of migrations stemming from the difficulty in the continuous tracking of crabs moving to deep offshore waters. The recent introduction of electronic data storage or archival tags allows for the continuous monitoring of depth and temperature in the inmediate habitat of the crabs, and for the reconstruction of the movement patterns using baseline data on habitat characteristics. This study was carried out on the Galician coast (NW Spain) for the calibration and use of electronic tags as a tool to study the migrations of the spider crab. In the summer of 1996, crabs were tagged with both ultrasonic transmitters and electronic tags for temperature and depth. Tracking was carried out discontinuously, at intervals of approximately 1 week, in order to locate the individuals with telemetry. Our results show a recapture rate of approx. 70% and the information provided by telemetry and electronic tags point to autumn migrations along bathymetric gradients (from areas of < 10 m deep to zones of up to 100 m) in short periods of time (mean=5.7 days, range=1.3 - 13.6 days). During these movements crabs travel through environments characterized by different temperatures and substrates. The available data on the bathymetry and oceanography of the study area and the records of the electronic tags could make it possible to reconstruct the tracks of the tagged individuals.

Introduction

Migratory movements are a key process in the life history and fishery of the spider crab *Maja squinado* (Decapoda, Majidae) in the NE Atlantic (González-Gurriarán & Freire, 1994, Freire *et al.*, in press). Spider crab juveniles inhabit shallow (<15 m) rocky and sandy areas (González-Gurriarán and Freire, 1994; Hines *et al.*, 1995). 2+ year old juveniles attain sexual maturity after a terminal moult that takes place in summer (González-Gurriarán *et al.*, 1995, unpublished data). Postpubertal adults carry out an autumn migration to deep bottoms (González-Gurriarán and Freire, 1994; Hines *et al.*,

1995) associated with the beginning of the development of the seminal receptacles and gonad maturation in females (González-Gurriarán *et al.*, 1993, 1998). On the southern coast of Galicia (NW Spain), the annual breeding period ranges from March to November, with hatchings mainly occurring from May to November (González-Gurriarán *et al.*, 1993, 1998). Mating occurs in the wintering habitats, when females have gonads in an advanced maturation stage (González-Gurriarán *et al.*, 1998).

In Galicia, the official fishing season of *Maja* opens in November or December (depending on the area and year), which coincides with the final stage of the autumn migration (Freire *et al.*, in press; this paper). Prior to this, the fishery starts in September, yielding considerable catches. The fishery is carried out primarily with tangle- and gill-nets, and catchability is contingent upon the behaviour of the animals - mainly their directional or migratory movements. In fact, the spatial distribution of the fishing effort changes seasonally: first, it concentrates mainly on bottoms near the shallow waters where the terminal moult takes place, and in the deeper zones in winter. Most of the catches in the Ría de Arousa and adjacent coastal areas (southern Galicia) are carried out during the initial stage of the fishing season, which coincides with the migration period - from 1989 to 1992 an average of 45% of the official landings from the tangle-net fishery were carried out prior to January and 66% prior to February (Freire *et al.*, in press; unpublished data).

The migrations of the spider crab have been studied using different methodologies ranging from the analysis of spatial and temporal changes of population structure (Meyer 1993) to the use of mark-recapture methods (Camus, 1983; Latrouite & Le Foll, 1989). A detailed analysis of the behaviour of juveniles and post-pubertal adults in shallow waters and during the early stages of migration has been carried out using ultrasonic telemetry (González-Gurriarán & Freire, 1994; Hines *et al.*, 1995).

In the spider crab, the use of telemetry for the study of migrations entails a number of logistic complications. Small boats, which are easy to manoeuvre in the shallow waters, are required to be able to monitor a large number of crabs in a short time. Another complication is due to the weather conditions, which during the autumn and winter prevent field work in the sea for extended periods of time. In addition to the above complications, the available data would appear to indicate that each crab has a very short migration period, which means that it is extremely difficult or even impossible to monitor them during the migration using telemetry (Freire & González-Gurriarán, 1998).

The recent introduction of electronic data storage tags or archival tags allows for the continuous monitoring of the immediate environment of the animal (Metcalfe *et al.*, 1994; Gunn *et al.*, 1994, Freire & González-Gurriarán, 1998). Based on the fact that the migrations of the spider crab *Maja* involve important bathymetric changes and movements through water masses having different oceanographic characteristics (temperature and salinity) (González-Gurriarán & Freire, 1994; Hines *et al.*, 1995), this study was designed to calibrate and use electronic tags as a tool to study migrations. Monitoring depth and water temperature using electronic tags could allow for the characterization of the large-scale (migratory) movements of the spider crab and the reconstruction of their tracks. Moreover, earlier data point to a high fishing mortality rate (tangle-nets and glass-box gears) on the SW coast of Galicia (Freire *et al.*, in press), and previous telemetry experiments had over 70% recapture rates (using advertisings and rewards to incentive fishers).

MATERIAL AND METHODS

The crabs were caught and tagged in the shallow waters of the outer area of the Ría de Arousa and then released in the same area (Fig. 1). These areas are the typical shallow habitats (<10 m), with mixed rocky and sandy bottoms, of juveniles and postpubertal adults in the early stages after the terminal moult. The crabs were caught, tagged and released in the summer of 1996 (8 multiparous females on 17/07/96 and 9 primiparous females on 29 and 30/8/96). The study was also designed to compare the behavioural patterns of primiparous and multiparous adult females (in their first annual reproductive cycle or consecutive cycles, respectively; see González-Gurriarán *et al.*, 1993, 1998), although this subject will not be analysed in this paper.

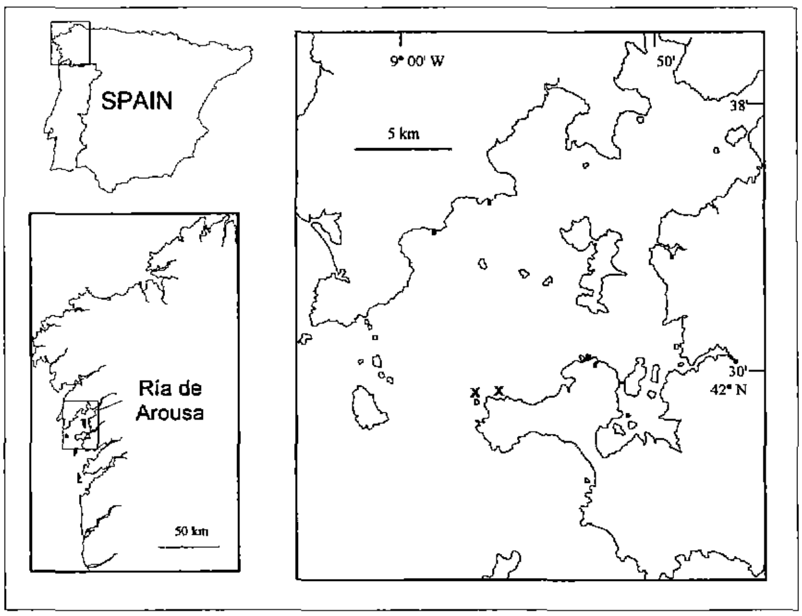

Figure 1. Ría de Arousa (Galicia, NW Spain). The shallow water areas where crabs were captured and released are indicated (X).

Each crab was tagged with an ultrasonic transmitter (V16 of VEMCO, Canada or CHP-87-S-M of SONOTRONICS, USA) and an electronic tag for temperature and depth (DST-100 of STAR ODDI, Iceland or occassionally MINILOG-TDX of VEMCO) which recorded these variables every 2 hours (for data analysis, depth was corrected by tidal height and it is represented here with respect to MLWS). The electronic tag and the transmitter comprised <5 % of the body weight (mean body weight of tagged females = 1053 g; range = 800 - 1500 g). Tracking was carried out discontinuously, at intervals of 3 - 15 days, with the exception of one interval of 22 days (average 7.9 days). The work at sea lasted until 13 November 1996, when bad weather made it impossible to continue. The objective of the telemetry work was to locate the animals in shallow waters and along the central channel of the ría, where depths range from 30 to 70 m (the zone of transit during the migration periods) and in the deep zones of the continental shelf near the mouth of the ría (60 to 100 m depth), which serve as migration zones and wintering habitats for adults.

Water temperature was monitored each 15 min with data loggers deployed at nominal depths of 5 and 10 m in the shallow area where crabs were captured and released. Complementary oceanographic data (surface and bottom temperature and salinity) were obtained from weekly CTD records carried out by the Centro Galego para o Control da Calidade do Medio Mariño (Xunta de Galicia) in two stations located in the Ría de Arousa at depths of approx. 40 m (A8 in front of the shallow water study area and A0 in the mouth of the Ría). Meteorological data (wind stress and direction and rainfall) of the zone were obtained from the Centro Meteorológico Zonal de A Coruña.

RESULTS AND DISCUSSION

A recapture rate of 68.2 % (15 recaptures from 22 releases of tagged females; some females were released after a second recapture in shallow waters) was found, which confirms the suitability of the use of the commercial fishery (combined with advertisings and rewards) as the recapture method. The time series of the depth and temperature of the crab habitat obtained from the records of the electronic tags (Fig. 2) allow us to characterize the movements along the bathymetric gradient. In this way, we may define 3 behavioural phases depending on the rate of bathymetric change: stationary, descent migration to the deep waters, and ascent migration to the shallow waters (Table 1).

The stationary phases make up the most frequent behaviour prior to the start of the migrations. They are characterized by limited movements around the bathymetric axis (1.0 m/day) which range between bottoms located at a mean depth of 9.6 m MLWS and intertidal areas. During these phases, the water temperature undergoes sharp fluctuations, pointing to the presence of relatively warm water masses (15-18 °C) which are shifted

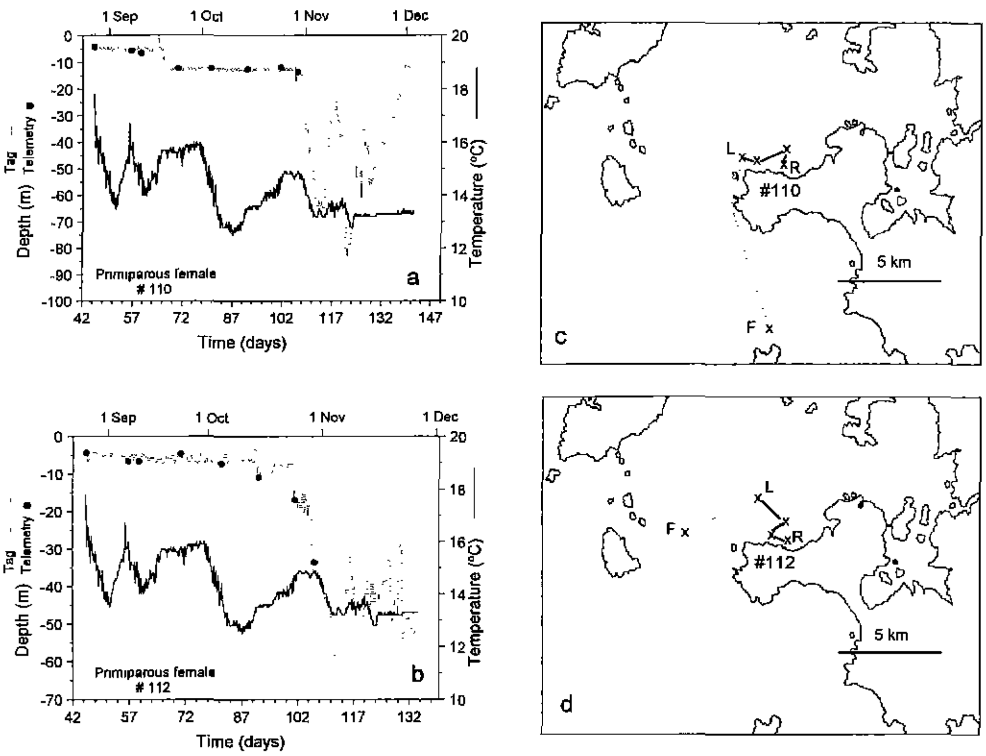

Figure 2. (a, b). Examples of time series of habitat depth and temperature for two female spider crabs tagged with electronic tags and ultrasonic transmitters. Depth has been corrected by the tidal height and it is represented respect to the MLWS. (c, d) Locations obtained using ultrasonic telemetry of the same crabs (R, release; L, last location by telemetry; F: location of recapture by the commercial fishery).

every 7-15 days by masses of upwelled water (12-13°C). The crabs experience from 1 to 3 stationary phases prior to the descent migration, which are separated by rapid, but unimportant bathymetric shifts, suggesting small-scale changes in habitat (either towards areas that are somewhat deeper or between areas having equal depths separated by deeper transit areas).

With the bathymetric recordings of the stationary phases it is possible to test the existence of rhythmic behaviours (associated with diel or tidal rhythms) which would be reflected in changes in activity or movements, and of associations between changes in activity and environmental conditions. A preliminary analysis of the autocorrelation functions of habitat depth during each stationary phase of all the crabs and of cross-correlation with tidal height and water temperature was carried out to investigate the potential relationships between the variables of interest (Fig. 3). We did not find a generalized cyclical pattern of vertical movement or any association with tidal cycles. In contrast, the autocorrelation functions of microhabitat temperature did, however, exhibited alternating phases of warm and cold water, that could be related to the upwelling processes

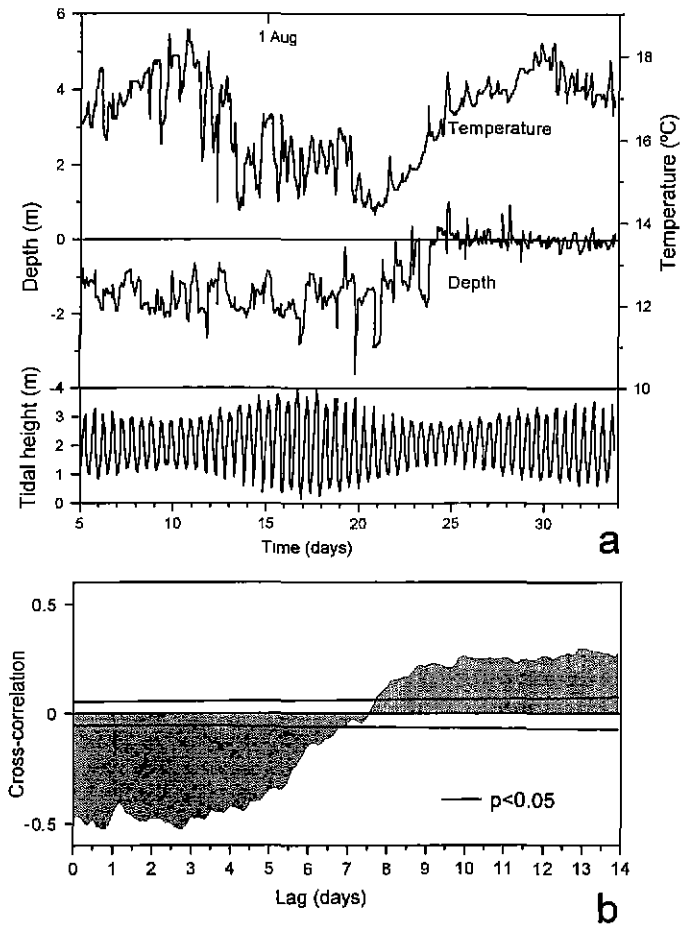

Figure 3. Example of a stationary behavioural phase of a spider crab in shallow waters. (a) Time series of habitat depth (corrected by the tidal height) and temperature, recorded with an electronic tag, and of tidal height. (b) Cross-correlation function of depth and temperature (depth is lagged behind temperature; both variables were detrended with a linear function).

mentioned earlier. With regard to these changes in the thermal environment, we found significant cross-correlations between temperature and depth with lags of between 0 and 15 days, although the pattern is complex and contingent upon the specific thermal conditions of each stationary phase and on seasonality (proximity to the start of migration). These results suggest that the small-scale movements of adult females in shallow waters may be related to thermal changes, and therefore to processes of water mass replacement. A detailed analysis of the potential relationships between movements and environmental changes is being performed now.

After the stationary period in shallow waters, the information provided by the electronic tags (corresponding to 8 crabs) point to autumn migrations defined by important bathymetric changes during short periods of time (Table 1). During these migrations, females moved from an average depth of 13.0 m to 53.9 m (range of maximum depths: 20-94 m), at a mean velocity of descent of 8.9 m/day. The mean duration of these movements to deep waters was 5.7 days (range= 1.3-13.6 days) and occurred in early November (mean starting date of migratory movements: 1 November). Migration was found to be clearly co-ordinated, as 6 females started movement within a week of each other (from 25 October to 2 November), while two other crabs started migration on 12 September and on 15 January. During the course of these movements, the tagged females travelled through clearly differentiated thermal environments (Fig. 2).

Given the high fishing mortality (and therefore the high recapture rate) during the initial stages of this study, most of the recaptured animals did not have the chance to carry out the characteristical ascent migration to shallow waters. We only acquired data on this process in 3 cases (Table 1). These data may be biased, as the probability of obtaining information on the ascent migration is greater in animals that carry out these movements earlier. In fact, the mean starting date of this migration (28 November) was extremely close to the end of the migration to deep waters (7 November) and the only ones recorded were in November and December, while some migrations of descent, were, however, recorded later. The velocity of bathymetric change in this migration phase to shallow waters was 12.0 m/day, with females returning to mean depths of 7.3 m.

An analysis of the gonad maturity stage, the content of the spermatheca and the presence of a brood in the recaptured females (whose migratory history is known) (Freire *et al.* in press; unpublished data) confirmed previous hypotheses on the role of migrations in the life history of the spider crab (González-Gurriarán *et al.* 1998). Females caught before or during their migration to deep waters did not carry out spawning. On the other hand, those caught after this migratory phase had already mated and spawned for the first time. These observations suggest that the wintering habitats in deep waters provide mating zones (probably involving the formation of aggregations), and the females return to shallow waters after spawning, where they find warmer temperatures that will accelerate incubation. They may also choose habitats that promote the dispersal of larvae to favourable zones for recruitment.

With telemetry tracking we were able to confirm the conclusions drawn from the analysis of the electronic tag recordings (Fig. 2), specially during the stationary phases in which movements were restricted to distances of <<100-500 m, and consistently occurred on shallow bottoms. The telemetric location allowed only a very rough characterization of the migration to deep waters, as only a limited number of locations (<15) were obtained of each specimen before it was "lost" (either because weather conditions made it impossible to work at sea during extended periods of time or because it was impossible to detect the ultrasonic signal, although a wide area was tested, most likely due to the great distance covered by the crab after the previous recording of its location). Lastly, we were not able to track any of the animals in the final stage of the descent migration, in the wintering habitats or in the ascent migration to shallow waters.

Table 1. Descriptive statistics of the different behavioural phases of the spider crab defined through the analysis of the time series of habitat depth recorded with electronic tags. Mean ± SD are showed. The rate of bathymetric change was estimated for each phase computing the mean of the changes in depth between sucessive days. Depth is represented respect to MLWS (after correcting the tidal height) and for this reason some of the values are negative (above MLWS).

Behavioural phase (No. crabs / No. phases)	Stationary (10 / 21)				Migration to deep waters (8 / 8)				Migration to shallow waters (3 / 3)			
	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min
Mean depth (m)	6.7	3.6	15.6	1.0	36.6	15.2	65.0	14.2	26.0	15.1	43.1	14.7
Depth range (m)	5.7	2.3	10.6	1.3	40.9	21.7	77.9	16.4	39.0	29.3	71.6	15.0
Maximum depth (m)	9.6	3.4	16.3	4.1	53.9	23.0	>96.0*	20.0	46.3	33.0	82.9	20.5
Minimum depth (m)	4.0	4.1	15.1	-1.0	13.0	5.1	17.6	2.2	7.3	3.5	11.2	5.1
Duration (days)	35.1	16.1	73.7	9.8	5.7	3.8	13.6	1.3	12.0	6.8	17.2	4.3
Start date (day 1 = 15 July 96)	59.4	36.2	151.8	2.8	110.6	34.2	184.8	60.0	137.5	21.9	162.6	121.8
	(11 Sep)		(13 Dec)	(16 Jul)	(1 Nov)		(15 Jan)	(12 Sep)	(28 Nov)		(24 Dec)	(12 Nov)
End date (day 1 = 15 July 96)	94.5	45.4	221.5	33.8	116.3	31.9	188.1	73.6	149.6	15.1	166.9	139.0
	(17 Oct)		(21 Feb)	(16 Aug)	(7 Nov)		(19 Jan)	(26 Sep)	(10 Dec)		(28 Dec)	(30 Nov)
Mean bathymetric change (m/day)	1.0	0.5	2.2	0.2	8.9	5.3	19.6	2.3	6.4	4.3	10.0	1.7
Mean temperature (°C)	14.6	0.9	16.5	12.5	13.8	0.6	14.6	12.6	13.2	0.1	13.3	13.2
Temperature range (°C)	3.5	1.0	5.1	1.4	1.3	0.6	2.1	0.3	0.7	0.1	0.7	0.6

* The electronic tags were programmed to record depths only up to 96.0 m

The precise definition of the migration periods through the recordings of the electronic tags has made it possible to analyse their timing in relation to weather (wind stress and direction, rainfall) and oceanographic conditions (temperature and salinity in stations located in the study area) (Fig. 4).

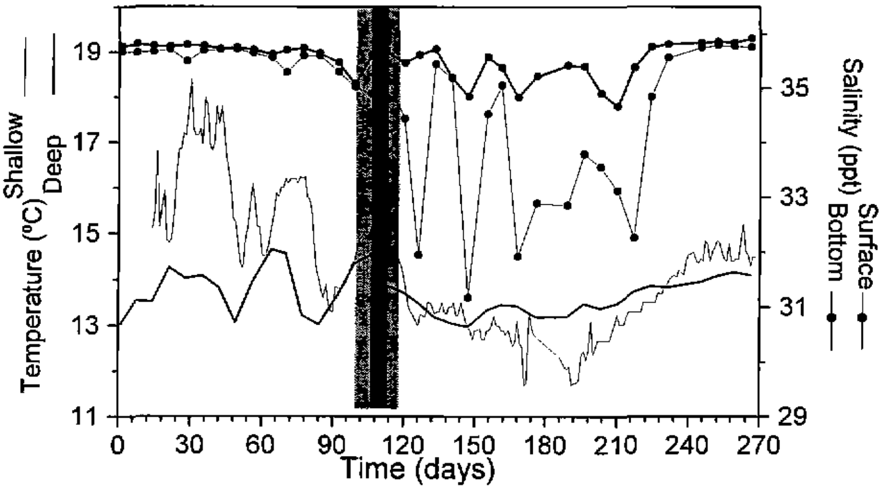

Figure 4. Meteorological and oceanographic conditions in the Ría de Arousa during the study period (the main migratory period, corresponding to 6 of 8 females, is represented: in light grey the period from the start of the migration of the first migrating female to the end of the migration of the last female; in dark grey the period from the average start to the end of the migration for the 6 females). Temperature data correspond to electronic tags deployed at 5 and 10 m in the study area in shallow waters (temperature was recorded each 15 min, only one record per day is presented here) and to bottom temperature obtained from CTD deployments carried out weekly in deep-water stations (approx. 40 m) (one located in front of the shallow water study area, A8, and other in the mouth of the ría, A0). Series corresponding to shallow (5 and 10 m) and deep water (stations A0 and A8) were averaged because differences were minimal. Salinity data correspond to surface and bottom water from the station A8 sampled with CTD.

The main migration period (end of October and beginning of November) was associated with a series of environmental changes that clearly defined two climatic and oceanographic seasons in shallow waters. Shallow water temperature dropped from approx. 16.5°C to 13.5°C about 15 days prior to the migration. This thermic fluctuation was of greater magnitude than the previous ones and temperature remained low after this drop (fluctating between 12 and 15°C), and slightly lower than temperature in deep waters. Inmediately previous to the start of the migration, salinity started to drop from values >35 ppt during summer and the beginning of autumn to 34.8 ppt the average day of the start of the migration. Salinity continued to decrease after the migration attaining mimimum values in shallow waters of 31.2 ppt. Salinity in deep waters remained almost constant with values of approx. 35 - 35.5 ppt. Comparing the meteorological conditions previous and posterior to the migration, winds changed from a predominant N-NE direction to a S-SW increasing their intensity, and rainfall was more frequent and abundant after the migratory period.

Our results suggest that it may be possible to reconstruct the tracks during the migration periods of the animals tagged with electronic tags. In order to do this, we must understand the mechanisms used for orientation, which basically appear to follow the bathymetric gradients in the zone; they carry out movements in the direction of the greatest slope. This aspect is currently being examined by implementing a movement model based on the previous orientation mechanism and the time series of the depth of the habitat occupied by the crabs, which was obtained using electronic tags in a geographical information system including the bathymetry of the area. Oceanographic data (primarily water temperature in depth) from a network of stations located in the study area along with information on habitat temperature provided by the electronic tags will allow for the tracks of the crabs to be adjusted in a second level. Moreover, we have begun a second stage of tagging with the large-scale use of electronic tags in order to determine the spatial variability (between nursery grounds) and between males and females in migration characteristics.

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