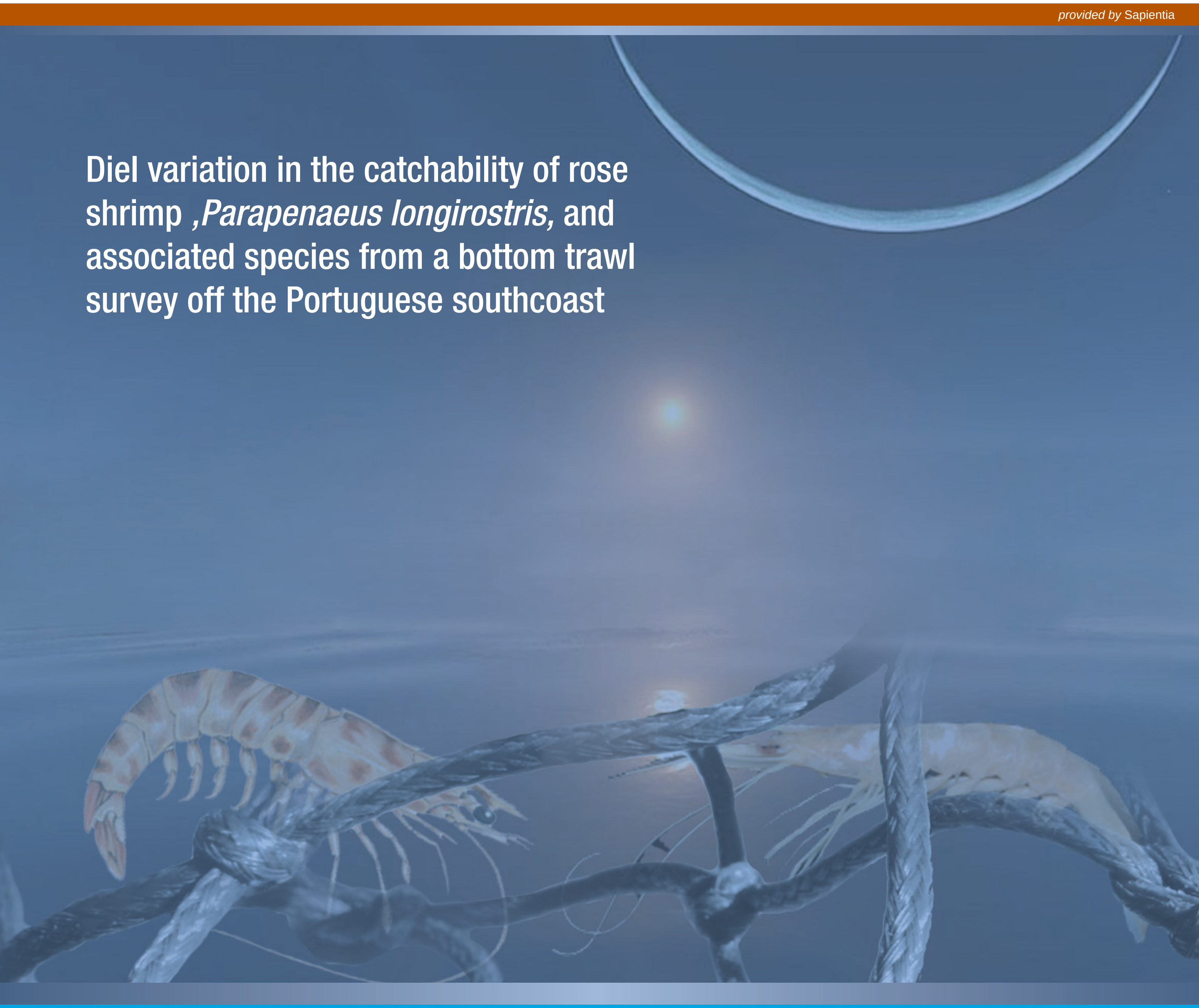

Diel variation in the catchability of rose shrimp ,*Parapenaeus longirostris,* and associated species from a bottom trawl survey off the Portuguese southcoast

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ABSTRACT

An experimental crustacean bottom trawling survey targeting the deep-water rose shrimp *Parapenaeus longirostris* was carried out off the south of Portugal over five 24-hour cycles. Although circadian bias in the catch rates for this fishery has been reported, no conclusive study had been carried out until now. Catch per unit effort oscillated with the time of the day. Total catches, both in numbers and weight considerably higher in daytime than at night, suggesting that the 24-hour light cycle strongly influences catchability of rose shrimp. The rose shrimp, shows a clear shift in abundance from daytime to night hours, with catches decreasing sharply at dusk and, then increasing significantly at dawn. Overall, the most captured fish species: european hake, *Merluccius merluccius*; monkfish, *Lophius budegassa*; european conger, *Conger conger*; and great forkbeard, *Phycis blennoides*; present the same trend, although less marked. The exceptions are: silver scabbardfish, *Lepidopus caudatus*; blue Whiting*, Micromesistius poutassou*; tongue sole, *Symphurus nigrescens*; atlantic mackarel *Scomber scombrus* and silver cod, *Gadiculus argenteus*; whose catches were higher in the night hours. Understanding, the circadian variability in catches of highly valuable commercial species such as the deep-water rose shrimp may contribute to an improved management, by allowing a better control of fishing effort and more efficient use of technical measures.

Keywords: catchability, circadian variability, deep-water rose shrimp, bottom trawling, Portugal

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1 INTRODUCTION

Trawl performance and fish behaviour studies are of great importance in support of marine resource assessment, where the main objective of a bottom trawl survey is to obtain an indicator of abundance (Engas and Soldal, 1992). Changes in species composition and abundance of demersal communities between day and night have been evidenced in a number of studies (Woodhead, 1963; Parrish ., 1963; Woodhead, 1966; Beamish, 1966; Bowman and Bowman, 1980; Valdemarsen *et al*., 1985; Engas and Soldal, 1992; Albert and Bergsatd, 1993; Pillar and Barange, 1997; Petrakis *et al*., 2001; Yousif, 2003; Suetsugu and Ohta, 2005; Bahamon *et al*., 2009; Aguzzi *et al*., 2009). Such changes have been shown to be species-dependent and driven by environmental factors such as depth, currents, tides and light availability, where the latter has been confirmed as the strongest geophysical agent in the regulation of the dynamics and structure of the demersal community (Aguzzi and Company, 2010).

Light in the sea undergoes continues changes in intensity and quality, and as on land, the sun’s azimuth diurnal and seasonal cycles and clouds formations are the major factors regulating the amount of light reaching the surface of the sea (Barnes and Hughes, 1999). The transmission of the light through the water column decreases rapidly with depth mainly due to the heavy absorption properties of the water and scattering by suspended matter, both profoundly affecting the light reaching the sea floor (Woodhead, 1966). Even in very clear and calm waters, about 80% of the total radiation reaching the surface is absorbed within the uppermost 10 m, thus there is seldom any significant light beyond 200 of depth (Tait and Dipper, 1998). Consequently, the vision of demersal fishes will depend on the light available at the sea bottom at different depths and will change according to species. Many bottom fish and crustacean do not present a sharp visual acuity, but their sensivity to light may be very high. It is estimated that the eyes of some deep-sea fish are able to detect daylight to depths of about 1150m (Tait and Dipper, 1998; Woodhead, 1966) There is strong evidence that many fishes considered as demersal species, and normally caught in trawls near the seabed, regularly assume a pelagic habit, swimming freely in midwater and frequently feeding there (Woodhead, 1966). As a general rule, demersal fish remain close to the bottom by day and move into upper layers with the onset of darkness

(Beamish, 1966). These patterns have been shown to regulate the available biomass and vertical distribution of demersal marine species over the diel cycle (Walsh, 2004).
Similarly, it has been described that some benthic and benthopelagic crustaceans display diel changes in their behaviour (Aguzzi *et al*., 2009), thus conditioning its availability. Those authors classify circadian species displacement behaviour in three major types:: *vertical*, in the water column; *nektobenthic*, across a depth gradient along the seabed, as is the case of the deepwater shrimps, namely the rose shrimp; and finally, *endobenthic*, for burrowers (e,g, Norway lobster, Nephrops norvegicus) and buriers (e.g,, many species of genus *Penaeus*), with phases of emergence from the substrate or burrows and retraction in it. In an extensive revision of the behaviour and catchability of some commercially exploited penaeids shrimps, Penn (1984) mentioned that some shrimp species which present higher catch rates during daytime due to an aggregation behaviour inducing shoaling. These behavioural features may vary greatly in its nature for different species of fish and crustacean, habitats and seasons. Thus, the catching efficiency of the fishing gear would also be expected to change accordingly.

Gear-induced behavioural changes can also be on the basis of diel changes in trawling efficiency. Herding behaviour into the path of the net by the action of the otter doors and trawl sweeps on the seabed stirring up a sediment cloud has been described for a number of species, while others show net-avoidance behaviour (Fraser *et al*., 2007). These herding effects may decrease at night when the different gear sections are less visible. Another important stimuli affecting the catch process is the sound generated by the different parts of the fishing gear in operation, such as the trawl chains and doors. These noises may be heard by fish well before the contact with the net leading to swim away from the sound source (Engas and Soldal, 1992). Thus catch efficiency may be vary considerably among species and throughout the day since the reaction distance, fish orientation and escape behaviour change with light level (Engas, 1994).

The Portuguese bottom trawl fishery for deep-water crustaceans is one of the most important *métiers* in the country, comprising about 30 vessels (ICES, 2010) operating off the continental slope of the south and southwest coasts of Portugal. The rose shrimp, *Parapenaeus longirostris*, and the Norway lobster, *Nephrops norvegicus*, are the main target species, although other highly-valuable deep-water shrimps such as the “blue and red shrimp”, *Aristeus antennatus*, the giant red shrimp, *Aristaeomorpha foliacea*, and the scarlet shrimp, *Aristaeopsis edwardsiana* are also occasionally caught in smaller numbers. In 2009, crustacean landings attained a total of approximately 1588 tons, corresponding to a first sale value of 16.07 M€ (million Euros) (Direcção Geral das Pescas e Aquilcultura, 2010). Additionally to the main target species, an important fraction of valuable by-catch comprising benthic and benthopelagic species differing in their ecological habits and behaviour towards the gear is captured. Blue whiting, mackerels, hake, megrims, and anglerfishes are, among others, frequent by-catch species.

Although it is widely known that diel changes occur in trawl catches, there is surprisingly little published data for the Portuguese bottom trawl fishery. Ribeiro Cascalho (1988) in an in-depth study on the ecology and fishery of the deepwater rose shrimp and 'blue and red' shrimp in south Portugal, reported higher catch rates during daytime for bottom trawling in the same area. A single related study could be identified for Portuguese waters on the relationships between fish abundance and light intensity. Zwolinski *et al*., (2007), using acoustic methods, described diel patterns in the schooling behaviour and vertical distribution of pelagic fish at different sites along the Portuguese coast. In the Mediterranean Sea, Carpentieri *et al*., 2005) found that season and time of the day had an important influence on the nekton assemblage structure on the Mediterranean shelf-break of west-central Italy. In the Barents Sea, Norwegian bottom trawl surveys for cod and haddock demonstrated that mean catch rates were substantially greater by day than by night, particularly in Autumn (Engas and Soldal, 1992). Recent studies in the Atlantic ocean have shown that light was among the main factors driving the abundance of gadoids (Pillar and Barange, 1997).

The development of models that take into consideration circadian bias in the estimation of abundance of important fishing resources is needed to improve stock assessment and enhance fishing operations and management. In this case, the fishery of deep-water rose shrimp provides a means for both scientists and fishermen to obtain benefits from planning and optimizing the fishing operation. It is the purpose of this paper to present results on circadian variability of catch rates of some important demersal species from the South Portugal deep water bottom trawl fishery. At the same time, the use of a longitudinal separator panel allowed for the characterization of species distributions in the near-bottom water column.

2 MATERIALS AND METHODS

2.1 Data collection

Data were collected during an experimental bottom trawl survey carried out in September 2007 off the south coast of Portugal (east of Cape Sta. Maria), at a mean depth of 245 meters, in rose shrimp grounds located inside the six-mile trawling exclusion zone, between longitude 08°8´W and 07°4´W and latitude 36°7´ N and 36°3´N (Fig.1), onboard R/V *Noruega*, a 1500 HP stern trawler belonging to IPIMAR. Five 24-hour cycles were completed during an 8-day period at sea in a total of 20 hauls. The towing direction followed the bathymetry to maintain a constant depth of operation. Whenever hauls were carried out at or near transitional hours, i.e. at dawn or at dusk, they were assigned to either day or night categories, with a total of 11 hauls during the light period and 9 hauls during the dark period. Hauls starting near sunset, where most of the tow was still carried out under daylight conditions, were considered as daytime ones, while those in early morning, starting in the dark period and finishing at sunrise, were grouped into the night-time category (Table 1). As all the hauls were of 1 h duration, this unit was adopted as the measure of effort. As such, catches either in weight or in number correspond to the CPUE (catch per unit effort) expressed as the number/weight of fish caught per hour.

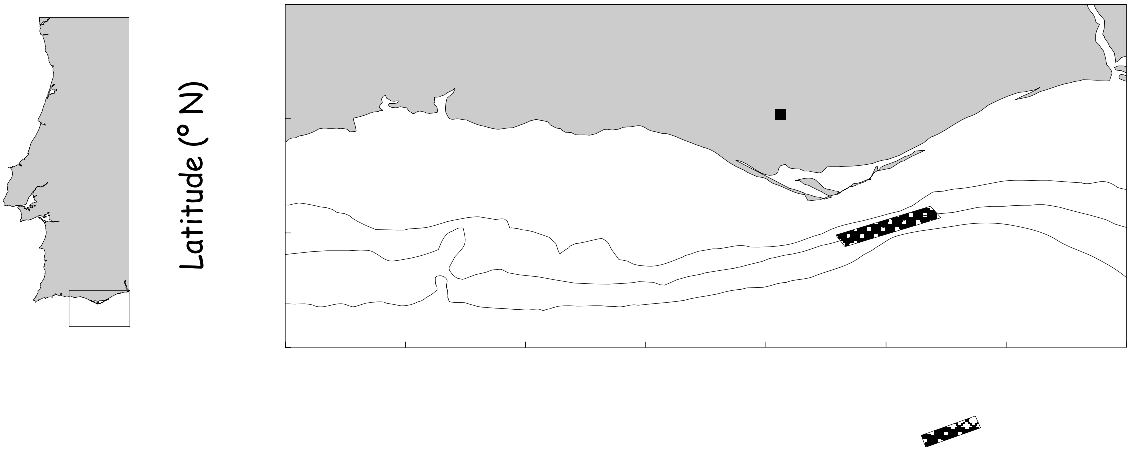

Figure 1. Location of the experimental hauls (dark striped filled rectangle) carried out onboard R/V Noruega in summer 2007.

2.2 Fishing gear

The experimental gear consisted of a modification of the crustacean sampling trawl used by IPIMAR. It is made up of twisted polyethylene 60mm mesh size, approximately 50m long from the wing tips to the codend joining row, with a circumference of 1064 meshes of 60mm at the footrope level (for full details see Fonseca *et al*., 2005). A horizontal separating panel of netting was introduced between the upper and lower trawl bellies, starting at the footrope level and dividing the net into two equal longitudinal compartments, ending in two independent 20 mm mesh size codends (Fig. 2a).

Table 1. Sequence of hauls along the diel cycles, catch in kilograms split into lower and upper codend. Haul: Haul number; Cycle: Day (D), Night (N); Low: lower codend, Up: upper codend; * Transition hours; (hour values correspond to solar hours; approximate sunrise: 5:30 am; approximate sunset: 10:30pm)

Haul	Depth (m)	Hour (hh:mm)	Cycle	Low (kg)	Up (kg)	Total (kg)
1	242	17:50	D	13.5	16.5	30.0
2	245	22:25	N	23.4	14.5	37.8
3	245	05:10	N	18.5	15.9	34.4
4	245	10:50	D	30.1	20.9	51.0
5	249	16:35	D	26.7	29.1	55.8
6	239	22:40	N	09.7	07.5	17.2
7	248	04:40	N	25.1	10.9	36.0
8	241	10:50	D	32.1	21.1	53.2
9	244	14:05	D	19.9	24.9	44.7
10	246	19:15	D*	22.6	29.3	51.9
11	245	01:20	N	14.7	07.9	22.6
12	245	07:50	D*	31.2	25.6	56.8
13	244	13:30	D	32.1	11.9	44.0
14	243	19:05	D*	09.1	09.1	18.2
15	245	02:05	N	15.0	08.9	23.9
16	238	06:45	N*	06.3	11.3	17.6
17	246	10:35	D	33.2	24.4	57.5
18	250	16:35	D	53.5	19.0	72.5
19	248	01:05	N	23.5	06.4	29.9
20	251	07:00	N*	24.2	05.4	29.6

This setup allowed for the evaluation of diel differences in the catch of benthic, demersal and pelagic species (Fig. 2b). Wingend and door spread, 25-27 metres and 100-130 metres, respectively, and vertical opening, 1.0-1.5 metres, were measured with a Scanmar acoustic sensors.

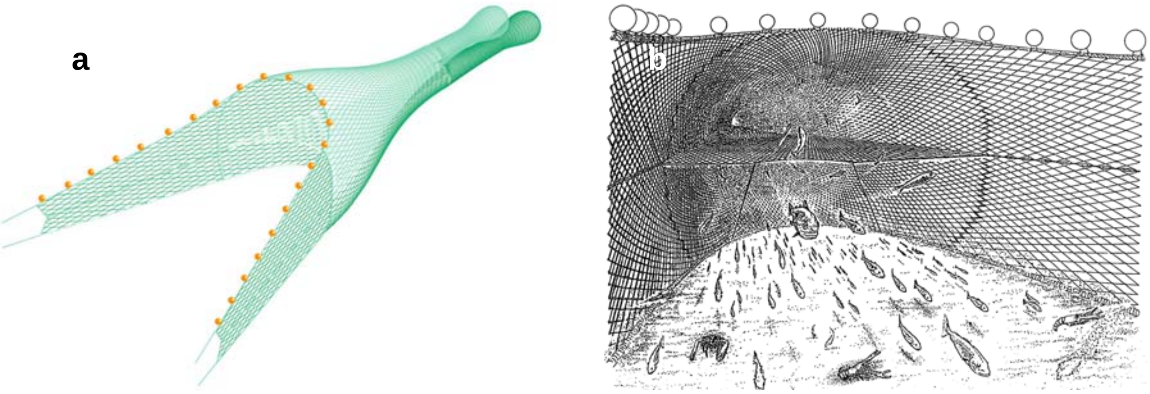

Figure 2. Artistic view of a low-opening crustacean bottom trawl with a horizontal separating panel dividing the net in two independent codends: a) global 3D aspect; b) Illustration of the mouth opening of the two-level trawl. (Courtesy of Marine Laboratory Aberdeen, © Crown copyright)

2.3 Sampling procedures

After haul-back, the catches were collected from the two separate codends and weighed, after which they were sorted and the taxa identified to the species level whenever feasible. The target species, commercial fish by-catch and most abundant non-valuable fish species were measured (total length to the centimetre below, for fish and carapace length, to the millimetre below, for crustaceans), and their weights recorded. When the catch of a given species in any of the codends was too large to be entirely processed, a random sub-sample (by weight) was taken. Rose shrimp was always the most abundant crustacean species caught, thus being sub-sampled for the majority of the hauls. Length class frequencies for the total catch were then estimated by scaling up the frequencies in the sub-sample by the ratio of total weight to the sub-sample weight.

2.4 Statistical analysis

The non-parametric Mann-Whitney test (Zar, 1999) was carried out to test for significant differences between day and night catch rates, both for total catch and catch of the most important species, by weight and by number. Differences in catch rates between the two distinct trawl sections corresponding to upper and lower codends can occur within the cycle, due to species or size-dependent behaviour at the trawl entrance. Therefore, the

Mann-Whitney test was also carried out for comparing catch split between codends separately for day and night-time. As rose shrimp exhibit sexual dimorphism, with females reaching a bigger size than males (Froese and Pauly, 2010) mean lengths of males and females, along with the mean lengths of the other most important species were also compared along the cycle and between codends, using t-tests. Also, the possible occurrence of significant differences in the overall proportion of sexes, within day and night-times and between codends, within day and night, were evaluated through a z-test, while the differences in proportions of a single sex in the different scenarios was carried out by a χ^2 test (Zar, 1999). For other the other species analysed comparison was made for sexes combined. The Man-Whitney and t-test analysis were implemented using the Statistica 6.1 software (StatSoft, 2003), while for proportions the MedCalc software 11.5.1 was used (http://www.medcalc.org/)

The functional relationships between trawling performance and time of the day are very likely to be non-linear (Woodhead, 1963). The use of smoothing curves to model the relationship between the response and the explanatory variable is an easy way to interpret a data set (Zuur *et al*., 2007). To evaluate the relationship between the 24-hour cycle and the CPUE (n/h) of rose shrimp, we used a Generalized Additive Models by estimating unspecific (non-parametric) functions of the predictor variable (time of haul start) which relates to the dependent variable, assumed to follow a Poisson distribution, via a log-link function. GAMs are very flexible tools and can provide an excellent fit in the presence of non-linear relationships and significant variability in the predictor variable (Venables and Dichmont, 2004). Plotting these models allows for the evaluation of the nature of the relationship between the predictor and the fitted dependent variable and hence the nature of the influence of the respective predictor in the overall model. The model was implemented using the software Brodgar ver. 2.6.4 (Highland Statistics Ltd) and can be expressed as:

$$\log\text{ (CPUE)} = \text{intercept} + f(\text{hour}) \qquad ^{(1)}$$

In order to explore similarities between the samples, a Non Metric Multidimensional Scaling (NMDS) was performed. This method has been recognized to preserve high dimensional structure with few axes, based on a distance matrix, allowing visualizing this matrix in two or three dimensions (Zuur, 2007). Data for this analysis was square root transformed.

3 RESULTS

3.1 Day vs. night catches

A total of 44 taxa were identified to the species level, 31 fish (31% of the bulk catch in kilograms belonging to 24 families), 5 crustaceans (4 families; 13%), and 8 cephalopods (4 families; less than 1%) (Table I, in Appendix). A fraction of the catch classified as “trash” accounted for about 55% (929.2 kg) of the total. It corresponded to discards constituted by small, non-commercial, fish and crustaceans, and other benthic invertebrates, but mostly by organic and inorganic debris. Figure 3a shows the total yield, in weight, of the targeted species, deep-water rose shrimp, and main commercial fish by-catch, without the “trash” fraction. Figures 3b and 3c show that, in terms of the main species, composition remains constant between day and night, but their relative percentages change considerably. While daytime catches are dominated by deep-water rose shrimp accounting for 26% of the total weight, at night it is partially substituted by silver scabbard fish (22%). Although hake catch rates were higher during daytime, the proportion of this species in the total catch weight was found to be slightly higher at night due to corresponding decrease in deep-water-rose shrimp weight to about 1/7 of the daytime catches. The remaining species did not present significant diel changes in CPUE.

For crustaceans, 92.5% of the total catches were recorded during the day, driven largely by the deep-water rose shrimp trend (Fig. 4), while for fish a global trend is not evident, mainly because of the different diel abundance patterns of a number of different species. Cephalopods, on the other hand, also present higher catch rates during daytime.

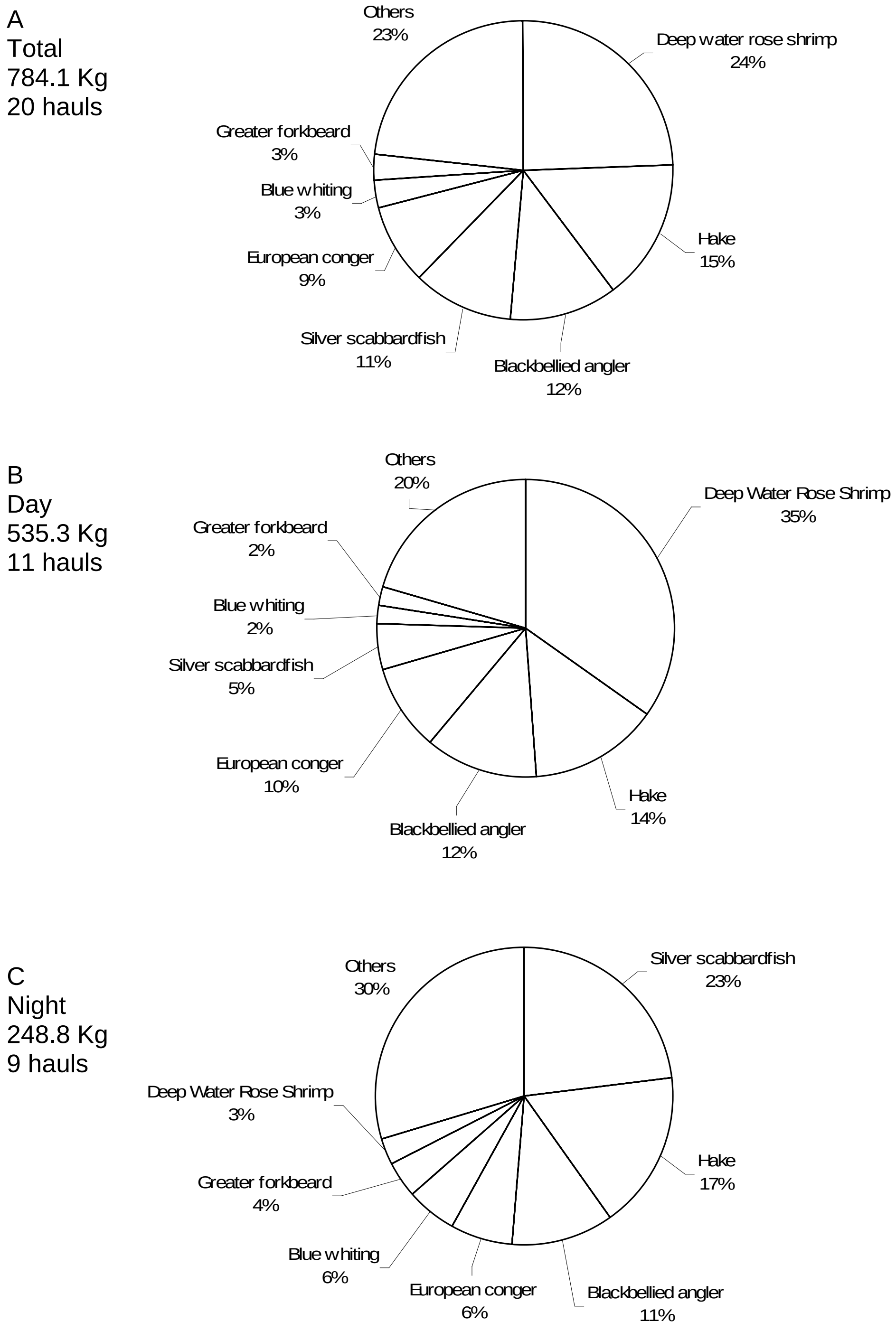

Figure 3. Species composition (percentage in weight); A) total catches; B) Day catches; C) Night catches. The “others” fraction includes non representative species in terms of abundances.

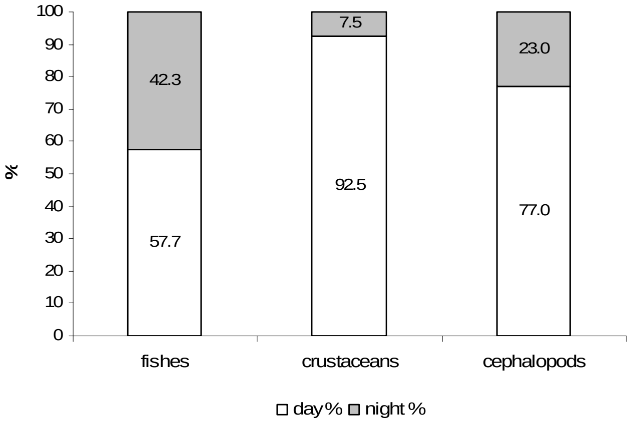

Figure 4. Day/night catch in weight (percentages rates) by taxonomic group.

A clear oscillation pattern due to day/night cycle is shown in Fig. 5, with the total yields in weight considerably higher during daytime than at night (Table II, in Appendix). Only a small number of species, such as silver scabbard fish, blue whiting, *Symphurus nigrescens* (tongue sole), *Scomber scombrus* (Atlantic mackerel) and *Gadiculus argenteus* (silver cod), presented higher catch rates at night (Fig. 6). The oscillation pattern due to the time of the day is also reflected in the catches for both codends, with overall catches in the lower codend usually much higher both during day and night-time (Fig. 5).

3.2 Statistical analysis

The Mann-Whitney (M-W) results for the day and night-time catch rates comparison are given in Table 2. Mean total catch showed statistical significant differences, in weight, between day and night-time periods ($p < 0.05$). Daytime average CPUE, in weight, was 48.6 Kg/h (sd = 14.5), approximately 1.8 times greater than the night-time average, 27.6 Kg/h (sd = 7.7) (Fig. 7; Table 2).

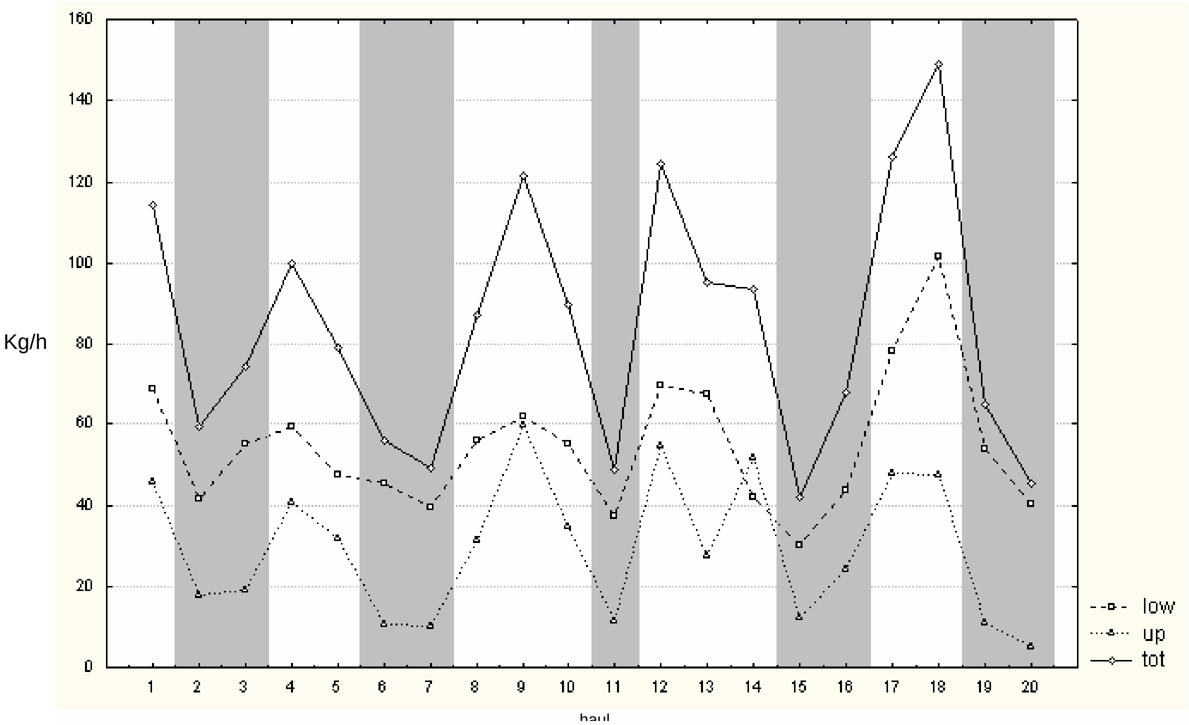

Figure 5. Total weight in kilograms per hour (Kg/h) caught by day/night-time and the lower and upper compartments division (white stripes = day-time; grey stripes = night-time).

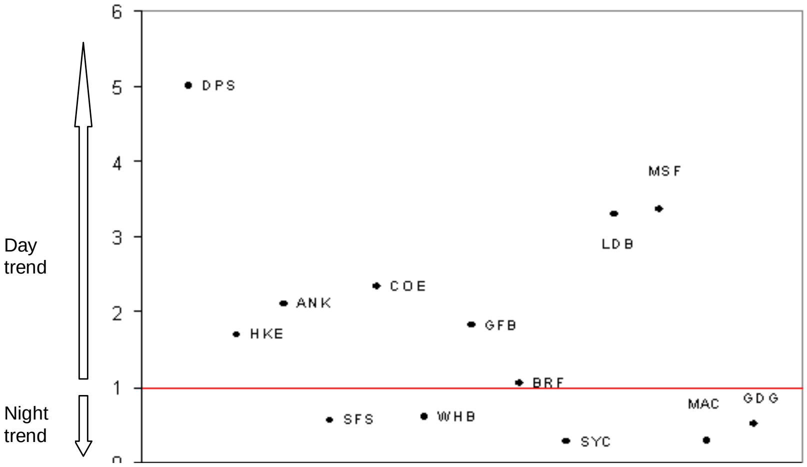

Figure 6. Day/Night ratio by species (number of individuals caught in day-time/night-time) Species over the horizontal line are higher in number during day-time rather than night-time and vice versa (D/N factor > 1 = Daytime; D/N factor <1 = Nighttime), for the 13 most important species.

Differences between lower and upper codends catches within cycles were also tested using M-W (Table 3); resulting in significant differences for the night period, with the lower codend presented a higher average catch rates (17.8 kg/h; sd = 3.6) when compared to the upper codend (9.8 Kg/h; sd = 7.7) ($p<0.05$) (Fig. 7; Table 3). Since the species identification during the survey was not exhaustive, differences in the total catch in number was not evaluated.

Table 2. Results from the Mann-Whitney test comparing mean CPUE in weight (Kg/h) and number (n/h) between day-time and night-time for total catches and the seven most captured species; p-values in bold correspond to statistical significance differences.

	Kg/h					**N/h**				
	DAY		**NIGHT**			**DAY**		**NIGHT**		
Specie	*mean*	*st.dev.*	*mean*	*st.dev.*	*p-value*	*mean*	*st.dev.*	*mean*	*st.dev.*	*p-value*
total	48.6	14.5	27.6	7.7	**0.002**	*NA*	*NA*	*NA*	*NA*	*NA*
Deep water rose shrimp	16.9	7.9	0.7	0.6	**0.000**	1603	800.0	75	68.3	**0.000**
European hake	10.2	6.6	5.7	4.1	0.102	43	28.6	21	12.5	0.074
Black bellied angler	5.9	3.7	3.0	3.0	0.073	4	2.7	2	1.1	**0.045**
Silver scabbardfish	2.4	2.2	6.5	5.6	0.087	36	33.8	103	89.1	0.119
European conger	4.7	2.9	1.8	0.9	**0.016**	31	16.2	14	10.3	**0.009**
Blue whiting	0.9	1.3	1.5	2.6	0.879	7	10.3	14	26.8	0.704
Greater forkbeard	1.1	1.0	1.1	1.0	0.710	19	17.2	12	8.9	0.456

Table 3. Comparison p-values from Mann-Whitney test for mean CPUE in Kg/h and N/h for most captured species and total catch (species overall). Numbers are p values, $p<0.05$ significance level in bold font.

	Kg/h					**N/h**				
DAY	**LOWER**		**UPPER**			**LOWER**		**UPPER**		
Species	*mean*	*st.dev.*	*mean*	*st.dev.*	*p-value*	*mean*	*st.dev.*	*mean*	*st.dev.*	*p-value*
total	27.6	11.8	21.1	6.6	0.082	*NA*	*NA*	*NA*	*NA*	*NA*
Deep water rose shrimp	10.9	6.5	6.0	2.7	**0.023**	1042	645.5	561	276.0	**0.033**
European hake	6.3	6.2	3.9	2.8	0.533	26	26.8	17	13.5	0.670
Black bellied angler	3.5	2.4	2.4	3.0	0.251	3	2.7	0	0.4	0.158
Silver scabbardfish	1.1	1.9	1.3	1.5	0.264	18	26.8	18	19.3	0.533
European conger	2.8	2.3	1.9	1.4	0.393	18	13.6	12	9.1	0.491
Blue whiting	0.4	0.6	0.6	1.0	0.393	3	5.2	4	7.9	0.450
Greater forkbeard	0.6	0.5	0.5	0.5	0.555	10	10.1	9	8.3	0.844
NIGHT	**LOWER**		**UPPER**			**LOWER**		**UPPER**		
Species	*mean*	*st.dev.*	*mean*	*st.dev.*	*p-value*	*mean*	*st.dev.*	*mean*	*st.dev.*	*p-value*
total	17.8	3.6	9.8	7.7	**0.019**	*NA*	*NA*	*NA*	*NA*	*NA*
Deep water rose shrimp	0.2	0.2	0.5	0.6	0.270	32.2	46.3	42.4	51.5	0.331
European hake	4.1	2.9	1.6	1.5	**0.022**	15.2	9.1	5.8	4.2	**0.009**
Black bellied angler	2.6	2.1	1.5	1.8	**0.001**	2.0	1.0	0.1	0.3	**0.001**
Silver scabbardfish	4.1	4.6	2.5	2.0	0.508	64.7	72.7	38.4	30.9	0.453
European conger	1.1	0.9	0.7	0.5	0.158	9.7	9.6	4.0	3.7	0.052
Blue whiting	1.1	2.1	0.5	0.6	1.000	10.2	20.3	4.1	6.8	0.930
Greater forkbeard	0.8	0.8	0.3	0.4	0.093	8.3	6.0	3.6	5.6	0.093

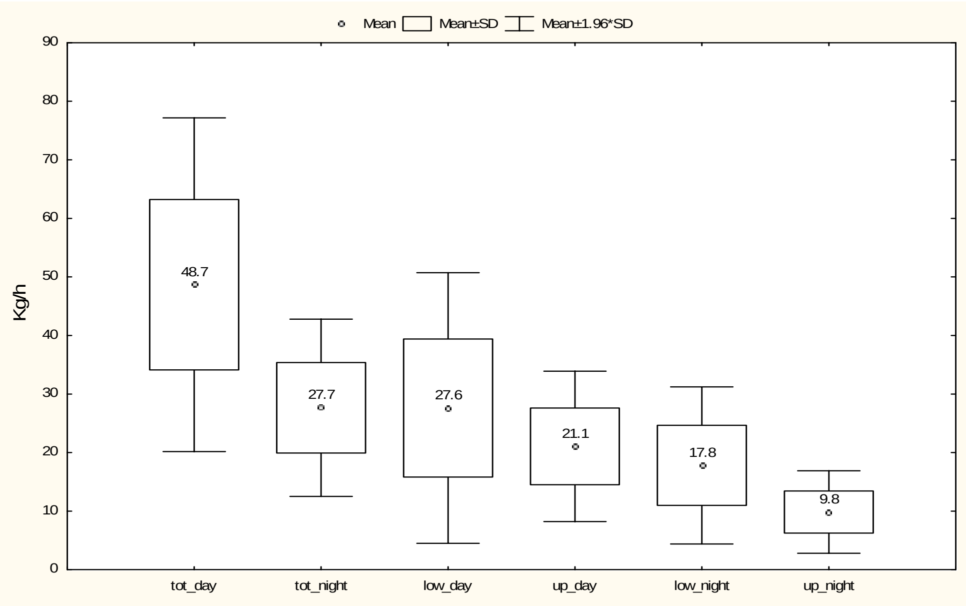

Figure 7. Box and whisker plots of total species CPUE (Kg/h) day-time/night-time (tot_day-tot_night) and lower/upper codend in the cycle (low_day-up_day; low_night-up_night).

3.3 Rose shrimp *(Parapenaeus longirostris)*

Rose shrimp showed a marked oscillation pattern along the diel cycle (Fig. 8a and b), with a daytime CPUE average (in weight) of 16.9 Kg/h (sd = 7.9), 24 times higher than at night, when CPUE was around 0.7 Kg/h (sd = 0.6) (Fig. 9a; Table 2). The Mann-Whitney test found statistical significance differences for both abundance indices, in weight and number between the day and night-time periods ($p<0.05$) (Fig.9a and 9b; Table 2).

The comparison of lower vs. upper codends, in weight, for daytime within the cycle, evidenced statistical significance p-values (M-W; $p< 0.05$), with the lower codend average catch of 10.9 kg/h (sd = 6.5) against 6.0 kg/h (sd = 2.7) recorded for the upper codend (Fig.9a; Table 3). The same trend, was registered when comparing catches in number, with a mean catch rate of 1042 n/h (sd = 645.5) in the lower codend and 561 n/h (sd = 276) in the upper one.(Fig.9b; Table 3). During night-time catches in the upper codend presented higher mean catch rate; both in biomass (0.5 kg/h, sd = 0.6) and in number (42 n/h, sd = 51.5) compared with lower codend; 0.2 kg/h (sd = 0.2) and 32 n/h (sd = 46.3) respectively. Both the latter differences were not significant (M-W; $p> 0.05$) (Fig.9a and 9b; table 3).

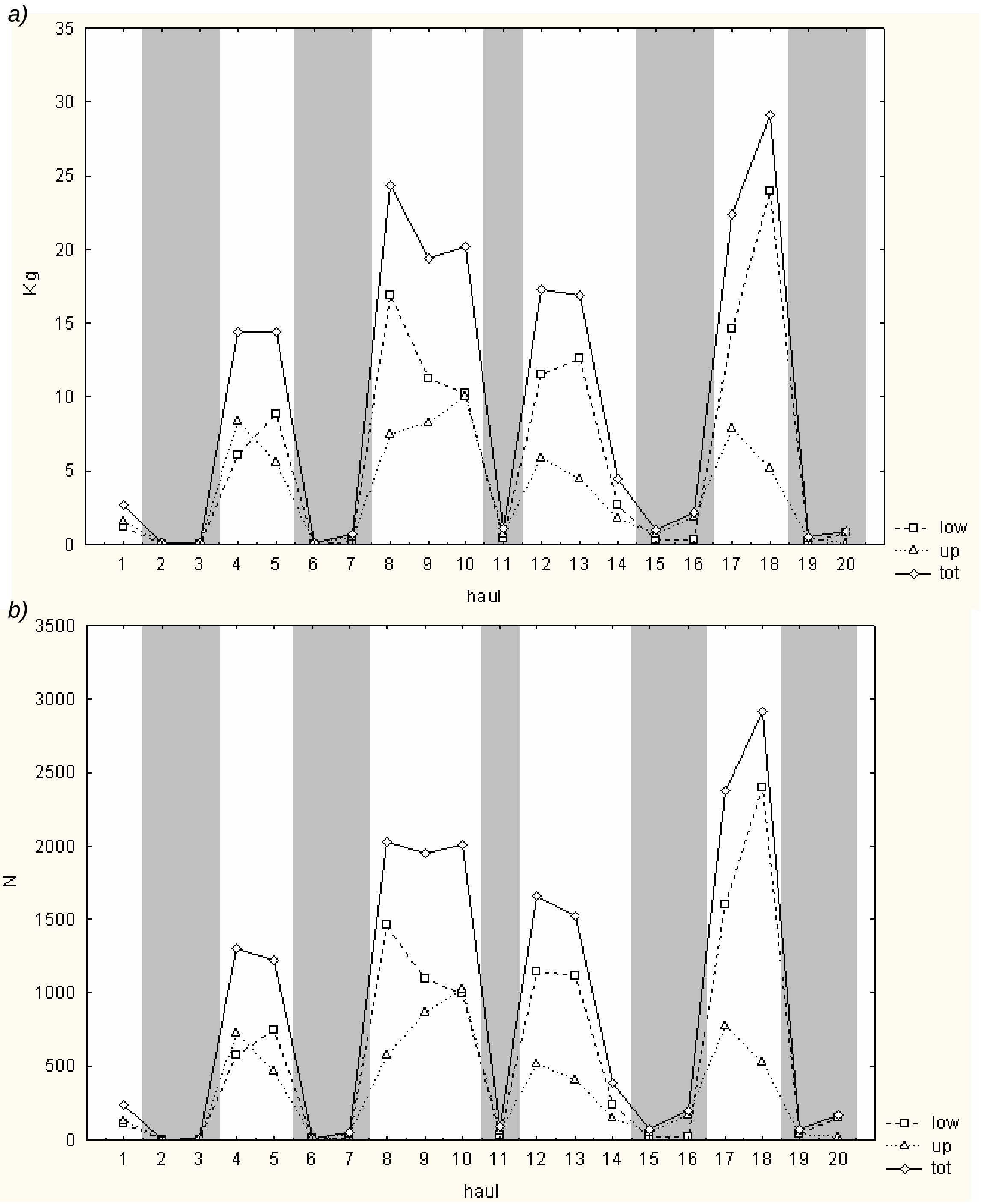

Figure 8. Deep Water Rose Shrimp total catch during night/day periods and in lower and upper codends (white strips = daytime; grey strips = nighttime). a) in weight, kg/h; b) in number, N/h.

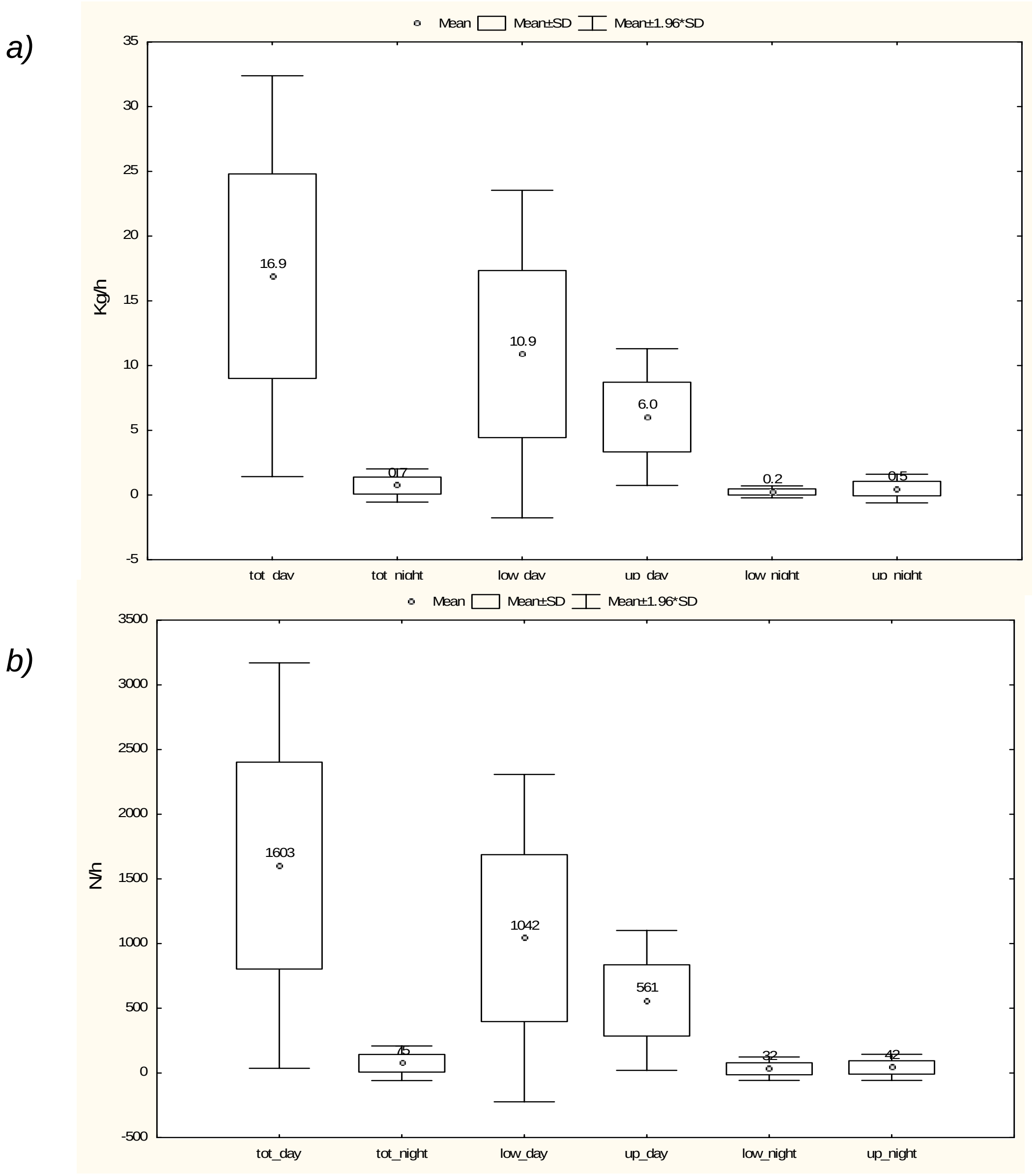

Figure 9. Box and whiskers plots of rose shrimp CPUE by day-time/night-time (tot_day-tot_night) and lower/upper codend compartments in the cycle (low_day-up_day; low_night-up_night). a) in weight, kg/h; b) in number, N/h.

Rose shrimp carapace length (CL) shows a very well defined unimodal distribution, with an overall mean of 25.8 mm (sd = 2.4), and a slightly smaller mean night-time CL of 25.6 mm (sd = 3.1), difference not significant (t-test, p = 0.132) (Fig. 10; Table 4). Mean CL between codends for each cycle was also tested. During daytime, the lower codend recorded a mean size of 25.7 cm CL (sd = 2.4), while the mean CL for the upper codend was 25.8 cm CL (sd = 2.4), with no statistically significant differences according to the t-test (p > 0.05;

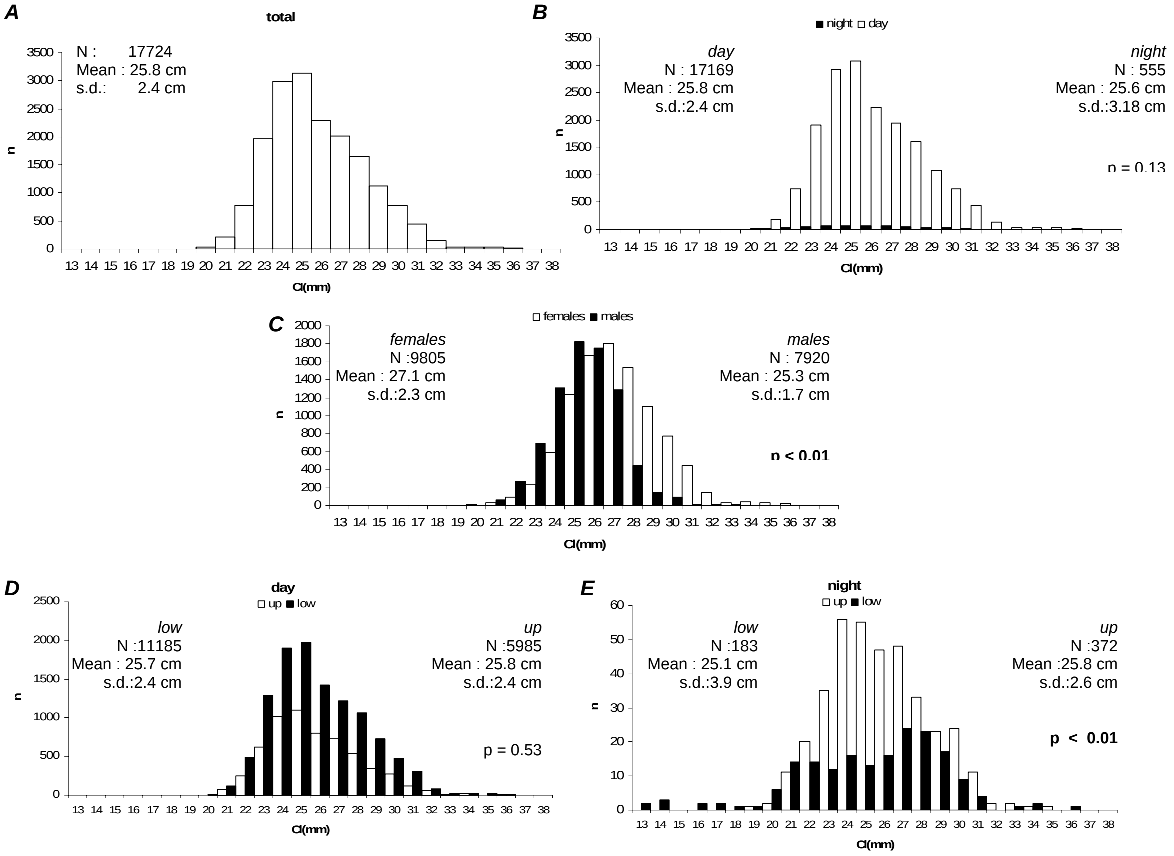

Figure 10. Size frequency distributions of deep water rose shrimp comparing: A, total observations; B, night/day; C, females/males; D day low/up; E, night low/up. P-values for t-test comparisons between means for each group (significant values in bold).

Table 4); while at night time, the slightly shorter size in the lower codend, 25.1 cm CL (sd = 3.9) versus upper one, 25.8 (sd = 2.6) resulted in a statistical significant difference ($p < 0.05$). In addition, females mean CL (27.1 mm) is significantly different than males (25.3 mm) ($p<0.01$).

Females are more abundant than males in all scenarios under analysed, representing 55% of the total catch, and 54 and 66%, of the catch during day and night-time, respectively. This pattern was found also for both lower and upper codend during the day and night hauls, where females were always more abundant. All figures differences are significantly different from 0.5 proportions (z-test; $p < 0.001$; table 5a). Similarly, when comparing proportions of female between day and night-time were directly compared, it was found that the night proportion is significantly larger (χ^2; $p<0.001$). However, no significant differences could be found between lower and upper codends proportions for both day and night-time (χ^2; p=>0.05).

Table 4. Mean total length (mean = TL cm) for the six principal species split into day and night comparison. P- values are the results from the t-test between the means (significant in bold font)

a)

	DAY			NIGHT			
species	mean	s.d.	N	mean	s.d.	N	*p- value*
Deep water rose shrimp	25.8	2.5	17169	25.6	3.2	1422	0.132
European hake	30.3	7.1	476	31.7	6.7	253	**0.019**
Silver scabbardfish	47.6	4.2	403	46.2	3.2	878	**0.000**
Greater forkbeard	18.4	2.6	220	20.4	5.2	113	**0.000**
Blue whiting	26.2	2.6	109	24.7	1.9	148	**0.000**
European conger	41.9	7.7	440	41.2	8.3	201	0.339

b)

DAY							
codend		*lower*			*upper*		
species	mean	s.d.	N	mean	s.d.	N	*p- value*
Deep water rose shrimp	25.8	2.5	11185	25.8	2.4	5985	0.54
European hake	30.5	6.8	289	30.1	7.5	187	0.53
Silver scabbardfish	47.4	3.9	201	47.8	4.5	202	0.33
Greater forkbeard	18.2	2.0	124	18.7	3.2	96	0.12
Blue whiting	26.0	2.9	51	26.4	2.4	58	0.48
European conger	41.8	7.4	272	42.3	8.1	168	0.50
NIGHT							
codend		*lower*			*upper*		
species	mean	s.d.	N	mean	s.d.	N	*p- value*
Deep water rose shrimp	25.2	4.0	183	25.9	2.7	372	**0.02**
European hake	31.6	6.6	139	32.1	7.1	52	0.60
Silver scabbardfish	46.2	3.2	451	46.1	3.5	351	0.57
Greater forkbeard	19.7	4.1	76	22.1	6.9	33	**0.03**
Blue whiting	24.6	1.6	101	24.8	2.4	45	0.70
European conger	40.4	7.5	85	43.0	9.6	38	0.11

The females (and males) proportions between the lower and upper codends were also analyzed, displaying different trends for day and night-time (table 5b). During the day a larger proportion of females (64%) was found in the lower codend compared to the upper codend (36%), while in the night period, the opposite was seen with the females concentrating in the upper codend (67%). Concerning males, the catch proportion between codends followed exactly the same pattern as for females, larger proportions in the lower codend during day (65%) shifting to larger proportion in the upper codend during the night (68%) (z-test; p < 0.001; table 5b).

Table 5. Rose shrimp. Comparison of sex proportions: a) Significance of female proportion compared to H0=0.50; b) significance of female and male proportions, for lower and upper codends, and day and night periods compared to H0=0.50; c) comparison of females proportion between lower and upper codends, for day and night periods. a) and b) z-test; c) Qui-square test. N - both sexes number; Nsex - total number by sex for both codends; Nlow and Nup -number of both sexes in lower and upper codends, respectively.

a)

Comparisons	Females	*H_0*	N	p-value
TOTAL	0.55	*0.50*	18065	<0,001
DAY	0.54	*0.50*	17499	<0,001
NIGHT	0.66	*0.50*	566	<0,001
low codend (DAY)	0.54	*0.50*	11303	<0,001
up codend (DAY)	0.55	*0.50*	6196	<0,001
low codend (NIGHT)	0.67	*0.50*	186	<0,001
up codend (NIGHT)	0.66	*0.50*	381	<0,001

b)

Comparisons	low	*and* up	*H_0*	N_{sex}	p-value
females					
DAY	0.64	0.36	*0.50*	9532	<0,001
NIGHT	0.33	0.67	*0.50*	373	<0,001
males					
DAY	0.65	0.35	*0.50*	7967	<0,001
NIGHT	0.32	0.68	*0.50*	193	<0,001

c)

Comparisons	low	*vs.* up	N_{low}	N_{up}	p-value
females					
DAY	0.54	0.55	11303	6196	0.2098
females					
NIGHT	0.67	0.66	186	380	0.8873

The adjusted Generalized Additive Model (Fig. 11) explains almost 80% of the total variance associated to the data indicating that the time of the day, within the diel cycle, is the most important variable conditioning the deepwater rose shrimp CPUE. The intercept estimates and associated statistics as well as the significance of the smooth term are given in Table III in appendix. The catch rate show a sharp increase at dawn, attaining a maximum before the solar midday, presenting some variation thereafter, and initiating a fast declining at dusk.

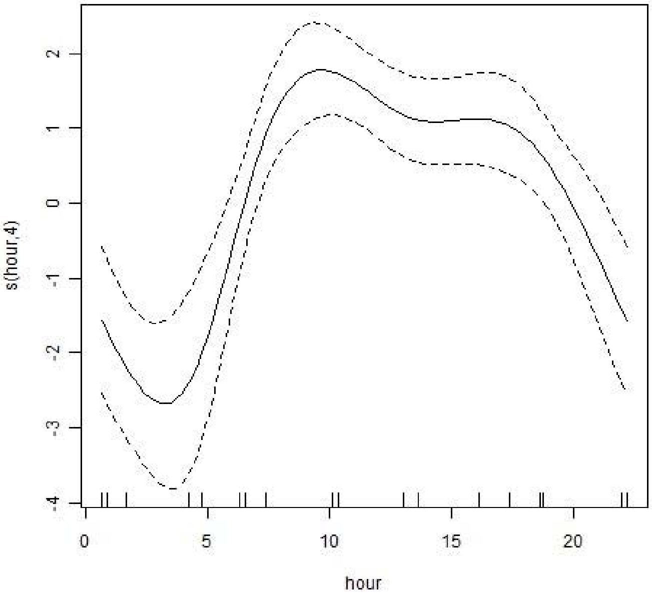

Figure 11. Generalized Additive Model for Deep Water Rose Shrimp CPUE (n/h) with 6 degrees of freedom. Dashed lines (or upper and lower brackets) indicate 95% confidence bands (levels).

3.4 Hake (*Merluccius merluccius)*

Total catch of hake was 163.2 Kg, corresponding to daytime yield of 111.7 kg, 2.1 times greater than in night-time (51.5 kg) (Table II in appendix). Mean catch rates, in weight and number (Fig.12a and 12b; table 2) did not differ significantly different between day (mean = 10.15 kg/h, 43 n/h ; sd = 6.61, 28.6) and night-time (mean = 5.72 kg/h, 21 n/h ; sd = 4.12, 12.5) as evaluated by the Mann-Whitney test ($p>0.05$).

Similarly, no statistically significant differences in catch, both in weight and in number, were found between codends during the day, in spite of the higher retention in the lower codend. On the other hand, at night-time, the M-W test rejected the null hypothesis (equal catches) with the mean catch rate of the lower codend, both in kilograms (4.1 kg/h; sd = 2.9) and in number (15 n/h; sd = 9.1) are significantly greater than those of the upper codend (1.6 kg/h; sd = 1.5) and (6 n/h; sd = 4.2) ($p < 0.05$) (Fig.12a and 12b; Table 3).

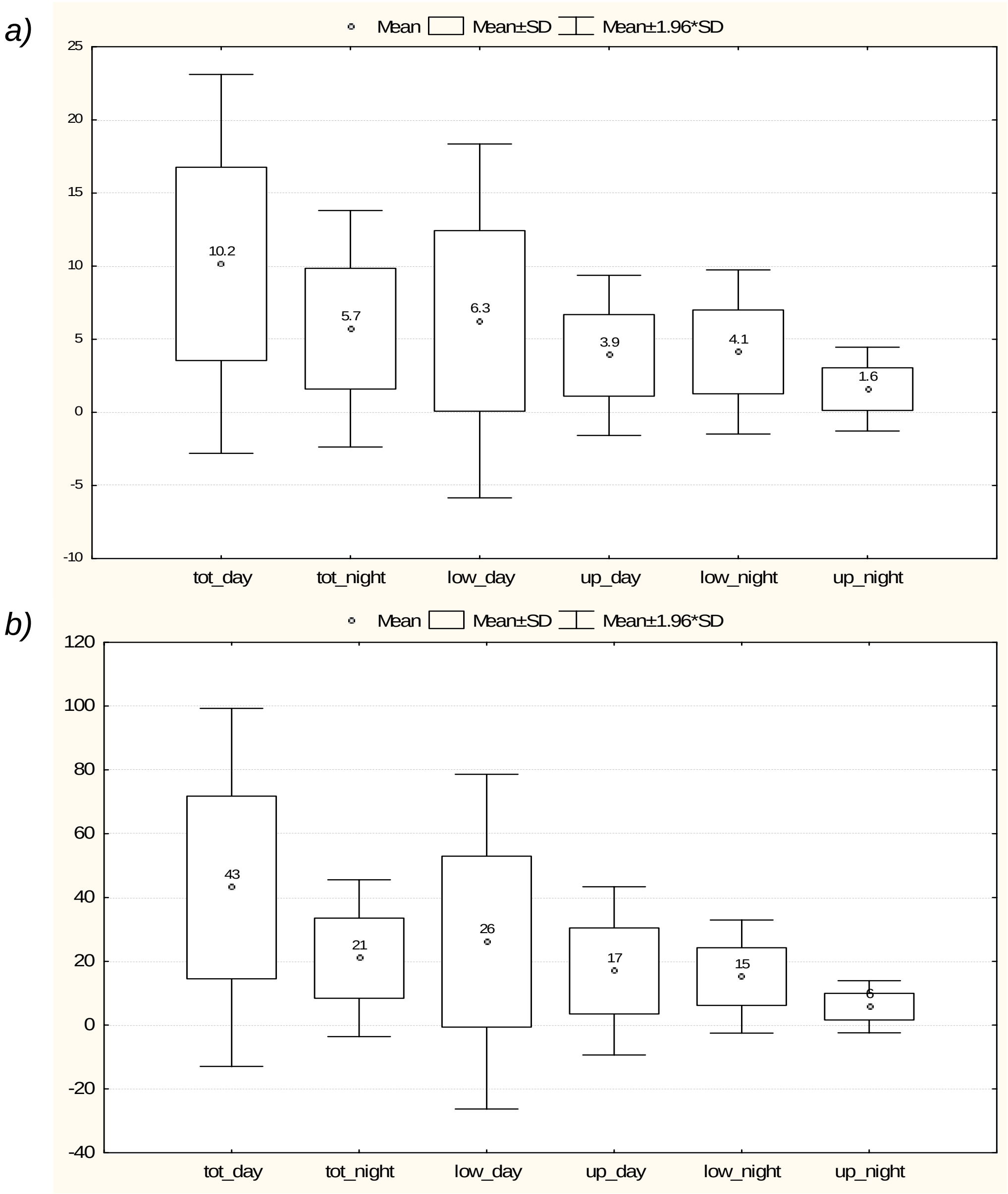

Figure 12. Box and whiskers plots of hake CPUE by day-time/night-time (tot_day-tot_night) and lower/upper codend compartments in the cycle (low_day-up_day; low_night-up_night). a) in weight, kg/h; b) in number, N/h.

The size frequency distribution for this species displays multiple modes, with an overall mean total length of 30.7 cm (sd = 7.0 cm) for the total catch (Fig. 13a). T-test comparison between mean lengths during the cycle found a significantly greater night-time mean total length (30.7cm; sd = 6.7 cm) compared to the daytime mean (30.3 cm; sd = 7.1, $p < 0.05$) (Fig. 13b; Table 4).

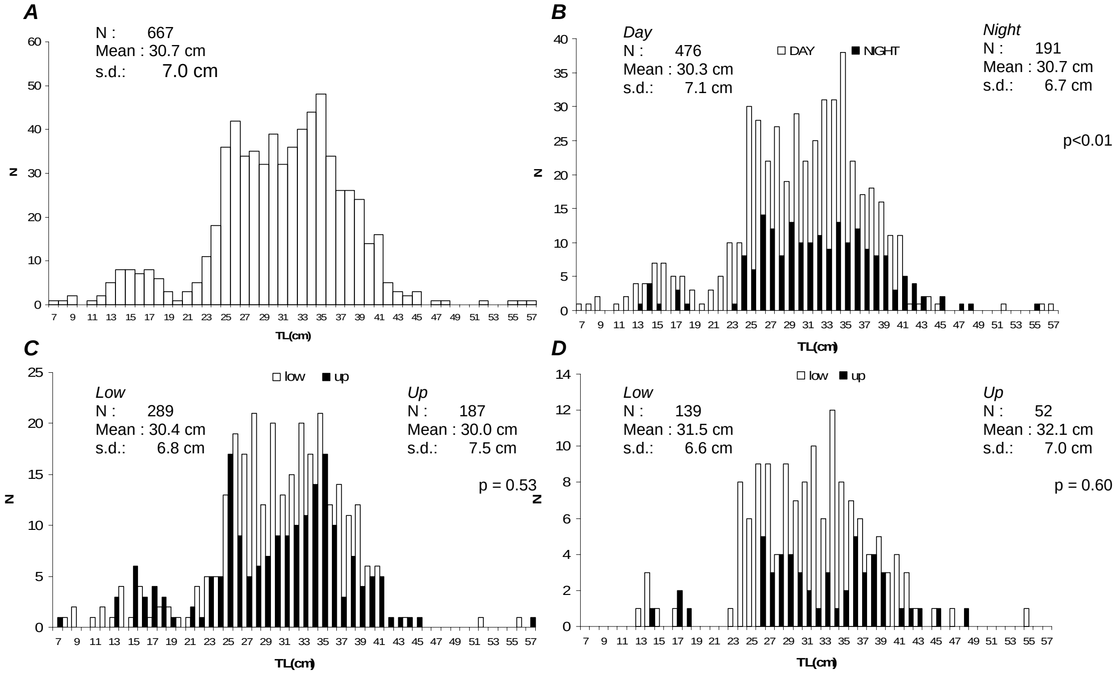

Figure 13. Size frequency distributions of hake comparing: A, Total observations; B, Night/day; C, day low/up; D, night low/up. P-values for t-test comparisons between means for each group (significant values in bold)

Conversely, there were no significant differences between mean size in lower versus upper codend for both day and night periods (P > 0.05; Fig. 13c and 13d; Table 4).

3.5 Black-bellied anglerfish (*Lophius budegassa)*

Twice as many fish of this species were caught in daytime, than during the night, when only 19 fishes were recorded (Table II in appendix). In terms of weight, the same pattern was also found, with 64.6 Kg and 27.7 kg respectively for day and night-time hauls (Table II in appendix). Although the Mann-Whitney showed no statistically significant difference in mean CPUE in weight between day (5.9 kg/h; sd = 3.7) and night-time (3.0 kg/h; sd = 3) (p>0.05); mean CPUE in number was significantly different during day with a larger mean of 4 n/h (sd = 2.7) compared to night-time, 2 n/h (sd =1.1) (p<0.05) (Fig.14a and 14b; Table 2).

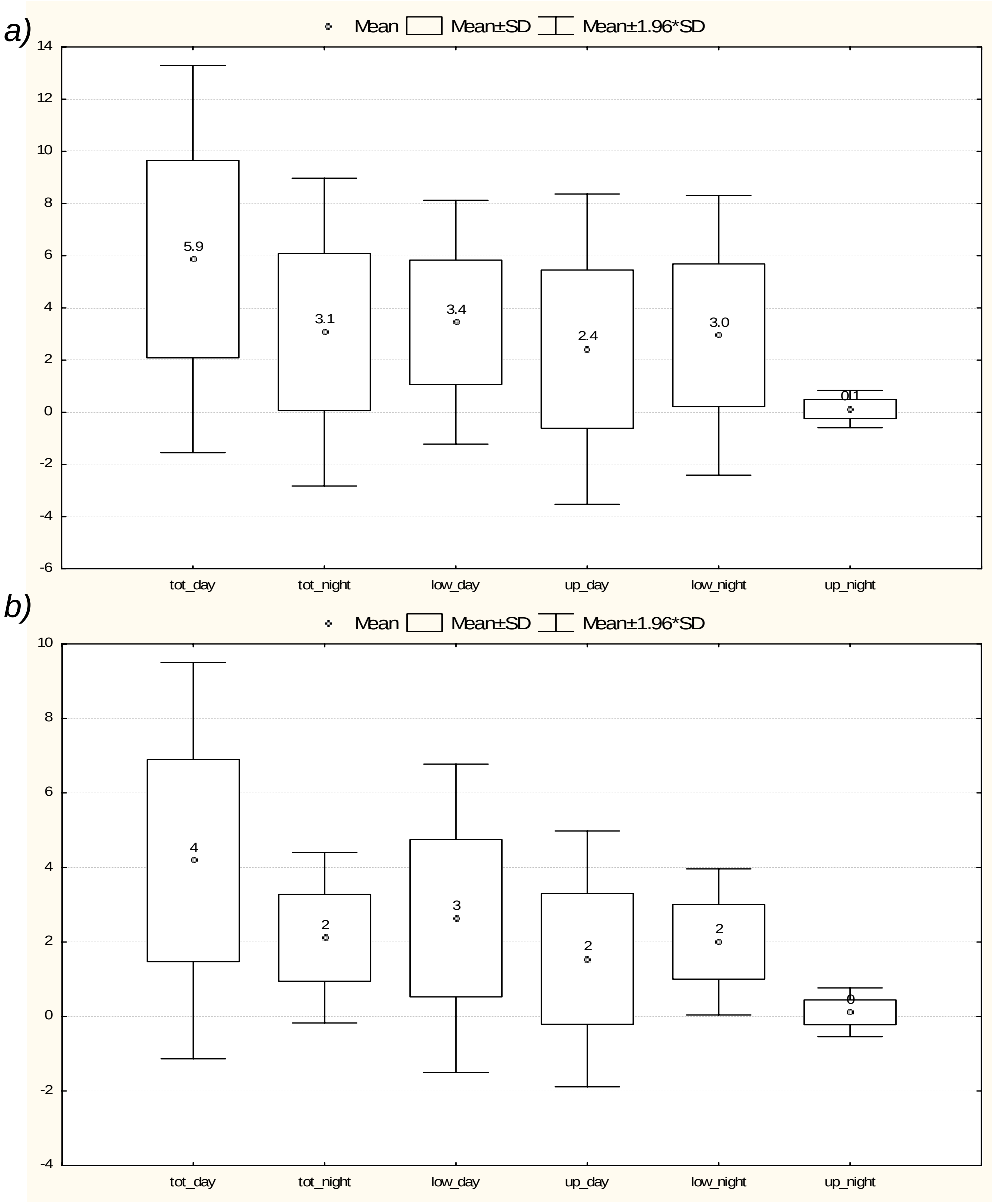

Figure 14. Box and whiskers plots of black-bellied angler fish CPUE by day-time/night-time (tot_day-tot_night) and lower/upper codend compartments in the cycle (low_day-up_day; low_night-up_night). a) in weight, kg/h; b) in number, N/h.

There were differences between codends for the night-time period, mean CPUE in kilogram and number ($p < 0.05$; table 3). These differences correspond to larger mean CPUE for the lower codend during night (mean = 2.6 kg/h, 2 n/h; sd= 2.1, 1.0) compared to the upper codend (mean = 1.5 kg/h, 0 n/h; sd= 1.8, 0.3); while no differences were found during daytime ($p > 0.05$; Table 3). The measurement of total length for this species was just taken from a small sample of 61 individuals, the mean total length was 43.6 cm (sd = 10.9 cm), with the minimum size of 13 cm (TL) and maximum 65 cm (TL).

3.6 Silver scabbardfish (*Lepidopus caudatus*)

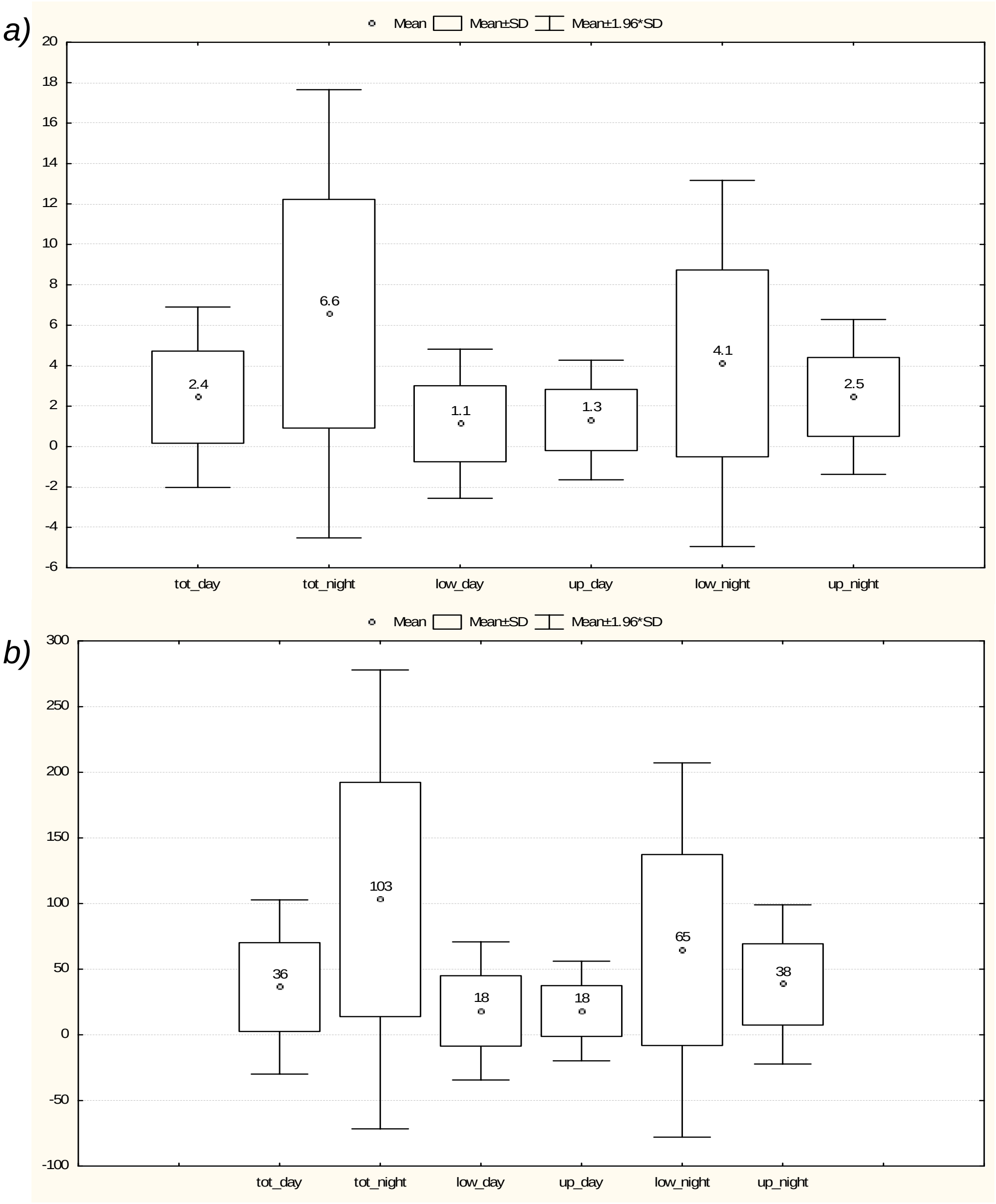

Figure 15. Box and whiskers plots of silver scabbardfish CPUE by day-time/night-time (tot_day-tot_night) and lower/upper codend compartments in the cycle (low_day-up_day; low_night-up_night). a) in weight, kg/h; b) in number, N/h.

This species presented a clear nocturnal trend, being 2.3 times more abundant during the night, with 928 individuals caught versus 401 fish during the daytime tows (Table II in appendix)., The trend in weight was similar, with night-time catches of 59.1 kg two times greater than during daytime (26.9 kg) (Table II in appendix). In spite of these differences, the M-W test found no differences between day and night-time catch rates, either in weight or in number (Fig.15 and b: table 2). In weight, the mean CPUE in kilograms during day was 2.4 kg/h (sd = 2.2) and in number 36 (sd = 33.8); while CPUEs for night-time tows were 6.5 Kg/h (sd = 5.6) and 103 n/h (sd = 89.1) (Table 2). There were no differences also between codend mean CPUE in kilograms and number between for both cycles (p > 0.05; Table 3).

The 1205 measured silver scabbardfish displayed an unimodal distribution with a mean total length of 46.6 cm (sd = 3.7) (Fig. 16). During night-time, the mean TL was 46.2 cm (sd = 3.2), slightly smaller than the daytime mean TL of 47.6 cm (sd = 4.2) TL. While mean day and night-time TLs were significantly different (p < 0.05; table 4), there were no significant differences between mean TLs from the lower and upper codend during both periods (p>0.05; Table 4).

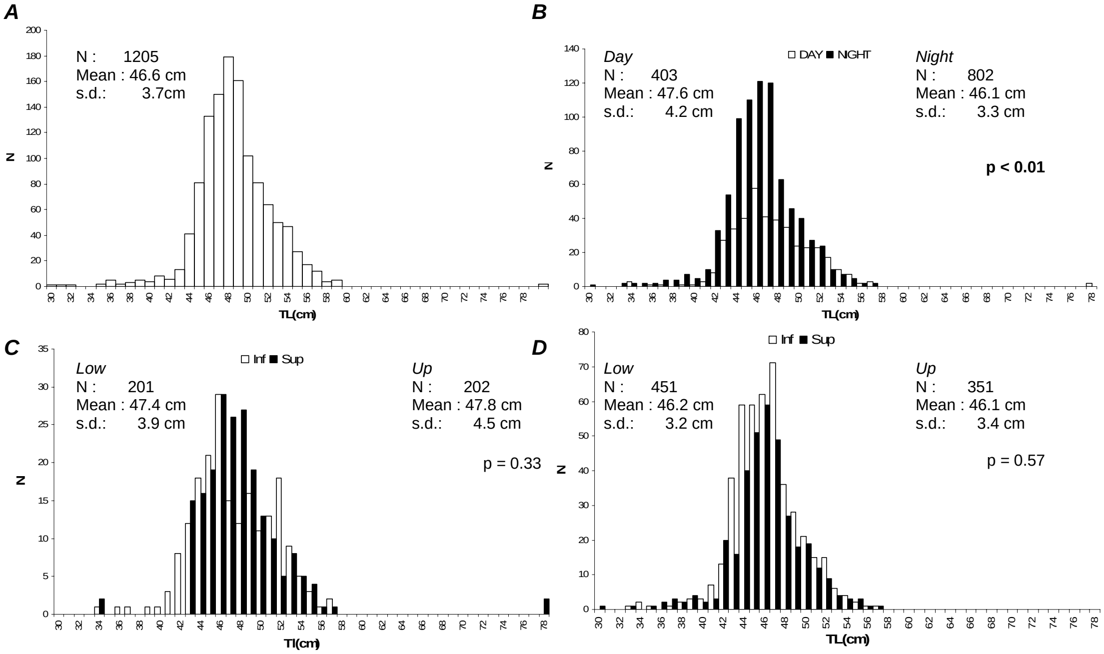

Figure 16. Size frequency distributions of Silver Scabbardfish comparing: A, Total observations; B, Night/day; C, day low/up; D, night low/up. P-values for t-test comparisons between means for each group (significant values in bold).

3.6 Greater forkbeard *(Phycis blennoides)*

During daytime the total catch of this species was 11.7kg, corresponding to 205 individuals, while during night it was 10.5 kg (107 individuals) (Table II in appendix). No significant differences were found with the M-W test for CPUE in weight or in number

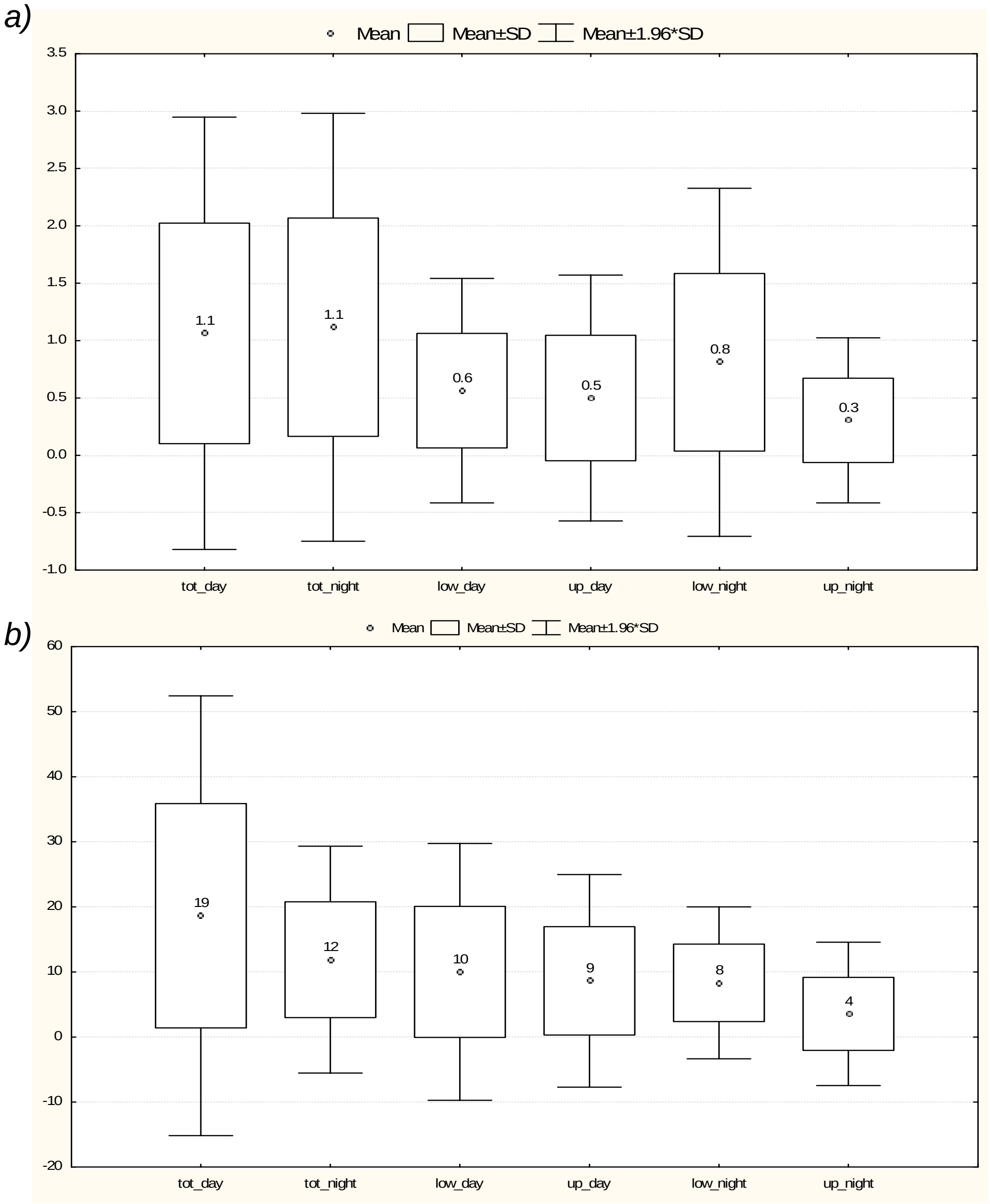

Figure 17. Box and whiskers plots of greater forkbeard CPUE by day-time/night-time (tot_day-tot_night) and lower/upper codend compartments in the cycle (low_day-up_day; low_night-up_night. a) in weight, kg/h; b) in number, N/h.

within the cycle (p>0.05) (Fig.17a and 17b; Table 2).The mean CPUE in weight during night-time 19 n/h (sd = 17.2) and 12 n/h (sd = 8.9) (Table 2). Similarly, no statistically significant differences were found between mean CPUE in kilograms and number between lower and upper codends for both cycles (p > 0.05; Table 3).

The size frequency distribution is unimodal, with a overall mean size of 19 cm TL (Fig.18a), and mean daytime and night-time TL's of 18.4 cm (sd = 2.6 cm) and 20.4 cm (sd = 5.19) respectively (Fig. 18b). The result of the T-test between day and night mean lengths was significant (p < 0.05; Table 5). Likewise for the comparison between codends mean size for the night-time (p < 0.05; Table 4), but not during the day (p>0.05) (Fig. 18c and 18d). During night-time, the mean TL for the lower codend was 19.7 cm (sd = 4.1 cm) considerably shorter than in the upper codend (22.1 cm; sd = 6.85 cm), while during daytime the range of variation was small (18.2-18.7cm) (Table 4).

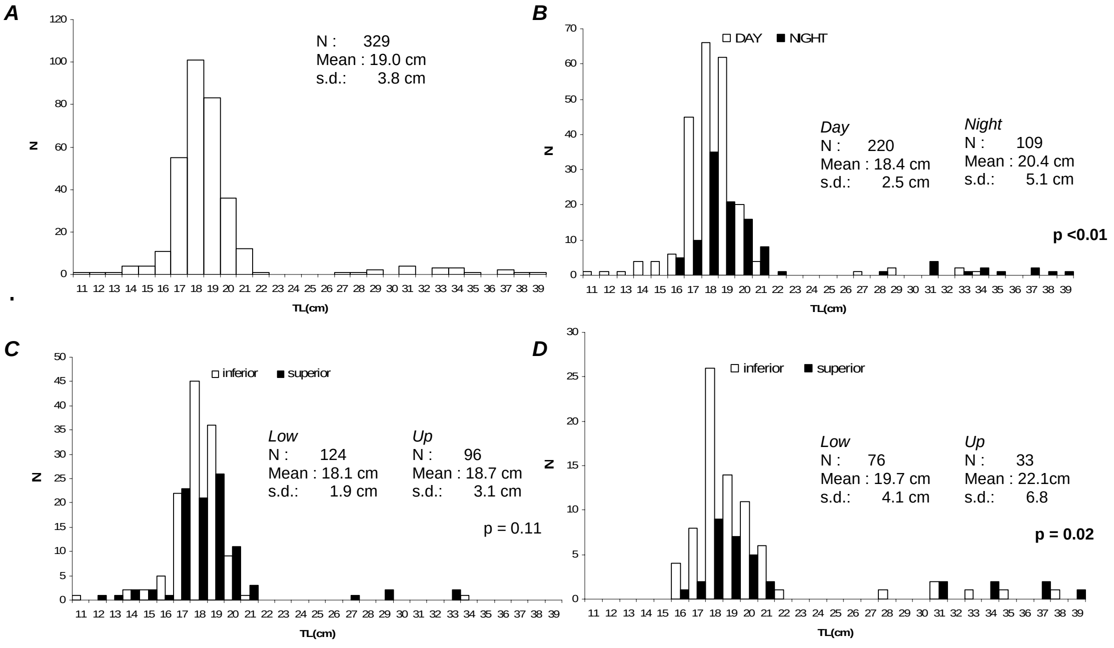

Figure 18. Size frequency distributions of Greater forkbeard comparing: A, Total observations; B, Night/day; C, day low/up; D, night low/up. P-values for t-test comparisons between means for each group (bold fold significance level).

3.7 Blue whiting (*Micromesistius poutassou)*

This species exhibits a night trend; total catch, both in weight and number, higher during night-time compared to daytime hauls: 1.4 and 1.6 times, respectively (Table II in appendix).

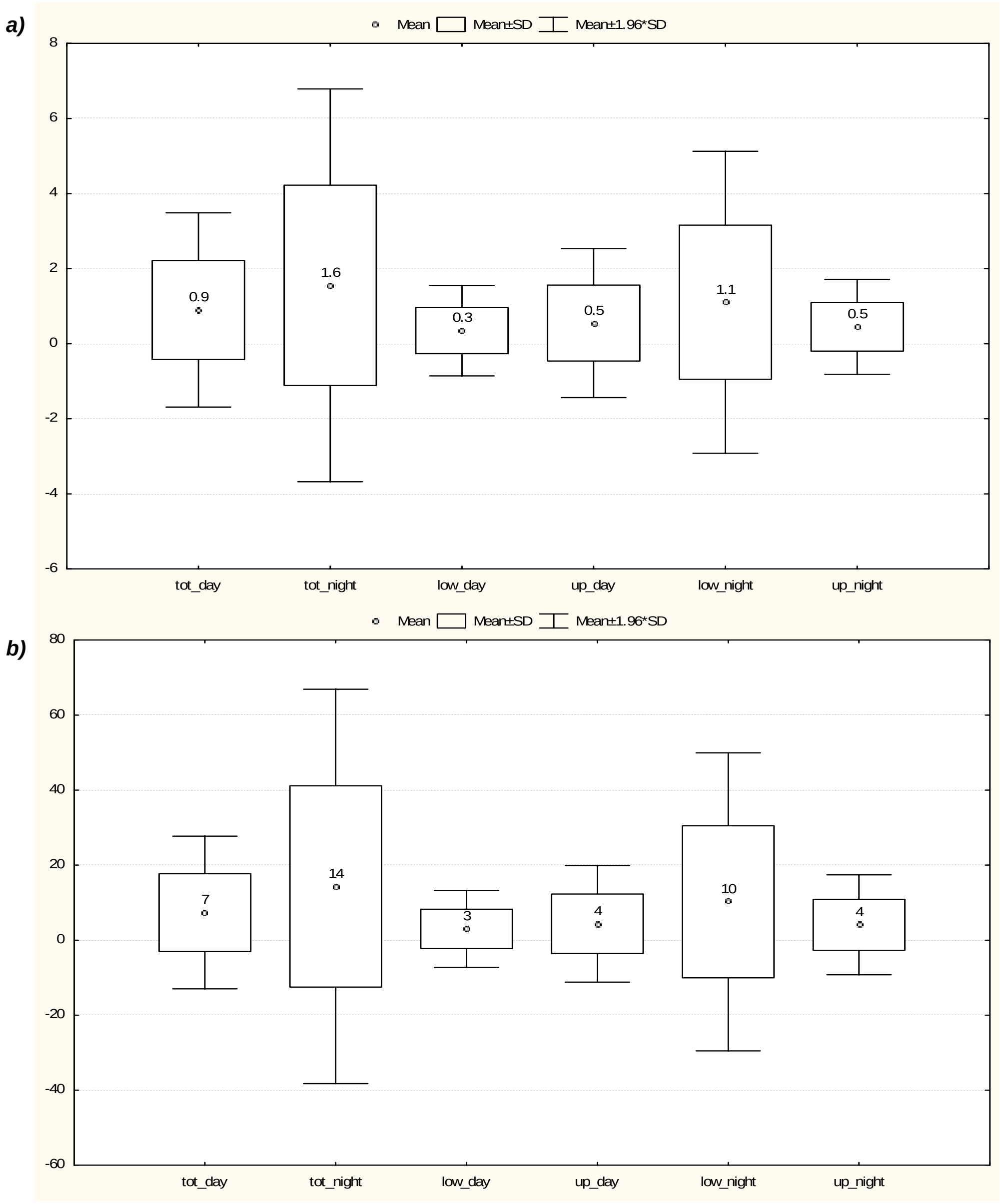

Figure 19. Box and whiskers plots of blue whiting CPUE by day-time/night-time (tot_day-tot_night) and lower/upper codend compartments in the cycle (low_day-up_day; low_night-up_night). a) in weight, kg/h; b) in number, N/h.

Similarly, the daily mean catch rates, in weight (0.9 kg/h; sd = 1.3 kg/h) and in number, 7 n/h (sd = 10.3 n/h) were also smaller than night-time samples, 1.5 kg/h (sd= 2.6 kg/h) and 14 n/h (sd= 26.7 n/h) (Fig. 19a and 19b; table 2). In spite of these trends, the M-W test did not show significant differences between the main factor (Day vs. Night), for number or for weight (Table 2). For the secondary factor (lower vs upper codend) there were also no statistically significant differences between mean CPUEs, in weight or in number ($p > 0.05$; Table 3).

Blue whiting mean length was 25.3 cm (sd = 2.3) (Fig. 20a), with daytime hauls recording larger individuals (26.2cm; sd = 2.62 vs. 24.7cm; sd = 1.9), respectively ($p<0.05$; Fig. 20b; Table 5). On the other hand, mean length comparisons between the codends (low/up) within the cycle have not reported significant differences (Fig. 20c and 20d; Table 4).

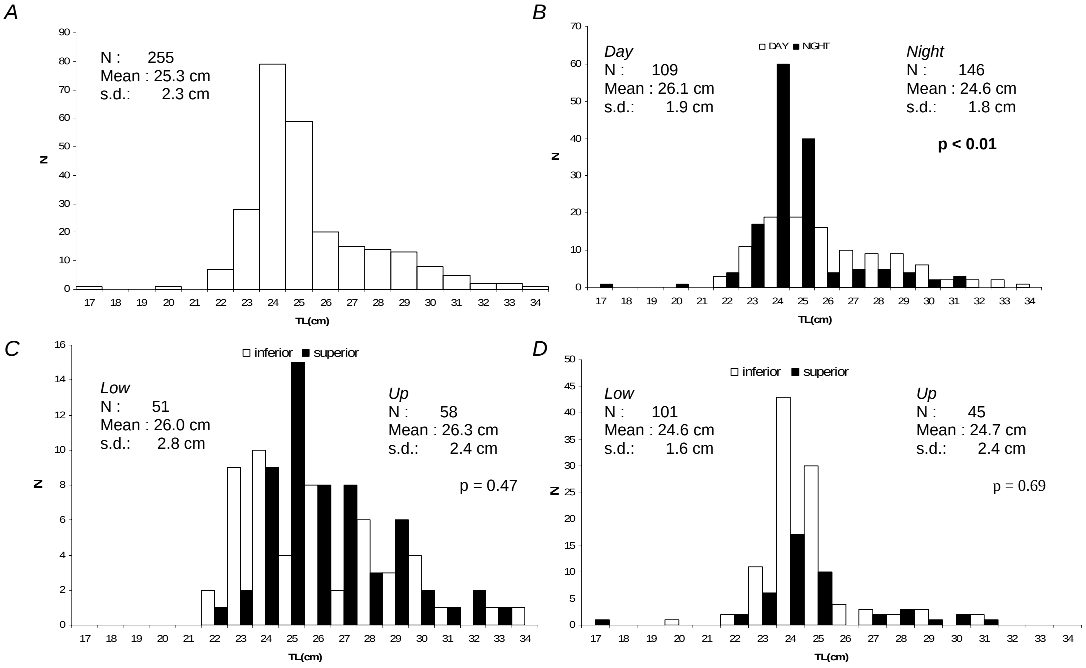

Figure 20. Size frequency distributions of blue whiting comparing: A, Total observations; B, Night/day; C, day low/up; D, night low/up. P-values for t-test comparisons between means for each group (bold fold significance level).

3.8 The European conger (*Conger conger*)

The total catch for this species was 2.7 times higher during the day compared to night-time, in number, and 3.2 times in weight (Fig.21; Table II in appendix). The M-W test shows significant differences between CPUE's indices for both periods, either in number or

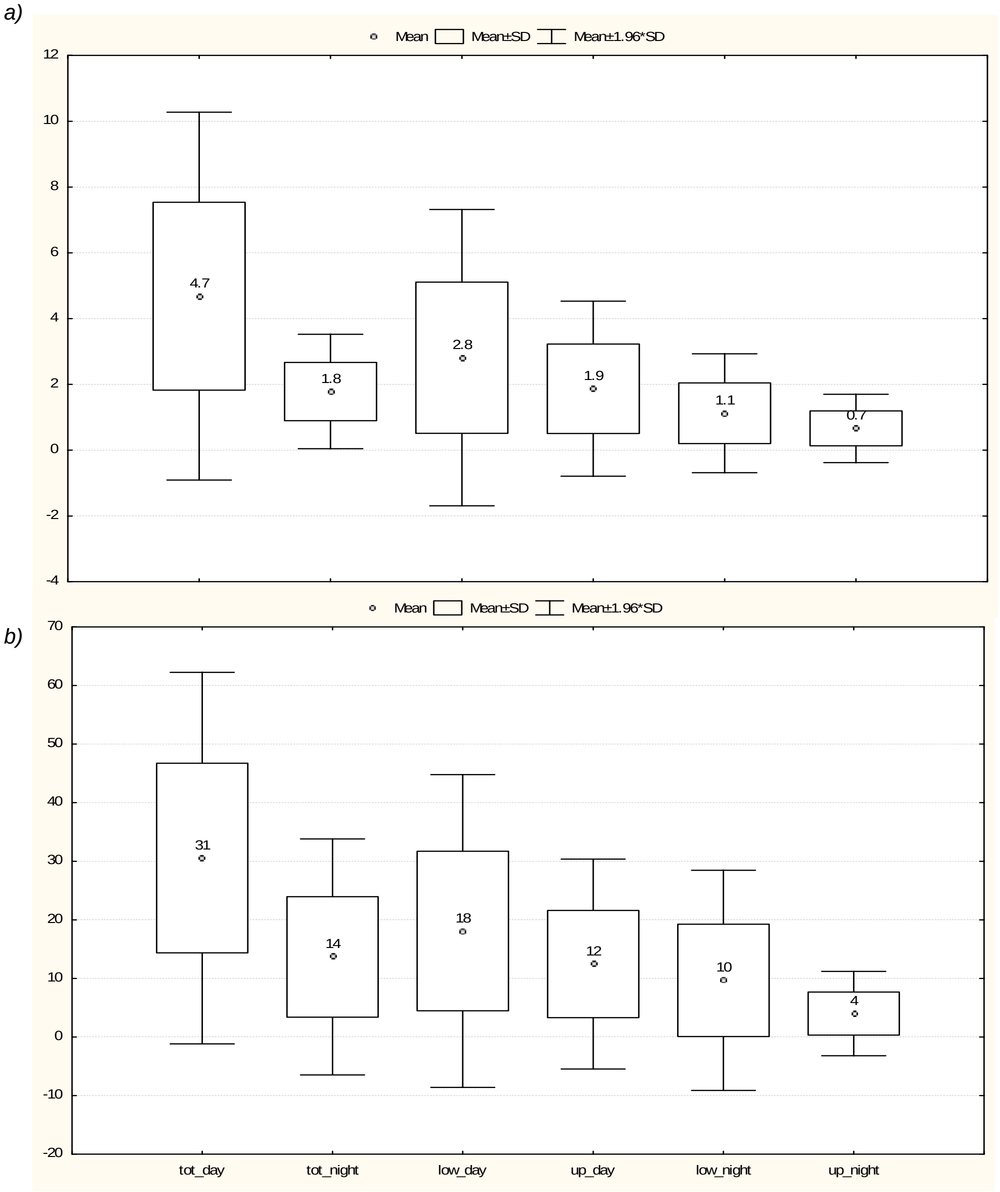

Figure 21. Box and whiskers plots of european conger CPUE by day-time/night-time (tot_day-tot_night) and lower/upper codend compartments in the cycle (low_day-up_day; low_night-up_night. a) in weight, kg/h; b) in number, N/h.

in weight (p<0.05; Table 2): 4.7 kg/h (sd = 2.9kg/h) and 31n/h (sd = 16.2), during daylight and 1.8 kg/h (sd = 0.9) and 14 n/h (sd = 10.2), for night hours (Fig.21a and 21b; Table 2). Conversely, there were no differences between mean CPUE in weight or in number between codends within the cycle (p > 0.05; Table 3).

The European conger presented a polymodal size distribution for the samples analyzed, with an overall mean length of 41.8 cm (Fig. 22a). Day and night-time mean sizes were very near to the overall length, 41,9 and 41,2 cm, respectively. Similarly, the figures obtained for lower and upper codends, separately for each period, did not display much difference to the overall mean (41.7 vs 42.3cm and 40.4 vs. 43.0 cm, respectively for day and night-time). t-test comparing the different pairs of values did not display any statistically significant difference (Fig. 22b, 22c and 22d; Table 4).

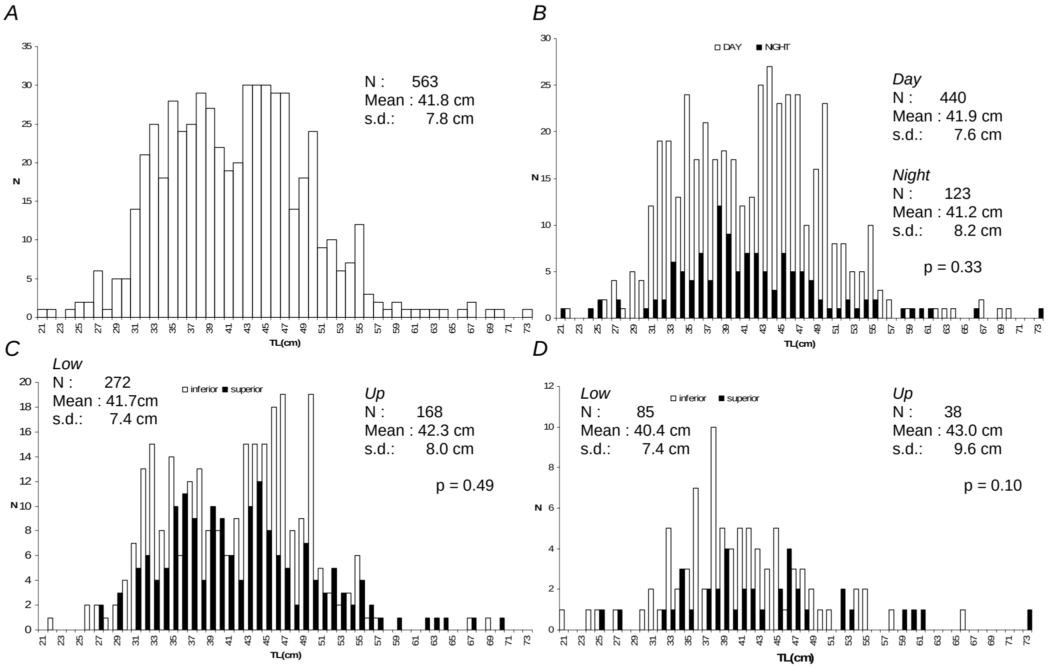

Figure 22. Size frequency distributions of European conger comparing: A, Total observations; B, Night/day; C, day low/up; D, night low/up. P-values for t-test comparisons between means for each group (bold fold significance level).

4 DISCUSSION

The analysis of the overall data (all species combined) shows that CPUE (kg/h) is significantly higher during daytime hauls when compared to those carried out at night. Still, at the species level the picture may be quite different with several of them displaying an opposite trend (e.g., silver scabbardfish, blue whiting, tongue sole, Atlantic mackarel and silver cod). The circadian variability in species abundance may have a major impact on the catchability of the fishing gear (and thus abundance indices), confirming the importance played by the diel cycle when establishing a sampling programme, either for commercial fisheries management purposes or the characterization of biological assemblages. These variations in abundance between day-night trawling are controlled by activity rhythms of the species assemblage in response of geophysical factors, in this case, the 24h light cycle, and species-dependent behaviour (Aguzzi and Company, 2010).

The deepwater rose shrimp, *P. longirostris*, dominates the bulk of the catch during the day, but its catch rate drops drastically in night hauls. This overall trend was previously reported by Arrobas and Ribeiro-Cascalho (1987), although the registered differences, in weight, between day and night-time hauls were smaller, eight-fold in the latter study against 24-fold in the present one. The GAM modelling strongly suggests that the time of the day (solar hour) is the key factor conditioning the variation in yields, by explaining a large percentage of the variability. The catch rate increases sharply at dawn, reaches a maximum between 10´clock and the midday (solar time), after which it displays some variability, followed by a sharp decline at dusk. Differences between catch rates in both horizontal compartments (lower vs. upper codends) were tested for both periods. Significant variations in yield were found both for day and night-time. During daytime the lower codend retained about 2/3 of the mean catch, both in weight and number, while at night the trend was opposite. However, these changes are not accompanied by alterations in the population structure, neither for sex proportion nor for mean size. Furthermore, this population structure is analogous to that reported by Arrobas and Ribeiro-Cascalho (1982) for the same depth strata in the same season.

A previous study in the Mediterranean shelf-break off west central Italy carried out at depths between 140-160m, resulted in higher yields of rose shrimp at night (Carpentieri *et al*., 2005). Weighing the latter results with our own, carried out in deeper waters, it may be argued that this species starts a displacement towards shallower waters, along the bottom at dusk. Concurrent with the displacement, vertical dispersal also seems to take place, as evidenced by the catch of a larger percentage of individuals higher in the water column, a behaviour possibly associated with avoidance of predation. Aguzzi and Company (2010), in a review on the chronobiology of deep-water decapod crustaceans on continental margins also report that rose shrimp perform horizontal displacements within the benthic boundary layer (BBL) of the continental margin, along bathymetric gradients, to shallower waters similarly to other nektobenthic species.

The diel activity of decapods has been subject of previous studies conducted in the Mediterranean. Razek *et al*., (2006) found the same pattern in the coast of Egypt, where females were also dominant in the catches, and were also larger than males (females, 22.6 mm CL; males 19.2 mm CL). The behaviour of the commercially important Penaeid species and their behavioural rhythms has been extensively reviewed by Penn (1984), who found that each species exhibited different behavioural patterns which would affect their catchability in trawls. Aguzzi and Company (2010) divided this family in 3 basic categories: pelagic, endobenthic and nektobenthic , where the latter have higher daytime catches due to the formation of aggregation patches, making them more vulnerable to capture by trawl. Acknowledging this feature as the major factor affecting catchability for this family, once again we suggest that the deep water rose shrimp may have the same aggregation pattern, where random trawling transects during daytime result in higher catches due to the aggregations of shrimp on the bottom.

The European Hake daytime CPUE was almost twice that of night-time, although this difference was not statistically different This species is a by-catch of high commercial value for the crustacean bottom trawl fleet, representing the most abundant fish in weight, caught during the survey. Woodhead (1963) found that the greatest diel fluctuations occurred in the catches for smaller hake less than 29 cm, with night-time catches of this length group 1/6 of the daytime values in the southern North Sea. In the present study hakes below 23 cm were very scarcely represented in the night-time hauls. Bottom trawling for different hake species commonly results in higher abundance indices during daytime when compared to night (Gordoa and Macpherson, 1991; Gillis, 1999; Johnsen and Iilende, 2007).). Parrish *et al*. (1963) also reported lower catch rates for hake during night hauls in bottom trawling off the British Isles. They found that for the greater part of the year, catches of all species were substantially higher at night than in daytime, but a shift towards better daytime fishing takes place in summer. In the North Sea, Petrakis *et al*., 2001) , found differences in catch rates between day and night during bottom trawl research surveys, and suggested that this could be attributed to fish behaviour, notably vertical migration or gear avoidance reactions. Woodhead (1963) reported that a number of commercial bottom trawled species, also from the North Sea, including hake, herring, saithe and redfish, have been generally caught in smaller amounts during the night than the day.

Bowman and Bowman (1980) found that for a similar species, silver hake, *Merluccius bilinearis,* taken by bottom trawlers at Georges Bank, off the NE U.S. Atlantic coast, catches at night were larger due to feeding habits on benthic organisms. Carpentieri *et al*. (2005) recorded higher abundance for this species in diurnal hauls on the Mediterranean shelf-break. Finally, a similar situation occurred for both *Merluccius capensis* and *M. paradoxus* off the west coast of South Africa, where considerable variation in catch rates between day and night was found, with daytime numbers and biomass being generally greater than night catches (Pillar and Barange, 1997). Most studies conclude that hake generally feed at night, undergoing vertical migration in night hours to midwater layers (Bowman and Bowman, 1980; Gillis, 1999). Observations from video transects from manned submersibles were used to assess patterns of associations of demersal species with habitat features on low relief bottoms across the southern New England continental shelf and slope. It was found that silver hake was associated with particular microhabitat features during the day, being randomly distributed at night (Auster *et al*., 2010) This suggests that hake moves into midwater at night in response to the movement of their prey, thus becoming less available to low headline height trawls, such as the one used in this study.

The blackbellied anglerfish, *L. budegassa,* was the third most captured species, both during day and night hauls. Higher catch rates were found during daytime, with significant differences for the catch rate in number, fitting into the same general trend of the survey. Bahamon *et al*., (2009) found higher catch rates for this species during night-time, especially at dusk. The horizontal separator panel presented larger catch rates for the lower codend for both cycles, but significant differences were only found during nighttime. This species is consider typically benthic, expending most of its time motionless on the sea bed waiting for its prey. However, they are sometimes found higher up in the water column. This probably happens when it lifts from the sea bed and uses ocean currents in connection with feeding or spawning migrations (Bjelland, 2011). Our results seem to confirm that this species displays a diel rhythm activity (higher during daytime) although not so marked as the rose shrimp, but still relevant for fisheries and demersal community studies as well.

The silver scabbardfish *Lepidopus caudatus*, showed higher yields during night-time, suggesting that a diel movement in the water column from the upper layers, in the day, to the bottom, at night. Another hypothesis could be associated with trawl avoidance during daytime, since this species is highly mobile, becoming more vulnerable in the dark. This species has been reported as the most important bycatch in commercial bottom trawling in the northeast Mediterranean Sea (Catalonian coast), at depths between 119 m and 391 m during daytime, with an average catch rate of about 14 kg/h, accounting for 68.5% of the discards (Sánchez *et al*., 2004). In the present study it ranked fourth in total landings, representing about 11% of the total catch. Albert and Bergsatd (1993) *in* Froese and Pauly (2010) considered the silver scabbardfish a species that migrates nightly to midwater, forming schools and occasionally found in inshore waters during upwelling periods, feeding on crustaceans. Bahamon (2009) found two different trends for this species according to the season, with night and day abundances of 53 and 40 individuals.km^{-2} in October, while June night and day abundances were 19 and 27 individuals/km^{-2} respectively The latter authors reported these results for an average depth of 400m, while the landings of the present study came from around 250 m. Generally speaking, the latter results seem to be in agreement with our own data obtained at the end of the summer.

The blue whiting was another species presenting a nocturnal trend, caught twice in number during the night-time hauls. The species is reported as being mainly caught by large pelagic trawld towed at depths of 200-500 m either in midwater or close to the sea bed Waterman (2001). Fishing yields are higher during daylight with shoals tending to disperse during darkness. Although our results suggest the opposite trend; overall catches were low due to the reduced fishing speed used by crustacean trawlers, thus preventing an adequate inference on the species diel behaviour.

While analysing the greater forkbeard acoustic recordings off the western British Isles, Johnsen and Godo (2007) found a circadian variation pointing to higher abundances in shallow waters (<350m) during night-time, while in general, the estimates of density were about 20% higher during the day. However, this diel shift was observed to vary considerably among years and depths. Although, present results point to higher catch rates during daytime, it is interesting to note that during night hauls the average size of individuals was larger. Moreover, during night-time there is a clear difference in the mean size of individuals captured in both codends, with the larger animal retained in the upper codend. Thus, not only does sampling during daytime not provide an adequate representation of the population size structure, but the apparent differential size distribution in the water column should be taken into consideration. The latter difference may well be related with gear avoidance issues, where larger individuals may react differently to the trawl, attempting to escape by swimming upwards,.

The evolution of conger catches does not bring any further novelty in terms of day/night trend. It is clearly a diurnal species that distributes itself more or less evenly by both codends, not displaying any statistically significant difference in the mean size of individuals captured during day and night-time or between codends. There is however an apparent tendency for larger individuals to be retained in the upper codend..

Several authors have reported diel variability in bottom trawling catch rates for a number of fish and crustacean species in different areas (Engas and Soldal, 1992; Yousif, 2003; Carpentieri *et al*., 2005; Aguzzi *et al*., 2009) but the magnitude and direction of the differences vary widely, not only between species but also according to places and season. Nevertheless, while drawing conclusions, the area and temporal limitations in sampling should not be forgotten. Diel variations in species composition and catch rates may change between fishing grounds and seasons. The catch rate pattern exhibited by one species may not be extrapolated as a widespread feature for the species over a broad geographical scale, since it can be related to specific conditions of the sampled area, such as bottom type and topography, prey and predator abundances, temperature and salinity, season and depth, as well as other factors. For example, research surveys conducted off the coast of Newfoundland and Labrador in the Northwest Atlantic showed that local differences may be confounded by the effects of depth on diel catchability; in deeper strata, catchability was higher during the day, while in shallower waters the abundances were higher during night-time (Casey and Myers, 1998).

If the day cycle is the main factor controlling the rhythm of the demersal community, a question about light availability at the depth sampled came up automatically. Light propagation into the sea has been widely studied by different fields. In marine ecology, Tait and Dipper (1998) refers that even in clear water about 80% of the total radiation entering the surface is absorbed within the uppermost 10m, where the water below 200m is termed the *aphotic zone*. Minima in light intensity are still recordable up to 1000m depth in oligotrophic areas such as the Mediterranean Sea (Margalef, 1986). Aguzzi and Company (2010) state that the effect of this diel rhythm behaviour on decapods is controlled by an “internal biological clock” functioning on the 24h scale, which is the major evolutionary constraint responsible for horizontal displacements along bathymetric gradients.

It is known that vertical migrations of demersal fish species in the water column can be associated either to feeding habits on mesopelagic organisms or to a predation avoidance mechanism. Trophic ecology research on demersal fish communities helps to understand the processes on which fish population assemblage structure depends. Through stomach contents analyses of 25 demersal fish species of the southern Bay of Biscay (Preciado *et al*., 2008), it was found that small pelagic fish species represent an important food source for demersal species. This suggests that feeding migrations to middle and upper layers of the water column represent a key issue in order to understand the availability of benthic fishes and crustaceans to bottom trawling through the day and night (Sousa *et al*., 2005). In this study, the overall catch in the lower codend was considerably higher than the upper codend in both cycles. However, this difference was just statistically significant during night-time. The vertical difference in CPUE between the upper and lower compartment might reflect the position of the species in the water column, as well as gear avoid reactions, where different species depending on size and sex could display different behaviour during the day cycle, e.g. swimming upward in attempts to escape. In the present study, just a small group of species had higher catches in the upper codend: deep water rose shrimp during night-time; blue whiting and silver scabbarfish during day time. Ashok and Sheshappa (1991) in an experiment carried out in the inshore waters of the Arabian Sea using a high opening bottom trawl (HOBT) with similar measurements found that catches in the lower codend, where most of the crustaceans were retained, were considerably higher, but the separator panel was not effective in separating any of the main fish species. Knowledge of the differences in behaviour of demersal species has already been successfully used for the separation between haddock and whiting in *Nephrops* fisheries, using a two level trawl with separate codends (Main and Sangster, 1982).

Valdemarsen *et al*. (1985) found that the proportion of the catch of haddock and cod in the lower codend was reduced in hauls carried out in the early morning, and also found significant differences in the length distributions of both species in the upper and lower codends, with smaller fish being caught in the lower one. In our study just two species displayed significant differences in length distribution between, the deep water rose shrimp (an irrelevant difference of few millimetres, although statistically significant) and greater forkbeard during night-time, the only species for which a bias in population structure induced by the diel cycle can be put forward.

5 CONCLUSIONS

The current study constitutes a mere snapshot of a complex biological system and the circadian dynamics of the most captured species, thus lacking the spatial and seasonal components needed for a full picture. Nonetheless, the overall results not only confirmed a circadian variation in the biomass available to fishing gears, namely research sampling bottom trawls, but also provided a hint on the community dynamics and structure of rose shrimp fishing grounds.

The species analysed within this study put in evidence the different aspects by which bias may be introduced when fisheries-independent sampling is carried out within the scope of research cruises, both species and gear-related. Changes in catches due to alterations in species availability to the fishing gear, such as those displayed by the deepwater rose shrimp, where catches vary markedly between day and night, and apparently also during daytime, are bound to introduce a strong bias in the estimation of abundance. Likewise, for species such as the silver scabbardfish and the blue whiting whose catchability is superior during night hauls, when most survey cruises are carried out during daylight hours. A further biological constraint may result not only from changes in availability during the diel cycle, but also from alterations in the size structure of the population, as is the case of greater forkbeard.

The potential different distribution of species in the water column along the diel cycle, either in terms of the global catch, as happens for the rose shrimp, or by displaying a size vertical gradient, as for the great forkbeard, poses a distinct problem. The latter may be defined as a technological issue, since it pertains to the suitability of the fishing gear to sample the entire size structure of a given population. Known phenomena such as avoidance reactions to the fishing gear, as a whole, or its individual components, or more prosaic problems such as its physical dimensions (mouth opening) may contribute to a biased estimation of overall abundance and/or population structure.

As suggested from the modelling of the catch rate, in numbers, as a function of the solar hour, there are huge changes along the day, especially at dawn and dusk, when rapid increases and decreases, respectively, in the available biomass takes place. Also, along the daylight hours a considerable fluctuation in the catch rate apparently takes place. Considering that this is a highly valuable commercial shrimp species, pivotal for the crustacean bottom trawling fleet profitability, it would be highly advisable that abundance indices are corrected for the towing hour. Likewise, the results obtained for the remaining fish species, although based in smaller overall catches, also advise caution in using raw, uncorrected, figures such as abundance indices. This may be particularly sensible for the European hake, currently submitted to a recovery plan, a species long known for seasonal day/night changes in abundance.

The analysis of catch rates, including the existing data from research cruises and their relationship with different physical and biogeographically factors would be of great help to understand the dynamics of the most important commercial species, and their variability along the circadian cycle, thus constituting a potential improvement in the scientific advise. Future work should concentrate on highlighting the underlying reasons for the differences between day and night periods, including the focus on transition hours (usually at sunset and sunrise), where important clues on the daily activity rhythm may be found. Not least important will be to deepen the knowledge of species behaviour towards the fishing gear an incorporate it in the experimental design and operational procedures of research cruises.

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8 Appendix

Table I. Species recorded during the experimental survey.

Commom Name	Specie	Family	Ecology
Fishes			
Argentine	*Argentina sphyraena*	Argentinidae	Bathydemersal
Scaldfish	*Arnoglossus laterna*	Bothidae	Demersal
Bogue	*Boops boops*	Sparidae	Demersal
Boarfish	*Capros aper*	Caproidae	Pelagic
Atlantic spotted flounder	*Citharus linguatula*	Citharidae	Benthic
European conger	*Conger conger*	Congridae	Demersal
Silvery cod	*Gadiculus argenteus*	Gadidae	Pelagic
Shore rockling	*Gaidropsarus vulgaris*	Lotidae	Demersal
Blackmouth catshark	*Galeus melastomus*	Scyliorhinidae	Bathydemersal
Blackbelly rosefish	*Helicolenus dactylopterus*	Sebastidae	Bathydemersal
Silver Scabbardfish	*Lepidopus caudatus*	Trichiuridae	Benthopelagic
Fourspotted megrim	*Lepidorhombus boscii*	Scophthalmidae	Benthic
Megrim	*Lepidorhombus whiffiagonis*	Scophthalmidae	Bathydemersal
Black-bellied angler	*Lophius budegassa*	Lophiidae	Benthic
Snipe fish	*Macroramphosus scolopax*	Centriscidae	Pelagic
European hake	*Merluccius merluccius*	Merlucciidae	Demersal
Thickback sole	*Microchirus variegatus*	Soleidae	Benthic
Blue whiting	*Micromesistius poutassou*	Gadidae	Bathypelagic
Serpent eel	*Ophisurus serpens*	Ophichthidae	Demersal
Common pandora	*Pagellus erythrinus*	Sparidae	Benthopelagic
Greater forkbeard	*Phycis blennoides*	Phycidae	Benthopelagic
Chub mackerel	*Scomber japonicus*	Scombridae	Pelagic
Atlantic mackerel	*Scomber scombrus*	Scombridae	Pelagic
Small spotted catshark	*Scyliorhinus canicula*	Scyliorhinidae	Demersal
Common sole	*Solea solea*	Soleidae	Benthic
Tongue sole	*Symphurus nigrescens*	Cynoglossidae	Demersal
Dragonnet phaeton	*Synchiropus phaeton*	Callionymidae	Demersal
Blue jack mackerel	*Trachurus picturatus*	Carangidae	Benthopelagic
Atlantic horse mackerel	*Trachurus trachurus*	Carangidae	Pelagic
African armoured searobin	*Peristedion cataphractum*	Peristediidae	Demersal
Velvet belly lantern shark	*Etmopterus spinax*	Etmopteridae	Bathydemersal
Crustaceans			
Shamefaced crab	*Calappa granulata*	Calappidae	Benthic
Swim crab	*Callinectes sp.*	Portunidae	Benthic
Norway lobster	*Nephrops norvegicus*	Nephropidae	Benthic
Rose shrimp	*Parapenaeus longirostris*	Penaeidae	Necktobenthic
Pinkglass shrimp	*Pasiphaea multidentata*	Pasiphaeidae	Demersal
Molluscs			
Homed octopus	*Eledone cirrosa*	Octopodidae	Demersal
Broadtail shortfin squid	*Illex coindetii*	Ommastrephidae	Pelagic
European squid	*Loligo vulgaris*	Loliginidae	Pelagic
Common octopus	*Octopus vulgaris*	Octopodidae	Benthic

Table II. Total in weight (Kg) and number (N) for total catches and the seven most captured species.

	Kg/h		Nº/h	
Species	DAY	NIGHT	DAY	NIGHT
total	535.3	248.9	*NA*	*NA*
Deep water rose shrimp	186.0	6.6	17631	672
European hake	111.7	51.5	475	189
Black bellied angler	64.6	27.7	46	19
Silver scabbardfish	26.9	59.1	401	928
European conger	51.5	16.1	336	123
Blue whiting	9.9	14.0	81	129
Greater forkbeard	11.7	10.5	205	107

Table III. GAM analysis for deepwater rose shrimp. CPUE in number modelled according to the haul starting time

Parametric coeficients				
	estimate	Std. Error	z-value	Pr(>|z|)
intersept	5.4946	0.2354	23.24	< 2E-16

Approximate significance of smooth term			
	edf	chi sq	p-value
s(hour)	4	38.25	9.96E-08

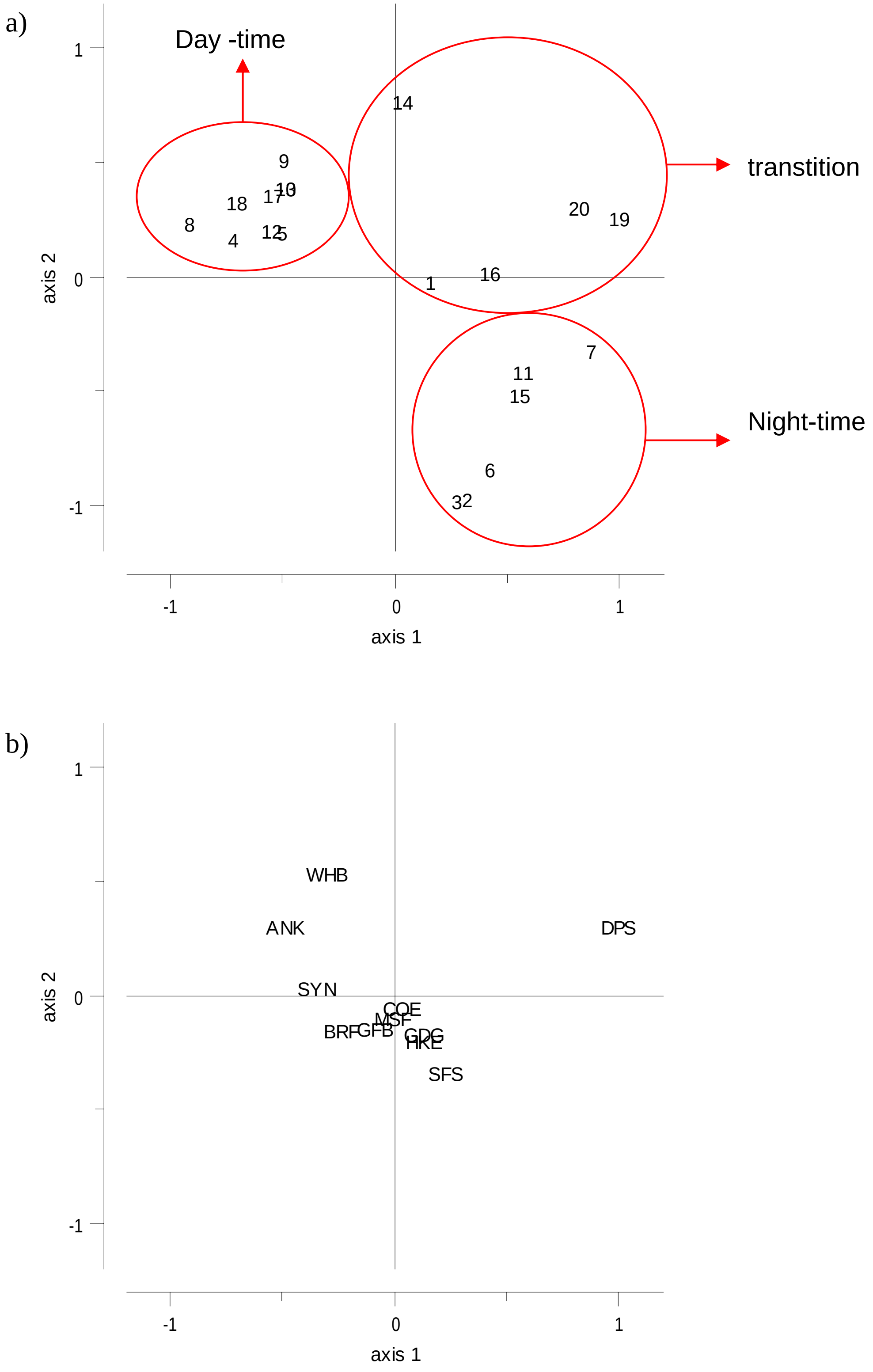

Figure I. Non Metric Multidimensional Scaling (NMDS) for the 11 most important species caught. Data used was abundance in number square root transformed. a) hauls number; b) species FAO codes. Red circles shows the grouping factor in the analyses.

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Statutory declaration

I hereby confirm that I have independently composed this Master thesis and that no other than the indicated aid and sources have been used. This work has not been presented to any another examination board.

Gambelas, 31 de março2011

Carlos Pombo Sonderblohm