Home range and diel behaviour of the ballan wrasse, *Labrus bergylta*,
determined by acoustic telemetry

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Running head: movement patterns of *Labrus bergylta*

Abstract

Effective fisheries management needs to consider spatial behaviour in addition to more traditional aspects of population dynamics. Acoustic telemetry has been extensively used to provide information on fish movements over different temporal and spatial scales. Here, we used a fixed-receiver array to examine the movement patterns of *Labrus bergylta* Ascanius 1767, a species highly targeted by the artisanal fleet of Galicia, NW Spain. Data from 25 individuals was assessed for a period of 71 days between September and November 2011 in the Galician Atlantic Islands Maritime-Terrestrial National Park. Fish were present within the monitored area more than 92% of the monitored time. The estimated size of individual home ranges, i.e. the area where fish spent most of their time, was small. The total minimum convex polygons area based on all the estimated positions was $0.133 \pm 0.072 \text{ km}^2$, whereas the home range size estimated using a 95% kernel distribution of the estimated positions was $0.091 \pm 0.031 \text{ km}^2$. The core area (50% kernel) was $0.019 \pm 0.006 \text{ km}^2$. *L. bergylta* exhibited different patterns of movement in the day versus the night, with 92% of the fish detected more frequently and travelling longer distances during the daytime. In addition, 76% of the fish displayed a larger home range during the day versus night. The linearity index was less than 0.005 for all fish suggesting random movements but within a relatively small area, and the volume of intersection index between consecutive daily home ranges was 0.75 ± 0.13 , suggesting high site fidelity. The small home range and the sedentary behaviour of *L. bergylta* highlight the potential use of small MPAs as a management tool to ensure a sustainable fishery for this important species.

46 **Keywords:** home range, diel behaviour, site fidelity, marine protected
47 areas, acoustic telemetry, *Labrus bergylta*.

1. Introduction

Fish movement patterns are particularly relevant to marine management and conservation (Alós et al., 2012b). Traditionally, management decisions were based on population-dynamic models that incorporated fishing effort and a number of biological traits. However, they assumed fish populations to be spatially homogeneous (Botsford et al., 2009), even when the biology of the fish and the management tools used had a spatial component (Babcock et al., 2005). As approaches for managing marine resources are improving, there is increasing evidence for the need to integrate spatial information into our understanding of population dynamics (Pech et al., 2006; Semmens et al., 2010).

Understanding fish movement patterns is important, for example, in the design and assessment of marine protected areas (MPAs). MPAs are a multipurpose fishery management tool (Martin et al., 2007), often used to protect a specific life history stage and to promote the healthy populations which will then spillover the boundaries of the MPA to other areas. Thus, the success of MPAs in a fisheries context largely depends on the scale of fish movements in relation to the size of the MPAs. If most of the individuals within the population have home ranges larger than the area of the reserve itself, then the fish will be exposed to fishing pressure and the effectiveness of the reserve will be limited (Kramer and Chapman, 1999). MPAs have been predicted to best serve benthic species with small home ranges and high residency, such as some scarids (e.g. Welsh and Bellwood, 2012), serranids (e.g. Afonso et al.,

2011; March et al., 2010) or labroids (e.g. Chateau and Wantiez, 2007; Topping et al., 2005).

In spite of its importance, quantifying movement patterns of marine fishes is difficult. Conventional approaches based on external tagging (i.e. mark-recapture studies; Fowler et al., 2002; Palmer et al., 2011) depend in large part on the rate of fish returned by fishermen or anglers. In contrast, acoustic telemetry is able to provide repeated estimates of the position of the same individual and has become a powerful approach that allows tracking of fish over different spatial and temporal scales (Alós et al., 2011; Heupel et al., 2006). In the last years acoustic telemetry has been increasingly used to determine home range size (Collins et al., 2007; Lowe et al., 2003), diel activity pattern (Hitt et al., 2011; Jadot et al., 2006; Meyer et al., 2007), site fidelity (Abecasis and Erzini, 2008; March et al., 2011), and habitat preference (Alós et al., 2011; Topping et al., 2005) of different fish species in a variety of ecoregions. Nonetheless, inference about temporal patterns from telemetry studies should be done with care, and effort must be made in disentangling animal behaviour and rhythms from other factors affecting the probability of detecting a fish (e.g. wind speed, current speeds, biological and environmental noise; Heupel et al., 2006) and the use of fixed control tags has been recently proposed to overcome this problem (Payne et al., 2010).

The ballan wrasse, *Labrus bergylta* Ascanius 1767, is one of 13 species of labroids occurring in Galicia, NW Spain (Bañón et al., 2010). It is distributed along the coasts of the north-east Atlantic (from Norway to Morocco) and the Mediterranean, from the shoreline to 60 m depth, and targeted throughout most

of this range (Porteiro et al., 1996; Talbot et al., 2012; Treasurer, 1994). In Galicia, it supports an important artisanal gillnet fishery, being one of the three most landed fish species in the last decade (www.pescadegalicia.com; last accessed: 25 Sep 2012), as well as a recreational fishery made up of anglers and spear fishers, who usually select for larger individuals (Lloret et al., 2008). The ballan wrasse is a benthic species, occurring most commonly at depths < 30 m (Dipper et al., 1977). It inhabits rocky reefs and kelp beds where it mostly feeds on small invertebrates (Figueiredo et al., 2005). It's long-lived (up to 29 yr), with slow growth and a protogynous hermaphrodite without sexual dimorphism in colour (Dipper et al., 1977), which spawns in the spring in northern Europe (Dipper and Pullin, 1979; Muncaster et al., 2010). Management of *L. bergylta* is based solely on a minimum landing size of 20 cm, even though it has been suggested that in sequential hermaphrodites larger individuals should be protected to ensure sex ratios are sufficient for effective mating and fertilization (Alonzo and Mangel, 2004).

There is little knowledge of home range size and temporal patterns in movements for this species. However, a pilot study suggested these topics could be successfully addressed with telemetry (Pita and Freire, 2011). In addition, males have been reported to defend small territories (< 300 m²) (Sjolander et al., 1972) and inactivity has been observed at night (Costello, 1991, pers. obs.). Thus, *L. bergylta* appears to be a good candidate for spatial management (i.e., MPAs), but the optimal reserve size lacks empirical testing.

In this study, we used acoustic telemetry to investigate the individual and temporal variability in the movement patterns of *L. bergylta* over a period of 71

days. Specifically, we estimated: (1) residence and site fidelity indexes, (2) temporal patterns and diel behaviour, (3) home range and core area size and (4) fish size related differences in spatio-temporal patterns.

2. Material and Methods

This study was conducted at the Cíes Archipelago (Galicia, NW Spain; Fig. 1) between 1 September and 10 November 2011. These islands are part of the Galician Atlantic Islands Maritime-Terrestrial National Park, created in 2002. It comprises an area of $\sim 32 \text{ km}^2$ where limited commercial fishing is allowed with some gear regulations, while recreational fishing is forbidden. The study area is located around a small islet in the channel between two of the main islands (Fig. 1). This is a shallow area with depths between 0 and 23 m encompassing different habitat types, namely rocky reefs, kelp beds, coralline algae and sandy bottoms.

2.1 Receiver array

In September 2010, a preliminary range test was carried out in Ría de Vigo at a location similar to the study area. We specifically tested detection range at 10-15 m depth and over 2 different substrates (soft and hard). We used ©Vemco range test tags V13 and V9 with the same power output as the tags used in this study. A line of 12 receivers was moored covering a distance of 350 m, and both tags were submerged 1 m above the bottom, at the location of the first receiver in the line. The test lasted 112 min, which is the time needed to send out 160 emissions. A generalized linear model (GLM, family

quasibinomial) was used for each substrate type to test for differences between proportions of emissions detected at each distance by each tag type. There was no significant difference in the reception range of either tag type with hard ($p = 0.340$) or soft ($p = 0.620$) bottom type. Therefore data from both tag types were pooled in subsequent analysis. Maximum detection range was ~ 200 m and ~ 300 m for hard and soft bottoms, respectively, so an intermediate value of 250 m was used to design the receivers array.

Based on this information a fixed array of 12 acoustic omni-directional receivers ([®]Vemco model VR2W) was deployed at the study site to monitor the spatio-temporal patterns of *L. bergylta* (Fig. 1). Receivers, previously treated with antifouling paint, were attached to the upper end of a metallic auger anchor (140 cm high), which was screwed ~ 60 cm into the substrate. This system allowed good fixation and resistance to bad weather conditions as well as a guaranty of vertical orientation of the receiver. Receivers were placed at depths between 5 and 21 m and the array covered an area of $\sim 1.6 \text{ km}^2$, with a higher density of receivers closer to the place where fish were tagged and released (islet shoreline). The receiver configuration allowed for range overlap and allowed fish to be continuously detected when present inside the monitored area.

2.2 Sampling and tagging

Sixteen fish were captured at depths < 10 m during daytime with hook and line and the swim bladder punctured quickly for venting the trapped gas. Another 9 fish were captured while resting at night by SCUBA divers at 6-10 m depth and slowly brought to surface ($\sim 4 \text{ m min}^{-1}$). After acclimatization fish

166 were anesthetized by immersion in a seawater solution of 100 mg l⁻¹ tricaine
167 methanesulfonate (MS-222) for 4.0 ± 1.6 min (mean ± sd; hereafter all values
168 expressed as mean ± sd) until total loss of equilibrium. Individuals were
169 measured to the nearest 0.1 cm and placed in a methacrylate v-shaped “bed”
170 submerged in, a seawater solution of 25 mg l⁻¹ of MS-222. Acoustic tags were
171 implanted into the peritoneal cavity of each fish through a 3 cm longitudinal
172 incision in the abdominal wall and the wound closed with 2-3 sutures. The entire
173 surgical process took less than 4 min. After complete recovery, fish were
174 released in the location of initial capture. Time out of the water was 35 ± 12
175 min. The GPS position, depth, date and hour of release were recorded for each
176 tagged fish.

177 Twenty one fish were tagged with ©Vemco V13-1L-A69-1601 tags (36 x
178 13 mm, 6.0 g in water), with a random delay of 40-80 s, while 4 of the smaller
179 individuals were tagged with V9-2L-A69-1601 (29 x 9 mm, 2.9 g in water) with a
180 random delay of 80-120 s. Battery life in both cases exceeded the duration of
181 the present study. An evaluation of the surgical procedure using dummy
182 transmitters with 8 individuals in captivity revealed normal activity 5-8 min after
183 surgery, normal feeding after 1 day, full cicatrisation without transmitter loss
184 after 3 weeks and 100% survival after 16 months. Fish were tagged before this
185 study (March-April 2011) as part of another experiment, so normal behaviour
186 and complete cicatrisation was assumed. As recommended by Payne et al.
187 (2010) a control tag (V13) was deployed inside the receiver array for the
188 tracking period to assess possible environmental effects on the detection
189 patterns and to have a means to measure fish position error.

2.3 Temporal pattern

Data processing and all analysis were conducted in R (R Development Core Team, 2011). Data were filtered to remove potential spurious detections, defined as any single transmitter code (fish ID) occurring alone at a specific receiver within a 24 h period (Meyer et al., 2007). The total period of detection (TP) for each fish was calculated as the time interval between the first day of the experiment and the last day the fish was detected, while the number of days detected (DD) reflected only those days an individual was detected. Thus, the residence index (RI) for each fish was defined (March et al., 2010) as:

$$RI = DD / TP \quad (1)$$

Detections of all receivers for each fish were pooled into hourly bins (time expressed in UTC). Then, continuous wavelet transforms (CWT) were used to identify periodicity patterns in the time series (Alós et al., 2012a; March et al., 2010). We computed the 2-dimensional wavelet spectrum and calculated a pointwise test at the 95% significance level using a Morlet wavelet with the *sowas* package (Maraun et al., 2007). To investigate diel patterns, the number of detections per hour were pooled and corrected by taking into account the mean hourly detection frequency of the control tag, as described in Payne et al. (2010). This approach quantifies the magnitude of variation of each hourly bin (as standardized detection frequencies, SDFs) around the mean daily detection frequency for the control tag:

$$SDF_b = \frac{B_b}{\mu}$$

where μ is the overall mean detection frequency across all hourly bins, b , and B is the mean detection frequency in each hourly bin for the control tag. The mean daily detection frequency for each fish tag was then divided by the corresponding SDF for each bin. Then, the total detections at day and night were pooled and standardized based on the different duration of each phase. Day and night phases were defined using sunrise and sunset data obtained from the U.S. Naval Observatory (<http://aa.usno.navy.mil>; last accessed: 14 Apr 2012) for the study area (March et al., 2010; Meyer et al., 2007). A Mann Whitney U-test was used to test for differences in the corrected number of detections between day and night.

2.4 Spatial pattern

We estimated the centres of activity (COA) for each fish at each time bin (Hedger et al., 2008; Simpfendorfer et al., 2008) using the Nadayara-Watson normal kernel estimator with the *sm* package (Bowman and Azzalini, 1997). The resulting set of estimated positions was used as input for the subsequent analysis. Fish position at each time, XY_{ij} , was based on the averaged positions of the receivers that detected fish i during the time bin j and weighted by the number of detections at each receiver over that period. Selection of an appropriate time bin size (Δ_t) is required to get accurate results when using this method and the optimal bin size must balance the need to record sufficient detections from different receivers and the need to not allow the fish to move too much (Simpfendorfer et al., 2002). To select the optimal Δ_t , we calculated the mean number of receivers detecting signals from an individual tag (NR), and then we averaged the number of detections from this tag across all receivers

(ND) during each time bin. We tested six different values of Δ_t : 10, 20, 30, 40, 50 and 60 min. NR is expected to increase asymptotically as Δ_t increases, whereas ND increases linearly with Δ_t . Better position estimates are obtained when the fish is detected multiple times by multiple receivers (Simpfendorfer et al., 2002). We considered a suitable Δ_t when the increase in NR was $< 10\%$ between two consecutive values of Δ_t and ND remained > 10 . The resulting value was $\Delta_t = 30$ min at which NR was 2.8 ± 1.8 receivers for both V13 and V9 tags and ND was 10.1 ± 6.9 and 14.4 ± 12.1 detections / time interval for V9 and V13 tags, respectively.

We used 2 approaches to estimate the home range of each fish over the total period. Minimum convex polygons were estimated based on the full set of fish positions (MCP_{100}). Bivariate normal fixed kernel utilization distributions (KUDs) were estimated based on 95% (home range) and 50% (core area) of the positions (KUD_{95} and KUD_{50} , respectively) using the *adehabitat* package (Calenge, 2006). The MCP_{100} provided information regarding the extent of an animal's range over a given period, while KUDs provided information regarding the use of space within that range including core area and home range. The overlapping area between the small islet located in the receiver array and the activity spaces was subtracted to produce the final results. A kernel bandwidth equal to the error in the estimation of the fish locations was selected (Alós et al., 2012a). As this error is unknown, it was approximated as the mean of the positioning error of the control tag. A linear regression was used to test for differences in the intercept and slope of the home range sizes estimated by MCP_{100} and KUD_{95} .

Changes in home range over time were investigated based on KUD₉₅. Observation-area curves were calculated by plotting cumulative home ranges over a period of days. It is expected that as tracking time increases the cumulative KUD₉₅ will initially increase and eventually reach an asymptote, indicating that no additional tracking time is needed to ascertain the true home range of the fish (Rechisky and Wetherbee, 2003). We assumed the asymptote was reached at the time when percent change of the observation-area curve was less than 5% between two consecutive days (Rechisky and Wetherbee, 2003). In addition, daily values of KUD₉₅ were estimated for the 71 days and diel (night vs. day) differences in these values were statistically tested using a Wilcoxon signed rank test. For comparison we also estimated the accumulated KUD₉₅ for day and night phases for each fish.

The linearity index (L_i) (Alós et al., 2011; Rechisky and Wetherbee, 2003) and the volume of intersection (VI) index (Fieberg and Kochanny, 2005) were calculated for each fish as a proxy for site fidelity. L_i was calculated as:

$$L_i = (F_n - F_1) / D \quad (2)$$

where $F_n - F_1$ is the distance between the first and last COA, and D is the total distance travelled by the fish. An L_i of 1 indicates linear movements between the first and the last COA and an L_i near 0 indicates little movement from the area and reuse of the same activity space (March et al., 2010). VI index computes the volumetric intersection between two activity spaces and was calculated with the *kerneloverlap* function in the *adehabitat* package (Calenge, 2006). The VI index ranges from 0 to 1 (Fieberg and Kochanny, 2005). We estimated 3 VI indices. First, VI index was calculated for daily values of KUD₉₅

in order to investigate patterns of space reuse from day to day. A value of 1 signifies complete overlap of activity spaces (sedentary behaviour) whereas a value of 0 indicates non-overlap (nomadic behaviour). Second, patterns in home range diel shift were evaluated by estimating the day-night values of VI index for the accumulated KUD₉₅ and third, the same was done with the accumulated KUD₅₀. In this case a VI index of 1 indicates complete overlap between day and night activity spaces whereas a VI index of 0 suggests a different use of space during the day and night. Total distance travelled per day (D_t) was approximated by adding up the distances between consecutive COAs for each day. Distance travelled per hour at daytime (D_d) and night time (D_n) were calculated for each day by dividing the distance travelled per diel phase by the duration of the phase, and the differences were tested with a Wilcoxon signed rank test.

In addition, linear regression models were used to determine the effects of fish total length (TL) on the home range size (both MCP₁₀₀ and accumulated KUD₉₅) and D_t . The normality of the residuals and model performance were examined by visual inspection of the residual distributions, plotting the residuals against the fitted values and using quantile-quantile (QQ) plots.

3. Results

The characteristics of the 25 *L. bergylta* individuals monitored are summarized in Table 1. A total of 822,251 detections were downloaded from the receivers, with a mean of $31,625 \pm 22,366$ detections per fish. On average, an individual fish was detected by 8.2 ± 1.9 receivers over the whole period. Fish

were detected by more receivers during daytime (3.8 ± 1.2 receivers per hour) than at night (2.1 ± 0.5 receivers per hour). The mean number of fish detected by a receiver was 17.3 ± 6.0 . The total period of detection was 71 days for all tagged fish with a mean of 70.2 ± 1.4 days detected. The RI varied from 0.92 to 1.00 with a mean of 0.99 ± 0.02 .

3.1 Temporal pattern

The corrected number of detections binned by hour and pooled ignoring day (Fig. 2) revealed a clear diel pattern for the majority of fish. The diel pattern was characterized by more detections during the day. Detections from the control tag indicated a significant variability in reception between day and night periods (Fig. 2), with more detections occurring during the night period ($p < 0.05$). The corrected mean number of detections was significantly higher during daytime compared to the night for 24 individuals (Table 2), with the exception of one fish which was more frequently detected at night.

The CWT spectrograms (some examples in Fig. 3) detected significant periodicities in the time series of the monitored fish, but not in the control tag. Twenty-four fish presented a clear 24 h periodicity in their spectrograms. In some cases this periodicity extended for the majority of the days ($n = 9$), whereas in others it was more sporadic ($n = 15$). Fish 305 also showed a significant 48 h periodicity in addition to the 24 h periodicity, probably corresponding to the second harmonic of the 24 h period. Fish 285 did not exhibit a 24 h periodicity, but did show a significant 12 h periodicity.

3.2 Spatial patterns

A mean of $2,651 \pm 574$ COAs (fish positions) were estimated for the tagged fish based on 30 min time bins (Table 3). For the control tag, 3,376 COAs were estimated and compared with the true tag position giving a mean estimation error of 45.5 ± 17.0 m.

The plots of daily cumulative KUD_{95} (Fig. 4) revealed that although all individuals stabilized their home range area during the study period (mean = 16.8 ± 18.6 days), the time needed to achieve it was highly variable, ranging from 1 to 56 days (Fig. 4 and Table 3). Home range (MCP_{100} and KUD_{95}) and core areas (KUD_{50}) are shown in Table 3 while some examples are plotted in Fig. 5. The estimation of home range size obtained with MCP_{100} was 0.133 ± 0.072 km². MCP_{100} was negatively correlated with fish TL ($\beta = -0.005$, $t = -2.907$, $p = 0.008$). The estimation of home range size obtained with KUD_{95} was 0.091 ± 0.031 km², exhibiting no relationship with fish TL ($p = 0.322$). MCP_{100} estimates were significantly larger than KUD_{95} estimates over the full range of home range sizes, i.e., the linear regression between the home range sizes estimated with MCP_{100} against those estimated with KUD_{95} revealed a slope significantly different from 1 ($\beta = 1.339$, $t = 3.346$, $p = 0.003$) and an intercept of 0. The core area based on accumulated KUD_{50} was 0.019 ± 0.006 km² showing no relationship with fish TL ($p = 0.070$).

Significant diel differences were found in 22 out of 25 fish in daily KUD_{95} (Table 3), with 19 fish showing significantly larger daily daytime KUD_{95} and 3 fish exhibiting larger nighttime KUD_{95} . Fish exhibited the same diel pattern when the accumulated, i.e. asymptotic, KUD_{95} was analyzed with the exception of one. Averaged D_t was 1570 ± 467 m d⁻¹ (Table 4). It was negatively correlated

with fish TL ($\beta = -35.06$, $t = -3.107$, $p = 0.005$) and showed a strong positive correlation with KUD_{95} (Pearson $r^2 = 0.82$). D_t varied significantly with the diel phase, with longer distances travelled at day hours in all cases except for one fish (Table 4).

L_i and VI indices are shown in table 4. L_i over the full period was 0.0008 ± 0.0009 . VI index was high based on a KUD_{95} daily shift (0.75 ± 0.13). Day-night VI index ranged between 0.00 and 0.41 in the case of the accumulated KUD_{50} (0.22 ± 0.12) and between 0.18 and 0.86 for the accumulated KUD_{95} (0.58 ± 0.17).

4. Discussion

4.1 Residence time and site fidelity

Residence time and site fidelity are important issues to be taken into account when designing MPAs for a given species. High residence time is a typical behaviour among reef associated fishes and has been documented for many different fish families (e.g. Labridae and Serranidae) at different time scales, such as days (23 d for *Xyrichtys novacula*, Alós et al., 2012a), months (up to 27 months for *Semicossyphus pulcher*, Topping et al., 2006) or years (up to 5 years for *Epinephelus marginatus*, Afonso et al., 2011). Our results of RI for *L. bergylta* over the 71 d of study agree with this general pattern of behaviour, with all fish being detected in the monitored area > 92% of the days. Moreover, the fact that all the 25 fish were tagged in the study area months before this study, and were still there in September 2011 when this research started,

suggests that the resident behaviour reported might be maintained over longer periods of time. The high residency of *L. bergylta* is supported by the low L_i and high daily VI index values obtained, which reveal a strong sedentary behaviour and non-directional movements.

4.2 Diel behaviour

L. bergylta showed a clear diel pattern with a much higher activity during daytime. The 24 h periodicity of this temporal pattern was also clearly observed in the CWT spectrograms for most fish. The interpretation of diel patterns in telemetry studies must, however, be done with care. Environmental conditions (e.g. temperature, salinity, conductivity) may produce spurious periodicities in the detection patterns, even if the animal does not have diel behaviour, which may lead to a misinterpretation of the results (Payne et al., 2010). To assess those effects we used a control tag, which recorded any environment-related temporal pattern and allowed us to remove this from the data prior to assessing movement patterns. Therefore, diel patterns observed were due only to fish behaviour, assuming that there was no spatial variation in environmental artefacts within the monitored area.

The existence of a diel pattern is a common characteristic of fish behaviour and has been previously reported for a wide variety of species (Alós et al., 2011; Arendt et al., 2001; Hitt et al., 2011). Some authors found that diel detection patterns were related to actual fish movement in and out of a certain area (Hitt et al., 2011; Topping et al., 2005). A similar pattern could, however, be observed if the animal does not leave the area but displays hiding or burying behaviour at night (March et al., 2010), as has been observed for many labroids

(Alós et al., 2012a; Topping et al., 2005). This seems to be the case of *L. bergylta* too, which is known to display decreased activity and sheltering behaviour at night hours, when individuals rest inside rock crevices or between the rocks (Costello, 1991; pers. obs.). This behaviour would impede the transmission of the acoustic signals, resulting in the low number of detections observed at night. During the day *L. bergylta* is more mobile and visible (Costello et al., 1993) allowing improved reception of the acoustic signals. This would also increase the potential for signal collisions during the day (Simpfendorfer et al., 2008), which may, at least in part, explain the observed pattern of detection of the control tag (fewer detections during daytime).

The temporal diel pattern observed was supported by our spatial results. Estimated home ranges differed between night and day, with most of the fish exhibiting larger daytime home ranges. This result suggests that estimates of home range based solely on data from the daytime, as is common with active tracking studies or direct underwater observations (Barrett, 1995), may not be accurate. Besides, distance travelled at daytime was greater for all but one fish, revealing higher activity during this phase in agreement with the increased diurnal detections. Given that the study period was out of the spawning season of the species, increased daytime movements and activity are presumed to be related to foraging activity. In addition, it is worth mentioning that for the purposes of this research we defined the day and night periods using the sunrise and sunset times, as in other telemetry studies (Alós et al., 2011; Hitt et al., 2011; March et al., 2010). This definition could potentially influence the results of diel behaviour if dawn and dusk movements (included in the night period) were important, resulting in a partially overestimated nocturnal activity.

The wide range of values obtained for day-night VI index (for both home range and core area) suggests intra-specific variability in diel patterns in the use of space. Some fish used relatively different areas for night and day activities (e.g. resting vs. foraging), while others remained in the same space throughout, similar to other temperate and tropical reef associated species (Lowe et al., 2003; Marshall et al., 2011; Meyer and Holland, 2005).

4.3 Home range size

The small home range obtained for *L. bergylta* ($KUD_{95} = 0.091 \text{ km}^2$) is in agreement with a sedentary behaviour previously reported for this species (Costello, 1991; Sjolander et al., 1972). Reported territory size for males during spawning was $< 300 \text{ m}^2$ (0.0003 km^2 ; Sjolander et al., 1972), much smaller than our estimations of home range size. Due to the nest guarding behaviour of the species (pers. obs), the estimation by Sjolander et al., (1972) likely corresponds to the range of movement of the guarding males during the day (when observations were made), rather than the true home range of the species.

Home range size estimations are determined by the temporal scale at which they are calculated. Measurements along several consecutive days are required to obtain an asymptotic, i.e. accumulated value, to be used as an index of home range (March et al., 2010). Therefore, not taking into account the temporal scale, i.e. measuring home range over short periods, can lead to biased results and erroneous conclusions. In the case of *L. bergylta* all the individuals stabilized their home range during the study period showing that no additional tracking time was needed for a reliable estimation of the home range size. Pita & Freire (2011) estimated a home range size of 0.003 km^2 and 0.005

km² for two individuals of *L. bergylta* that were manually tracked for 1 and 4 days, respectively, which might lead to underestimated results. The home range size reported in the present study for *L. bergylta* is in the range of other hermaphroditic labroids with complex social structures like *Xyrichtys novacula* (0.32 km²; Alós et al., 2012a), *Coris julis* (0.13 km²; Palmer et al., 2011) or *Semicossyphus pulcher* (0.02 km²; Topping et al., 2005).

Intra-specific variability in home range sizes may be influenced by many biological or environmental factors (Quinn and Brodeur, 1991). Different relationships have been found between fish TL and home range size for sedentary species, from positive (Jones, 2005) to negative (Kaunda-Arara and Rose, 2004; Meyer and Holland, 2005), or no relationship (Alós et al., 2011; March et al., 2010). Additionally, the estimation of the home range size is highly dependent on the method used (Walter et al., 2011), which was supported by our results. Home range size of *L. bergylta* based on MCP₁₀₀ was negatively correlated with fish TL, although KUD₉₅ was not correlated at all. The strong correlation between KUD₉₅ and D_t further supports the idea that home range size is correlated with fish TL. Smaller fish travelled longer distances, resulting in larger home ranges, as evidenced by the negative relationship between fish TL and D_t. Higher mobility and larger home range (based on MCP₁₀₀) in smaller individuals of *L. bergylta* may indicate that they are too small to effectively defend a territory, in contrast with adult territorial individuals that can satisfy their energetic demands within a small area in high quality habitats (Grüss et al., 2011). In addition, KUD estimates are influenced by the selection of the bandwidth. Smaller values are preferred with large sample sizes as they produce less biased results (Kie et al., 2010). In this study, we used the mean

of the positioning error of the control tag which allowed us to incorporate the uncertainty of positional errors into the home range estimates (Alós et al., 2012a) while increasing the spatial resolution.

4.4 Implications for fishery management

Results from this research have direct implications for conservation and should be integrated into the management of *L. bergylta*. At present, this species is managed solely on a minimum landing size of 20 cm, an inadequate measure for protogynous species as the larger males may then have inadequate protection (Alonzo and Mangel, 2004). We have demonstrated that *L. bergylta* exhibits a high site fidelity and a limited home range that together with the reported slow growth rate (Dipper et al., 1977) and their hermaphroditic reproductive strategy makes this species particularly vulnerable to overfishing (Sattar et al., 2008). Those fisheries which target larger individuals such as angling and recreational spear fishing may especially impact resident populations.

In the present study, clear diel behaviour was observed with increased distance travelled during day hours. The probability of catching a fish in a gillnet is directly proportional to the probability of the fish encountering the net and being trapped in it, which in turn depends on the distance travelled by the fish (Rudstam et al., 1984). Thus, a higher catch rate is expected for *L. bergylta* during the daytime. Moreover, the negative relationship between fish TL and distance travelled (a proxy of activity) suggest a complex catchability pattern: small fish will be more prone to be caught because they move more actively but only when they reach the size threshold of the gear.

A consequence of the sedentary behaviour of the species and the small home range is that relatively small MPAs may effectively protect this species (Barrett, 1995). Effective protection of *L. bergylta* by small MPAs could augment the number and size of the individuals inside it (reserve effect), increasing the reproductive potential of the population due to the allometric increase in fecundity with size of most fish (Alonso-Fernández et al., 2008; Birkeland and Dayton, 2005). Maintaining an intact population structure inside the MPA would also prevent sperm limitation (Alonzo and Mangel, 2004) and thus favour fertilization rates. The protected population would function as a source of larvae to adjacent harvested areas, maintaining sustainable population levels. Furthermore, if the population biomass within MPAs increases, density-dependent factors may force small and intermediate-sized fish to migrate and relocate their home range outside the MPA (Grüss et al., 2011; Kramer and Chapman, 1999; Lowe et al., 2003) thus being accessible to the fishery. All this information should be taken into consideration by managers designing small MPAs, at a point when their use is starting to be considered as an effective management tool in NW Spain.

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Figure captions

Figure 1 Map of the study site showing the location of the 12 acoustic receivers and the extension of the monitored area

Figure 2 Plot of mean detections and standard deviation for the control tag (a) and mean corrected detections per hour (UTC) for each tagged *Labrus bergylta* (b, c, d, e and f). Vertical lines represent sunrise and sunset. Diel phase is indicated as “n” (night) or “d” (day). Note the difference in Y-axis scale

Figure 3 Wavelet sample spectrums fitted for individuals 283, 285, 288, 291, 292, 296, 299, 304, 305 and the control tag. Individuals were selected to represent the different periodicity patterns obtained, covering the full range of fish sizes. Continuous lines represent the cone of influence (COI). Values outside de COIs should not be interpreted due to edge effects. Thick contours represent the 95% confidence level

Figure 4 Daily cumulative home ranges based on KUD₉₅ for all the tagged *Labrus bergylta*. Days needed to reach the asymptote are indicated in the legend. Information is presented in four different plots to improve visualization. Note the different Y-axis scales

Figure 5 Plots of total, night and day space utilization estimated for fish 283, 288, 289, 293, 302, 304, 306 and 429. Individuals were selected to represent the full range of home range sizes and IOR values. Fixed acoustic receivers are shown as black points, and location of capture and release for each fish as a red dot. MCP = minimum convex polygons based on 100% of the positions; KUD₉₅ = kernel utilization distribution based on 95% of the positions; KUD₅₀ = kernel utilization distribution based on 50% of the positions