World Rabbit Science

World Rabbit Sci. 2013, 21: 263-270
doi:10.4995/wrs.2013.1332

BEHAVIOURAL ACTIVITY OF WILD RABBITS (*ORYCTOLAGUS CUNICULUS*) UNDER SEMI-NATURAL REARING SYSTEMS: ESTABLISHING A SEASONAL PATTERN

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Abstract: The activity of 2 populations of wild rabbits (*Oryctolagus cuniculus*, L. 1758), consisting of 14 adults (>9 mo of age) each (4 males and 10 females), was analysed over 2 consecutive years. Rabbits were captured in the wild and kept in 2 separate enclosures of 0.5 ha, with each enclosure divided into 2 zones: a smaller area where warrens were located (breeding area) and a larger area where food and water were provided (feeding area). Seven rabbits in each enclosure were individually tagged with a microchip (2 males and 5 females) and, after installing 2 detection devices, it was possible to identify which of the 2 areas they were located in and record the length of time spent in each. To regulate the size of the breeding population, young rabbits produced in the enclosures were captured and removed regularly. Considering the number of movements between areas and the time spent in the feeding area, a circadian activity pattern was found, reporting 2 maximum activity peaks coinciding with twilight (18.35% of the total movements, 6-8 a.m.) and daybreak (22.95%, 7-10 p.m.) while activity was dramatically decreased during the midday hours (1.86%, 10 a.m.-4 p.m.). Rabbits displayed a seasonal pattern throughout the year, with maximum activity levels during winter (45.76% of the total movements, January-March) and spring (42.91%, April-June), which could be related to higher reproductive activity at this time of the year as a higher breeding output was reported in June and September. The levels of activity exhibited by males (13.44% daily activity rate) were significantly higher than those displayed by females (9.80%). No significant differences were found regarding time spent on the feeding area in relation to season or gender. The average duration of each foray to the feeding area was higher during the summer, higher for females than males and higher during the middle of the night than the rest of the day.

Key Words: wild rabbits, rearing, behaviour.

INTRODUCTION

In order to aid the recovery of wild rabbit *Oryctolagus cuniculus* populations from drastic declines, captive rearing of the species has been developed in Spain over the last decade (González-Redondo, 2006; Sánchez-García *et al.*, 2012), aimed at increasing numbers to allow for sustainable hunting and assist with predator conservation efforts. Despite the attention paid to the effects of rearing systems on reproductive performance (Parer *et al.*, 1987; Arenas *et al.*, 2006; Guerrero-Casado *et al.*, 2013), welfare (Letty *et al.*, 2006; González-Redondo, 2009), behavioural patterns (Myers, 1958; Fullagar, 1979) and nutrition (Stodart and Myers, 1966), other important aspects remain under-studied, such as activity patterns in captivity.

Although some studies have dealt with wild rabbit behaviour under captive conditions (Hoy and Selzer, 2003; González-Redondo, 2010) and research using discontinuous observations has been undertaken far from the species area of origin (Mykytowycz and Rowley, 1958; Fullagar, 1979; White, 2003), no specific research on activity patterns has been carried out in the Iberian Peninsula. Taking into account the importance of the species for Mediterranean

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http://dx.doi.org/10.4995/wrs.2013.1332

ecosystems (Delibes-Mateos *et al.*, 2008), a better understanding of wild rabbit activity patterns in this ecosystem would help to improve management decisions for wild populations, as well as further developing rearing techniques for re-establishment purposes, particularly topics such as handling and welfare.

With the aim of increasing knowledge of wild rabbit behaviour under semi-natural rearing systems, the activity patterns of the species were studied over 2 consecutive years in the Mediterranean climate of central Spain. The objectives of this research were (1) to determine daily and seasonal activity patterns under specific rearing conditions and (2) to assess possible differences in activity patterns between sexes.

MATERIAL AND METHODS

Study Area

The study was carried out in 2 rearing enclosures situated 100 m apart and constructed on the 'Finca Coto Bajo de Matallana', a private cultivated area in Valladolid, northwest Spain (lat 41° 53' 45"N, long 4° 52' 50"W). The area had an average altitude of 755 m, with mainly calcareous soils of alkaline pH and poor drainage. The climate was Mediterranean dry continental (Papadakis, 1966) with hot dry summers, harsh winters, and a mean annual rainfall of 435 mm (Spanish Meteorological Agency Database, 2011).

Animals and marking method

Considering the suggestions of available literature and data from the same study site about the size and sex ratio in warrens (Arenas, 2006), the objective was to monitor a constant number of 2 adult (>9 mo of age) males and 5 adult females per enclosure during the whole study period. Thus, 14 adults (4 males and 10 females) were placed in each enclosure at the beginning of the protocol. All rabbits were captured in the same area in autumn-winter of the previous year, in accordance with Spanish law. The rabbits were captured using metal traps (60×20×20 cm) designed to protect captured rabbits from predators. The traps were baited with fresh lucerne (*Medicago sativa*), placed near wild rabbit warrens and checked twice daily for a month. Although all rabbits were ear tagged, 2 males and 5 females were individually marked using a subcutaneous microchip (AVID® Identification Systems, Inc.) measuring 15 mm in length and 2 mm in width.

When a rabbit was caught it was sexed, weighed and a basic health check was performed. As part of the health check, vaccines against myxomatosis (Poxlap®), haemorrhagic viral disease (Arvilap®) and parasites (Cunitotal®) were applied. This procedure was repeated with the animals in the enclosures twice a year and when animals were re-captured their health was carefully observed. If a microchipped rabbit was found dead or if was suspected that it might be dead (absence of movements for more than 7 d), a new adult rabbit of the same sex was captured in the enclosure and marked with a microchip.

Young rabbits produced in the enclosure were captured regularly and subsequently released, within the same area, for re-establishment purposes in accordance with Spanish law (Table 1).

Experimental enclosures

Two identical enclosures of 0.5 ha area, with sides of 75 m, were constructed and divided into 2 separate areas (Figure 1). A smaller area (0.1 ha), called the 'breeding area', was established in one of the corners. The highest part of each enclosure was used for the 'breeding area' and 4 semi-natural warrens were constructed using wood, sand and stones to create a 4×2×1 m structure. The rest of the area (0.4 ha) was designated the 'feeding area', where a water trough and a feeder containing a mixture of seeds were provided (*Hordeum vulgare* and *Triticum aestivum*), in addition to lucerne and common vetch (*Vicia sativa*) which were sown previously.

Connection between the 'breeding' and 'feeding' areas was possible through 2 PVC tubes (12 cm diameter, 50 cm length) allowing free movement of the animals from one side to the other. There was a 2 m high perimeter fence, buried 50 cm into the soil, of 5 cm size galvanised wire mesh reinforced in the lower part by another galvanised wire mesh of 2 cm size, and triple torsion of 1 m in height. This wire mesh was hung on wooden posts of 10 cm in diameter, 2 m in height and positioned at 3 m intervals. The entire perimeter was protected by an exterior double

Table 1: Number of young rabbits captured/year for the whole study and each enclosure separately.

	Year 1		Year 2		
Month	1	2	1	2	Total
January	-		-	-	-
February	13	12	10	8	43
March	-	-	-	-	-
April	14	16	17	22	69
May	-	-	-	-	-
June	44	32	26	29	131
July	-	-	-	-	-
August	-	-	-	-	-
September	39	34	42	31	146
October	-	-	-	-	-
November	21	23	9	21	74
December	-	-	-	-	-
Total	131	117	104	111	463

line of livestock electric fencing, positioned at a height of 0.5 and 1 m, and an interior line at a height of 0.5 m. To minimise the effect of aerial predation, a nylon fishing line 1.10 mm in width in the form of a net was suspended above the breeding area, while in the feeding area 20 PVC tubes (12 cm diameter, 2 m length) were provided as refuges for the study animals.

Data Collection

Data collection on rabbit activity was carried out daily during 2002 and 2003. A detection device composed of a circular microchip reader 12 cm in diameter (AVID©) and a model DI-160 (MERICAN©) platform weighing scale (with accuracy of 1 g) was installed in each of the 2 PVC tubes. The records were sent via a cabled system to the computer equipment, with data stored until weekly collection for subsequent processing. To allow multiple entering of data from both PVC tubes at the same time, a PCL 746 (ADVANTECH©) multi-port plate was fitted to both computer systems.

Each of the records contained 4 values: PVC tube used, the rabbit's microchip identification code, rabbit weight and the time of day at which the movement took place. All information collected was filtered and processed using Microsoft Excel© for Windows©.

Data analysis

The number of passages per time unit between the breeding and feeding area was considered a reliable measure of rabbit behaviour, as it was the most accurate way to differentiate patterns related to feeding (no food was given in the breeding area) from resting and reproduction (apart from the PVC tubes and the crop, no shelter was provided in the feeding area).

Four different variables were studied: daily activity rate, the mean number of movements that rabbits made through all exits during each hour of the day; monthly activity rate*,* the mean number of movements that rabbits made through all exits during each month of the year; time spent in feeding area: the mean period of time spent in the feeding area by each rabbit per day, expressed in minutes; stay length in feeding area: the mean duration of each rabbits visits to the feeding area, expressed in minutes.

After using the Levene test, it was confirmed that our data fitted a normal distribution. The Student-Fisher test was used to assess whether there was an effect of year,

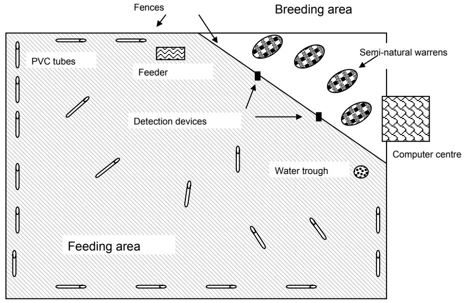

Figure 1: Sketch of the experimental enclosures.

group of rabbits (1 and 2) and sex for each variable. Possible differences between the variables, hours and months were evaluated using a one-way ANOVA. Finally, the Student-Newman-Keuls test was used for the post-hoc comparisons (shown in Figures). Differences with $P<0.05$ were considered significant and all tests were carried out using SPSS (version 17.0 for Windows, StatSoft Inc., Tulsa, OK). Values of variables are reported as means±standard deviation.

RESULTS AND DISCUSSION

After using the Student-Fisher test, no significant differences were found between the daily activity rates over the 2 yr of the study ($t_{(1, 6211)}=-3.33$, $P<0.05$). This allowed us to subsequently consider data independently of the year factor. Two rabbits died in the first year (1 male and 1 female) and 3 in the second (1 male and 2 females), each being replaced by a different rabbit of the same age and sex.

Daily activity rate

No significant differences were found between the daily activity rates for the 2 populations ($t_1=10.48$, $P=0.38$). Significant differences were found between this variable and time of day ($F_{(23, 660)}=97.81$, $P<0.05$). The highest activity was reported at 19, 20, 21, 6 and 7 h, while the period from 10 to 16 h had the lowest rate of daily activity (Figure 2). Males were significantly more active than females ($t_2=8.14$, $P<0.05$).

The results obtained for this variable could be associated with the Mediterranean ecosystem, where the wild rabbit is a prey species for a wide range of raptors and mammals (Delibes-Mateos *et al*., 2008). At our study area, the main raptor species were diurnal and terrestrial predators nocturnal, so rabbits would be expected to concentrate their activity when predation risk was reduced (Aschoff, 1966). Our results agree with previous research that confirms that wild rabbits display a high level of activity during the night, dusk and dawn, while activity during the daylight hours is very limited (Kolb, 1986; Wallage-Drees, 1989; Villafuerte *et al*., 1993). However, as suggested by Jilge (1991), external factors such as food restriction or disturbances might change the normal activity patterns of the species. The higher values reported for males could be explained by the marked hierarchy of the species, as males would increase their activity to establish and maintain order of dominance (Cowan, 1987), due to intense territoriality (Fullagar, 1979; White *et al*., 2003).

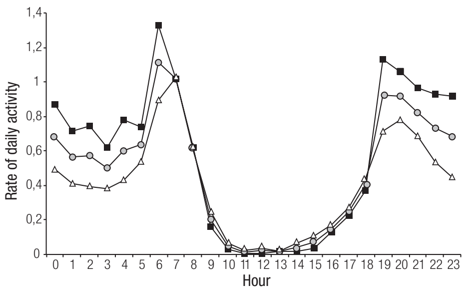

Figure 2: Daily activity rate (mean number of movements/day) considering gender. —○— Mean; —■— Males; —△— Females.

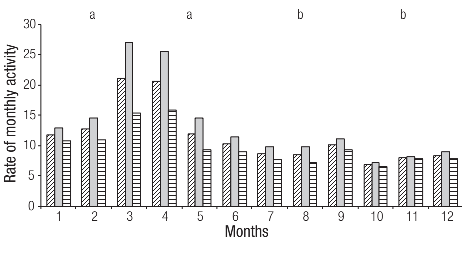

Figure 3: Monthly activity rate (mean number of movements/month) considering gender. [a,b] Different letters indicate significant differences between quarters ($P<0.05$) after using the Student-Newman-Keuls test. ▨ Total; ▢ Males; ▤ Females.

Monthly activity rate

Although one of the populations showed a higher rate of monthly activity (group 1), no significant differences in activity rate were found between them ($t_1=1.36$, $P=0.68$). As expected, statistically significant differences were found between the daily activity rate and the month of the year ($F_{(11,264)}=13.47$, $P<0.05$). To improve the interpretation of our results, records were grouped on a quarterly basis (January-March/ April-June/July- September/October-December), and a significant statistical difference was also found between quarters ($F_{(3,272)}=20.74$, $P<0.05$). Subsequent analyses indicated that the monthly activity rate was significantly higher during the first half of the year, declining until reaching the lowest values by the final quarter (Figure 3). March and April showed the highest values for activity and significant differences were found between sexes ($t_1=4.49$, $P<0.05$).

Considering the higher number of young rabbits captured between June and September in both enclosures (Table 1), significant variation in monthly activity could be explained by the higher number of interactions during March and April (Von Holst *et al.*, 2001; White *et al.*, 2003). According to Stoufflet and Caillol (1988), in early pregnancy females are hardly receptive to males and this would increase male activity for mating. Similar values have been reported in other lagomorphs such as the cottontail rabbit (*Sylvilagus floridanus*) (Trent and Rongstad, 1974). In contrast, a marked reduction in activity was observed from April to October, which could be attributed to the changes in environmental conditions and decreased food and water availability, though both requirements were provided *ad libitum* (Boyd, 1986; Boag, 1992; Eiserman *et al.*, 1993; Ballinger and Morgan, 2002). Results for monthly activity in relation to gender are in agreement with those published by Mykytowycz and Rowley (1958) and Gibb (1993), who suggested that males display a higher level of activity throughout the year to defend territories against rival males.

Time spent in feeding area

No significant differences were found between the time spent in the feeding area and the 2 populations (t_1=12.01, P=0.42), although there was a significant variation across the year ($F_{(11,264)}$=3.15, P<0.05); the longest time spent was reported in March, while September registered the lowest values (Figure 4). When the data were grouped quarterly as described previously, no statistically significant differences were found ($F_{(3, 272)}$=1.375, P>0.05) and the time spent was not affected significantly by the sex of the rabbit (t_1=1.61, P=0.31) (Figure 4).

Activity patterns described here are similar to those described by Mykytowycz and Rowley (1958), who studied wild rabbits kept in enclosures, which spent 360 min/d in the feeding zones during the breeding period, a very close value to ours for the same variable in the same period. In this study, rabbits spent longer periods in the feeding area during the first half of the year, which could be explained by the higher energy requirement when breeding, as this period was when the largest number of copulations would take place, as well as seeing an increase in the number of agonistic interactions between individuals. However, analysis of the data grouped quarterly found no significant differences between quarters.

Our results are similar to those reported by Villafuerte *et al.* (1993), who observed that rabbits spent more time in the feeding areas at dawn in summer, while in winter the highest number of animals were outside the warrens at night, although the mean daily time spent in the feeding area shows hardly any variation in relation to the season of the year. Our results are in disagreement with Kolb (1991) and Boag (1992), who found that the presence of the wild rabbit outside warrens varied considerably throughout the year, influenced mainly by reproductive activity, but also by other factors such as climate or night length.

The results for both sexes for time spent in the feeding area during the day conflict with those reported by Kolb (1986, 1991) and Gibb (1993), who reported that radio-tagged dominant males spent longer time outside warrens, although the variation on the techniques between studies and sample sized could explain these differences. Moreover, Mykytowycz and Rowley (1958) suggested that the dominant rabbits of each sex are the ones which spend longer outside warrens every day, which could be attributed to the existence of an independent hierarchical level for males and females.

Stay length in feeding area

When the mean stay length of visits to the feeding areas was considered, no significant differences were found between the 2 populations (t_1=0.34, P=0.27), but statistically significant differences were found between stay length and time of day ($F_{(23, 660)}$=98.52, P<0.05). During midday and mid-afternoon, most of the animals remained inside the breeding area, while after sunset the average stay length in the feeding area increased, with high levels maintained during the night but then declining again towards sunrise (Figure 5). No significant differences were found between this variable and sex

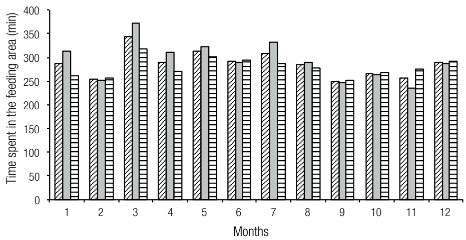

Figure 4: Time spent in the feeding area (min) considering gender. ▨ Mean; ▩ Males; ▤ Females.

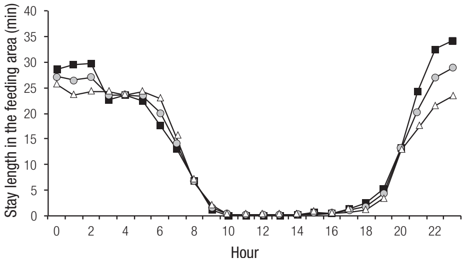

Figure 5: Stay length (min) in the feeding area considering hour and gender. –○– Mean; –■– Males; –△– Females.

(t_2=1.61, *P*=0.15). When data were grouped together on a monthly basis, statistically significant differences were found ($F_{(11,264)}$=7.87, *P*<0.05). July and August showed the highest stay length in the feeding areas, while the first months of the year showed the lowest values (Table 2).

Considering previous results, when the number of social interactions was increased the level of activity also increased, and consequently the stay length throughout the day was reduced, a finding in agreement with Mykytowycz and Fullagar (1973), Von Holst *et al.* (2002) and White *et al.* (2003). Moreover, the fact that the animals displayed higher values in the summer could be due to the reduction of food quality, so rabbits would spend longer periods of feeding in each foray as indicated by Ballinger and Morgan (2002).

Our results are also in agreement with Wallage-Drees (1989), who stated that the length of stay outside warrens varied considerably in relation to the season of the year considered, with the lowest values found between November and February and higher values during the rest of the year.

Differences observed in relation to sex for this variable were probably explained again by the higher activity displayed by males. Our results are similar to those of Von Holst *et al.* (2002) and White *et al.* (2003), who suggested that adult females are outside the warrens for longer periods of time than males due to the higher level of activity displayed by the latter.

The finding of significant differences for this variable in relation to the time of day could be associated with a circadian activity pattern; likewise, the stay length outside warrens could also vary. Our results are in full agreement with several authors such as Gibb (1993), who stated that wild rabbits are mainly nocturnal, as their activity patterns are linked to reduced light, a period in which a high proportion of rabbits can be found in the feeding areas. However, these records do not correspond with those of Lombardi *et al.* (2003) who stated that wild rabbits in natural conditions increase their diurnal activity and, therefore, the length of their stays outside in areas of sparse vegetation, as a strategy against predators. Differences could be explained by our enclosure characteristics and radio-monitoring performed in that study.

In conclusion, wild rabbits show a circadian activity pattern with 2 peaks in activity at twilight and daybreak, displaying a seasonal pattern with higher levels of activity during winter and spring, with this pattern strongly related to the

Table 2: Stay length in the feeding area. Differences according to months and sexes.

			Females		Males	
Month	Stay length feeding area	Quarter	Mean Values	SD	Mean Values	SD
January	287,87		261,38	60,08	314,37	29,72
February	253,72	295,48	255,67	45,52	251,78	85,89
March	344,83		317,25	83,82	372,41	59,18
April	290,16		270,42	48,27	309,91	40,59
May	313,05	298,27	302,29	42,10	323,80	76,86
June	291,61		293,96	59,40	289,26	84,28
July	309,60		287,88	47,14	331,33	91,90
August	284,44	281,48	278,71	52,56	290,17	50,87
September	250,40		252,77	48,03	248,04	91,92
October	265,60		267,42	55,90	263,78	66,26
November	255,78	270,38	275,38	56,87	236,19	60,92
December	289,76		291,48	68,47	288,04	37,70
Mean	286,40		279,55	55,68	293,26	64,67

SD: Standard deviation.

breeding behaviour of the species. This research has implications for the welfare and handling in wild rabbit rearing, as the study of daily and seasonal activity patterns might help to guide farmers in the development of improved breeding programmes.

Acknowledgements: This study is part of the first author's PhD thesis, kindly supported by the Ministry of Education and Science and the Provincial Council of Valladolid. This research complies with ethical guidelines for animals formulated by the British Society of Animal Science. Carlos Sánchez-García received a post-doc grant from Fundación Caja Madrid (Spain). We are grateful to Juan Antonio Olmedo for his support and Rufino Mucientes, who did his best throughout the whole protocol.

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