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Use of Radio Telemetry for Studying Flight Movements of *Paysandisia archon* (Lepidoptera: Castniidae)

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Abstract The moth *Paysandisia archon* is an invasive species that infests palm trees in the Mediterranean Basin. The immature stages occur exclusively inside the palm crown, whereas adults fly to mate and locate a new host plant. Here, we describe the use of small radio transmitters (0.27 g) for tracing the movements of *P. archon* adults. We report the first successful use of radio telemetry to track flight distances and space use of a flying moth. Our study was carried out using 11 tagged moths released on the Maguelone Peninsula in southern France. Although the males were successfully tracked within a restricted area, estimated at 4 ha, most of the tagged females immediately flew distances over 500 m, disappearing beyond the maximum detection range of the 30 ha study area. Flights for mating, resting and, likely, oviposition covered distances of 11.6 m to 224 m in males and 16.8 m to >500 m in females. We found evidence that both sexes are active during the warmer temperatures of the day. In contrast, the moths were inactive when the relative humidity was high. Moreover, the *P. archon* moths do not seem to reside on the host palm trees. Our data show a high mobility of females, which may be responsible for the spread of the first recorded Castniidae in France by laying eggs far from the palm trees where they emerged.

Keywords Radio telemetry · *Paysandisia archon* · Lepidoptera · flight activity · dispersal distance · behavior

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Introduction

Paysandisia archon (Burmeister) is a neotropical species that was introduced from South America to the Mediterranean basin, where it is now a serious pest of palm trees (Aguilar et al. 2001; Sarto i Monteys 2013). In Europe, the species' life cycle was studied by Sarto i Monteys and Aguilar (2005) and summarized by Sarto i Monteys (2013). Damaging infestations are reported on *Trachycarpus fortunei*, *Chamaerops humilis* and *Phoenix canariensis*, which are by far the most attacked palm species in France and Spain (Drescher and Jaubert 2003; Sarto i Monteys et al. 2012; André and Tixier-Malicorne 2013), although the moth infests many other palm species.

The female lays eggs individually on the crown of the palm. Young larvae start boring, develop within the palm stipe and make large galleries during winter and spring, leading to serious damage including palm death. The pupal stage is spent in a cocoon made from palm fibers. The first adults emerge at the end of June and the last flying moth is observed in late September. The adult palm borer is a large diurnal moth (Drescher and Jaubert 2003; Sarto i Monteys et al. 2012) with wingspans of 9.3 ± 0.7 cm and 8 ± 0.9 cm for females and males, respectively. Sarto i Monteys and Aguilar (2005) estimate an average of 23.8 days for male adult life span and 14.1 days for females. The adult *P. archon* does not feed.

It is not clear to what extent the infested palm trees recorded in the Mediterranean region have resulted either from separate introductions, from movement in international trade of infested plants within the region, or from the natural spread of flying adults. Apart from the movement of infested plants, which can facilitate long-distance dissemination, only few records consider the flying performance of *P. archon* as a probable reason of increasing infestation. Drescher and Jaubert (2003) noted that males show a territorial behavior with low mobility, remaining perched on palms. The males were observed to be active only at a female approach (courtship) or to chase another male away (Delle-Vedove et al. 2014). Sarto i Monteys and Aguilar (2005) reported an infestation of old palm trees 10 km away from Girona (Spain) with no link to an introduction of potentially infested material in the vicinity. So natural spread of flying adults may be important and we investigate this here.

Different techniques are available for studying insect movement, including mark-recapture (Mader et al. 1990; Englund 1993; Ranius and Hedin 2001), harmonic radar (Mascanzoni and Wallin 1986; Riley et al. 1996; Cant et al. 2005; Hardersen 2007), RFID (Vinatier et al. 2010; Silcox et al. 2011; Schneider et al. 2012) and radio telemetry (Riecken and Raths 1996; Hedin and Ranius 2002; Beaudoin-Ollivier et al. 2003; Hedin et al. 2008). Radio telemetry was selected for this study as the most suitable technique for investigating the movements of *P. archon*, the main advantage being that it is possible to individually follow the movement of several specimens using different frequencies.

Radio transmitters have been widely used to study the spatial distribution and movements of vertebrates (Cochran and Lord 1963; Priede and Swift 1992). However, transmitters have only recently become sufficiently small in size to be used on invertebrates such as crabs (Gherardi and Vannini 1989), spiders (Janowski-Bell and Horner 1999) and flightless insects (Riecken and Raths 1996). The first studies on flying insects using radio telemetry were carried out on beetles (Sprecher-Uebersax and Durrer 2001; Hedin and Ranius 2002; Beaudoin-Ollivier et al. 2003). Today, miniaturized radio transmitters are the smallest active tags available (Naef-Daenzer et al. 2005). These tags have allowed researchers to track other flying insects, such as bees (Pasquet et al. 2008; Wikelski et al. 2010; Hagen et al. 2011), dragonflies (Wikelski et al. 2006; Levett and Walls 2011), grasshoppers (Fornoff et al. 2012) and monarch butterflies and neotropical moths (Wikelski in Kissling et al. 2014).

To date, there is no record in the literature of tracking diurnal flying moth movements with similar radio telemetry techniques (Kissling et al. 2014). Flight performance is a trait to take into account when studying the infestation of trees by insects and in general pest spread. Thus, this paper focuses on the flying ability of *P. archon* to estimate its dispersal patterns and investigate its environment. The main research questions of this work are as follows: (1) is radio telemetry suitable for tracking and estimating flying distances of *P. archon*; (2) is there any sexual behavioral differences; and (3) are flight movements affected by air temperature and relative humidity?

Materials and Methods

Study Area

The study was conducted in the south of France on the site of the Cathédrale de Maguelone (43°30.75'N, 3°53.02'E), close to Montpellier and the Mediterranean Sea. The site is located on a peninsula 4 km from Palavas and between Arnel and Prévost ponds; it is connected by a coastal bar to the mainland. Due to the historical monument, the site is primarily dedicated to tourism and cultural activities, and the rest of the landscape is devoted to the agricultural and fisheries industries.

The peninsula has the advantage of being isolated, small and oblong in area (30 ha). Today, the park has a botanical diversity of Mediterranean and introduced plant species. The landscape is characterized by 65 % vineyard (19.5 ha) located around a noncultivated area (9 ha). Palm trees at the site have been infested by *P. archon* for several years, making the site suitable for our study.

Materials

We used LB-2X transmitters (Holohil Systems Ltd., Carp, Ontario, Canada). Each one had a mass of 0.27 g, including a 140-mm long antenna, a frequency range in the 151 MHz band and a battery life of approximately 12 days. The transmitter was activated by a solder connection to the battery and the best reception frequency was checked on an Australis 26 K Scanning Receiver, manufactured by Titley Electronics (Ballina, Australia). Transmitters were activated for 4 h, then checked for frequency drift and attached to the prothorax of the moth with a piece of permanent, strong, water-proof, temperature and UV resistant adhesive (3 M, Neuss, Germany) reinforced by a drop of Cyanolit Ultra Flex Gel (IDEAL, Vaulx-en-Velin, France) (Fig. 1a). Due to their size, *P. archon* adults can be easily manipulated. A Yagi antenna (Wildlife Materials, Carbondale, IL, USA) provided a maximum tracking range of 500 m at ground level (Fig. 1b).

A Global Positioning System (GPS, Garmin eTrex® 20) was used to record the exact position of each insect tracked. Air temperature (T) and relative humidity (RH) were recorded using a thermo-hygrometer (Oregon Scientific, Portland, OR, USA).

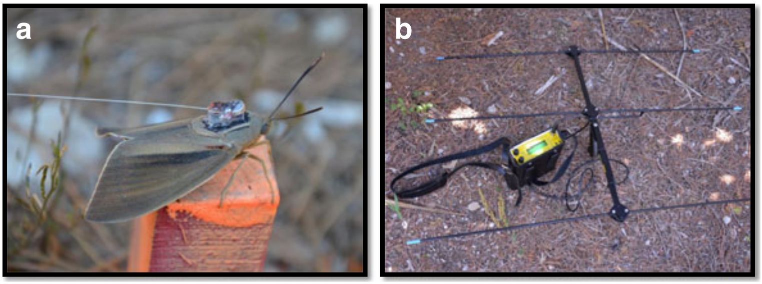

Fig. 1 **a** Virgin *P. archon* tagged with a transmitter at the release point. **b** Receiver and Yagi antenna. ©Maud LIEGEOIS

Methods

We first conducted a pilot study to evaluate whether the transmitter impeded the flight of the insect. Adult moths used for this experiment emerged under laboratory conditions (T = 25 °C, RH = 70 %, natural photoperiod) from cocoons collected from infested palm trees (June 2014, Montpellier, Hérault). They were equipped with the radio transmitter and released in a wind tunnel (12.2 m length, 7.10 m width and 2.80 m height). Compared with non-equipped moths, no obvious signs of changed behavior were observed. This pilot study revealed that the transmitter did not impede the flight of the insect for either sex. Average weight for males and females emerging in the laboratory were 2.08 ± 0.38 g (n = 209) and 3.23 ± 0.66 g (n = 195), respectively. Thus, the weight of each transmitter plus the adhesive complex (0.3 g) was typically 8 % of the moth's weight for females, and 13 % for male.

The adults tagged for the experiment originated from the study area (Cathédrale de Maguelone site). Both sexes emerged from infested *C. humilis* or *P. canariensis*. In August 2014, 11 virgin *P. archon* adults (six males, no. 1 to 6, and five females, no. 7 to 11) were tagged with transmitters and released.

Because this insect is recorded as flying between 12:30 and 17:00 h (Sarto i Monteys and Aguilar 2005), we studied the movements of the specimens between 09:00 and 18:00 h. The release point was located at the center of a clear area (20 m in diameter) surrounded by tall trees such as pines (*Pinus pinea*, *P. halepensis*, *P. pinaster*), cedars (*Cedrus sp.*) and hackberries (*Celtis australis*). The insects were initiated flight from a wood stick that was 20 cm high (Fig. 1a). No measurements were taken at night. To track the tagged insects, we used the "homing" method (Mech 1983). We located each specimen six times a day on average, by walking in the direction in which the signal was strongest. As we approached the transmitter, the signal increased, and the receiver gain was reduced to optimize the signal sound. This process of proceeding forward and continually decreasing the gain was repeated until we visually located the insect. Once the insect was located, its position was recorded using the GPS. In some cases, it was not possible to visually locate the insect, but the signal was sufficiently strong to locate the specimen within a radius of 0 to 5 m. The habitat, air temperature and relative humidity were also noted. Every movement with a distance greater than 5 m was considered a displacement. The duration between two successive reading-points for the same specimen was 50 min on average. The spatial data were reported on maps using GIS analysis (Quantum GIS 2.4.0 software) and the distances between two records were measured following a straight line, directly on these maps by using the "measure distance" tool.

Finally, the statistical analyses were performed with R 2.15.0 and 3.1.0 software (R Development Core Team 2014) with an alpha level of 0.05. First, we used non-parametric tests (Kruskal-Wallis, assuming unequal variances) to analyze the flight distances of both sexes and compare them. Secondly, we used generalized linear mixed model (GLMM) to analyze the effect of climatic conditions (relative humidity and temperature), sex and the time of the day (TOD, fraction of the day, % of 24 h) on the dispersal distance of *P. archon* (with negative binomial distribution of the response variables). The negative binomial distribution is appropriate to account for over dispersion (Venables and Ripley 2002). In this model, we considered the identity of each insect to be a random factor to account for the inter-individual sources of variance. The model was performed as follows. We first examined the need to include the random effects (Bolker et al. 2009). We then removed non-significant fixed-effect parameters in a backwards-stepwise process. The selection procedure was continued until a model was found in which all effects were significant (Zuur et al. 2009). GLMM was estimated using the 'glmer' function in the 'lme4' package of R (Bates et al. 2012), in which the maximum likelihood of parameters is approximated by the Laplace method (Bolker et al. 2009).

Results

The movements of *P. archon* are shown in Fig. 2a and b and are summarized in Table 1. The specimens were tracked during a maximum of 3 days for males and only 2 days for females. For two of the 11 insects released, the transmitter ceased to function within 48 h (male no. 6 and female no. 7). These two moths were not considered in our statistical analysis. However, all of the insects tagged are presented in Fig. 2 (a and b). A total of 6 specimens (no. 1, 2, 3, 4, 5 and 8) were found damaged, still equipped with transmitters but laying on the ground after bird predation.

Four different positions were recorded for two males (no. 4 and no. 5) across 3 days and 2 days, respectively; 5 different positions were recorded for two other males (no. 1 and no. 2) across one and 2 days, respectively; and 6 different positions were recorded for one male (no. 3) during a total of 3 days. All males first flew within a radius of a minimum of 11.6 m (no. 3) to a maximum of 28.8 m (no. 2) from the release point. Between two successive points where the specimens landed, we measured an average of 32.2 m (Fig. 3a). The maximum cumulative distance recorded was 224 m in only 1 day (no. 1) (Fig. 3b). The maximum linear distance measured between the last point recorded and the releasing point was 111 m (no. 1). *Paysandisia archon* males never left the peninsula, and the preferred direction for their movements appeared to be west, in open area with low vegetation (Fig. 2a).

Figure 2b shows the movement patterns of 5 females (no. 7 to 11), and Table 1 shows an overview of the collected information. On their first flight, most of the females flew far from the release point (90–500 m), although one (no. 9) flew only 17 m (Fig. 3a). The maximum cumulative distance for female no. 8 was 207 m, whereas the three others females flew beyond the range of our receiver (>500 m) (no. 9, 10 and 11) (Fig. 3b). Females no. 10 and 11 immediately moved more than

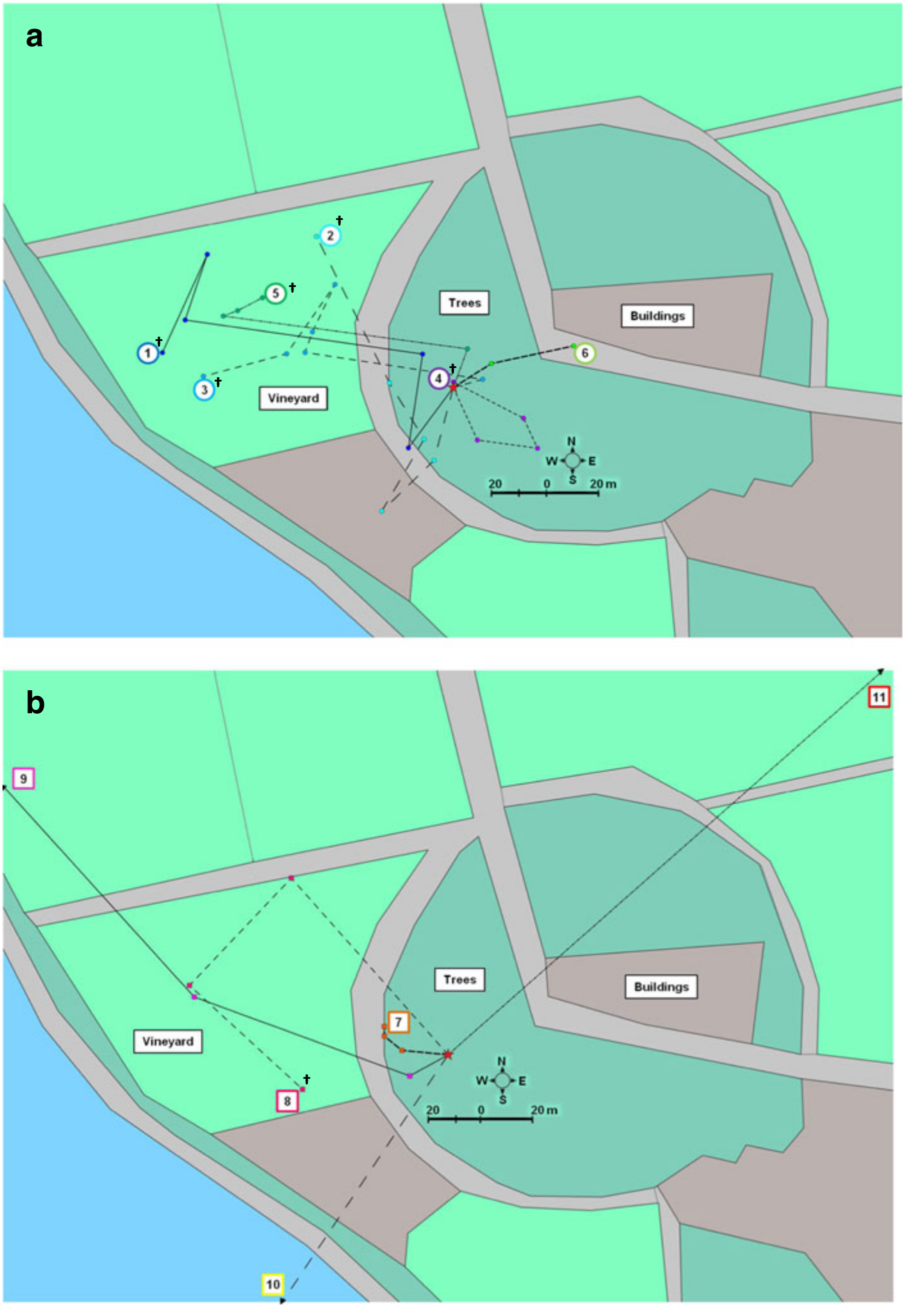

Fig. 2 **a** Flight movement patterns of 6 *P. archon* males. The transmitter no. 6 stopped working after only 1 day. †: dead males as a result of bird predation. **b** Flight movement patterns of 5 *P. archon* females. The transmitter no. 7 stopped working after 48 h. Females no. 9, 10 and 11 flew outside the telemetry range. †: dead female as a result of bird predation

500 m within just a few minutes after release. A maximum of 3 different positions were recorded for the 3 other females (no. 7, 8 and 9) (Fig. 2b). We attempted to locate

Table 1 Sex, body weight flight distance and resting substrate of the 11 individuals radio-tagged in August 2014

Sex	No.	weight (g)	Flight distance (m)	Cumulative distance (m)	DDr (m)	DD_{av} (m) ± sd	Number of days tracked	CDmax/24 h (m)	Resting substrate	Release date (2014)
Male	1	2,46	28.7	28.7	28.7	44.76 ± 26.8	1	182.6	Yucca	31 July
			36.1	64.8	18.5				Cedar	
			91.5	156.3	104.6				Vineyard	
			26.4	182.6	106.2				Vineyard	
			(41.2)	(223.8)	(110.8)				Dead, on ground	
Male	2	2,40	28.7	28.7	28.7	35.15 ± 15.4	2	113.4	Stone	05 August
			27.8	56.5	55.4				Tractor	
			31.8	88.3	23.1				Yucca	
			25.1	113.4	24.6				Bush	
			(62.3)	(175.7)	(76.9)				Dead, on ground	
Male	3	n.r.	11.6	11.6	11.6	28.93 ± 21.9	3	76.8	Pine	06 August
			68.5	80.1	57.7				Vineyard	
			8.3	88.4	56.9				Vineyard	
			20.0	108.5	60.0				Vineyard	
			32.2	140.7	64.6				Vineyard	
			(32.9)	(173.6)	(90.8)				Dead, on ground	
Male	4	n.r.	22.0	22.0	22.0	21.95 ± 7.2	3	42.7	Cedar	12 August
			23.1	45.1	40.0				Tree	
			12.6	57.7	29.2				Bush	
			(30.1)	(87.8)	(3.1)				Dead, on Yucca	
Male	5	n.r.	15.7	15.7	15.7	31.55 ± 41.8	2	115.5	Yucca	12 August
			94.0	109.7	90.8				Vineyard	

Table 1 (continued)

Sex	No.	weight (g)	Flight distance (m)	Cumulative distance (m)	DDr (m)	DD_{av} (m) ± sd	Number of days tracked	CDmax/24 h (m)	Resting substrate	Release date (2014)
			5.9	115.5	86.2				Vineyard	
			(10.7)	(126.2)	(80.0)				Dead, on ground	
Male	6[a]	2.24	17.2	17.2	17.2	24.63 ± 10.5	2	32.1	*Chamaerops humilis*	01 September
			32.1	49.3	49.2				Bush	
Female	7[a]	n.r.	17.9	17.9	17.9	10.09 ± 7.2	2	17.9	Yucca	31 July
			8.7	26.6	26.4				Pine	
			3.7	30.3	28.0				Bush	
Female	8	3,45	91.0	91.0	91.0	69.02 ± 19.0	1	148.0	Vineyard	05 August
			57.0	148.0	106.4				Vineyard	
			(59.1)	(207.1)	(59.2)				Dead, on ground	
Female	9	3,94	16.9	16.9	16.9	125.06 ± 95.4	1	> 500	Yucca	06 August
			88.5	105.4	102.4				Vineyard	
			153.9	259.2	227.1				Weeds	
			> 240.8	> 500	> 500				n. r.	
Female	10	n.r.	> 500	> 500	> 500	500	1	> 500	n. r.	12 August
Female	11	n.r.	> 500	> 500	> 500	500	1	> 500	n. r.	12 August

DDr direct distance from the release point, DD_{av} average direct distance covered between two successive points, $CD_{max/24h}$ maximum cumulative distance per day

[a] no signals after 48 h; *n.r.* not recorded; Numbers in brackets indicate displacement of moth carcass by a predator

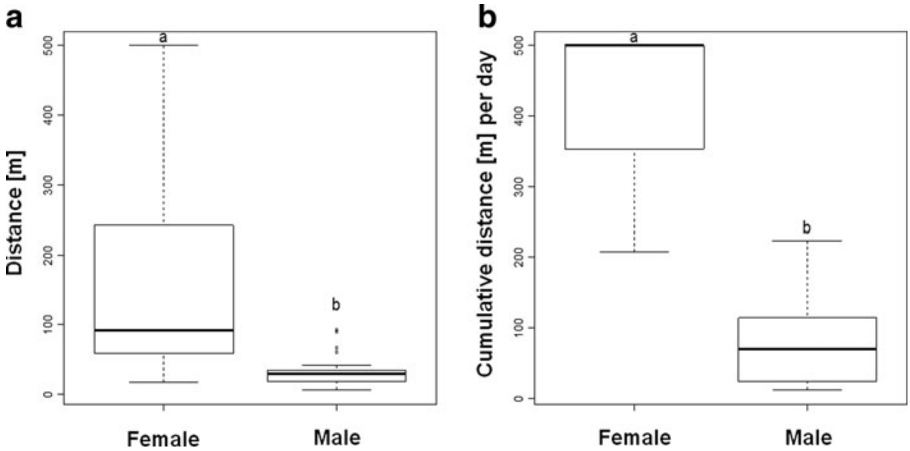

Fig. 3 **a** Direct distance between two successive points for both sexes. **b** Cumulative distance covered in 24 h for both sexes. Different letters indicate significant differences at the chosen level (α = 5 %)

females no. 9, 10 and 11 after they disappeared from the receiver range by walking around the peninsula during the day of release and the following days, but they remained undiscovered.

After taking off from the release point, the insects (both males and females) flew several circles (around 10 m in diameter) in the cleaning area before dispersing over a larger area in zigzag paths. During the individual record collections for the movement study, the insects were observed to select different types of vegetation to land, rest and mate. Neither sex showed clear perching preferences. However, three of the virgin specimens (two females no. 8 and 9; one male no. 5) were observed mating with untagged partners exclusively in the western vineyard area between 12:00 and 14:00 h. Only one male was recorded landing on a palm tree, *C. humilis*, just after its preliminary flight. All males showed scratching behavior, on any type of substrate, using the first tarsus of the second pair of legs (Frérot et al. 2013) to call females.

Typical summer weather was recorded during our experiment, consistent with normal Mediterranean climate except for 3 cloudy days. *Paysandisia archon* movements occurred at an air temperature of 27.9 ± 2.7 °C and relative humidity of 27.1 ± 6.1 %. No moth was observed flying at temperature below 22 °C. The distance moved was significantly correlated to the relative humidity and the interaction between sex and time of the day (Table 2). There was no significant effect of air temperature (df = 9, chisq = 0.0701, p = 0.791). However, tagged females were recorded flying at temperatures strictly between 25 °C and 30 °C, whereas males were observed flying over a larger range of 22 °C to 40 °C. There was a clear and strong effect of the time of the day (Table 2, Fig. 4), with a maximum dispersal during the middle of the day. These results correspond to the flying activity we observed for both sexes (males from 11:00 to 15:00 h; females from 12:00 to 17:00 h). Moreover, the insects tracked (no. 2, 3, 4, 5, 6 and 7) were always retrieved at the same point on the next day, indicating that no movements occurred during the night. Most of the insects flew between 20 % and 32 % RH. The more the relative humidity increased, the less the insects dispersed (Fig. 4). During cloudy days, moths usually avoiding flying, as was observed with male no. 4. Finally, *P. archon* flights occurred only at low wind speeds (not quantified).

Table 2 Results of the analysis of deviance on the effect of relative humidity (RH), sex and time of the day (TOD) on the distance moved. The complete model selected included as predictor variables the RH, the interactions between sex and TOD, and the interactions between sex and the cubic value of TOD. The identity of each insect was used as a random factor. The distance moved was assumed to follow a negative binomial distribution

Model	Df	AIC	logLik	deviance	χ^2	χ^2_Df	P
Complete model	8	786.2	−385.1	770.2			
-RH	7	810.6	−398.3	796.6	26.5	1	2.7e-07
-sex:TOD	6	840.5	−414.3	828.5	58.4	2	2.1e-13
-sex:TOD^3	6	857.2	−422.6	845.2	75.1	2	< 2.2e-16
Null model	3	901.7	−447.9	895.7	125.6	5	< 2.2e-16

Df degrees of freedom, *AIC* Akaike

Discussion

Radio Telemetry Technique

Our study demonstrated the use radio telemetry to track individual diurnal flying moths in the field and provide direct information on when and where movements have occurred. Other techniques, such as harmonic radar, do not provide information for several individuals simultaneously (Riley and Smith 2002; Cant et al. 2005). As no method provides a complete picture of a species' dispersal biology (Ranius 2006), a combination of several different methods to study dispersal is often useful. In this way, a combination of radio telemetry and the mark-recapture method (Ranius and Hedin

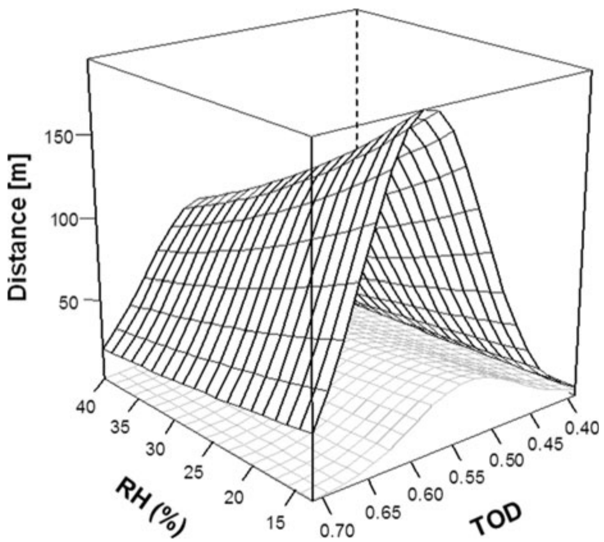

Fig. 4 Predicted distance moved by *P. archon* according to relative humidity (RH), time of the day (TOD-fraction of the day), and sex (*black* for females, *grey* for males) (see Table 2 for the details of the model)

2001; Hedin et al. 2008) may have to be considered. However, to date, there is no way to recapture this moth.

Paysandisia archon presents the advantage of being a very large species that is easy to manipulate. Indeed, the use of radio telemetry is currently restricted to large species which are able to carry a still relatively heavy radio-transmitter (Riecken and Raths 1996). In *P. archon*, the weight of the transmitters ranges between 8 % and 13 % of the insect body weight. In most studies using active radio transmitters, the weight of a transmitter has been less than one third of the body weight of a species (Kissling et al. 2014). Furthermore, our pilot study showed that the presence of the transmitter did not impede the flights of the tagged individuals. Nevertheless, the burden of carrying the transmitter may have some effect on behavior (Hedin and Ranius 2002). However, common and specific behaviors for *P. archon* were observed, such as those described by Sarto i Monteys and Aguilar (2005); Delle-Vedove et al. (2012); Frérot et al. (2013) and Delle-Vedove et al. (2014). Our study did not consider the existing polymorphism of sizes and weights for both sexes (unpublished data) and whether that may cause a bias for individual dispersal capabilities.

Flight Movements

There is a clear difference between sexes: females covered longer distances while males dispersed shorter distances. This same pattern was observed for the beetle *Scapanes autralis* (Beaudoin-Ollivier et al. 2003). But a reverse pattern was observed for the stag beetle, *Lucanus cernus*, where males covered larger distances than did females (Sprecher-Uebersax and Durrer 2001; Rink and Sinsch 2007). Moreover, some other studies have shown that there was no clear difference between sexes, as for the banana weevil, *Cosmopolites sordidus* (Gold et al. 1999) and for the beetle *Osmoderma eremita* (Hedin et al. 2008).

The monitoring of the released moths revealed that males remain in a restricted area showing a quite territorial behavior previously observed by Drescher and Jaubert (2003) and Sarto i Monteys and Aguilar (2005). This territoriality has also been observed for other castniids (Salt 1929; Lara 1964; Miller 1986; Romero 1998). This might be related to the unusual system of mate recruitment in this moth group, namely that males attract females. Males have been reported to fly over 100 m (Sarto i Monteys and Aguilar 2005), but no record was previously reported for females prior to our study.

Although the radio telemetry technique was shown to be feasible for obtaining dispersal information for *P. archon*, contact was lost in 2 days for 18 % of the tagged insects. It is probable that the batteries were damaged or expired before the nominal lifetime because of moisture (Riecken and Raths 1996). Of the remaining 82 % of the released insects, only 66.7 % of them were relocated and measured during a maximum period of 3 days. However, tags were found on the ground with only thorax parts. This suggested that the tagged moths have suffered predation, likely due to birds such as magpies (*Pica pica*) or peafowls (*Pavo cristatus*), which are present in the study site. This predation might be due to the transmitter, which makes the tagged insect more visible. Indeed, our 14 cm antenna may decrease the moth survival chance (Mech and Barber 2002).

For the remaining 33.3 %, all of which were females, contact was lost during the day of release. This observation has also been made for beetles such as *O. eremita* (Hedin and Ranius 2002; Hedin et al. 2008) and *S. australis* (Beaudoin-Ollivier et al. 2003). Therefore, better data were obtained for males than for females. It seems likely that the female moths had dispersed out of the study area and detection range. For *P. archon* females, the mobility over long distances from their emergence site might be explained by their need to ensure the dispersal of the species. However, as some individuals have mated and other not complicates interpretations on dispersal.

Paysandisia archon showed diurnal activity with a flight peak synchronized to the warmest time of the day. A similar pattern has been recorded for two other Castniidae by Lara (1964) for *Castniomera atymnius* and Miller (1986) for *Telchin licus*. Drescher and Jaubert (2003) and Sarto i Monteys and Aguilar (2005) previously observed this flight activity in *P. archon*, but did not provide detailed figures. They merely noted inactivity of adults under laboratory conditions when rainy and cloudy conditions were observed outside. In contrast, our study considers the flying period during particular ranges of temperature and humidity. While a high correlation has been shown between relative humidity and flight distance, this was not demonstrated for temperature. Air temperature might partly explain the maximal dispersal during the middle of the day (hot hours), but the photoperiod and barometric pressure could also play an important role.

Although Sarto i Monteys and Aguilar (2005) observed adults flying between 12:30 and 17:00 h, our data showed males starting to fly before the females in the morning, whereas the females continued to fly later in the afternoon. The data and observations from this study add information on *P. archon* behavior during the daytime. In addition to the scratching behavior only observed in males on substratum, as described by Delle-Vedove et al. (2014), mating was reported for the first time in natural conditions. Sarto i Monteys and Aguilar (2005) described the behavior under laboratory conditions, and Delle-Vedove et al. (2012) recorded mating under outdoor conditions with insects enclosed in mesh cages. Finally, during the tracking period, courtship behavior was observed, similar to that described by Delle-Vedove et al. (2014).

The host plants, such as *C. humilis* and *P. canariensis*, were not visited as often as expected, though many such plants are present on the peninsula. Palm trees seem to be only a support for oviposition and larvae development. They do not even serve as a food source for the adults because they do not feed at all (Sarto i Monteys and Aguilar 2005). So, moths do not seem to reside on the host palm trees. Instead, habitat analyses of *P. archon* at the landscape scale indicate that vineyards and shrubs are most often used. Our data seems to show that areas characterized by low vegetation are more favorable for adult dispersal, perhaps by helping in orientation, as previously observed in bush areas where palms are not targeted (unpublished data).

Conclusion

Our study represents the first successful use of radio telemetry methodology for studying movement, distances and space use of the diurnal flying moth *P. archon*. The technique provided direct measures of individual flights and allowed us to describe habitat preferences and the precise location of mating sites. Additionally, it demonstrated previously unknown sexual differences in flight patterns and distances of movements of *P. archon*. Although our results are limited to a small number of individuals, it gives us a better insight of *P. archon* flight movements, which is critical for understanding the impact of this pest on palm trees.

Up to now, it has not been possible to determine whether the spread of this pest was due to movements of infested plants as a result of trade or to the natural spread of flying adults. This study demonstrates that *P. archon* females can disperse over long distances and therefore may be responsible for the spread of the species.

A high priority for future investigation would be the use of a flight mill to measure the distances, speeds and the periodicities of *P. archon* flights. Furthermore, the question of mating of the females before or after dispersal has to be investigated and elucidated.

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