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SHORT REPORT

## Brood-guarding behaviour in Bulwer's Petrel (*Bulweria bulwerii*) at two East Atlantic colonies

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**Capsule** We characterized the brood-guarding behaviour of the Bulwer's Petrel *Bulweria bulwerii* at two Atlantic colonies. Our results suggest that predation avoidance might be a major factor driving brood-guarding duration on this species.

During the days after hatching, most seabird chicks are continuously attended by at least one of the parents, a behaviour that is generally referred to as brood-guarding (Catry *et al.* 2010). The duration of the brood-guarding period is highly variable between species (Ricklefs & Roby 1983, Varpe *et al.* 2004), ranging from less than a week in small petrels (Boersma *et al.* 1980) to more than three weeks in some albatrosses Diomedidae (Catry *et al.* 2010). Brood-guarding allows for the reduction in the thermoregulatory energy costs of the newly hatched heterothermic chick (Klaassen 1994). However, in many colonial bird species, chicks are brood-guarded for longer than the time needed to reach homeothermy (Catry *et al.* 2009), suggesting that brood-guarding is important in other ecological functions related with chick condition and survival. Small petrels often breed in sympatry with predators such as skuas, gulls, raptors and crows, which can take both adult and young petrels as prey (Oro *et al.* 2005, Matias & Catry 2010).

The lunar cycle might also play an indirect role in regulating brood-guarding duration, by influencing the colony attendance patterns (Mougeot & Bretagnolle 2000). Most small petrels avoid attending the colony during moonlit nights, when many predators

experience higher success rates (Nelson 1989, Oro *et al.* 2005, Watanuki 1986).

In this study, we analysed the brood-guarding behaviour of the Bulwer's Petrel *Bulweria bulwerii* breeding on the two most important colonies for this species in the Atlantic, located in the Madeira archipelago (Macaronesia; BirdLife International 2015). The Bulwer's petrel is the most nocturnal of all seabird species studied so far (Dias *et al.* 2015); therefore, we also evaluated the possible effect of the lunar cycle on brood-guarding duration and chick development.

Field work was conducted on Selvagem Grande Island (30°09'N, 15°52'W) and on Deserta Grande Island (33°20'N, 17°20'W), Madeira archipelago, Portugal, in 2012 and 2014, respectively. Eighty-eight nests were marked in each study site during incubation (early June). Nests were checked daily in the same order during the morning (when no adult arrivals or departures were recorded) until the end of the breeding season (mid-September) on Selvagem and until mid-August (with additional visits on the 19th and 30th August and on the 5th of September, to assess fledging success) on Deserta. Diurnal nest attendance by the parents was recorded in both colonies. On Selvagem, chicks were weighed daily (to the nearest g), and wing length was measured (to the nearest mm) every three days. On Deserta, the chicks were weighed only when they were

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10 days old. A record of chicks found dead or missing from their nest was kept in both colonies, with a note of the possible cause.

We defined brood-guarding duration (hereafter *Brood*) as the total number of days in which chicks were found attended by one of the parents in the first 10 days after hatching; Mass10 as the mass of the chicks at 10 days of age; Mass30 as the mass at 30 days of age (the point at which the exponential chick growth ceases; Nunes & Vicente 1998) and Wing11 as the wing length at 11 days of age.

Spearman's rank correlations were used to test for a correlation between *Brood* and hatching date in each colony. We used linear models to analyse the influence of *Brood* on Mass10, Mass30, mass at fledging and Wing11. The two colonies were analysed separately, since environmental factors such as weather conditions and food availability are known to influence chick early development and may vary between colonies and years (Konarzewski & Taylor 1989, Kitaysky *et al.* 2000). Linear mixed models were also used to test for the influence of moonlight at hatching date (measured as the percentage of visible moon disk at midnight <http://aa.usno.navy.mil/data/docs/MoonFraction.php>) on *Brood* and Mass10. Generalized linear models (binomial family, with logit link) were used to test for the effect of *Brood* on chick survival and fledging success (both binomial response variables), and of hatching date on fledging success. All statistical analyses were performed with the statistical software R (R Development Core Team 2012), considering a level of significance of 0.05. Means  $\pm$  SD are presented, except if otherwise stated. Sample sizes may differ depending on the tests, due to chick mortality in the first days of age.

Hatching success of Bulwer's Petrel was 65% ( $n = 88$ ) on Selvagem and 64% ( $n = 88$ ) on Deserta. The hatching period lasted for 17 days on both colonies (10–26 of July on Selvagem and 13–29 of July on Deserta).

A total of 19 of the studied chicks died on Selvagem and 14 on Deserta, resulting on a final fledging success of 67% ( $n = 57$ ) and 71% ( $n = 56$ ), respectively. Chicks found missing from the nests (11 in Selvagem and 10 in Deserta) were considered to have been predated (most likely by Atlantic Yellow-legged Gulls *Larus michahellis atlantis*, which are often seen predated Bulwer's Petrel chicks in these colonies; personal observations; Matias & Catry 2010). One chick in Selvagem was found being predated by Madeiran Wall Lizards *Teira dugesii*. Chick survival at 10 days of age and fledging success did not differ

significantly between the two colonies (Fisher's exact test:  $P = 0.074$  and  $P = 0.54$ , respectively).

*Brood* varied from 0 to 6 days and was significantly higher on Selvagem ( $2.16 \pm 1.24$ ; range 1–6 days;  $n = 55$ ) than on Deserta ( $1.67 \pm 1.00$ ; range 0–4 days;  $n = 52$ ;  $t$ -test:  $t = 6.05$ ,  $P < 0.001$ ). Mass10 was similar in chicks from Selvagem ( $45.16 \pm 10.16$  g,  $n = 44$ ) and Deserta ( $43.57 \pm 10.01$  g,  $n = 51$ ;  $t = 0.74$ ,  $P = 0.46$ ). We found a significantly lower Mass10 for chicks brooded for longer in Selvagem, while no relationship was found between Mass10 and brood-guarding duration on Deserta (Table 1). We did not find any other influence of *Brood* on the condition or survival of chicks, either on Selvagem or Deserta (Table 1). Chicks hatching earlier in the season were brood-guarded for longer than late-hatched chicks on Selvagem, but not on Deserta (Spearman's rank correlation test:  $r = -0.30$ ,  $P = 0.042$ ,  $n = 45$  and  $r = 0.14$ ,  $P = 0.340$ ,  $n = 51$ , respectively; Fig. 1). Fledging success was not affected by hatching date (Selvagem,  $Z = -0.048$ ,  $P = 0.96$ ,  $n = 57$ ; Deserta,  $Z = 0.57$ ,  $P = 0.57$ ,  $n = 57$ ). *Brood* was negatively influenced by moonlight at hatching date ( $t = -2.24$ ,  $P = 0.028$ ,  $n = 96$ ), while Mass10 was not significantly influenced by the moonlight ( $t = 1.19$ ,  $P = 0.24$ ,  $n = 96$ ).

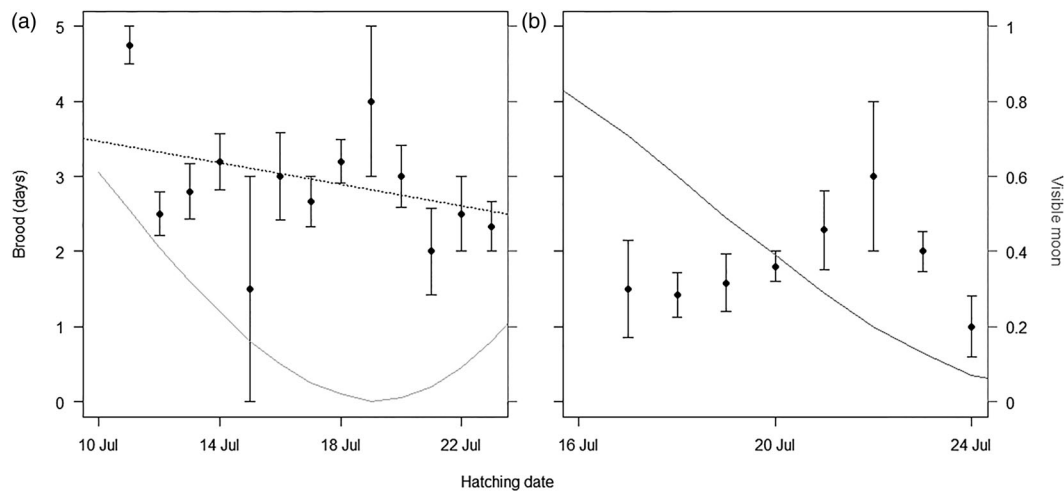
Our results showed that longer brood-guarding periods in Bulwer's Petrel did not positively affect chick survival or growth. In fact, the opposite pattern was found on Selvagem (i.e. brood duration negatively correlated with chick mass at age 10), suggesting that there are factors, other than the body condition of the chicks, driving this behaviour.

We also found a negative relationship between hatching date and brood-guarding duration in Selvagem. A seasonal decline in brood-guarding duration has been shown in other seabird species such as albatrosses (Catry *et al.* 2010), and is often related with predation risk (the *synchronization hypothesis*; Catry *et al.* 2009) given that, by synchronizing the end of brooding, the individual probability of a chick being predated decreases due to a dilution effect (Ims 1990; Catry *et al.* 2009).

The population size of Bulwer's Petrels on Deserta (approximately 45 000 pairs; Catry *et al.* 2015) is several times higher than on Selvagem (approximately 5000 pairs; Ramírez *et al.* 2008), so the individual predation risk on Selvagem is probably much higher than on Deserta, which could explain the seasonal trend in brood-guarding duration only being obvious in the former, and the longer brood-guarding duration on Selvagem. Both adults and chicks of Bulwer's Petrels

**Table 1.** Influence of brood-guarding duration (*Brood*) on chick growth, development and survival. Mass10 = mass of chicks at their 10th day of age, Mass30 = mass of chicks at their 30th day of age, Wing11 = wing length of the chicks on their 11th day of age. GLM = general linear model. Chicks from Deserta were not monitored until fledging, therefore no results are presented for the influence of *Brood* on Mass30, Mass at fledging and Wing11 in Deserta.

	Selvagem		Deserta	
	Statistics	P-value	Statistics	P-value
Mass10	Linear model: $t_{44} = -0.35$	= 0.021	Linear model: $t_{51} = 0.34$	= 0.73
Mass30	Linear model: $t_{43} = 0.33$	= 0.75	–	–
Mass at fledging	Linear model: $t_{38} = -0.93$	= 0.36	–	–
Wing11	Linear model: $t_{43} = -1.0$	= 0.31	–	–
Chick survival at 10 days of age	GLM (binomial): $Z = 0.78, n = 45$	= 0.11	GLM (binomial): $Z = -0.52, n = 51$	= 0.60
Fledging success	GLM (binomial): $Z = 0.91, n = 45$	= 0.36	GLM (binomial): $Z = -1.04, n = 51$	= 0.30



**Figure 1.** Relationship between hatching date and brood-guarding duration (*Brood*, average  $\pm$  SD days) in Bulwer's Petrel breeding on (a) Selvagem ( $n = 45$ ) and (b) Deserta ( $n = 51$ ). Dashed line in panel (a) represents the significant correlation found for Selvagem colony (Linear model:  $t_{44} = -0.35$ ,  $P = 0.021$ ). Grey lines represent the proportion of visible moon, which had a significant influence on *Brood* (Linear mixed model:  $t = -2.24$ ,  $P = 0.028$ ,  $n = 96$ ).

are a common prey species of Atlantic Yellow-legged Gulls on Selvagem (Matias & Catry 2010) and on Deserta (pers. obs.; Lourenço Alves pers. obs.). Other predators of very young chicks from Selvagem and Deserta are the highly abundant Madeiran Wall Lizards (Matias *et al.* 2009).

The lunar cycle had a significant effect on the brood-guarding duration of Bulwer's Petrel in the two studied colonies, with chicks hatched around full moon being brood-guarded for shorter periods. The lunar cycle is known to impact colony attendance in small nocturnal

Procellariiformes (Mougeot & Bretagnolle 2000). In general, birds attend the colony more often on dark, new-moon nights, which is usually explained as an anti-predator behaviour (Rubolini *et al.* 2014). The lunar cycle may also affect the foraging success of Bulwer's Petrels by influencing the sub-surface availability of mesopelagic fishes and squids (Hernandez-Leon *et al.* 2002), which represent the bulk of their diet (Neves *et al.* 2011). However, we did not find any relationship between Mass10 and moonlight, suggesting that it is predation risk, rather

than foraging efficiency, driving the observed relationship between brood-guarding and the moon phase. This conclusion is also supported by the recent evidence that the lunar cycle has no significant effect on the nocturnal at-sea flying activity of this highly nocturnal seabird (Dias *et al.* 2015). The influence of the moon on brood-guard duration was evident under different lunar patterns and by pooling the data from the two studied colonies (hatching peak occurred during full moon in Selvagem in 2012 and during the last quarter in Deserta in 2014), revealing that this factor should be further considered in studies aiming to characterize the brood-guarding behaviour of other similar species.

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