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Parental care and chick growth rate in the Mediterranean Storm-petrel *Hydrobates pelagicus melitensis*

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Abstract – Few studies on parental care in monomorphic seabirds are available, whether or not differences between sexes are reported. We studied the Mediterranean subspecies of Storm-petrel *Hydrobates pelagicus melitensis* from 2007 through 2012 to determine the nature of parental care for each sex and to evaluate the birds' breeding behaviour. We found that parents' investment is equally divided during incubation and first days after hatching. When chicks grow older females invest more time in taking care of their offspring. The variability in parents effort observed in the five years lead us to conclude that parental care changes from year to year is an adaptation to variability in environmental conditions and food availability balancing long lived species vulnerability.

Key-words: chick feeding, chick growth rate, Storm-petrel *Hydrobates pelagicus melitensis*, parental care, seabirds.

INTRODUCTION

Bi-parental care in seabirds includes a wide variety of strategies, ranging from little parental care to nest attendance by only one parent, to nest attendance by both sexes, although this last strategy can vary according to the relative amount of time spent in attendance by each sex (Tershy & Croll 2000, Daunt *et al.* 2003, Lagarde *et al.* 2004, Gladbach *et al.* 2009, Elliott *et al.* 2010). Many possible explanations exist for differential parental investment in dimorphic seabird species. The smaller sex would be more flight-efficient and could reach more productive areas, whereas the larger sex would have to make shorter foraging trips, probably to less productive waters (Gonzalez-Solis *et al.* 2000). For monomorphic species, the statement mentioned above may not be valid. However, evidence suggests that some species have differential parental care (Creelman & Storey 1991, Gray & Hamer 2001). During the breeding period, the adults must double their feeding activity to feed their chicks and at the same time maintain themselves in peak condition (Golet *et al.* 1998, Weimerskirch *et al.* 2001). Having a good body condition increases survival and enhances reproductive success for the subsequent season.

Among Procellariiformes, albatrosses have been found to exhibit sex-specific feeding patterns (Weimerskirch *et al.* 1997, 2009). In a study on a smaller procellariiform, Wilson's Storm-petrel *Oceanites oceanicus*, no evidence of sex-specific parental care was found (Gladbach *et al.* 2009), however different techniques were used by each member of the breeding pair to reach the same amount of parental care.

Studying Procellariiformes species is challenging, and information about parental care patterns and breeding behaviour of these species is therefore generally lacking. Part of this difficulty stems from the birds' nocturnal habits and from the fact that their breeding sites are often difficult to access, and part of the difficulty stems from the sensitivity of these species to disturbance (Warham 1990, Saffer *et al.* 2000, Blackmer *et al.* 2004, O'Dwyer *et al.* 2006, Carey 2009).

Mediterranean Storm-petrels *Hydrobates pelagicus melitensis* are apparently monomorphic, and the sexes do not differ in size (Albores-Barajas *et al.* 2010). In monomorphic species it has been reported all different possibilities of parental care, with females providing more food (Creelman & Storey 1991), males providing more food (Gray & Hamer 2001, Peck & Congdon 2005) or no differences between sexes (Gladbach *et al.* 2009). As for other species of Storm-petrels, differential parental care has

not been reported in the Mediterranean Storm-petrel and we would expect the same proportion of nest attendance (during incubation and chick rearing) in both sexes. In an Atlantic colony of the European Storm-petrel *Hydrobates p. pelagicus* that was checked daily during the chick rearing period there were no differences on the amount of food provided between males and females, as each sex fed the chick independently of a visit from the partner (Bolton 1995).The location of the nest in a colony is a factor that may determine the breeding success of a pair (Forbes *et al.* 2000, Velando & Freire 2001, 2003, Rounds *et al.* 2004). As the colony we studied is located in a large cave with a single entrance, we believe that in the absence of predators, the location of a pair's nest in the colony relative to the location of the colony entrance may determine the breeding success of that pair because areas near the entrance are closer to possible sources of disturbance, such as motor boat and people shouting.

Accordingly, the objectives of our study were to describe Mediterranean Storm-petrel parental care from nest site choice to chick rearing. We evaluate the parents' choice of nest site and describe the birds' breeding strategy by monitoring chick growth, and determine the parental care patterns investigating whether both parents exhibit the same effort or show sex-stereotyped behaviour.

We applied several field methods in order to limit disturbance gathering a wide range of information. We compared adult body size and body condition in different parts of the cave to locate the core area of the colony and to distinguish early from late breeders (Velando & Freire 2001). We used adults' physical characteristics as indicators of better-quality parents capable of producing better offspring (Chastel *et al.* 1995). Using IR video recordings, we sought to detect the strategies of food delivery that the parents were providing to their chicks.

METHODS

Study site and species

Field work took place from June through August during 2007-2012. We studied a colony of ca. 2,500 breeding pairs of the Mediterranean subspecies of the European Storm-petrel on Marettimo Island, Italy (37°58'20"N 12°3'20"E). The colony is divided in two main sub-colonies. There is an outer sub-colony more exposed to external factors (less than 100 nests) and a main one, in the inner part of the cave. Field work was carried out under permission from the Marine Protected Area No. 3/2011 and 1721/2012. There were no ethics committee approval requirements to carry out this project.

Storm-petrels lay single-egg clutches asynchronously, starting in May-June. Most hatching occurs during the first half of July, and chicks remain in the nest for more than 60 days. Chicks are left unattended during the day when about one week old, and they are fed by adults during nocturnal visits until 10-15 days before fledging. Fledging starts from the second half of August.

Sample collection and adult/egg/chick measurement

To minimize the potential disturbance due to intensive sampling, we alternated between different field methods to reduce the time spent in the cave and number of visits. Nests were marked at the beginning of the 2007 breeding season, and other nests were added during the following seasons. During 2007-2012, we measured 269 adults from both the inner and outer parts of the colony. These individuals were captured directly on the nest. We did not record any nest desertion by captured individuals (compared to 98% of desertion in Malta; J. Borg, pers. comm.). Each individual was fitted with a metal ring if it was not already ringed. We measured wing length to the nearest 1 mm with a wing rule; tarsus length from the middle of the midtarsal joint to the distal end of the tarsometatarsus; head plus bill, bill depth and width to the nearest 0.1 mm using Vernier calipers. Some individuals were captured more than once during the same breeding season. In these cases of recapture, we only recorded body mass before releasing the bird. To examine the nest attendance of parents during incubation and chick rearing, we recorded the sex of the first adult captured per nest in each season (30 nests per season). Sex was determined by DNA analysis and/or the measurement of rump/wing ratio (Albores-Barajas *et al.* 2010). If both sexes attend the nest equally, the probability of recording an adult of a certain sex as the first-captured adult should not be significantly different from 50% (Gladbach *et al.* 2009).

Egg length and breadth were measured to the nearest 1 mm using Vernier calipers. We candled the eggs in order to determine the incubation stage (Lokemoen & Koford 1996), using a portable lamp and taking advantage of the darkness of the cave. We recorded whether the embryo was alive and recorded its development stage for a total of 84 eggs (53 in 2008 and 31 in 2009).

We followed chick growth in July-August 2007 and 2010. A total of 89 nests were surveyed. Chicks were assigned to one of three age classes: class 1, newly hatched chicks, covered entirely with down; class 2, covered with down and pin feathers, aged between 20 and 40 days; and class 3, older chicks, fully feathered.

The growth curve of each individual was obtained from a quadratic regression (Quillfeldt & Peter 2000) from

mass and wing length measurements taken approximately every five days until the chick was fully feathered and then 2-3 times until fledging. We considered peak mass as the highest weight recorded for each individual, within a ± 2.5 days error. To avoid disturbance, we kept handling time to a minimum. We obtained blood samples for DNA sexing 73 chicks in total, 29 in 2007, 24 in 2008 and 20 in 2010.

Video recording

We collected 111 hours of video recording in five breeding seasons (2007-2009 and 2011-2012) during the first stages of chick rearing, from 3 days until 1 month old (age classes 1 and 2). We used two infrared digital video cameras (Sony DCR-SR72) to prevent disturbing the nestlings during their normal activities. These video cameras were left recording overnight and they were retrieved the following day for downloading the video and battery charging. Owing to the limitation of battery life, we recorded 8 hours every session. When analyzing video recording, the sex of the adult was assessed on the basis of vocalizations (James 1984).

Data analysis

Adult size and size-corrected mass (SCM) were determined by applying principal components analysis (Tabachnick & Fidell 1996) to biometric measurements (wing length, tarsus, head size, bill width and length). As there were no significant differences between the body size of males and females, we pooled the data together. The first principal component, factor one, was used as a measure of body size. The weight of the individual was linearly regressed on the values of factor one, and the residuals were used as an indicator of SCM (Catry & Furness 1999). Egg volume (V) was estimated from egg length in mm (L) and breadth in mm (B): $V = 0.51LB^2$ (Preston 1974).

We used the sex of the adult first caught in the nest, the number of feedings, the feeding duration and the time spent at the nest as proxies for parental care. We then compared all but the first of these proxies between the sexes using Mann-Whitney U-test. We used the Kruskal-Wallis test to compare feeding rates between males and females of the same nest. We used parametric and nonparametric tests as appropriate for the distribution of the data analyzed.

RESULTS

Male-female differences

We found no difference on body size and SCM between the inner and the outer part of the colony (Anova; BS: $F_{1,46}$

= 0.021, P > 0.05; BC: $F_{1,46}$ = 0.266, P > 0.05). However, we found a significant difference in SCM in July with heavier birds nesting in the outer part of the colony (Anova; $F_{1,36}$ = 4.684, P < 0.05). In general females had better SCM (Fig. 1a) compared to males (Fig. 1b) in 2007-2009 while in 2011-2012 the situation is reversed, these differences are not statistically significant except in 2012 (t-test; T = 1.938, P = 0.05). Often in July we found freshly laid eggs and late-breeding parents in better SCM in the outer part of the colony. We estimated an average weight loss of 0.334 g/day based on 10 adults that were weighed three times during a period of 15 days. These adults were weighed at the same time of day each time they were captured.

Chick growth and egg volumes

Chicks have a constant growth rate during the first 50-60 days. They reach peak body mass (the maximum mass that a chick attains before the parents stop feeding it) approximately ten days before fledging, and they subsequently lose body mass until fledging (Fig. 2). We found that chicks reach a mean peak body mass of 45.56 g ± 0.55 g (N= 20) before starting to lose weight (Fig. 2). Fledglings had a mean fledging mass of 33.7 g ± 1.15 g, compared with the mean mass of 29.77 g ± 0.21 g (N = 157) of adults. In 2010, chicks' mean fledging mass was significantly lower than in 2007 (29.76 g ± 0.63 g; T_{28} = 8.178, P < 0.001).

We observed significantly different egg volumes in 2007 and in 2008 (15 and 23 eggs measured, respectively, T_{36} = -3.450, P < 0.001). Larger eggs were found in 2008 (in mm³, 2007: Mean = 8135.71, SE = 229.68; 2008: Mean = 8943.47, SE = 119). We detected no differences in the volume between the eggs laid in the inner or outer parts of the colony (2007: T_{12} = 0.769, P = 0.457; 2008: T_{22} = -0.185, P > 0.05). We did not observe either significant differences or correlations between the SCM and the size of the egg (Fig. 3).

Candled eggs allowed us to confirm the presence of live embryos at different stages of development in all 38 samples. We did not find infertile eggs or dead embryos, although it was common to see abandoned and broken eggs on the floor of the cave. These eggs probably fell from upper nest chambers.

Behavioral observations

We observed similar rates of nest attendance by both sexes (2007: males 52%, females 48%; in 2008: males 54%, females 46%; 2009: males 51%, females 49%; in all years X^2_1 = 0.08, P > 0.05). However, from 2011 the situation is the opposite, with more females caught first (in 2011:
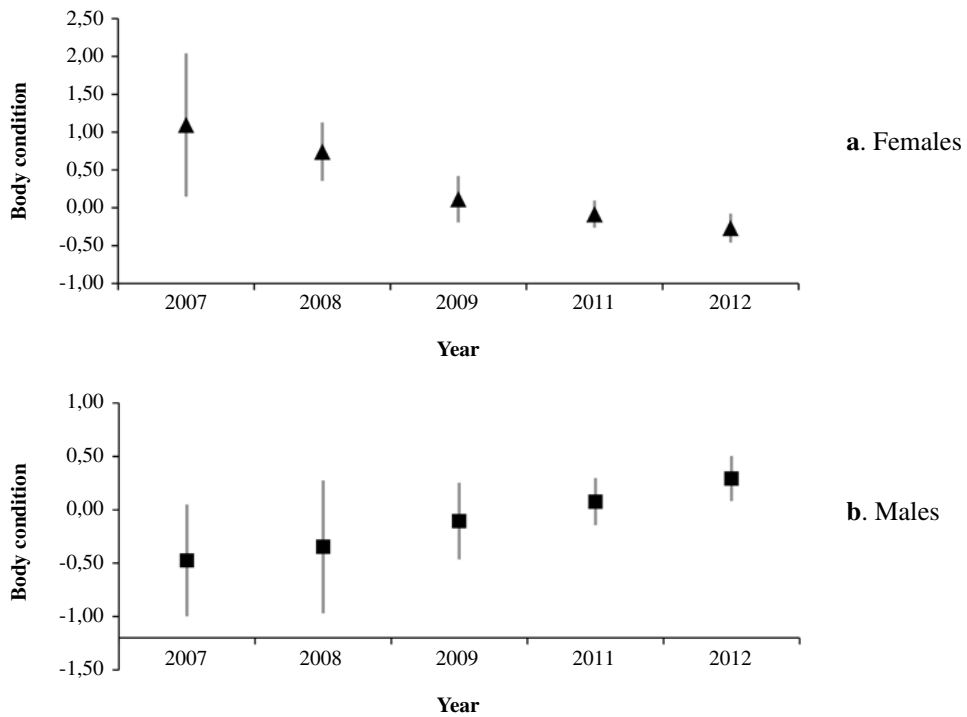
**Figure 1**. Differences in body condition between males and females from 2007 through 2009 and 2011-12.

males 47%, females 53%; in 2012 males 49%, females 51%).

We assumed breeding success to be near 1 in the inner part of the colony, based on lack of abandoned eggs or chick carcasses. In the outer part of the colony, we found a small proportion of abandoned eggs (<10%), but we found no dead chicks.

The overall sex ratio of chicks in our sample was not significantly different from equality. The proportion of males/females was 0.812 in 2007, 0.846 in 2008 and 0.818 in 2010.

From comparisons of separate feeding sequences, we found the first feeding events to be longer (average duration of the first feed 23 sec; duration of the first 10 feeds exceeded 2.30 min, each feed lasting 15 sec in average). The duration of each feed then declined to fewer than 10 sec (after the 11th feed, the average duration was 8 sec). The number of feeds in a feeding sequence was variable
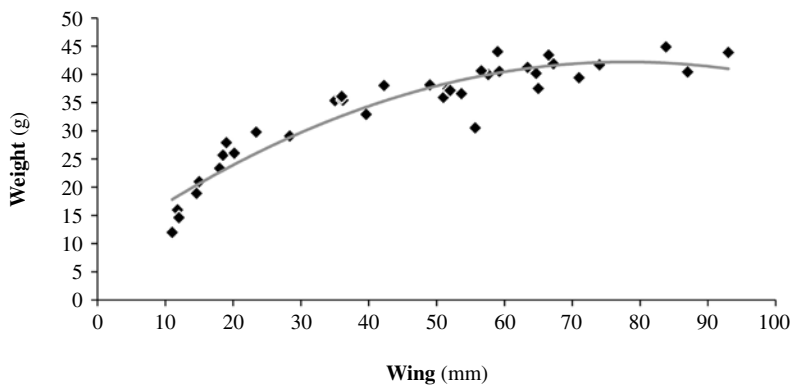
Figure 2. Chick growth curve estimated from measurements of 69 individuals. The peak body mass of chicks is almost double that of the adults. After attaining peak body mass, chicks lose mass until hunger forces them to abandon the nest.
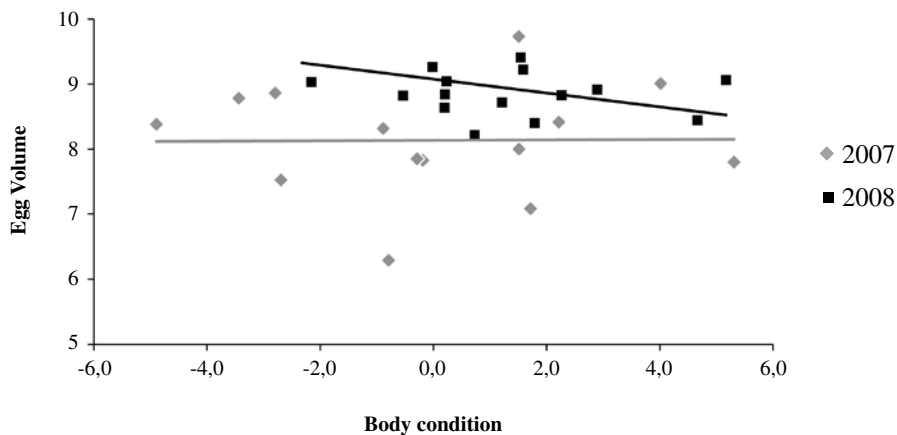
Figure 3. Egg volumes (in cm^3) vs body condition of the females. There is no correlation between the body condition and the volume.

and ranged from 1 to 40 feeds, with a mean 16 feeds. The maximum observed duration of a feeding sequence was 9.59 min for a sequence of 16 feeds. We found that the duration of the feeding sequence was correlated with the number of feedings in females (Pearson P = 0.917, P = 0.004) but not in males (Pearson P = 0.308, P = 0.245).

We found that there is no difference on attendance between sex when chicks are very young (1st age class), but when chicks grow older (2nd age class) male parents tend to spend less time than females in parental care (Mann-Whitney, Z = -2.622, P = 0.004).

Although we observed feedings of partially digested fish delivered to younger chicks (1st age class), almost entire fish were delivered to older chicks (2nd age class). We found that feeding sequences were slightly shorter in older chicks (2nd age class) and that the numbers of feeds in each sequence were fewer, compared with the feeding sequences in smaller chicks (1st age class) (2nd class mean = 5.8 sec, 1st class mean = 8.1sec; $H_{1,244}$ = 6.55, P = 0.01)

DISCUSSION

Male-female differences

As a monomorphic species, both sexes of Storm-petrels are expected to be fairly similar in size under the same conditions. However, in the middle of the breeding season (the third month of the five-month long breeding period) we found differences in body condition between the inner and the outer part of the colony. Differences may be explained by the fact that older and usually more experienced birds, arrive at the colony earlier and tend to occupy the best sites, namely sites in the inner part of the colony away from disturbance and, when present, predators

(Meathrel & Carey 2007, Berman *et al.* 2009). Therefore, the birds in the inner part of the colony are involved in parental care for longer and have been losing weight for a longer period of time.

Given the patchiness of resource distributions at sea, seabirds may have adapted their life history to reduce the energy requirements for chick growth by extending the growth period (Drent & Daan 1980), giving the parents more time to feed for themselves and to provide for the chick. During incubation parents alternate every two to three days (Warham 1990). Therefore, the figure of 0.33 g/day weight loss is probably an underestimate, because the individuals measured must have made some foraging trips in the interim. During some night-time visits we observed several individuals feeding just outside the colony, therefore the daily weight loss must be greater than that. Comparing the weight loss between males and females we observed that males lose more weight. This may be a confirmation of different strategies with males foraging far from the colony and thus fasting for longer and females foraging closer to the colony (Gladbach *et al.* 2009), thus larger paternal investment during incubation.

Chick growth and egg volumes

In single-egg species, the size of the egg may reflects the environmental conditions and the condition of the mother (Muller *et al.* 2005, Meathrel & Carey 2007). Our results show contrasting evidence with this (Fig. 3). We have a large variation of egg volumes between years, but no significant differences in body condition of the females with measured eggs. Our observations of the candled eggs indicated that all the eggs that were incubated contained a live embryo. This result suggests that Storm-petrels may recognize an egg containing a dead embryo and that they will

abandon it and, in some rare cases, eventually may replace a broken egg (Minguez 1997).

The chick growth curve showed a peak and then decreased until fledging, due to the fact that chicks continue to accumulate fat, and the adults abandon the chick one week before fledging, so the accumulated mass is used for feather and skeletal growth. The same has been previously observed in the Atlantic (Bolton 1995) and also in the Mediterranean subspecies (Minguez 1996). Interestingly, the sex ratio at hatching was slightly biased towards females. As we did not find any carcasses, we can assume that the sex ratio at fledging remained the same as at hatching during 2007-2010. Weight at fledging in 2010 was significantly lower than in previous years. This result confirms that chicks had greater difficulty in gaining weight. It is noteworthy that during 2010, the cave was unusually wet, owing to temperatures below and precipitation above the mean of the previous 20 years (climatic data from 1981 through 2010; the colony has been followed since 1986) (SIAS 2002). In fact, a cold and wet nesting place may require the chick to produce greater metabolic expenditure in order to thermo regulate, and this greater expenditure would lead to mass loss confirming that nest site quality may affect reproductive output.

Behavioral observations

We observed variable patterns in parental care regarding roles distribution between sexes during incubation and feeding. This finding agrees with the pattern of parental care found in *H. p. pelagicus* in the Atlantic (Bolton 1995) and other Storm-petrel species. For example, the Wilson's Storm-petrel does not exhibit a general pattern of sex-specific parental investment, rather tending to exhibit context-dependent sex-specific investment during years of food shortage (Gladbach *et al.* 2009). However, the same species was found to exhibit different patterns of parental provisioning (Beck & Brown 1972). This contrast indicates that parental strategies may be flexible and adaptable to the environmental conditions.

In other procellariiform species, it has been found that males provide a larger amount of food than do females and that males visit the nest more often (Beck & Brown 1972, Weimerskirch *et al.* 2001, 2003). Differential parental care by males is found in less than 5% of bird species, and the species exhibiting this pattern of paternal care are primarily those having reversed sexual size dimorphism or reversed sex roles. Its evolution, especially in monogamous species, remains puzzling (Maurer 2008). Checking birds on nests during diurnal surveys, we observed no differences in nest attendance by sex while from the IR recordings (of nocturnal activity) a different pattern arose. We

observed that although only one parent was present during the day, during the night both birds were present at the nest and they were observed together for larger percentage of time with 1st age class chicks than with 2nd age class; in this latter case the chicks were left alone during the day. Parents incubating 1st age class chicks were observed feeding the chicks during daytime, meaning that they were fastening at least since the night before, but continuing providing food at close time intervals. We found that males were responsible for more feeding events, whereas females performed more visits, probably as a result of shorter feeding events, confirming the theory of different feeding strategies (Cherel *et al.* 2002, Gladbach *et al.* 2009). Comparison of the parents' nest attendance in terms of the proportion of time spent brooding and feeding revealed a significant difference in parents' investment. In fact although there is no difference between sexes when chicks are very young (1st age class) male parents tend to invest less effort than females for older chicks (2nd age class).

Longer nest attendance by males during the first days may be explained in different ways that are not mutually exclusive: first, males compensate for the effort made by females to produce the egg, an energetically costly event, and explaining a larger nest attendance by males on younger chicks; second, due to diurnal feedings the effort of both parents is required; additionally, males may be better at defending the nests from conspecifics. From our IR recordings, we observed that when both adults were present on the nest, one of them (the male) defended against conspecific intruders, while the other remained in the nest. If only one adult was on the nest, males showed a more aggressive response, but they did not move away from the nest.

During our long term monitoring at Marettimo's colony we have observed that Storm-petrels may use different parental care strategies according to the climatic conditions. In this paper we provide an idea supporting the plasticity of the species regarding its breeding biology. This makes us suppose a capability in facing environmental change balancing the high vulnerability of long-lived species.

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