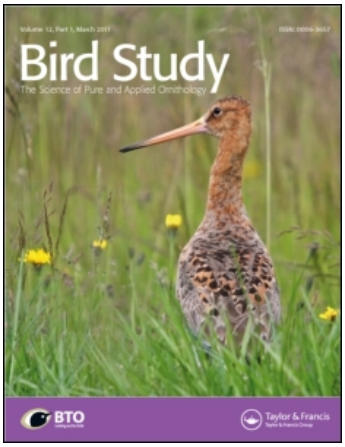

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Diet and diving behaviour of European Storm Petrels *Hydrobates pelagicus* in the Mediterranean (ssp. *melitensis*)

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Capsule Unlike Atlantic populations, which feed on krill, Mediterranean populations feed mainly on pelagic fish *Gymnammodites cicerellus.*

Aims To determine the diet and dive depth of the Mediterranean subspecies of European Storm Petrels *Hydrobates pelagicus melitensis*.

Methods Analysis of regurgitates of adults arriving at the colony for chick feeding and by determination of dives depth using the capillary tube method.

Results The main prey is *Gymnammodites cicerellus*, a pelagic fish. Storm Petrels dive for their prey and can reach up to 5 m in depth. They also make short foraging trips just outside the colony where they capture Opossum Shrimps Misydacea.

Conclusions European Storm Petrels in the Mediterranean exploit pelagic fish which are taken by diving. This contrasts with the Atlantic populations which feed mainly on krill. Mediterranean birds also feed on Opossum Shrimps *Mysidacea* during short foraging trips made at night just outside the colony. Differences in diet between long and short foraging trips may be because adults have to forage for both themselves and their chicks.

When devising conservation strategies for seabirds, it is important to consider not only the breeding sites of the species, but also the areas in which they forage and for which prey (Hazlitt *et al.* 2010). For seabirds, this delimitation of areas may be a difficult task, as some species make foraging trips up to several hundred kilometres away from the colony (Magalhaes *et al.* 2008). Furthermore, the colonies of many seabird species are located on inaccessible sites, which make it difficult to study their biology. Among seabirds, nocturnally active species, such as European Storm Petrels *Hydrobates pelagicus* are even less accessible to study due to their habits of breeding in burrows (Brooke 2004).

European Storm Petrels have large colonies. In the Atlantic part of their range, colonies often contain several hundred thousand breeding pairs, but in the Mediterranean, the largest colonies have between 7000 and 9000 breeding pairs (del Hoyo *et al.* 1994). Genetic analysis has suggested a division between the Atlantic and the Mediterranean populations at the subspecies level (Cagnon *et al.* 2004). Based on this genetic difference and on the decreasing number of breeding pairs per colony in the Mediterranean (Lo Valvo & Massa 2000), this Mediterranean population *Hydrobates pelagicus melitensis* can be considered an endangered subspecies, given that all individuals within the Mediterranean breed in only a few colonies (Massa & Sultana 1991).

Dietary analysis of the Atlantic populations of the European Storm Petrel found two main prey groups, krill Euphausiacea and microzooplankton (D'Elbee & Hemery 1998). Other petrel species have been observed to dive in search of prey, with recorded depths of 2 m for the Madeiran Storm Petrel *Oceanodroma castro* (Bried 2005). Given the absence of krill in the Mediterranean, it can be assumed that the diet of the Mediterranean populations is different from that of

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the Atlantic populations. As there is no information on the diet of the Mediterranean populations or on the diving behaviour of the European Storm Petrel, our objective was to determine the diet of the Mediterranean population of this species during the breeding season and to describe their feeding behaviour.

METHODS

The Mediterranean Storm Petrel colony in Marettimo Island, Italy (37°58′20″N 12°3′20″E) has been monitored since 1985, with about 6000 individuals ringed (Lo Valvo & Massa 2000, Sanz-Aguilar *et al.* 2009). The main colony comprises between 2000 and 2500 breeding pairs and is located in a cave accessible only from the sea. The colony is distributed in two main chambers of the cave and on several terraces. Nests are all scattered inside the cave and most of them are not inside crevices or under rocks, therefore it is easy to mark nests and study the behaviour of pairs. Due to their lack of an anti-predator response, these Storm Petrels are easily caught on their nests by hand while brooding. We monitored the colony for the breeding seasons of 2007–2009.

In order to determine the diving depth of the adults, during the three breeding seasons, we attached capillary tubes (Mougin & Mougin 2000) on rump or tail feathers (two or three feathers) of 112 birds using waterproof duct tape. Birds were caught at the nest and when possible we placed capillary tubes on both individuals of a pair. A total of 56 single adults and 28 pairs were studied. During the 2007 breeding season we followed Mougin & Mougin's (2000) method for tube placement on tail feathers in their study of Bulwer's Petrel *Buweria bulwerii*. In 2008 and 2009, we modified the method by placing the tubes on rump feathers. As European Storm Petrels are smaller than Bulwer's Petrel (mean body weight 26 g compared to 99 g), we shortened the tube from the 12 cm length used by Mougin & Mougin (2000) to 7 cm in order to avoid it being too obstructive. The capillary tubes allow the determination of diving depth by using the general gas compression formula (Mougin & Mougin 2000). To assess the efficacy of the capillary tubes, we attached a capillary tube to a buoyancy compensator on a SCUBA diver and controlled the maximum diving depth recorded by the capillary tube with a SCUBA computer. The tubes proved to be accurate and during three trial dives at 10 m recorded an error of ± 10 cm.

The sex of adult birds was determined by measuring the length of the white rump band of both individuals in each pair; females have a larger rump band compared to males, and this is an accurate indicator of sex (Albores-Barajas *et al.* 2010).

Although we visited the colony every 3–5 days during daylight for adult and chick measurements during the three breeding periods, we only visited the colony at night once per breeding season in order to get regurgitated material from the adults as they returned from foraging trips. We used these samples to determine the food they provided to chicks. Birds were attracted to the rocks illuminated by our head lamps. They sat on the rocks disoriented and it was then possible to catch them. Procellariiformes often regurgitate the contents of the upper digestive tract (Barrett *et al.* 2007) in the presence of danger. Regurgitates can provide important information of the diet of the individual at sea and of the food they provide to chicks as they enter the breeding colony (Gladbach *et al.* 2009, Votier *et al.* 2003, Kitson *et al.* 2000). We observed in video recordings that the food is provided to chicks a few minutes after the adult's arrival at the nest (unpubl. data). In this study we have assumed that the regurgitates collected in this way represented the diet of the chick. As Storm Petrels regurgitated the material before we could catch them, material recovered from bare rocks near the nesting site was analysed (only regurgitates found on bare rock were kept in order to reduce the possibility of contamination of the samples). The regurgitated material was collected and preserved in 4% buffered formalin for later identification. Visits were kept to one per season, as during the late parts of the breeding period adults make one feeding trip every two or three days. Therefore making multiple visits increases the possibility of the same chick losing multiple meals. Given that the birds captured immediately regurgitated considerable quantities of food, we assumed that the adults were intending to provide the regurgitate to a hatchling and were not just returning to the nest to replace their partner.

Diet analysis

We analysed 25 regurgitates. Each prey item was identified to the lowest taxonomic level (Tortonese 1975). The relative importance of each item was expressed as a percent of occurrence of food items in stomachs (OF%, occurrence frequency) (Hyslop 1980). Data obtained with this kind of analysis are qualitative, not quantitative.

RESULTS

We recovered 30% of the capillary tubes placed (33/112 tubes) and recorded a mean diving depth of 146 cm (se = ±0.25 cm). However, we observed a large variation in mean diving depth from year to year: 190 cm in 2007, 120 cm in 2008 and 150 cm in 2009 (Table 1), but these means were not significantly different (one-way ANOVA $F = 0.50$, $P = 0.61$). We did not observe a significant difference in diving depth according to sex, on 17 individuals sexed (*t*-test, $t = -0.749$, $P = 0.46$). During the 2007 breeding season we recovered only 20.83% of tubes deployed and we observed in IR video recordings that the tube placed on the tail could be obstructive for the birds and could be easily lost. Thus we decided to place the tubes on rump feathers in the 2008 and 2009 seasons. This resulted in higher recovering rates (28.57% in 2008 and 34.78% in 2009).

We observed that Storm Petrels also feed during the night immediately outside of the colony. The prey available in this area consists mainly of Opossum Shrimps Mysidacea. Adults may alternate two feeding techniques: traditional long trips, where they spend all day out at sea, and short trips, where they feed immediately outside the colony during the night.

In general, dietary composition in terms of the main prey items did not differ among samples of different years. The main prey species, both in volume and in number, were fish. Otolith analysis identified the ingested species as *Gymnammodites cicerellus*, a pelagic fish species common in deeper waters in this part of the Mediterranean Sea during the sampling season. On the basis of OL (otolith length) and the ratio between OL and TL (total length), reported for the species in Tuset *et al.* (2008), it is possible to suggest that all the specimen of *G. cicerellus* found in the regurgitates analysed were about 4 cm in length. *G. cicerellus* (OF% = 0.92; mean content per regurgitate = 1.6 individuals). In one regurgitate, the head of a shrimp was found, while in another a bulk of organic matter was present (probably algae or jellyfish). These latter items were a minor component of the whole diet.

Table 1. Diving depths of European Storm Petrels. Minimum, maximum, mean and se are given. No significant differences between years were observed.

Year$_{(\text{sample size})}$	Minimum (cm)	Maximum (cm)	Mean (cm)	se (±cm)
2007$_{(5)}$	65	470	190	72
2008$_{(12)}$	26	513	120	38
2009$_{(16)}$	27	556	150	38

DISCUSSION

The recovery of capillary tubes deployed in this way on birds is a difficult task. As foraging trip length is variable, it is sometimes difficult to find the individuals with the tube attached. We also visited the colony every 3–5 days to reduce disturbance. Therefore, after three or four visits the probability of finding an adult with a capillary tube was very low, as tubes may also be lost during the foraging trips. Despite these problems, we recovered a good number of capillary tubes (30%), and these provided valuable information about the feeding trips and diving behaviour of this population of European Storm Petrels, a species thought to feed mainly on the surface (D'Elbee & Hemery 1998). The shortening of tube length and placement on rump feathers in comparison to the techniques used by Mougin & Mougin (2000) allowed an improvement in recovering rates and possibly implied lower impact on birds' flight capability.

As in other Storm Petrel species (Bried 2005), we found that *H. pelagicus melitensis* dives for its prey. Although there are no significant differences in diving depth between the three years probably due to small sample size, there was a large variation in these depths. The differences may be the effect of different sea-surface temperatures, forcing prey to move up and down in the water column (Hutchinson 1967). Many taxa of zooplankton perform diel vertical migrations with amplitudes from a few to 100 metres (Hutchinson 1967). The 'normal' pattern is an evening ascent and a morning descent, although several cases of 'reversed' migrations have been described (Ohman *et al.* 1983, Bayly 1986). Migrating animals spend the day in deep water, but stay near the surface at night, followed by fish predators. The amplitude of the movements and the shape of the vertical distribution of the population may be very different between species and between ontogenetic stages of the same species and may be influenced by factors like turbidity and food abundance (Bohrer 1980, George 1983). The *Gymnammodites cicerellus* is a pelagic fish species usually found in schools and in the upper 10 m of the water column (Bauchot 1987). Differences in diving depth in Mediterranean subspecies of European Storm Petrel may be a temporal adaptation to better exploit the resources present at the time of breeding.

The fact that we observed adults feeding immediately outside the cave during the night leads us to think they feed on different prey during diurnal and nocturnal foraging trips. When they first arrive adults carry material collected out in the open sea during the day. On subsequent trips, during the night, adults carry the material caught outside of the breeding grounds, which consist mainly of Mysidacea. In fact, as observed in video recordings, adults may feed an entire fish to the chick in the first feed of the night, and then make shorter foraging trips providing smaller quantities of food (C. Soldatini, unpubl. data) during subsequent visits. Mysidacea were not found in the regurgitates collected at first arrival of adults to the colony, leading us to think that this is a secondary prey as its abundance is lower, compared to the abundance of krill in Atlantic waters (Thiriot-Quievreux *et al*. 1998).

The diet of European Storm Petrels has now been determined for both the Atlantic (D'Elbee & Hemery 1998) and the Mediterranean populations (this paper). What we did not study for a Mediterranean colony was whether prey items differed by sex as suggested by Elliott *et al*. (2010). We did, however, determine diving depth of both, males and females and found no difference. It may either be that both sexes feed on the same prey, or each sex uses a different foraging area, therefore feeding on different prey.

The information presented in this paper is a first step toward determining the diet of this Mediterranean subspecies of European Storm Petrels. This information and further dietary analysis may help in determining some conservation management options for this population.

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