

## Estimating the population size of Scopoli's Shearwaters (*Calonectris diomedea*) frequenting the Strofades islands (Ionian Sea, western Greece) by raft counts and surveys of breeding pairs

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**Abstract.** The Strofades Island complex in the Ionian Sea comprises two small islands, i.e. Stamfani and Arpyia, and several rocks. The islands host a significant Scopoli's Shearwater (*Calonectris diomedea*) colony, which is regarded as the largest one in Greece, although no complete national population census has ever been carried out. Here we present data of the first complete survey of the species population in the area, evaluated via coastal counts of rafting birds at sea and nest surveys of occupied burrows. Both methodologies provided similar estimates. The maximum number of Scopoli's Shearwaters visiting the Strofades archipelago during the pre-laying period was estimated at 17,000-18,000 individuals, based on the maximum counts of 3,068 and 2,723 rafting individuals/km of suitable nesting coastline of Stamfani and Arpyia islands, respectively. The breeding population was censused by inspecting apparently occupied sites in 30 100 m<sup>2</sup> sampling units, randomly located along the coastal habitats of each island. Sampling was made over two habitat types of different quality for nesting. We estimated that a total of ca. 5,550 pairs breed on the two main islands, of which 64% were located on the larger Stamfani Island. The study reveals that the Strofades archipelago harbors the largest known Scopoli's Shearwater colony in the eastern Mediterranean.

**Key words:** Procellariiformes, seabirds, Mediterranean Sea, marine ecosystems, National Marine Park of Zakynthos.

### Introduction

The population size assessment of wild avifauna species on a global, national, and local scale is crucial for effective conservation. Information of trends and population sizes are used by the IUCN to assess the risk of extinction and by BirdLife International for EU "Bird Directive" (2009/147/EC) reporting about the status of conservation of species listed in the Annex I. Long-term population trends are also the basis for monitoring projects focusing either on protected areas or species of concern, and these data are used for establishing conservation priorities and defining Action Plans (Gregory et al. 2004, Massa 2006).

The Scopoli's Shearwater (*Calonectris diomedea* Scopoli, 1769) is a colonial pelagic seabird, recently recognised as endemic in the Mediterranean Sea (Sangster et al. 2012). Based on its taxonomic status, it is considered as of Least Concern (BirdLife International 2015) but a trend towards population decline has been observed at a local as

well as at a global scale (Igual et al. 2009, Sanz-Aguilar et al. 2011, Derhé, 2012). The species is potentially threatened by invasive mammalian predators such as black rats *Rattus rattus* (Igual et al. 2006, Pascal et al. 2008, Ruffino et al. 2009) and feral cats *Felis catus* (Karris unpubl.), by-catch incidental mortality in fishery gears (Belda & Sánchez 2001, García-Barcelona et al. 2010, Karris et al. 2013a, Báez et al. 2014), marine pollution (Ristow et al. 1992, Roscales et al. 2010, Roscales et al. 2011), accumulation of plastics (Codina-García et al. 2013), overfishing (Arcos 2001) and extreme large-scale climatic phenomena (Brichetti et al. 2000, Jenouvrier et al. 2009, Boano et al. 2010, Genovart et al. 2013). A population assessment for the species is required, though, before any Action Plan is produced or updated, particularly as the current size and trend of several national populations are still unclear or unknown (Derhé 2012). Therefore it is urgent to establish, improve, or enhance coordinated monitoring projects for the population status and trends of the species in the

Mediterranean Basin, especially in important colonies within its breeding range. Available data for population trends of Scopoli's Shearwater in the eastern Mediterranean are scarce, and this is particularly true for most Greek colonies, apart from one in the Aegean Sea, even though population estimates have not been updated (Ristow et al. 1991).

Procellariiform seabird species such as Scopoli's Shearwater exhibit a nocturnal behaviour forming huge flocks or "rafts" during dusk, just before coming ashore to their breeding sites at night; and during dawn, just after departing their breeding colonies. Studies using different telemetry tools have also indicated that shearwaters tend to form rafts close to the coastal cliffs where they breed or which they prospect for nesting sites (Furness et al. 2000, Wilson et al. 2008, Rubolini et al. 2015). This behaviour was also observed through GPS tracking of actively breeding Scopoli's Shearwaters on Stamfani Island as tracked birds formed rafts adjacent to their breeding sites (Karris 2014).

Nocturnal behaviour of burrowing seabirds which is assumed to be an avoidance adaptation strategy against invasive predators (Mougeot & Bretagnolle 2000, Keitt et al. 2004, Riou & Hamer 2008, Wilson et al. 2008), facilitates counting rafting birds from land (Furness et al. 2000). Raft counts are generally regarded as weakly accurate to estimate population sizes because the number of rafting birds varies markedly according to weather conditions, moon phases, the period of the breeding season, and other unidentified factors. Thus, counts of rafts are rarely used to estimate seabird population sizes. However, these counts are useful to identify seaward extensions of breeding colonies (Ramirez et al. 2008, Arcos et al. 2009, Wilson et al. 2009), and they can provide a rough estimate of the number of birds visiting breeding colonies.

Numerous studies on the breeding population size of burrowing seabirds have been carried out by assessing burrow density in sampling plots, and by estimating the total breeding population by extrapolation of the total nesting area. These studies have been based on Gilbert et al. (1998) who have suggested two methods for estimating breeding populations of burrowing nocturnal seabirds. Counting Apparently Occupied Sites / Burrows (AOSs) in sampling plots could be pursued a) by direct observations of nest occupancy or b) by stimulating acoustic responses from birds on

the burrows by using playback calls. The line-transect distance sampling method described by Buckland et al. (2001), constitutes an alternative methodological approach trying to estimate detection probability by modelling the latter as a function of the distance of the objects from the observer on the line-transect. This method is time consuming and it is used for areas where burrows are difficult to locate, e.g. in a terrain of dense vegetation and steep cliffs, as it was the case of the Scopoli's Shearwater colony situated on Zembra Island (Defos du Rau et al. 2015).

A seabird study on Strofades colony was initiated in 2007 aiming to evaluate the species' status, breeding biology, foraging behaviour and population ecology in the Ionian Sea (Karris et al. 2013b, Karris 2014). A further perspective was to enhance our knowledge on the Greek seabird populations and to gather the basic prerequisite information for an inventory of marine IBAs for Scopoli's Shearwater in Greece (Fric et al. 2012). The knowledge gained would subsequently contribute to the enhancement of the Natura 2000 network in the marine environment, a high priority conservation measure according to the European Commission (E.C. 2007). In this work we report the results of the first survey aiming to estimate the number of Scopoli's Shearwaters which use the Strofades islands, and the size of the species breeding population on these islands.

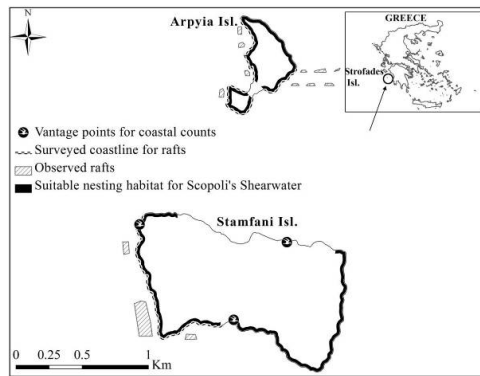
## Materials and Methods

### Study area

The Strofades islands (37° 15' N, 21° 00' E) constitute a remote group of two small and low islets (22 m -a.s.l.) and several rocks, lying in the Southern Ionian Sea, 32 n.m. south of Zakynthos island and 26 n.m. west of Peloponnese (Fig. 1). The two main islands (Stamfani and Arpyia) cover an area of 4 km<sup>2</sup>, with the former inhabited by a single monk in the last 40 years. The island group constitutes part of the National Marine Park of Zakynthos and is identified as a Wildlife Refuge and a Natura 2000 site (GR2210003), as well as a Site of Community Interest and a Special Protection Area, according to respective EU legislation (E.C. 2006, E.C. 2009). Additionally, Strofades have been recognized as an Important Bird Area (GR087) because of the presence of a putatively large Scopoli's Shearwater population (Portolou et al. 2009).

### Estimating population size

A pilot study during the breeding season of 2008 allowed for identification of the suitable coastline for nesting by Scopoli's Shearwaters on the major islets (Stamfani and Arpyia). The total population was estimated by censusing



**Figure 1.** Location of Strofades Islands, and Scopoli's Shearwater rafts during the pre-laying period.

rafts along defined sectors of coastline with suitable nesting habitat. As regards the count of rafting birds during the pre-laying phase, we used the methodology proposed by Furness et al. (2000) for the Atlantic population of a closely-related species, i.e. *Calonectris borealis*. This methodology was based on relevant studies which have assumed that rafts during the incubation period include a fixed proportion of non-breeders and individuals breeding in colonies, and that non-breeders in a shearwater population are equal to the number of breeders (Mougin & Stahl 1982, Skira 1991), though attendance cycles at the nesting colonies is still under debate (Granadeiro et al. 2009). However, in the present study we assumed that the proportion of non-breeders to breeders in rafts during the pre-laying phase exhibit the same ratio (1:1), since nests are not yet active and breeders do not visit them for chick provision.

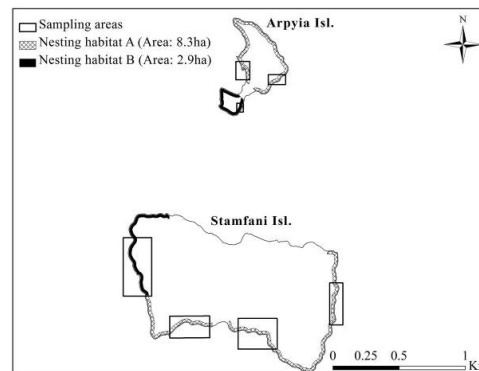
Fieldwork involved three teams of 2-3 observers working simultaneously during the pre-breeding period of 2009 and 2013, and more specifically from late April till early May, when both breeders and prospectors are present in the colony. The three observation points remained unchanged over the study years, permitting the survey of about 49.8% of the suitable nesting coastline of both islands (Fig. 1). Observations were carried out during the last couple of hours before sunset and when wind intensity was less than force 5 of the Beaufort scale. Positions of rafts were mapped and bird numbers were tallied with the aid of binoculars and 30-60x spotting scopes. We assumed that birds forming rafts along a particular sea area close to the islands (<1 km) constitute the breeders and prospecting individuals for the adjacent segment of the coastline. Based on this assumption, the density of rafting Scopoli's Shearwaters was calculated as the mean number of individuals per km of surveyed coastline.

In total, four observations based on coastal counts were undertaken from late April to early May in 2009, and in 2013 so as to assess the colony's population size. The vantage points on the NE, W and SW coast of Stamfani Island allowed the survey of rafts along defined sectors of suitable nesting habitats, using natural landmarks on both islands. Overall, we surveyed 1,548 m (41.8%) of

Stamfani coastal breeding habitat and 1,528 m (69.7%) of Arpyia coastal breeding habitat (Fig. 1).

#### Breeding population estimation

During a pilot study in early August 2008 we prospected all accessible areas of both islands trying to visit active nests and assign their geographical coordinates of their location. The survey of the breeding population of Strofades islands was based on direct assessing of AOSs, as the coastline of Strofades islands is generally accessible and can be exhaustively searched. Thus, it is possible to survey the entire coastal zone and to count shearwater burrows in the breeding habitats. The boundaries of the colony were also marked using GPS devices during the pilot study. On the two islands, more than 95% of the nests were found within a 20-m wide area only 5 m from the coastline. Two different nesting habitats were identified during the designation of colony boundaries, having as main criteria the density of possible nests (Fig. 2). The first (nesting habitat A) was characterized by a rocky coastline with maquis vegetation cover and very little bare soil, whereas the second (nesting habitat B) was characterized by a rocky coastline, with sparse shrub cover and bare soil suitable for excavation.



**Figure 2.** Location of sampling plots used to census Scopoli's Shearwater Apparently Occupied Sites (AOSs) on Strofades islands.

A team of 2-3 field workers checked nesting habitats with different burrow characteristics by using a burrowscope with a wide-angle CCD camera and 2 m extension cable, ensuring minimum bias in detection of occupied nests. Each nesting habitat was treated as a separate subcolony, and random sampling was followed for the selection of locations for the sampling units. This sampling method over different nesting habitats has been used to increase the accuracy of estimates regarding seabird abundance in a colony (Cuthbert & Sommer 2004). A rope was used to designate sampling units so as to count the number of occupied burrows within the area covered. Direct observations of breeders and/or nestlings but also fresh eggshells or abandoned eggs were used as signs for burrow occupancy, so as to include attempted breeding pairs that fail. Sampling plot coordinates, nesting habitat

type and the number of AOSs were entered in ArcGIS 9.3 (ESRI 2008) for spatial mapping and analysis.

Both islands were divided into five large coastal areas of suitable nesting habitat, following previous findings of the preliminary surveys of the pilot study (Fig. 2). In total, 30 square sampling units of 100 m<sup>2</sup> each were used, 15 per nesting habitat within the colony. Fieldwork was carried out during the breeding period of 2009, between late June to early August and from 16h00 to 19h30. This time schedule was more efficient for work, since egg laying had already taken place and breeders were still present attending their chicks. Additionally, by working during daytime, we avoided counting burrows occupied by prospecting birds which are mainly active during the night.

The mean number of AOSs per sampling plot in each habitat was used in order to obtain an estimation of the breeding population. More specifically, we multiplied mean density (AOSs/m<sup>2</sup>) by total area (in m<sup>2</sup>) of each suitable habitat type for burrow occupancy, and 95% confidence intervals were calculated taking into account uncertainty arising from variance in burrow density. SPSS (2008) was used for all statistical analyses.

## Results

### Raft counts

During 4 simultaneous raft counts we recorded a mean of 5,040 individuals (SD: 2,700) (Tables 1 & 2). Counts ranged from 1,570 to 4,750 individuals and 1,060 to 4,160 individuals around the Stamfani and Arpyia islands, respectively (Table 2). Based on the extent of coastline with suitable habitat surveyed (49.8%) and the mean raft counts, we estimated a total of 10,120 individuals frequenting the study area.

It is possible that the observed high variance of raft counts could be due to variable weather conditions during fieldwork. Wind intensity and sea swelling may influence visibility and, thus, the reliability of counts. We can assume that the most reliable count was made on 29 April 2013, when weather and sea conditions as well as moon phase were ideal, since the 28 and 29 April nights were the first with a dark window at beginning of the night after a couple of full-moon nights (Rubolini et al. 2015) (Table 1). During that day, we counted 8,910 individuals in rafts along the surveyed coastline, suggesting that 17,892 Scopoli's Shearwaters gathered in the study area. The density along the surveyed coastline was 3,068 inds/km along Stamfani Island, and 2,723 inds/km along Arpyia Island. Considering an equal ratio of breeders to non-breeders, we estimate that the rafts around the Strofades islands included 4,473 breeding pairs

and 8,946 non-breeders.

### Breeding pair counts

Suitable nesting habitat was estimated at 112,439 m<sup>2</sup> (64.20% in Stamfani Island and 35.80% in Arpyia Island). Nesting habitat A was the dominant one, covering an area of 53,617 m<sup>2</sup> and 29,720 m<sup>2</sup> in the Stamfani and the Arpyia islands, meanwhile relevant figures for nesting habitat B were 18,569 m<sup>2</sup> and 10,533 m<sup>2</sup>, respectively. In the 30 (100 m<sup>2</sup>) sampling plots we surveyed, we recorded 161 breeding pairs, with the number of AOSs varying between 1 and 15 per plot (Fig. 3). Overall burrow density was higher in nesting habitat B compared to in nesting habitat A (Table 3), though this difference was not statistically significant (Mann-Whitney U test,  $p = 0.148$ ).

Considering the average nest density over the sample plots and the amount of suitable nesting habitat, the total breeding population was estimated at ca. 5,550 pairs [95% C.I.: 3,463 - 7,626], of which 3,561 breeding pairs [95% C.I.: 2,220 - 4,894] on the Stamfani Island and 1,989 breeding pairs [95% C.I.: 1,242 - 2,732] on the Arpyia Island, respectively (Table 4).

## Discussion

Seabirds are increasingly viewed as important bio-indicators of marine ecosystems that may be useful in assessing the impacts of global climate change on marine biota (Parsons et al. 2008, Mesquita et al. 2015). Consequently, these top marine predators are used as key species in conservation and management planning (Schreiber 2002, Schreiber & Burger 2002, Sandvik & Erikstad 2008). Additionally, both the inner Ionian Sea and the eastern Aegean Sea constitute two out of the top 10 priority areas of the Mediterranean Sea for conservation of marine habitats (Micheli et al. 2013). However, studies on seabird abundance in Greece are scarce, and adequate information about seabird populations and their trends at local and national levels is generally lacking, with the exception of some recent works (Fric et al. 2012, Zakkak et al. 2013).

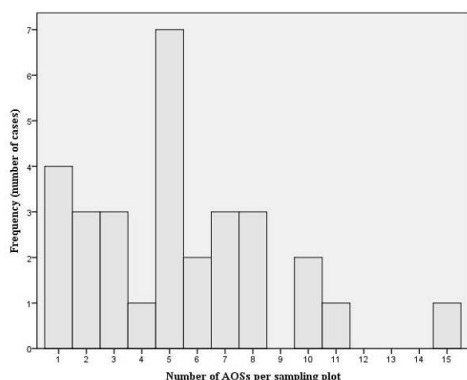
Selecting the most suitable method for quantifying population size of colonial burrow-nesting seabirds is a difficult and debated task, since an inappropriate survey method would bias estimates. It is generally accepted that confidence intervals of seabird population estimations increase

**Table 1.** General information of raft counts of Scopoli's Shearwaters on Strofades colony. Wind condition: intensity (Beaufort scale) and direction, Moon: moon phase and moonrise time, Tdis: temporal distance (days) to the mean laying period of the season during which the survey was carried out.

Date of raft counts	Scopoli's Shearwater individuals		Wind condition		Moon		Tdis
	Total	Intensity (Beaufort scale)	Direction	Phase	Moonrise time	Days	
4 May 2009	2,630	3-4	NW	Waxing gibbous	15:54	29	
27 April 2013	4,190	2	S	Waning gibbous	22:30	39	
28 April 2013	4,430	2-3	S	Waning gibbous	23:34	40	
29 April 2013	8,910	1-2	S	Waning gibbous	00:32	41	

**Table 2.** Raft counts (n=4) of Scopoli's Shearwater on Strofades Islands during the pre-breeding periods of 2009 and 2013.

	Suitable coastline for nesting		Raft counts		Scopoli's Shearwater individuals			
	Total length (m)	Surveyed for rafts (m) (%)	n	Mean (SD)	Minimum	Maximum	Total no. (100% of suitable coastline)	
Stamfani Island	3,702	1,548 (41.8%)	4	3,018 (1,310)	1,570	4,750	7,219	
Arpyia Island	2,192	1,528 (69.7%)	4	2,023 (1,436)	1,060	4,160	2,901	
Strofades Islands	5,894	3,076 (49.8%)	4	5,040 (2,700)	2,630	8,910	10,120	



**Figure 3.** Distribution frequency of Scopoli's Shearwater Apparently Occupied Sites (AOSs) per sampling plot on Strofades colony.

with decreasing survey effort (Schumann et al. 2013). On the other hand, it is often impractical and costly to apply extensive surveys in order to conduct a seabird population census given their usually remote and difficult to access colonies. Therefore a trade-off between cost and acceptable

levels of accuracy is necessary. Our censuses of rafting birds and of AOSs resulted in similar estimates of the Scopoli's Shearwater breeding population size on Strofades islands.

Our data confirm that this remote insular area of the southern Ionian Sea hosts the largest known breeding colony of Scopoli's Shearwater in the eastern Mediterranean. According to the survey of AOSs, Strofades islands host ca. 5,550 pairs of Scopoli's Shearwater, representing 50-60% of its total breeding population in Greece (Table 5). Taking into account the new population estimate on Strofades islands, the total breeding population of Greece is now estimated at ca. 8,000-11,000 pairs, representing the 3% of the known global population. It should be mentioned that population increase reported here might be influenced by the increased census efforts, compared to earlier studies.

Other authors have found that the presence of steep cliffs is associated with species density (Furness et al. 2000, Granadeiro et al. 2006); nevertheless Strofades islands are generally flat, so that no significant effect of nesting habitat type was

**Table 3.** Number of Scopoli's Shearwater Apparently Occupied Sites (AOSs) censused in each habitat on Strofades Islands (95% C.I.).

Habitat Type	n	AOSs Mean (SD) [95% C.I.]	Minimum	Maximum
Crevice and burrows with maquis vegetation (Habitat A)	15	4.47 (3.40) [2.58 - 6.35]	1	11
Crevice and burrows with maquis vegetation and bare soil (Habitat B)	15	6.27 (3.17) [4.51-8.02]	2	15

**Table 4.** Estimation of Scopoli's Shearwater Apparently Occupied Sites (AOSs) per habitat type and number of breeding pairs per island of Strofades island complex (95% C.I.).

	Habitat A			Habitat B			Total
	Suitable nesting area (m <sup>2</sup> )	AOSs /100m <sup>2</sup> [95% C.I.]	No of pairs [95% C.I.]	Suitable nesting habitat (m <sup>2</sup> )	AOSs /100m <sup>2</sup> [95% C.I.]	No of pairs [95% C.I.]	No of pairs [95% C.I.]
Stamfani Isl.	53,617	4.47 [2.58 - 6.35]	2,397 [1,383 - 3,405]	18,569	6.27 [4.51 - 8.02]	1,164 [837 - 1,489]	3,561 [2,220 - 4,894]
Arpyia Isl.	29,720	4.47 [2.58 - 6.35]	1,329 [767 - 1,887]	10,533	6.27 [4.51 - 8.02]	660 [475 - 845]	1,989 [1,242 - 2,732]
Strofades Islands	83,337	4.47 [2.58 - 6.35]	3,725 [2,150 - 5,292]	29,102	6.27 [4.51 - 8.02]	1,825 [1,313 - 2,334]	5,550 [3,463 - 7,626]

**Table 5.** Population estimates of Scopoli's Shearwater in Mediterranean basin, Greece and Strofades Islands.

Area	Population	Reference
Mediterranean breeding population (pairs)	141,000-223,000	Defos du Rau et al. (2015)
	142,478-222,886	Derhé (2012)
	50,000	BirdLife International (2004)
	60,000-80,000	Thibault (1993), Zotier et al. (1999)
Breeding population of Greece (pairs)	8,000-11,000	this study
	5,200 - 8,300	Fric et al. (2012), Derhé (2012)
	5,000	BirdLife International (2004)
Breeding population of Strofades Islands (pairs)	5,550	this study
	2,000-3,000	Fric et al. (2012)
Total population of Strofades Islands (individuals)	17,000-18,000	this study
	5,000-8,000	Portolou et al. (2009)

found. The slight difference in burrow density between the two habitats may be attributed to the existence of soft soil for excavation and (to a lesser extent) to vegetation cover which might impede access to suitable nest sites. Additionally, results of raft counts were comparable to those achieved by counting AOSs and could be used as complementary data, even though this methodology is sensitive to weather conditions and survey.

Micheli et al. (2013) have recently recognized the urgent need for initial information-based plans for the southern and eastern Mediterranean as a prerequisite for a holistic approach regarding regional conservation planning. Thus, it is of vital importance to continue monitoring the Scopoli's Shearwater population on Strofades islands, in view of the fact that this remote Ionian colony hosts more than 50% of the Greek population. Establishing a long term monitoring scheme for the population of Strofades islands is also important as Scopoli's Shearwater can be susceptible to over-fishing and by-catch mortality around Zakynthos Island and western Peloponnese, suffering large declines mostly due to bottom long-line fishery (Karris et al. 2013a, Karris 2014). Feeding associations with fishery industry appear to play a key role in the population dynamic of Scopoli's Shearwater colony on Strofades, and therefore conservation issues in the southern Ionian marine

ecosystem need to be approached at a broader scale (Issaris et al. 2012).

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