Figure 5. Post-breeding, roosting Mediterranean Shags *Phalacrocorax aristotelis desmarestii*, March 2006, Cabrera National Park. The breeding season in the Balearic Islands starts in November and the first fledged birds can be seen in January–February. *P. a. desmarestii* has feet with yellow webs, and a longer and more slender bill than *P. a. aristotelis*. In the photo are two adults, four fledged juveniles and three second calendar-year immatures (the head popping out on the top could belong to a 1Y or 2Y). Juveniles show a whitish throat, breast and belly. Second calendar-year birds (e.g. the bird on the far right) have pale abraded wing coverts, showing as a pale wing panel. First-year birds have fresher, darker coverts and a less noticeable pale wing panel (second bird from the right). © *Miguel McMinn*.

Summer diet of European Shags *Phalacrocorax aristotelis desmarestii* in southern Mallorca

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Abstract

Analysis of pellets of European Shags *Phalacrocorax aristotelis desmarestii* collected at a non-breeding roost site in southern Mallorca identified 36 species of fish prey, belonging to 27 genera and to 16 families. This diversity is higher than in the diet of *P. a. aristotelis* in the Atlantic, and higher than in the previous literature for *P. a. desmarestii* in the Mediterranean. European Shags in southern Mallorca foraged mainly on fishes with a mean estimated length of 11.6 cm (84.1% ranging from 6.1–15.0 cm in estimated length), most being pelagic species (59.6 %). The most

important fish in numerical frequency (43.9%) and estimated biomass (37.2%) was the Bogue *Boops boops* (Sparidae). This species has not been reported in European Shag diet in the Atlantic, and its importance was low in other *Ph. a. desmarestii* populations studied. The second most frequent prey was sand smelt *Atherina* (15%), but its contribution to biomass was low (1.4% of estimated biomass) because of its small size, as has been reported from other Mediterranean locations. The occurence of Scorpaenidae (10.7% by frequency, 17.4% of estimated biomass) was higher than in previous studies of *Ph. a. desmarestii*. Scorpaenids have not been found in the diet of *Ph. a. aristotelis*. Sandeels (Ammodytidae), a key prey for *Ph. a. aristotelis* in the Atlantic, were very scarce in this study, as in other recent Mediterranean studies. The relative abundance of species anatomically well protected against predation, such as scorpaenids and trachinids, and the diversity of prey probably reflects the scarcity or absence of other preferred prey. This study reflects the opportunistic behaviour of European Shags in the Mediterranean Sea, foraging on fish with very different ecological requirements, in an environment that is poor but diverse.

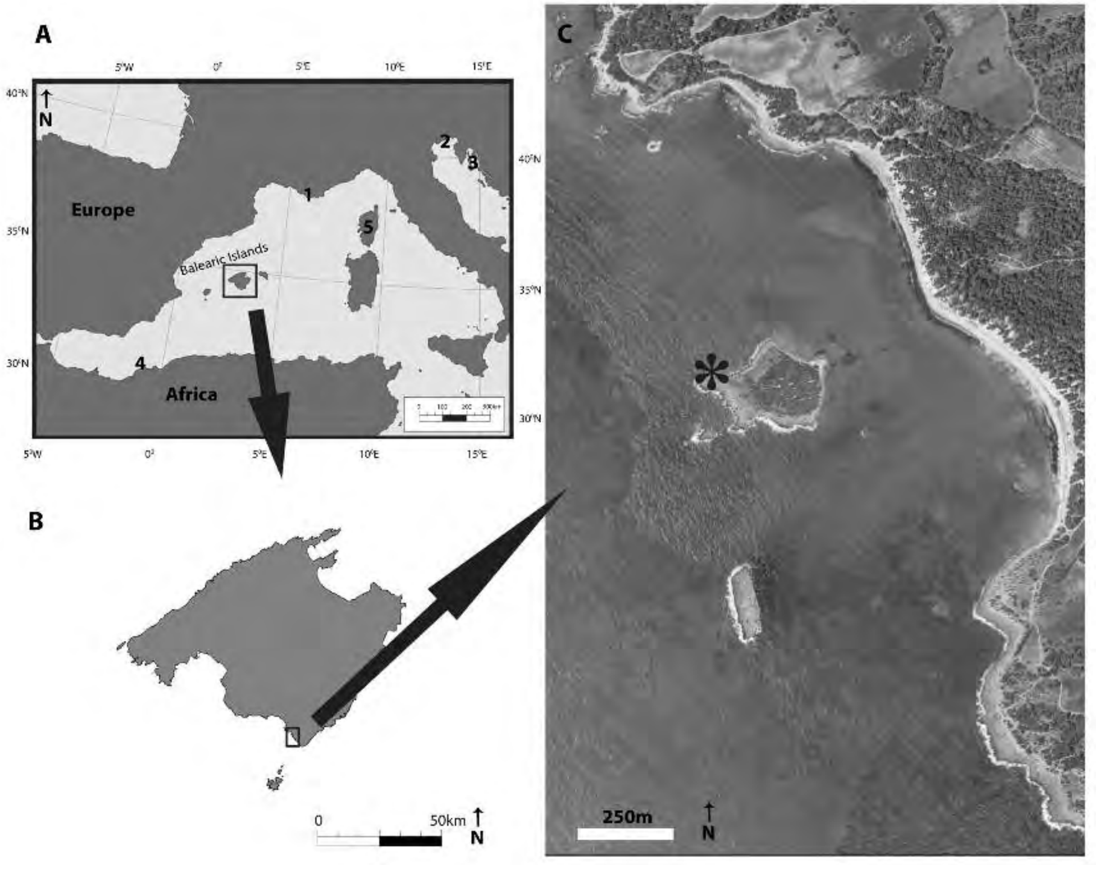

Figure 1. The location of the Na Moltona study site in Mallorca. The locations of previous European Shag *Phalacrocorax aristotelis desmarestii* dietary studies in the Mediterranean Sea are shown upper-left: 1. Archipelago of Riou (Morat 2007; Morat *et al*. 2011); 2. Gulf of Trieste (Cosolo *et al*. 2011); 3. Losinj Archipelago (Cosolo *et al*. 2011); 4. Habibas Islands (Morat 2007); 5. Corsica (Guyot 1985).

Introduction

The European Shag *Phalacrocorax aristotelis* is distributed along the coasts of the Western Palaearctic with three subspecies recognised: *Ph. a. aristotelis*, with 66–73,000 pairs breeding along Atlantic coasts from the Kola Peninsula in Russia to southern Portugal (Wanless & Harris 2004); *Ph. a. riggenbachi* in south-western Morocco; and *Ph. a. desmarestii*, which is endemic to the Mediterranean, from the Iberian Peninsula to the Black Sea, with an overall breeding population estimated at between 3,000 (Velando & Munilla 2008) and 10,000 (Muntaner & Mayol 2007) pairs. *Ph. a. riggenbachi* and *Ph .a. desmarestii* are morphologically smaller than the nominal subspecies, having a smaller crest, and a brighter yellow coloration at the basis of the bill. However, differences between the subspecies are slight, and their taxonomic separation has not been evaluated genetically.

The European Shag is a coastal feeding seabird, showing a strong preference for rocky coasts and small islands with clear, shallow waters over sandy or rocky seabeds (del Hoyo *et al*. 1992). Birds mainly feed on fish, with a few species dominating the diet, and within a foraging range of up to 20 km around their breeding and roosting sites (Wanless *et al*. 1991; Velando 1997). Although almost exclusively piscivorous, small numbers of polychaetes, cephalopods, other molluscs and small benthic crustaceans have been reported in the diet (e.g. Barrett *et al*. 1990; Velando & Freire 1999; Hillersøy 2011). Prey-items taken can differ spatially, even between neighbouring colonies (Velando & Freire 1999), or seasonally, between the breeding season and the rest of the year (Lilliendahl & Solmundsson 2006), depending on availability, suggesting opportunistic foraging behaviour (Barrett 1991).

There is abundant literature on the diet of Atlantic/North European Shags. With exception of the northernmost latitudes where gadoids are often their main prey (Barrett *et al*. 1990; Hillersøy 2011), different species of sandeels (Ammodytidae) are usually, but not always (Fortin *et al*. 2013), the main food source for *Ph. a. aristotelis* (Steven 1933; Lack 1945; Lumsden & Haddow 1946; Snow 1960; Pearson 1968; Harris & Wanless 1991, 1993; Velando & Freire 1999; Furness & Tasker 2000; Pennington *et al*. 2004; Lilliendahl & Solmundsson 2006). However, fewer dietary studies have been performed in the Mediterranean Sea, where the diet seems to be much more varied, especially during the breeding season, with some fish families such as Atherinidae, Labridae, Sparidae or Gobiidae playing an important role as prey items (Araujo *et al*. 1977; Guyot 1985; Morat 2007; Cosolo *et al*. 2011; Morat *et al*. 2011).

The Balearic Islands hold one of the most important populations of *Ph. a. desmarestii* (hereafter 'Mediterranean Shag'). Censuses carried out on Menorca, Eivissa and Formentera in 2005, and on Mallorca and Cabrera in 2006, estimated their populations at 1,800 breeding pairs, 95% of the Spanish population for this subspecies, and 18% of its world population (after Muntaner & Mayol 2007); a further census in 2006 and 2007 estimated 2,017 breeding pairs (Álvarez & Velando 2007). It has been suggested that the Balearic Islands could be a source region for individuals dispersing to other areas (García *et al*. 2011). Despite the importance of this area, the only information on their diet in the Balearic Islands comes from stomach contents analysis of eight specimens, with 16 individual fish identified, and several prawns (Araujo *et al*. 1977). Shags regurgitate pellets containing fish bones, otoliths and scales, small invertebrates, marine vegetation and even small stones. Although several authors (Ainley *et al*. 1981; Duffy & Laurenson 1983; Johnstone *et al*. 1990) estimated that pellets were regurgitated at least once a day, Russell *et al*. (1995) obtained a mean production of one pellet every four days for birds in the wild. Here, we present diet data inferred from an analysis of pellets from Mediterranean Shags collected on an islet off southern Mallorca (Balearic Islands). This information contributes to our knowledge of the diet of this species in the Mediterranean Sea.

Methods

Mediterranean Shags breed during the winter months and in this study pellets were collected during the non-breeding period, in a single visit on 3 July 2009 to Na Moltona, a small islet in southern Mallorca. Pellets were produced by adult and juvenile Shags, and the proportion belonging to each age-group was unknown. Na Moltona is used as a post-breeding roosting site by Shags from colonies on (mostly) Cabrera and Mallorca that feed in the channel between the two islands (Figure 1). They use the islet when sea conditions are not very favourable in the open sea around Cabrera, but better close to the Mallorcan coast. We collected a total of 60 pellets, of which at least eight were incomplete. Dislodged parts of the 60 pellets were also collected and analysed to avoid information loss, and all pellets were stored frozen until analysis. Once taken out of the freezer, each pellet was soaked in a solution of water and commercial washing powder for 24–48 h to separate its content. Bones and otoliths were separated from the remaining mucus layer and other soft tissues by precipitation, and rinsed through a sieve (1 mm). Remains of a few crustaceans, such as two small crabs and some legs of prawns, were also found, but they were not included in our study as they could have belonged to fish stomach contents. After drying, the content of each pellet was labelled and packed for subsequent identification.

Initially, two approaches were performed for the analysis of the diet: 1) identification of bones and teeth (pharyngeal, mandibular and premaxillar), and 2) identification of otoliths (Figure 2). Both methods fitted well with each other for prey classification. However, otoliths have highly diagnostic characters (Tuset *et al*. 2008), show lower digestibility, and permit the identification of a larger number of prey items (c. 800 specimens) than bones (c. 200 specimens). Results presented here are therefore derived from otolith identification only. In comparison with other sampling methods, such as analysis of stomach contents or direct observation of foraging activity, pellet analysis is a relatively easy method, allowing the collection of a large number of samples, and involving little or no disturbance to the birds. Nevertheless, the method is not free of biases. At least five sources of error have been highlighted for the assessment of diet through pellet analyses (Carss *et al*. 1997). Thus, our work should be only considered as indicative of the diet of the Mediterranean Shag in Mallorca.

Table 1. Parameters of the relationships between Otolith Length (OL) and Fish Length (FL) and between Fish Length and Fish Weight (FW), established for the fish species found within pellets of the European Shag *Phalacrocorax aristotelis desmarestii* at Na Moltona, Southern Mallorca.

	OL versus FL parameters FL= a + b*OL					**FL versus FW parameters** FW = a * FLb				
Species	**a**	**b**	**n**	**R^2**	**Source**	**a**	**b**	**n**	**R^2**	**Source**
Arnoglossus imperialis [1]	NA	NA	NA	NA	Fishbase.org	0.0045	3.17	17	0.946	Fishbase.org [2]
Atherina boyeri	38.848	14.295	5	0.869	AFORO	0.004168	3.15	426	0.95	Leonardos & Sinis 2000 [15]
Blenniidae unidentified [3]	-58.145	77.657	8	0.883	AFORO	0.0168	2.91	30	0.9801	Merella *et al.* 1997 [2]
Blennius ocellaris	-58.145	77.657	8	0.883	AFORO	0.0168	2.91	30	0.9801	Merella *et al.* 1997 [2]
Boops boops	35.649	28.111	10	0.838	AFORO	0.0119	2.8554	228	0.986	Morey *et al.* 2003 [4]
Chromis chromis	-27.472	28.450	5	0.978	AFORO	0.0189	2.93	369.00	0.935	Morey *et al.* 2003 [4]
Citharus linguatula	-33.120	41.599	10	0.959	AFORO	0.003	3.3	50	0.9604	Merella *et al.* 1997 [2]
Coris julis	-58.289	76.785	7	0.970	AFORO	0.007	3.0462	473	0.976	Morey *et al.* 2003 [4]
Dicentrarchus labrax	-96.743	38.856	9	0.960	AFORO	0.0051	3.1589	14	0.992	Morey *et al.* 2003 [4]
Diplodus annularis	-30.716	35.522	10	0.974	AFORO	0.0115	3.1668	848	0.972	Morey *et al.* 2003 [4]
Diplodus puntazzo	-192.040	66.786	6	0.941	AFORO	0.026	2.8188	43	0.988	Morey *et al.* 2003 [4]
Diplodus sargus	-81.474	47.432	11	0.821	AFORO	0.0114	3.1317	75	0.989	Morey *et al.* 2003 [4]
***Diplodus* sp.** [5]	NA	NA	NA	NA	NA					
Diplodus vulgaris	-82.594	45.758	13	0.940	AFORO	0.0149	3.0058	328	0.997	Morey *et al.* 2003 [4]
Gobiidae unidentified [6]	NA	NA	NA	NA	NA					
Gobius bucchichi [7]	NA	NA	NA	NA	Fishbase.org	0.011	3.192	21	0.996	Fishbase.org
Gobius cruentatus	-16.984	30.598	6	0.982	AFORO	0.0044	3.4108	49	0.994	Morey *et al.* 2003 [4]
Gobius paganellus [7]	NA	NA	NA	NA	Fishbase.org	0.011	3.192	21	0.996	Fishbase.org
Gymnammodytes semisquamatus	67.614	26.498	6	0.079	AFORO	0.0006	3.476	23	NA	Fishbase.org [8]
Labrus merula	-88.272	88.473	7	0.885	AFORO	0.0076	3.1862	124	0.959	Morey *et al.* 2003 [4]
Labrus viridis	-17.920	62.707	6	0.984	AFORO	0.058	3.2216	63	0.97	Morey *et al.* 2003 [4]
Lithognathus mormyrus	-69.445	44.440	7	0.959	AFORO	0.0102	3.0327	441	0.986	Morey *et al.* 2003 [4]
Merluccius merluccius	-16.876	24.826	16	0.986	AFORO	0.0048	3.055	96	0.924	Morey *et al.* 2003 [4]
Oblada melanura	-140.770	48.219	6	0.928	AFORO	0.024	3.567	25	0.984	Fishbase.org [9]
Pagellus erythrinus	-32.382	33.048	9	0.924	AFORO	0.0164	2.8936	58	0.983	Morey *et al.* 2003 [4]
***Parablennius* spp.** [10]	-0.503	47.615	3	0.590	NA	0.012	2.769	27	0.97	Fishbase.org [4]

Parablennius tentacularis	-0.503	47.615	3	0.590	AFORO	0.012	2.769	27	0.97	Fishbase.org [4]
Paralipophrys trigloides [11]	-7.440	59.982	3	0.897	AFORO					Nieder *et al.* 1994 [4]
Sarpa salpa	-86.983	50.915	6	0.957	AFORO	0.0323	2.7004	79	0.966	Morey *et al.* 2003 [4]
Scorpaena notata	2.328	18.692	12	0.964	AFORO	0.016	3.0384	83	0.988	Morey *et al.* 2003 [4]
Scorpaena porcus	-123.630	40.034	9	0.713	AFORO	0.0183	3.0202	980	0.969	Morey *et al.* 2003 [4]
Scorpaena scrofa	-44.830	26.693	9	0.982	AFORO	0.022	2.9418	359	0.981	Morey *et al.* 2003 [4]
***Scorpaena* sp.** [12]	NA	NA	NA	NA	NA					
Serranus cabrilla	-25.114	29.757	10	0.927	AFORO	0.0092	3.0658	298	0.978	Morey *et al.* 2003 [4]
Serranus hepatus	-13.121	24.559	9	0.983	AFORO	0.0044	3.5681	22	0.928	Morey *et al.* 2003 [4]
Sparus aurata	-169.500	56.697	9	0.973	AFORO	0.0053	3.2393	14	0.978	Morey *et al.* 2003 [4]
Spicara smaris	36.095	21.966	6	0.955	AFORO	0.0113	2.8696	52	0.982	Morey *et al.* 2003 [4]
Spondyliosoma cantharus	-80.069	38.841	9	0.925	AFORO	0.0158	2.9957	86	0.994	Morey *et al.* 2003 [4]
Symphodus mediterraneus	7.971	41.117	6	0.960	AFORO	0.0123	3.0653	214	0.988	Morey *et al.* 2003 [4]
***Symphodus* spp.** [13]	NA	NA	NA	NA	NA					
Synapturichthys kleinii	AFORO	-52.510	86.603	3	0.961	0.058	2.724	34	0.889	Fishbase.org [14]
Trachinus draco	AFORO	-44.429	30.966	8	0.829	0.0101	2.8354	27	0.989	Morey *et al.* 2003 [4]

NA not available.
1 Only the FL mean value was available (N=17, R2= 0,946).
2 From Balearic Islands specimens.
3 *Blennius ocellaris* parameters from AFORO and Merella *et al*. 1997 used.
4 From Spanish Mediterranean coast specimens.
5 FW calculated as the mean weight of all the *Diplodus sp*. classified to species level.
6 FW calculated as the mean weight of all the *Gobius sp*. classified to species level.
7 FL as mean value of FL for *G. paganellus* in Mar Menor (Fishbase.org).
8 From UK specimens.
9 From Turkish (Gökceada Island) specimens.
10 *Parablennius tentacularis* parameters from Fishbase.org used for FL.
11 Mean weight from Nieder *et al*. 1994 used.
12 FW calculated as the mean weight of all the *Scorpaena sp*. classified at species level.
13 FW calculated as the mean weight of *S. mediterraneus*.
14 From Croatian specimens.
15 From Greek specimens.

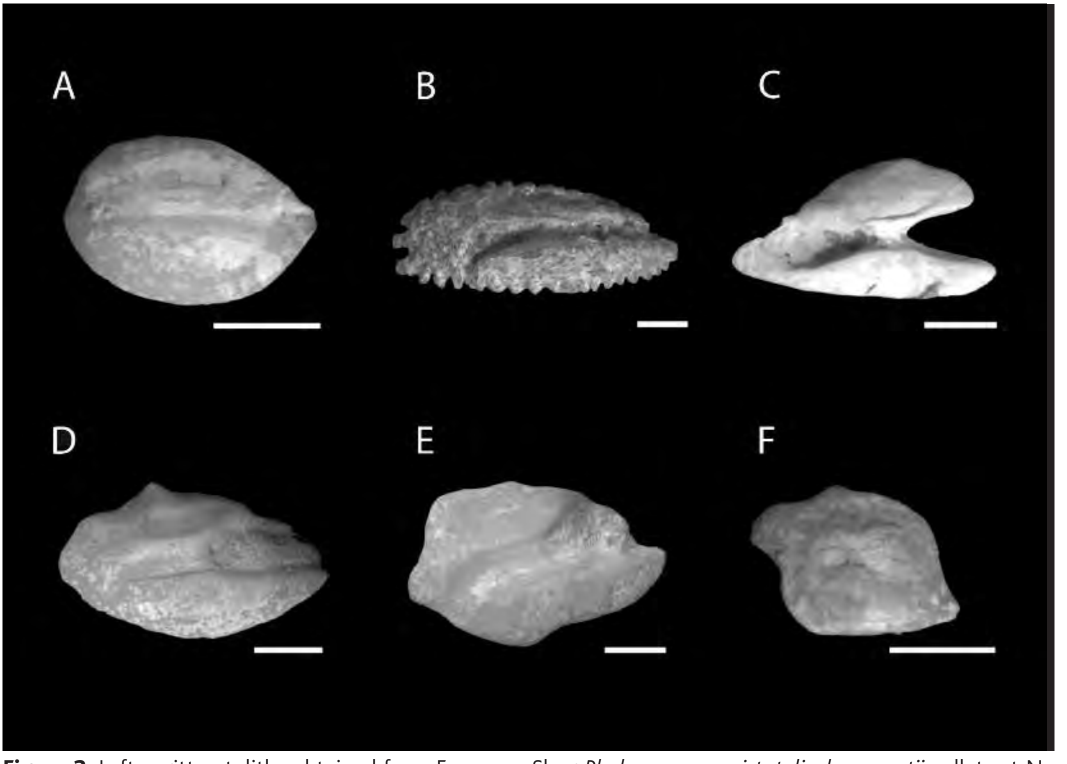

Figure 2. Left sagitta otoliths obtained from European Shag *Phalacrocorax aristotelis desmarestii* pellets at Na Moltona, Mallorca. A. *Atherina sp*. B. *Scorpaena porcus*. C. *Labrus merula*. D. *Boops boops*. E. *Diplodus vulgaris*. F. *Gobius bucchichi*. Scalebars = 1 mm.

Otoliths were identified to species or genus level at the Institute of Marine Sciences (ICM) in Barcelona, distinguishing their right or left sides. The most numerous side was used to calculate the minimum number of individuals of each fish species in each pellet. Otoliths were measured with the software ImageJ on the images obtained using a Marlin® b/w camera, adapted to a stereomicroscope Leica® MZ160. Regression equations were used to estimate fish length from otolith length with the AFORO database (http://www.cmima.csic.es/aforo/; Lombarte *et al*. 2006) for the species available on it (Table 1, left) whilst relationships between fish estimated length and fish estimated weight were obtained from the literature, using almost exclusively studies of Mediterranean fish populations (Table 1, right). When otoliths were only identified to genus or family level, we used the average weight of all the preyed specimens of the genus (or family) that were identified to species. An arbitrary size was applied to Gobiinae (length 5.6 cm, mass 2.7 g, based on average size for *Gobius paganellus* from Mar Menor, Murcia, Spain; *Fishbase.org*), when adequate otolith/size relationships were not available.

In order to address the ecological significance of Shag feeding behaviour, prey items were classified according to their habitat preferences in three categories (benthic, demersal and pelagic) and seven arbitrary size classes.

Results

A total of 808 otoliths were obtained, of which 68 were too eroded to be identified. Of the remaining 740, 730 were identified to species and 10 to genus level (Table 2). A total of 36 different fish species were identified, belonging to 27 different genera and to 16 families. The most numerous fish species was the Bogue *Boops boops* (43.9%) followed by sand-smelts (*Atherina*) (15.0%), *Scorpaena porcus* (6.1%), *Diplodus sargus* (4.5%), *S. notata* (3.5%), *Serranus hepatus* (3.0%), *Lithognathus mormynus* (3.0%), *D. vulgaris* (2.8%), *Coris julis* (2.0%), *Spicara smaris* (1.9%), *Trachinus draco* (1.8%), and *D. annularis* (1.5%). The remaining 24 individual species accounted each for < 1% of diet composition.

The most common genera were *Boops* (43.9%), followed by *Atherina* (15.0%), *Scorpaena* (10.7%), *Diplodus* (10.1%), *Serranus* (3.1%), *Lithognathus* (3.0%), *Coris* (2.0%), *Spicara* (1.9%), *Trachinus* (1.8%) and *Gobius* (1.2%). The most represented families were Sparidae (58.9%), followed by Atherinidae (15.0%) and Scorpaenidae (10.7%).

In terms of estimated biomass, 64.7% of all prey belonged to Sparidae. Scorpaenidae was also well represented, comprising 17.4% of the estimated total mass of the sample studied. Other, less represented families were Labridae (9.8%), Trachinidae (2.3%), Atherinidae (1.4%), and Centracanthidae (1.3%). All remaining families each accounted for < 1% of estimated total diet mass. At a lower taxonomic level, five species belonging to the three most important families in terms of estimated biomass represented up to 75% of total diet mass: Bogue (37.2%), *Scorpaena porcus* (12.7%), *Diplodus sargus* (12.6%), *Labrus merula* (6.3%), and *Lithognathus mormyrus* (6.0%).

Table 2. Number of otoliths (individuals), frequency, estimated biomass (g), and percentage in estimated biomass of the fish species found in pellets of European Shag *Phalacrocorax aristotelis desmarestii* at Na Moltona, Southern Mallorca.

FAMILY	SPECIES	Otoliths		Estimated biomass	
		N	%	g	%
Sparidae	*Boops boops*	325	43.9	6,134	37.2
	Diplodus annularis	11	1.5	308	1.9
	Diplodus sargus	33	4.5	2,069	12.6
	Diplodus vulgaris	21	2.8	415	2.5
	Diplodus puntazzo	3	0.4	251	1.5
	Diplodus sp.	7	0.9	313	1.9
	Lithognathus mormynus	22	3.0	988	6.0
	Oblada melanura	4	0.5	10	0.1
	Pagellus erythrinus	1	0.1	28	0.2
	Sarpa salpa	2	0.3	100	0.6
	Sparus aurata	1	0.1	33	0.2
	Spondyliosoma cantharus	6	0.8	19	0.1
	Total Sparidae	**436**	**58.9**	**10,688**	**64.7**

Scorpaenidae	*Scorpaena notata*	26	3.5	514	3.1
	Scorpaena porcus	45	6.1	2,098	12.7
	Scorpaena scrofa	7	0.9	213	1.3
	Scorpaena sp.	1	0.1	36	0.2
	Total Scorpaenidae	**79**	**10.7**	**2,861**	**17.4**
Labridae	*Labrus merula*	6	0.8	1,030	6.3
	Labrus viridis	1	0.1	279	1.7
	Coris julis	15	2.0	231	1.4
	Symphodus mediterraneus	6	0.8	61	0.4
	Symphodus sp.	1	0.1	10	0.1
	Total Labridae	**29**	**3.9**	**1,611**	**9.8**
Trachinidae	*Trachinus draco*	**13**	**1.8**	**378**	**2.3**
Atherinidae	*Atherina* sp.	**111**	**15.0**	**233**	**1.4**
Centracanthidae	*Spicara smaris*	**14**	**1.9**	**221**	**1.3**
Blenniidae	*Blennius ocellaris*	2	0.3	73	0.4
	Parablennius tentacularis	1	0.1	5	0.0
	Parablennius spp.	1	0.1	5	0.0
	Paralipophrys trigloides	1	0.1	5	0.0
	Blenniidae unidentified	4	0.5	48	0.3
	Total Blenniidae	**9**	**1.2**	**137**	**0.8**
Serranidae	*Serranus cabrilla*	1	0.1	14	0.1
	Serranus hepatus	22	3.0	121	0.7
	Total Serranidae	**23**	**3.1**	**135**	**0.8**
Pomacentridae	*Chromis chromis*	**5**	**0.7**	**51**	**0.3**
Citharidae	*Citharus linguatula*	**4**	**0.5**	**50**	**0.3**
Soleidae	*Synapturichthys kleini*	**2**	**0.3**	**48**	**0.3**
Gobiidae	*Gobius paganellus*	3	0.4	8	0.0
	Gobius bucchichi	4	0.5	11	0.1
	Gobius cruentatus	1	0.1	13	0.1
	Gobiidae (not identified)	1	0.1	6	0.0
	Total Gobiidae	**9**	**1.2**	**38**	**0.2**
Ammodytidae	*Gymnammodytes semisquamatus*	**2**	**0.3**	**22**	**0.1**
Merlucciidae	*Merluccius merluccius*	**1**	**0.1**	**11**	**0.1**
Bothidae	*Arnoglossus imperialis*	**1**	**0.1**	**9**	**0.1**
Moronidae	*Dicentrarchus labrax*	2	0.3	1	0.0
	Not identified or broken	68			
Total		**808**	**100.0**	**16,477**	**100.0**

Fish species recorded in the diet were mostly pelagic (59.6% of the total), followed by demersal (22.6%) and benthic (17.8%) species, with 84.1% of all prey being 6.1–15 cm in estimated length (Figure 3). The most frequent estimated size for benthic and demersal prey was 9.1–12 cm. The estimated size distribution of pelagic prey was bimodal, with higher frequencies at 6.1–9 cm and 12.1–15 cm being due to the respective prevalence of *Atherina* spp. and Bogue in the diet, each with rather narrow size ranges. Shags at Na Moltona fed on fish of medium size, with only 3.7% of prey items estimated to be < 6.1 cm in length, and only 4.1% to be 18.1 cm or more (mean estimated length = 11.6 cm).

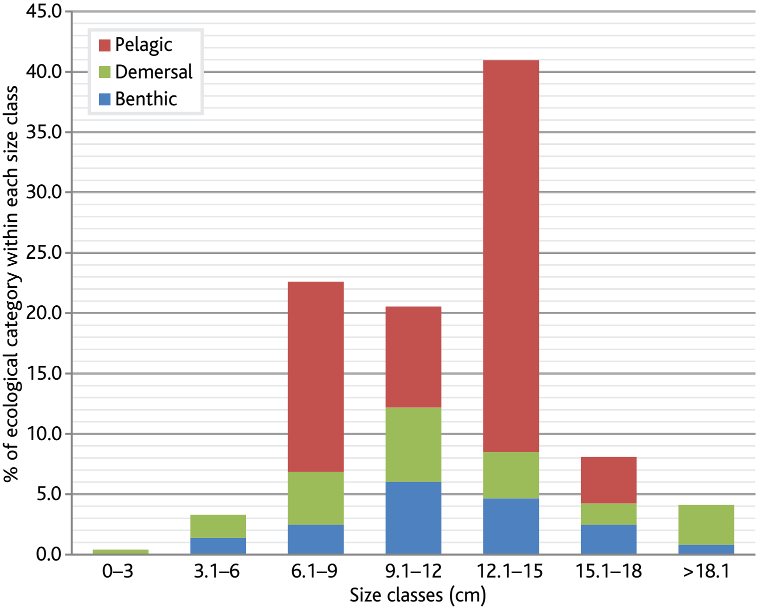

Figure 3. Estimated size classes of fish preyed by European Shags *Phalacrocorax aristotelis desmarestii* roosting at Na Moltona according the three ecological categories considered.

Discussion

This study highlights the great variety of fish (36 different species belonging to 27 genera and 16 families) present in the summer diet of Mediterranean Shags in Mallorca, which reflects the fish diversity of the Balearic coast and confirms the generalist diet of these birds. Although more work is required to improve knowledge of the spatio-temporal dynamics of diet choice in this species in Mallorca, the results obtained considerably enlarge available ecological information.

Our results are in agreement with other recent studies, showing a higher diversity of prey caught by Mediterranean Shags (Table 3), compared with that caught by *P. a. aristotelis* on Atlantic coasts. At most Atlantic localities, sandeel is the dominant prey item (Barrett *et al*. 1986; Harris & Wanless 1991, 1993; Grémillet *et al*. 1998; Velando & Freire 1999; Furness & Tasker 2000; Lilliendahl & Solmundsson 2006), especially during chick-rearing (Harris & Wanless 1993), when it can represent 100% of the chick diet (Barrett *et al*. 1986). Further, the diversity of taxa found in pellets from Na Moltona was higher than in all other studies conducted in other localities in the Mediterranean Sea (Table 3), despite the fact that our sampling was limited to a single day.

Table 3. Comparison of sampling period, number of recovered otoliths, and the number of fish families and species recorded in dietary studies of the European Shag *Phalacrocorax aristotelis desmarestii* in the Mediterranean Sea.[1]Range of mean lengths of the different species consumed.

Locality	Period	Number of otoliths	Number of families	Number of species	Mean length (cm)	Range of lengths (cm)	Author
Riou Archipelago, France	April–September 2004–07	2,462	12	25	7.4–14.0[1]	5.1–21.9	Morat 2007; Morat *et al.* 2011
Habibas Islands, Algeria.	July 2005	284	6	12			Morat 2007
Gulf of Trieste, Italy.	May–October 2005	20,716	17	31	7.6	1.5–29.0	Cosolo *et al.* 2011
Losinj Archipelago, Croatia.	January–April 2006	3,272	15	26	7.5	1.6–25.1	Cosolo *et al.* 2011
Na Moltona, Mallorca.	**3 June 2009**	**808**	**16**	**36**	**11.6**	**1.6–31.9**	**This study**

Unlike European Atlantic Coasts, the Balearic Sea is characterised by a low productivity (UNEP 2008; Cognetti *et al*. 2001). The islet of Na Moltona is formed by sandstone substrate, and is separated from the Mallorcan coast by a 5–6 m deep channel with a sandy bottom colonised extensively by the seagrass *Posidonia oceanica*. Close to Na Moltona there are also submerged sandstone blocks and remains of fossil dunes. In this habitat, there is not a clear dominance of one fish species as is the case in Atlantic waters where sandy substrates have high densities of sandeels.

In our study, the most important fish, both in frequency of occurrence and estimated biomass, was the Bogue (43.9% and 37.2% respectively). This sparid is a common pelagic inhabitant of coastal waters of the Eastern Atlantic and Mediterranean Sea, which can be found in shoals over rock, sand or mud substrates (Froese & Pauly 2011). In Balearic waters, the species can be found over seagrass meadows as well as over rocky and sandy bottoms at depths of 2–30 m (Fischer *et al*. 2007). This species has not yet been found in the diet of *P. a. aristotelis* in the Atlantic. For Mediterranean Shag, it has only been found in low frequency (0.2–2.8%) at Riou Archipelago (Morat 2007; Morat *et al.* 2011).

The second most frequent species found at Na Moltona (15% of otoliths) were sand smelts *Atherina* spp. However, atherinids were irrelevant in terms of biomass (1.4% of estimated biomass) due to the small size of the captured specimens. The same was found in the Adriatic Sea during the non-breeding season, where atherinids represented 10.7% of Shag prey but only 1.4% of estimated biomass; their frequency in the diet was higher on Riou (11.5–36.8%), and the Habibas Islands (28.5%).

Scorpaenids were less numerous (10.7%), but were the second most important prey in terms of estimated biomass (17.4%) after Bogue, and the contribution to the diet of Shags of the three species identified at Na Moltona was high compared with other locations. In Croatia, they were only found in March in the breeding season (one *Scorpaena scrofa* only, frequency 0.1%, estimated biomass 0.6%), while on Riou two species (*S. notata* and *S. porcus*) comprised 3.8% of prey items in the non-breeding season. Although most studies on the diet of the European Shag have been performed in the Atlantic (e.g., Steven 1933; Lumsden & Haddow 1946; Furness & Barrett 1985; Barrett *et al*. 1990; Wanless *et al*. 1991; Harris & Wanless 1993; Álvarez 1998; Lilliendahl & Solmundsson 2006; Hillersøy 2011; Fortin *et al*. 2013), scorpaenids have not been reported in the diet of *P. a. aristotelis*.

Other sparids, such as *Diplodus sargus* and *Lithognathus mormyrus*, and labrids, such as *Labrus merula*, were also important in terms of biomass (6–13% of estimated biomass), and were extremely scarce or have not been reported in the diet of Atlantic Shags. Other closely related species such as *Labrus bimaculatus and L. bergylta*, *Crenilabrus melops* and *Ctenolabrus rupestris* were present in some studies (Álvarez 1998; Hillersøy 2011), but, with the exception of *C. melops* in the Cantabric sea, generally at low frequency. In the literature available from the Mediterranean Sea, *D. sargus* and *L. mormyrus* have also been reported, but their contribution to the diet was limited (Morat *et al*. 2011; Cosolo *et al*. 2011), and *L. merula* was not found.

Only two sandeel otoliths, representing 0.3% of prey items, were found in our study. On Riou, sandeels represented only < 1.5% of prey items, and were not found in the diet of Shags in the Adriatic Sea, either in the breeding or non-breeding seasons. In great contrast, sandeels are an essential food resource for the growth of many young seabird species in the Atlantic (Pearson 1968), especially for European Shags (Harris & Wanless 1991; Velando & Freire 1999).

The ecological categories of fish prey at Na Moltona were in similar proportion to those reported from the Archipelago of Riou (64.6% pelagic, 29.8% demersal, 5.6% benthic; Morat 2007), with differences in the last two categories being partly due to different criteria used for classification as demersal or benthic for some species. Nevertheless, at other localities the diet of Mediterranean Shag can include different proportions of the ecological categories used here, with demersal gobids comprising 81.5% of prey in the northern Adriatic during the non-breeding season (Cosolo *et al*. 2011). This all further suggests opportunistic foraging behaviour of Mediterranean Shags.

The size distribution of the prey was similar to that found in other Mediterranean studies (Table 3), with Shags at Na Moltona feeding largely on medium-sized fish (84.1% of prey estimated at 6.1–15 cm in length, mean 11.6 cm).

The fish families preyed on by Mediterranean Shags roosting at Na Moltona include species with different ecological requirements. Gobies are strictly demersal and poor swimmers (Louisy 2006), characteristic of sandy or rocky bottoms (Fisher *et al*. 2007). Sparids are also demersal, but less linked to substrate, i.e., with species characteristic of different substrates (rock, sand or seagrasses), and with a few species, such as Bogue, more characteristically linked

Figure 4. Second calendar-year Mediterranean Shag *Phalacrocorax aristotelis desmarestii,* south coast of Mallorca, June 2009. © *Miguel McMinn*.

to the water column (Fisher *et al*. 2007). Labrids are also typically demersal, and do not occur in pelagic waters (Fisher *et al*. 2007). On the other hand, atherinids can aggregate in schools lying at different depths in the water column (Riedl 1991; Louisy 2006), and others such as the pomacentrid *Chromis chromis* are typically pelagic in coastal areas (Fisher *et al*. 2007). This wide prey range reflects the opportunistic feeding behaviour of the European Shag, as suggested for *Ph. a. aristotelis* (Barrett *et al*. 1990; Velando & Freire 1999), and for Mediterranean Shag (Morat *et al*. 2011). The relatively high abundance of species armed with hard scales and venomous spines (Scorpaenidae and Trachinidae), both well camouflaged on the sea bottom, suggests a scarcity of other more palatable prey for Mediterranean Shags roosting at Na Moltona. The higher prey diversity found in their pellets, compared with other locations, reinforces this hypothesis.

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