Aquatic Living Resources

The demography and ecology of the European shag *Phalacrocorax aristotelis* in Mor Braz, France

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Abstract – An integrated research program was initiated to evaluate if the European shag *Phalacrocorax aristotelis* can be used as a robust indicator of the marine environment in Mor Braz, Brittany, France. This program focuses on aspects of the ecology of the shag including its abundance, demography, diet and at-sea distribution measured at three breeding colonies. The annual population growth rate was estimated at 1.01 for the period 1987–2009. The number of breeding pairs (mean: 565) was highly variable from year to year. Part of this interannual variation was explained by variations in sea surface temperature and sea surface height in winter and spring: the number of breeding pairs was negatively related to sea surface temperature and sea surface height. First year, second year and adult survival probabilities were 0.44, 0.76 and 0.81, respectively. Juvenile survival rate varied between colonies, despite the short distances separating these islets. Average productivity was one young fledged per nest, but it varied between years and islets. Density of individuals at sea varied between 1.40 ind.km^{-2} during the breeding season and 3.08 ind.km^{-2} after the breeding season had ended. Individuals foraged up to 7 km from the nest and performed on average 2.7 foraging trips per day. The average number of dives deeper than 5 m varied from 126 to 400 per day. Mean diving depth, dive duration and time spent at bottom were 13 m, 28 s, and 19 s respectively. Regurgitated pellets were collected regularly. Four fish families (Gadidae, Gobiidae, Atherinidae and Labridae) represented more than 65% of the preys throughout the year, a percentage reaching more than 95% of the prey from May to October. The other fish in the diet were Cottidae, Ammodytidae, and Clupeidae. The diet of the European shag consisted of benthic fish throughout the year, and also included pelagic fish more frequently between June and October. The synchronous variations of productivity between colonies suggest that some common environmental factors affect this demographic parameter at the regional scale. Thus, the European shag has a good potential for being a reliable ecological indicator of the state of this marine environment. Finally, improved knowledge on the foraging ecology of shags will be useful in the process of designing Marine Protected Areas in the Mor Braz to help ensure sustainable management of marine resources and biodiversity conservation.

Keywords: Seabirds / Breeding pairs / Population density / Diet / Wildlife surveys / Bay of Biscay / Atlantic Ocean

1 Introduction

There is an increasing need to develop reliable indicators of the ecological state of the marine environment to support ecosystem-based management of living resources. Seabirds may be useful in this process, since their position at or near the apex of most marine food webs potentially makes them good, reliable sentinel organisms for monitoring changes within marine ecosystems (Furness and Camphuysen 1997; Harding et al. 2005; Piatt et al. 2007). However, producing reliable indicators is challenging and requires a clear definition of the objectives of the indicator, a choice of the seabird species ac-cording to the objectives, and ideally a good understanding of the ecosystem functioning (Durant et al. 2009).

In 2010, we initiated a research and conservation program (CORMOR) aiming to investigate the use of the European shag *Phalacrocorax aristotelis* (Linnaeus 1761) an inshore generalist bird species, as an ecological indicator of the marine ecosystem of the Mor Braz, Bay of Biscay, France. The main objective of this integrated program is to evaluate whether the European shag can be used as a robust indicator of the marine environment.

The program is based on existing data including: i) long-term data on the abundance of breeding pairs collected annually since the mid-1980s, ii) phenology and breeding performance data collected annually since 2003, iii) multisite capture-mark-recapture data collected annually since 2004, iv)

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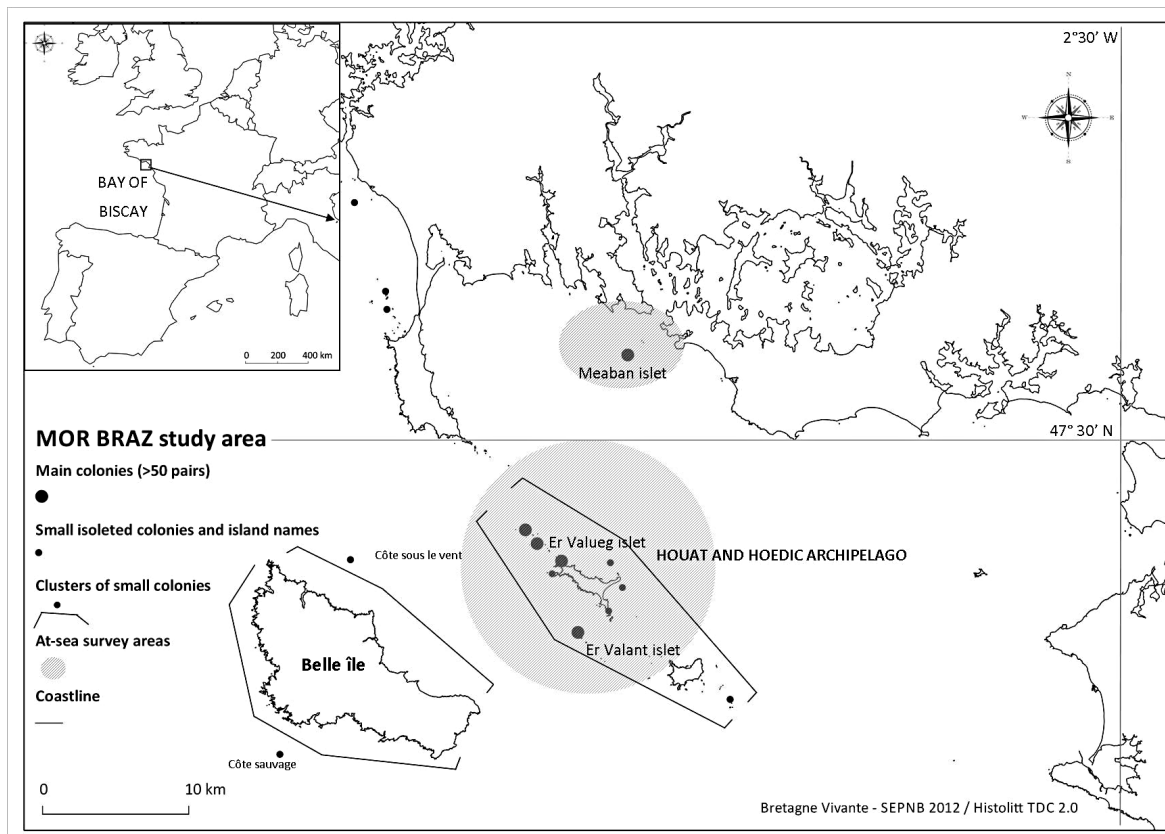matthieu.fortin@bretagne-vivante.org

Fig. 1. Map of the study area (Mor Braz) showing the location of the main breeding colonies of the European shag (*Phalacrocorax aristotelis*) and the areas covered by at-sea surveys.

diet data collected annually since 2010, and v) at-sea spatial distribution data from at-sea based surveys and telemetry. All data were collected on islands and islets of the Houat and Hoëdic archipelago (3° 06′–2° 30′ W, 47° 30′–47° 18′ N, Fig. 1), Mor Braz, Brittany. The program also aims to continue data collection in the coming years, particularly on diet and at-sea spatial distribution data, which will allow an understanding of how shags use their oceanographic environment and how its variability affects their demography and population dynamics.

The aims of this study are threefold. First, we present long-term variations in the number of breeding pairs of the European shag in Mor Braz and investigate whether these variations are related to climatic or oceanographic parameters. Second, we provide the first estimates of survival and productivity for this population issued form a capture-mark-recapture program. Third, we present data on the diet and foraging behaviour and distribution of this shag population, which combined with the population parameters, will help to develop a comprehensive ecological indicator of this marine ecosystem

2 Materials and methods

Abundance of breeding pairs was estimated from nest counts undertaken during annual surveys between March and June, performed since 1987. Nest contents (number of nests with or without eggs, number of eggs per nest, number of chicks per nest, approximate age of the chicks based on plumage development) were recorded during population surveys. We used a log-linear Poisson regression to assess between-year changes in the number of breeding pairs using logarithms of nest counts with eggs and/or chicks (TRIM software, Pannekoek et al. 2004).

In 2004, we initiated a capture-mark-recapture program. Each year in April and May most chicks of pairs breeding on three islets, which represent a large proportion (50−60%) of the entire breeding population (900 to 1100 breeding pairs), were ringed with a stainless steel ring on one leg and with a plastic ring on the other leg. Adults were also ringed when captured. Each year during surveys, we searched for marked individuals over the entire study area. From these capture-recapture data, juvenile and adult survival was estimated using the software M-SURGE (Choquet et al. 2004).

From March 2010 to April 2011, we collected and analysed 161 pellets collected on roosting sites and at the proximity of nest sites from one colony (Meaban islet, Fig. 1). A total of eight months were sampled. Pellets were dissected under stereo microscope and otoliths identified by using classical identification guides (Härkönen 1986; Campana 2004; Lombarte et al. 2006).

Mean number of otoliths per pellet, prey frequency and the Shannon's diversity index (Tramer 1969) were calculated. The total number of otoliths was divided in half to obtain the estimated prey number, assuming that two otoliths corresponded to one individual fish. A complete one-way analysis

of variance (ANOVA) was used to compare the means of total prey numbers obtained for different months, after a log transformation of the data.

In 2011, we initiated a study of the at-sea movements of breeding individuals that could be easily captured. Birds were fitted with GPS tracking devices fixed to their back feathers with Tesa tape, and with a temperature depth recorder (TDR) fixed to a plastic ring on the leg. Tags were deployed on breeding individuals with young chicks and recovered 5 days later.

We performed transects at sea to get independent data on shag foraging distribution during the breeding season. Transects covered the entire study area and were performed using an inflatable rubber boat. During each transect, all shags detected on the water were counted and their distance and angle relative to the ~~measured~~ transect. The density of birds at sea was estimated using the software DISTANCE (http://www.ruwpa.st-and.ac.uk/distance/, Thomas et al. 2010).

3 Results

The number of breeding pairs was highly variable from year to year, ranging from 370 ± 34 to 780 ± 51 with a mean of 565 ± 250 (Fig. 2a). The annual population growth rate for the period 1987–2009 was estimated at 1.010 ± 0.004, indicating that the breeding population size was slowly increasing at a rate of 1% per year. However, there was strong inter-year variation in the number of breeding pairs, as indicated by the low precision of the mean number of breeding pairs (coefficient of variation: 44%). Part of this interannual variation was explained by variations in sea surface temperature and sea surface height in winter and spring. Indeed, the number of breeding pairs was negatively related to a principal component variable representing variations in sea surface temperature and sea surface height from January to April ($R^2 = 0.50$, $p = 0.0002$, Fig. 2b). No significant relationship was found between the annual number of breeding pairs and the North Atlantic Oscillation (NAO).

From 2004 to 2011, 2 700 individuals were ringed and 3 400 resightings were made. Resighting probability increased with age from 0.20 for one year old individuals to 0.85 for five years old and older individuals. As expected, there was a strong age effect on annual survival probability. First year, second year and adult survival probabilities were respectively 0.44 ± 0.04, 0.76 ± 0.07 and 0.81 ± 0.03. In addition to age effects on survival, island effects were detected, particularly on juvenile survival. At Er Valueg islet, juvenile survival was lower than at Er Valant islet and Meaban islet (0.24 ± 0.03, 0.43 ± 0.05, and 0.60 ± 0.08 respectively), despite the short distances separating these islets. No sex effect was detected on adult survival.

Average productivity was 1.00 ± 0.47 young fledged per nest, but varied a great deal between years and islets. The mean number of young fledged per nest was particularly low in 2007 (0.42), and to a lesser extent in 2006 and 2008 (0.87 and 0.97 respectively). Productivity was lower on one islet than on the two other islets, which were monitored regularly, but interannual variations were highly synchronised between islets.

A total of 231 individual shags were observed sitting on water or feeding at sea on the 53 transects, which represented a
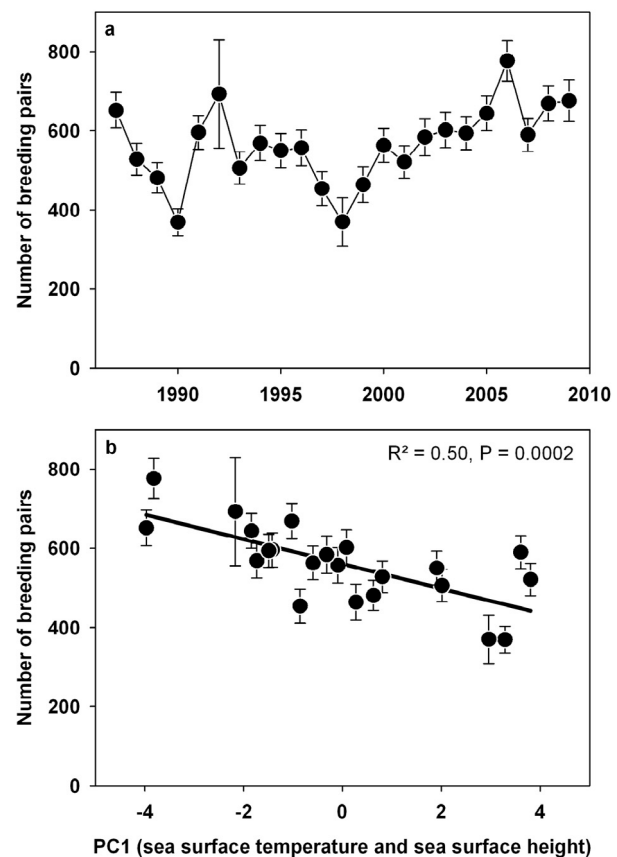

Fig. 2. Number of breeding pairs as a function of (a) year, and (b) a covariate representing variations in sea surface temperature anomalies and sea surface height on a $1° \times 1°$ rectangle area centred on the study area (B). The covariate was the first axis of a principal component analysis run on monthly sea surface temperature anomalies and sea surface height in January, February, March and April. Errors bars are ±1 SD.

total distance covered of 188 km. The probability of detecting shags sitting on the water declined differentially in spring and summer, with increasing distance from the transects: it was respectively 0.94, 0.26 and 0.07 at 100 m, 300 m and 600 m from transects in spring, and 0.90, 0.37 and 0.02 at 100 m, 300 m and 600 m from transects in summer. Density of individuals at sea varied between seasons: in spring during the breeding season, it was 1.34 ± 0.27 ind.km^{-2}, but this reached 3.08 ± 0.98 ind.km^{-2} in summer following the end of the breeding period.

A total of four breeding individuals raising young chicks (1–2 weeks old) were equipped and recaptured with GPS and TDR in 2011. Preliminary results indicate that on average individuals performed 2.7 foraging trips per day. The average number of dives deeper than 5 m varied from 126 to 400 per day. Mean diving depth was 13 m (maximum recorded 38 m), mean dive duration was 28 s, and mean time spent at bottom was 19 s. During foraging trips, the maximum recorded distance from the nest was 7 km, but some individuals foraged no further than 1.5 km from their nests.

In Mor Braz, the European shag diet mainly consisted of seven fish families. Three of them are benthic or demersal,
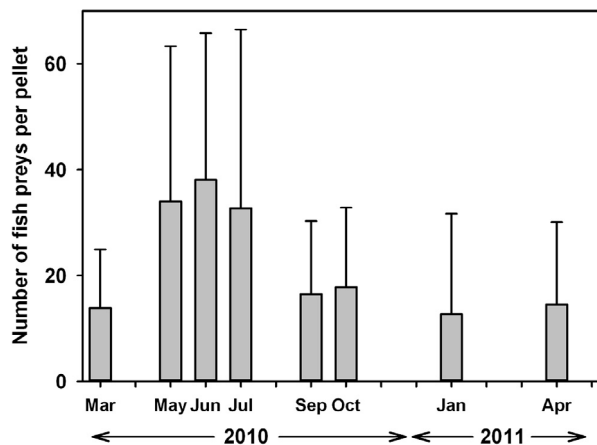
Fig. 3. Mean monthly number of preys per pellet of European shags from the colony of Meaban islet, Mor Braz, France. Errors bars are ±1 SD.

while the other four are schooling pelagic fishes (Table 1). This table also compares the abundances of different prey types in different sites distributed along the European Atlantic coastline from the north of Norway to Corsica (Mediterranean sea). It concerns two of the three sub species of the European shag, *P. a. aristotelis* and *P. a. desmarestii*. Our results show that four families represented more than 65% of the preys throughout the year: Gadidae, Gobiidae, Atherinidae and Labridae; this reached more than 95% from May to October. The other fish were, in descending order, Cottidae, Ammodytidae, and Clupeidae. Results showed that benthic fishes were preyed upon throughout the year. Gobiidae represented more than 30% of shags' diet during five of the eight months sampled. Labridae and Cottidae were regularly preyed upon during the four seasons and contributed from 1% to 20% of the diet. Pelagic fishes were preyed upon more frequently between June and October. Gadidae were the main preys in June with a contribution of 59% of the diet, which then gradually decreased to 35% in October. Atherinidae could also reach high percentages, but represented more than 30% of the diet only during two months. The diversity index showed a rather uniform value during the studied year (values ranged from 1.01 to 1.67).

The monthly mean (±SD) of the total number of preys found per pellet was 22.7 ± 3.6, when calculated over the entire time period of the study. However, there were significant monthly differences (ANOVA: $F_{7,151} = 4.63$, $p < 0.001$). During the chick-rearing period (from May to July) the average number of preys found per pellet was significantly higher (34.8 ± 7.4) than in the rest of the year (14.4 ± 3.1). There was no significant difference between months within (May to July; $F_{2,61} = 0.39$, $p = 0.68$) or outside the chick-rearing period (August to April; $F_{4,91} = 0.37$, $p = 0.83$).

4 Discussion

Using long-term monitoring data, our results showed that the number of breeding pairs of shags varied from year to year. Our analyses suggest that 50% of this interannual variation could be explained by environmental variability, particularly by variations in sea surface temperature and sea surface height. As winter and spring sea surface temperatures and sea surface height increased the number of breeding pairs decreased.

At present, the demographic causes of the variations in breeding numbers remain unknown, but the high annual survival probabilities and their relative stability suggest that a change in adult survival is not the main driver. Adult survival in our study population was intermediate between adult survival estimates obtained in more northerly or more southerly breeding populations. For example, adult survival rates were 0.72 ± 0.05 at Cíes Island, north-western Spain (Velando and Freire 1999), and 0.88 ± 0.01 in Isle of May, Scotland (Harris et al. 1994). As in Frederiksen et al. (2008), first year and second year survival appeared more variable than adult survival. We suspect variations in breeding probabilities, productivity and/or recruitment of breeding individuals to be the main drivers of interannual changes in the number of breeding pairs. In the near future, we plan to quantify the respective contributions of these demographic parameters to the changes in the population growth rate, using longer time series and retrospective analyses (see Caswell 2001).

The ecological mechanisms responsible for the negative relationship between the number of breeding pairs and the sea surface temperature, are still unclear. As suggested or shown in several seabird species (e.g., Kitayski and Golubova 2000; Durant et al. 2003; Harris et al. 2005; Bertram et al. 2005), we strongly suspect an indirect effect of sea surface temperatures and food abundance and/or accessibility, which in turn affect the birds' energetics and population parameters. In the shag population nesting on the Isle of May, attendance of breeders, timing of breeding, annual chick production and first year survival were shown to be linked to herring (*Clupea harengus*) abundance or the size of sandeels (*Ammodytes marinus*) taken by puffins (*Fratercula arctica*) breeding on the island (Aebischer and Wanless 1992). Furthermore, on this same island, laying date and breeding success of shags were correlated with local sea surface temperature (Frederiksen et al. 2004), and Frederiksen et al. (2007) showed that shag productivity (number of fledged chicks per nest) was positively linked to the larval sandeel (the main prey species) abundance in the previous spring. However, Frederiksen et al. (2008) also showed that, within the same population, survival of second year and adult shags was substantially reduced in years when high precipitation and strong offshore winds coincided at the end of winter. These authors suggested both direct and indirect impacts of weather events on shags, with strong winds and high precipitation causing mortality, presumably through hypothermia because shag plumage is not completely waterproof (Grémillet et al. 1998), and onshore gales inhibiting foraging, perhaps because of increased turbidity during the strongest wind episodes (Daunt et al. 2006). Together, these results suggest that late winter is a stressful period for shags. Studies similar to those conducted in Scotland now need to be conducted at more southerly localities, such as our study site, since environmental conditions and diet of shags may differ there.

Our tracking study, at-sea observations and previous studies on the European shag (Wanless et al. 1991) clearly suggest that, during the breeding period, individuals forage in waters situated in the vicinity of their nests (typically less

Table 1. Diet of European shags in different locations of the Atlantic and Mediterranean. Data are expressed as percentage of frequency of occurrence (OF) or of numerical frequency (NF), depending on the method used by the different authors. (−) indicates that a prey group is absent or accounts for less than 0.1%. Completed and modified from Velando and Freire (1999).

Location	Method	Gobidae	Gadidae	Atherinidae	Labridae	Cottidae	Ammodytidae	Clupeidae	Other	Ref. (*)
Hornoy (Norway)	NF	–	40	–	–	–	56	–	3	8
Bleiksoy (Norway)	NF	–	69	–	–	–	15	–	16	8
Rogaland (Norway)	NF	–	50	–	20	–	15	–	15	8
Clyde (Scotland)	NF	3	13	–	1	–	78	0.6	4	2
Farne (Scotland)	NF	–	4	–	–	–	81	–	15	3
Loch Ewe (Scotland)	NF	–	59	–	–	–	41	–	–	4
Shetland (Scotland)	OF	–	–	–	–	–	100	–	–	7
Isle of May (Scotland)	OF	11	45	–	–	–	95	–	15	9
Cornwall (England)	OF	2	4	–	13	–	51	30	14	1
Brittany (France)	NF	–	35	–	16	–	26	–	23	5
Meaban (Morbihan, France)	NF	33	27	19	10	6	2	–	3	This study
Caladoria (Asturias, Spain)	NF	–	11	35	52	–	–	–	2	10
Cies (Galicia, Spain)	NF	6	7	3	5	–	75	–	4	11
Ons (Galicia, Spain)	NF	30	4	20	5	–	38	–	3	11
Corcega (Corsica, France)	OF	–	–	5	78	–	33	–	28	6

(*) 1 Steven (1933), 2 Lumsden and Haddow (1946), 3 Pearson (1968), 4 Mills (1969), 5 Pasquet (1987), 6 Guyot (1988), 7 Harris and Riddiford (1989), 8 Barret et al. (1990), 9 Harris and Wanless (1991), 10 Alvarez (1998), 11 Velando and Freire (1999).

than 10 km). Therefore, at least during the breeding season, we might expect site specific effects of local oceanographic conditions on foraging performances and possibly on some demographic parameters. This idea is congruent with our results showing site specific variations in juvenile survival and productivity. Although our sample size was relatively small, mean diving duration and depths tended to be slightly lower than those recorded in other populations, with mean dive durations varying between 38 s to 70 s and mean depths between 20 m and 35 m (Wanless et al. 1991; 1997; Grémillet et al. 1998). This may be due to specific bathymetric characteristics of our study site, which has an average depth of 21 m while the average depth around the Isle of May is 40 m.

The increase in density estimates observed between the breeding season and the summer following the end of the breeding period has also been observed in the double-crested cormorant (*Phalacrocorax auritus*) on the Laurentian Great Lakes, using the same approach to estimate density (line transect distance sampling, Ridgway 2010). In both cases, the increase in density may correspond to individuals from areas beyond the study sites moving into the sampled region at the end of the nesting period, and/or a reflection of fledging and the dispersal of the fledglings from their birth place.

Our results confirm that the European shag is an opportunistic predator that takes advantage of particular species abundance in a given season (Barret 1991), and that the variability in its dietary composition in different locations may be related to geographical differences in the availability of potential prey species (Velando and Freire 1999). This was particularly obvious in summer, when diet markedly shifted to the Gadidae. Assuming that one pellet, on average, is produced per day (Johnstone et al. 1990), it may be inferred that the number of daily ingested preys more than doubles during the reproductive period, especially during the feeding of

chicks. However, assessing diet from pellets in shags might have underestimated the number and size of prey items taken (Johnstone et al. 1990). At our study site, diet markedly differed from the main prey consumed by shags on the Isle of May and Cíes Islands, where sandeels constitute the dominant prey species in the diet of breeding individuals (Wanless et al. 1993; Velando and Freire 1999). However, as observed by Velando and Freire (1999) on the Islands of Ons (NW Spain), we found seasonal changes in diet, where Gobiidae and Gadidae were the most frequently consumed prey species in winter (Table 1).

Thus, the synchronous variations of productivity between different colonies suggest that some common environmental factors affect this demographic parameter at the regional scale. This, together with the strong relationship between the number of breeding pairs and sea surface temperature, and the high interannual variability in productivity and number of breeding pairs suggest that the European shag has good potential to make a reliable ecological indicator of the state of this marine environment. However, our preliminary results also indicate that local factors (at the scale of the islet and its surrounding) may also affect demographic parameters. Identifying these factors and the relationships between demographic parameters and environmental factors will be an important step towards developing a long-term indicator. Behavioural data using telemetry further reinforce the potential of the European shag as an ecological indicator, since its foraging distribution during the breeding period appears to be restricted to a few kilometres from the nest.

Improved knowledge on the foraging ecology and demography of shags will be useful in the process of designing Marine Protected Areas in the Mor Braz, which will help to ensure sustainable management of marine resources and biodiversity conservation. Our results suggest than the European shag

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could be used as a reliable ecological indicator of the state of such a Marine Protected Area.

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