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Population trends and reproductive success of the European shag *Phalacrocorax aristotelis* on the Iberian Peninsula following the *Prestige* oil spill

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Abstract In 2003, immediately following the *Prestige* oil spill in Galicia, Spain, we studied the population trends and reproductive performance of European shags (*Phalacrocorax aristotelis*) at oiled and unoiled colonies. This bird is an important member of the nearshore marine community, breeding in the area affected by the *Prestige* oil spill. The European shag feeds around the breeding colonies throughout the year, making it a useful indicator of environmental change. Before the oil spill, population trends were similar between oiled and unoiled colonies. Nevertheless, colonies located within the path of the oil suffered greater declines (ca. 10%) compared with pre-spill trends and with population trends at unoiled colonies. In 2003, the breeding success was 50% lower in oiled colonies compared with unoiled colonies. The data available from pre-spill years suggest that the annual reproductive success did not differ among colonies before the impact. European shags breeding at colonies affected by oil showed a negative initial impact from the *Prestige* oil spill. The reduction in reproductive success at oiled colonies may be due to sublethal effects of oil exposure or low food availability after the oil spill.

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Introduction

On 13 November 2002, the hull of the *Prestige* oil tanker split and the ship began to spill heavy bunker oil off the coast of Galicia, NW Spain. During the next 6 days, the ship followed an erratic course back and forth along the Galician coast, spreading around 19,000 tonnes of oil, and finally sank 130 miles west of Illas Cíes (42°12′N, 12°03′W). During the following months, a further 40,000 tonnes of oil were released. Wind and currents spread the oil across a vast coastal area, as far as the Isle of Wight, on the south coast of England, and the Canary Islands, close to West Africa, making this one of the largest oil spills in Europe.

Seabirds are probably at greater risk of suffering the negative impact of oil spills than most other marine wildlife (Piatt and Ford 1996; Lance et al. 2001; Peterson et al. 2003) because they spend much of their lives in contact with the sea surface and because coastlines, where seabirds congregate to breed, may receive a build-up of oil via wave and current action (Piatt et al. 1990; Irons et al. 2000). Following the *Prestige* wreck, thousands of birds were killed due to the acute effects of the spill (García et al. 2004). In addition, the oil remained for several months within nearshore environments (Freire and Labarta 2003), which are important for large numbers of vertebrates including breeding colonies of seabirds. Birds may be directly exposed to oil through a range of processes including oiling of plumage and eggs, ingestion of oil during preening, ingestion of oiled prey, absorption, and inhalation of oil through the skin or eggs. Exposure to oil through contaminated sediments or prey items could potentially elicit adverse physiological responses (Leighton et al. 1983; Butler et al. 1988; Walton et al. 1997) and birds may be affected indirectly via habitat change and reduced food availability, which in turn, could have long-term population and reproductive consequences (Esler et al. 2000; Golet et al. 2002).

The European shag (*Phalacrocorax aristotelis*), a typical nearshore seabird, is found throughout the area affected by the *Prestige* oil spill (see Velando et al. 1999). It is a foot-propelled pursuit-diver, feeding predominantly on pelagic and benthic fish (Velando and Freire 1999), typically within a radius of 20 km around the breeding colonies (Velando 1997; Wanless et al. 1997; Velando and Freire 1999). Although the spill occurred 3 months before the onset of shag breeding, these species are largely sedentary and remain around breeding colonies throughout the year (Velando 1997). Although mortality of European shags after the *Prestige* appeared relatively low, with 340 oiled shags being found (Xunta de Galicia, unpublished data), total mortality was probably higher than this (see Piatt et al. 1990). In addition to acute mortality, European shags were exposed to the long-term effects of oil pollution around both breeding sites and foraging areas (Freire and Labarta 2003).

We studied population trends and reproductive success of European shags to determine if this species was affected by the *Prestige* oil spill at the population level. One of the main problems in detecting population effects related to oil spills is that seabird populations show spatial and temporal fluctuations for a number of different reasons, whose effects may be difficult to disentangle (Wiens and Parker 1995). The existence of pre-spill data for population trends of European shags at oiled and unoiled colonies in the Iberian Peninsula allows the use of temporal and spatial replicated before-after-control-impact (BACI) design. By comparing pairs before and after the spillage event we are able to distinguish between effects of the *Prestige* oil spill and natural and spatial variation. Because there are no replicated data in pre-spill years, we only compared the reproductive success between oiled and unoiled areas.

Methods

After the *Prestige* wreck, the most heavily oiled area was located between Illas Sisargas and Illas Cíes (Fig. 1), and European shag colonies in this area were considered as "oiled". Colonies in the North of Galicia and Asturias (see Fig. 1) were not affected by oil until after the shag breeding season and were considered as "unoiled". From pre-spill years, the population trends were estimated in 19 colonies (colonies in the oiled area: Illa do Faro [Cíes], Sagres, Gavoteiro, Cabo da Nao; colonies in the unoiled area: Engaramada, El Islía, El Castelo, A Campella, Punxéu, La Caladoria, El Cabu Vidíu, El Rebeón, La Deva, La Herbosa, Os Castríos-Represas, As Pantorgas, A Forcada, A Punta del Gavioteiro, El Castellón, Oleiros). Population counts—apparently occupied nests in April–May—were made annually between 1994 and 2002 in part or the whole of the colonies (see details in Velando et al. 1999). The instantaneous growth rate was estimated by $r = (\ln N_t - \ln N_0)/t$, where N_0 is the population size at the outset, t is the time in years, N_t is the population size after time t and r is the instantaneous growth rate of the population, the annual multiplication rate (λ) was estimated by $\lambda = e^r$, and the annual growth rate (%) was expressed as $(\lambda - 1) \times 100$. From pre-spill years, all the colonies were initially counted once in the

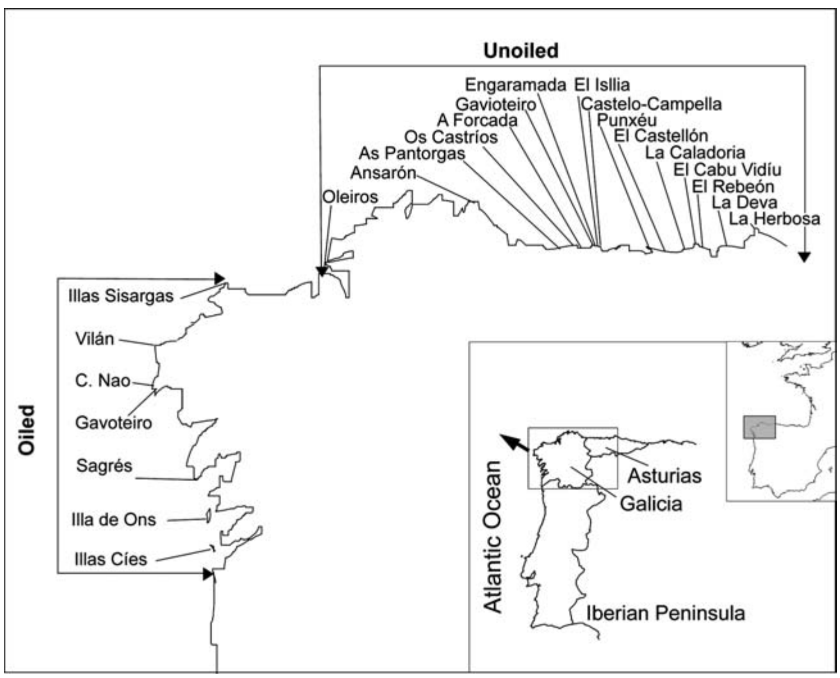

Fig. 1 Map of the study colonies of European shag (*Phalacrocorax aristotelis*) in Galicia and Asturias, Iberian Peninsula. Colonies are grouped within oiled (moderate and heavily oiled) and unoiled (none and lightly oiled) areas

1994–1997 period and, after the spill, in 2001 or 2002, so the per capita growth rate of each colony in this period (thereafter "1994–2002" period) was estimated and compared with population growth in the post-spill period, between 2002 and 2003. The population trends were compared by repeated measures (RM) ANCOVA, comparing the differences between oiled and unoiled colonies in pre- and post-spill trends within each colony, controlling for the effects of initial trends. The oil spill impact should be detectable as different pattern (statistical interaction) in population trends before and after impact between the oiled and unoiled colonies (Underwood 1994). We also compared the pre-spill population trends using a *t*-test.

In 2003, the reproductive success (defined as number of chicks surviving to 50 days) was estimated in 17 colonies (6 oiled and 11 unoiled) by monitoring marked nests during the breeding period. The number of marked nest varied among colonies (number of nests: Illas Cíes, 31; Illa de Ons, 39; Sagres, 24; Fisterra, 28; Cabo Vilán, 29; Illas Sisargas, 32; Oleiros, 26; Ansarón, 55; Pantorgas, 31; Castríos, 10; A Forcada, 19; El Gavioteiro, 12; La Osa, 9; La Caladoria, 32; Cabo Vidiu, 11; El Rebeón, 4; Isla La Deva, 12). In pre-spill years, the annual reproductive success was only monitored in a few colonies, within the oil path: Illas Cíes (7 years), and in the unoiled area: Pantorgas (5 years), A Forcada (5 years) and Castríos-Represas (3 years). In order to test the "spatial coherence" in pre-spill years, we compared mean annual reproductive success of Illas Cíes with the colonies in the unoiled area. Data are expressed as mean ± SE.

Results

In the pre-spill period (1994–2002), there were no differences in the population trends between colonies in the oiled and unoiled areas (Fig. 2; $t = 0.21$, $df = 17$, $P = 0.83$). After *Prestige* oil spill, the annual population growth of each colony was influenced by its previous population trend (RM-ANCOVA, $F_{1,16} = 73.18$, $P < 0.001$), but the oiled colonies displayed a significant decrease in annual population growth after the *Prestige* oil spill compared to unoiled ones (Fig. 2; RM-ANCOVA, $F_{1,16} = 7.98$, $P = 0.012$). The annual population growth of oiled colonies decreased by 9.6 ± 7.3 and unoiled colonies remained stable with a slightly decrease of 1.0 ± 2.3.

In 2003, the season immediately after the spill, there were significant differences in the reproductive success between oiled and unoiled colonies ($t = 6.23$, $df = 15$, $P < 0.001$), thus the reproductive success was reduced by a half in oiled areas relative to unoiled ones (oiled: 1.09 ± 0.13 chicks fledged per pair, unoiled: 2.00 ± 0.08 chicks fledged per pair). In pre-spill years, the annual reproductive success was only monitored in a few colonies, within the oiled area: Illas Cíes (7 years), and in the unoiled area: Pantorgas (5 years), A Forcada (5 years), and Castríos-Represas (3 years). Before the *Prestige* oil spill, there were no differences in the annual reproductive success of Illas Cíes and the colonies in the unoiled area (Cíes vs Pantorgas: $t = 1.76$; $df = 10$; $P = 0.11$; Cíes vs A Forcada: $t = 0.48$; $df = 10$; $P = 0.64$; Cíes vs Castríos-Represas: $t = 0.35$, $df = 8$; $P = 0.73$). In Illas Cíes, the lowest annual reproductive success was recorded in 2003, after the *Prestige* oil spill (2003: 0.48 fledglings per pair, range of 1994–2002 period: 1.15–1.87 fledglings per pair).

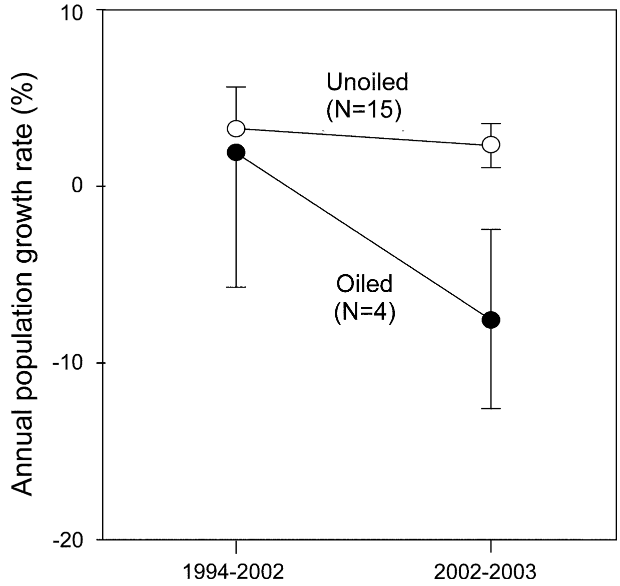

Fig. 2 Annual population growth rates (mean ± SE) of oiled (*closed circles*) and unoiled (*open circles*) colonies of European shag before (1994–2002) and after (2002–2003) the *Prestige* oil spill. Numbers of colonies are indicated in parentheses

Discussion

The European shag population in NW Spain was negatively affected following the *Prestige* oil spill. In the breeding season following the *Prestige* disaster, the oiled European shag populations suffered a steeper population decline (ca. 10%) compared with pre-spill trends and with population trends in unoiled colonies. The *Prestige* oil-spill affected a vast geographic area (see Fig. 1), and, as with many unplanned environmental accidents, it is not well replicated and colonies used in our analyses are not entirely spatially independent (Hurlbert 1984; Paine et al. 1996). During the 8 years before the oil spill, there were no differences in population trends between oiled and unoiled colonies, suggesting similar dynamics ("temporal coherence") in pre-spill years, an important ecological assumption of pre-post pair comparisons (Osenberg et al. 1994; Wiens and Parker 1995). Therefore, we suggest that the *Prestige* oil spill negatively affected European shags at the population level.

The decline observed in oiled colonies after the *Prestige* oil spill could be attributed to changes in survival, non-breeding, or both. The recorded death toll for shags was less than 5% of the population in the oiled colonies (A. Velando, unpublished data). Nevertheless, only a small (unknown) fraction of the birds that are killed at sea by oil are likely to be recovered (i.e. Piatt et al. 1990; Piatt and Ford 1996). Alternatively, the population decline after the oil spill could also be attributed to some breeding adults deferring a breeding attempt, a common feature of shag biology (Aebischer and Wanless 1992; Harris et al. 1998; Velando and Freire 2002). Similarly, some kittiwakes (*Rissa tridactyla*) did not breed in years following the *Braer* oil spill in Shetland, Scotland, probably due to sub-lethal physiological effects as a result of exposure to oil (Walton et al. 1997). Both hypotheses could explain the observed effects of the *Prestige* oil spill on European shags.

In 2003, the breeding success was 50% lower in oiled colonies compared with unoiled ones. The data available from pre-spill years suggest that the annual reproductive success did not differ among colonies before the impact. In Illas Cíes, an oiled colony with good previous data, the reproductive success was 50% less than the lowest value recorded in the period 1994–2002 (Velando and Freire 2002). Thus, before-after and control-impact comparisons agree and strongly suggest that European shags suffered a negative impact from the *Prestige* oil spill. The reduction of reproductive success in oiled colonies probably indicates sub-lethal effects of oil exposure or reduced food availability after the oil spill; further studies are needed to discriminate these hypotheses.

Oiled seabirds can experience adverse physiological effects, as suppression of reproductive hormones (Fowler et al. 1995), leading to lower rates of nest establishment, egg laying, hatching success, and a decrease in offspring growth and/or survival (e.g. Miller et al. 1978; Butler et al. 1988; Giese et al. 2000). Although poorly documented, long-term depletion of sediment fauna by oil-spill could have an adverse effect on seabirds (Golet et al. 2002). Seabirds are sensitive to changes in food availability and one response is evidenced by changes in reproduction (Cairns 1987; Monaghan et al. 1989), reducing their reproductive effort when food availability is low (Drent and Daan 1980; Velando and Alonso-Alvarez 2003). The reduction of reproductive success in oiled colonies of European shag after the *Prestige* oil spill highlights that risk assessment models based solely on acute mortality underestimate impacts of oil pollution by overlooking the effects of chronic exposures, and/or indirect effects driven by ecosystem processes (Kimball and Levin 1985).

Seabirds are long-lived animals and upper trophic level consumers. Thus, seabirds can be indicators of changes in the marine ecosystem (Furness and Greenwood 1993), especially as indicators of marine pollution (e.g. Moser and Lee 1992; Becker et al. 1993; Bearhop et al. 2000). After the *Exxon Valdez* oil spill, seabirds were used as indicators of persistent oil pollution in the marine habitat, especially in nearshore habitats (Golet et al. 2002; Lance et al. 2001). The European shag is an important avian member of the inshore marine community, breeding in the area affected by the *Prestige* oil spill. They are vulnerable to pollution persistence because they use the nearshore habitat around the breeding colonies throughout the year (Velando 1997). The colonial nesting habits and high nesting fidelity of established breeders (Aebischer et al. 1995; Velando and Freire 2002) allow long-term comparisons in trends of breeding success between oiled and unoiled habitats. Thus, by monitoring the breeding biology of European shags, we might gain an insight into the recovery of the marine ecosystem following the catastrophic effect of the *Prestige* wreck.

Zusammenfassung

Bestandsentwicklung und Bruterfolg der Krähenscharbe auf der Iberischen Halbinsel nach dem Ölunfall der *PRESTIGE*

Unmittelbar nach der Havarie des Öltankers *Prestige* im Jahre 2003 mit der Folge einer Ölpest an der galizischen Küste, Spanien, untersuchten wir die Bestandstrends und den Bruterfolg der Krähenscharbe (*Phalacrocorax aristotelis*) an verölten und nicht verölten Koloniestandorten. Diese Vogelart ist ein bedeutendes Glied der küstennahen marinen Lebensgemeinschaft und brütet in dem durch die *Prestige*-Ölkatastrophe beeinflussten Areal. Krähenscharben fressen das ganze Jahr hindurch in der Nähe der Brutkolonien, so dass sie ein nützlicher Indikator für Umweltveränderungen sind. Vor dem Ölunfall verliefen die Bestandstrends der verölten und nicht verölten Kolonien ähnlich. Danach wurden bei den Kolonien im Einflussbereich des Öls stärkere Bestandsabnahmen (ca. 10%) verzeichnet, einmal im Vergleich mit den Bestandstrends vor der Ölkatastrophe und zum zweiten mit den Trends der nicht verölten Kolonien. Im Jahre 2003 fiel der Bruterfolg der verölten Kolonien 50% niedriger als der nicht verölten Kolonien aus. Die verfügbaren Daten legen nahe, dass vor der Ölkatastrophe dagegen der jährliche Bruterfolg zwischen den Kolonien nicht verschieden war. Somit zeigten sich bei Krähenscharben aus den Kolonien, die von der Ölverschmutzung betroffen waren, schon rasch negative Einflüsse der Ölbelastung. Die Reduktion des Bruterfolgs an den verölten Standorten dürfte durch subletale Effekte aufgrund der Ölexposition oder durch niedrige Nahrungsverfügbarkeit nach der Ölkatastrophe verursacht worden sein.

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