CHICK MORTALITY IN EUROPEAN SHAG *STICTOCARBO ARISTOTELIS** RELATED TO FOOD LIMITATIONS DURING ADVERSE WEATHER EVENTS.

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This study analyses the mortality of chicks of the European Shag *Stictocarbo aristotelis* in the Cíes Islands (NW Spain). Chick mortality on this island is the main cause of the yearly variation in chick production. By visiting the nests after hatching occurred we determined the periods of high mortality in four years of study. The weather conditions, especially rain and wind, during these periods were significantly more adverse than in the periods showing no mortality. There was a significant relationship between the yearly mortality rate in chicks and the number of windy and rainy days during the growth period of the chicks (May) during four years of study. The physical quality of the nest site during the four seasons of study was similar between nests affected by mortality and those that were not. In the colony we studied, feeding is almost exclusively by co-operative groups capturing sandeels, with this prey accounting for over 70% during the breeding season. During a period of heavy rains in 1997, the sandeels were found to be present in only 22% of the pellets and during this time co-operative fishing groups were not recorded. The most important factor involved in the mortality would appear to be food limitation.

Key-words: *Stictocarbo (Phalacrocorax) aristotelis* - Cíes Islands - chick mortality – weather - food availability – Ammodytidae - sandeel

**Stictocarbo aristotelis*, formerly known as *Phalacrocorax aristotelis*

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INTRODUCTION

In studies of population dynamics and their application to management and conservation, it is essential to determine the mortality rate and its causes (Perrins 1991). Adverse weather events are the main cause of the variability in the reproductive success of many bird species (e.g. Jehl & Hussell 1966; Elkins 1988; Coulter & Bryam 1995; Zatac 1996; Reynolds 1996; Siikamaki 1996). In seabirds heavy rains and storms have been identified as the main cause of the destruction of eggs and chick mortality (e.g. Aebischer 1993). Crawford *et al.* (1980) reported 800 dead chicks of the Cape Cormorant *Leucocarbo (Phalacrocorax) capensis* after heavy rainfall. In some species of Antarctic penguins chick mortality rises during periods of heavy snowfalls and storms (Sladen 1955). In the Sandwich Tern *Sterna sandvicensis* the availability of food decreases during periods of bad weather as poor visibility at the surface of the water make it more difficult for these birds to catch prey (Dunn 1972). The metabolic rate at sea of seabirds increases with wind speed (Gabrielsen *et al.* 1987, in Black-legged Kittiwake *Rissa tridactyla*; Gabrielsen *et al.* 1991, in Little Auk *Alle alle*). In other species with high speed gliding in high winds, such as the Northern Fulmar *Fulmarus* *glacialis*, windless periods decrease the metabolic rate (Furness & Bryant 1996).

In the European Shag *Stictocarbo aristotelis* adverse weather conditions have been related to laying date (Aebischer 1986), the size of the breeding population and the ratio of non-breeding adults (Aebischer & Wanless 1992) in addition to mortality and eruptive movements in winter (Potts 1969). Aebischer (1993) studied the effect of a storm on the Isle of May (Scotland) in 1982, which caused a 31% drop in reproductive success, due to the fact that some pairs abandoned the nest and others were obliged to lay a second brood. In February, 1994 between 3000 and 5000 dead European Shags were washed up along the coasts of Great Britain. This catastrophic mortality was attributed to an extended period of strong winds (Harris & Wanless 1996).

Aebischer (1985) has reported that 94% of the deaths of the Shag chicks on the Isle of May in 1982 could be linked to strong rainfall. He explains that rains affect medium-sized chicks and proposed that this may be due to parents being unable to protect medium-aged chicks that have not yet developed feathers. The mortality may therefore be related to the quality of the nest site. The present four-year study analyses European Shag chick mortality on the Cíes Islands (NW Spain) and how it relates to climatic factors in the breeding areas. We also examine the effect of the nest site quality on mortality and the changes in the diet during periods of bad weather.

METHODS

The Cíes Islands have a European Shag breeding population of 1000 pairs which prefer to nest in caves formed by granite rocks that fall from the cliffs (Velando 1997). Chick mortality has been monitored in three subcolonies adjacent on the Cíes Islands (42°15' N, 8°53' W), where the nest sites have been tagged since 1993. During the laying period, these colonies were visited daily or every other day in 1994-97. The laying date was recorded in each nest and the eggs were marked according to the laying sequence (Velando 1997). Chicks begin to hatch at the beginning of April (median hatching date 1994-96: 28 April, range 4 April - 6 June) and they fledge at the end of June. After hatching, we visited the areas every ten days in 1994 and 1995 (some of the visits were at greater time intervals because of the weather conditions) until fledging time. In 1996 the colonies were visited every five days from hatching to fledging. In 1997 we only made 3 visits in April and May and 4 visits in June, and mortality was estimated from the number of birds born in April and May and the number found dead. During each visit the death of the chicks in each of the monitored nests were recorded.

Daily weather data (daytime rainfall, total daily precipitation (day and night time), wind (mean speed and maximum daily gusts), and daily maximum and minimum temperature) were provided by the weather station of the Instituto Nacional de Meteorlogía at Vigo Airport (Peinador), 20 km from Cíes Islands. Weather conditions were compared between periods with or without mortalities during the same year (periods without mortalities were considered to be those periods where the mortality rate was less than 0.5% day^{-1}). Interannual variability of the mortality rate was related to the number of days with wind and rain during May for each season. The month of May was analysed because this is when the highest chick mortality occurred during the years under study and it is an important period for the parental care of the chicks. In this month, there are predominantly southerly winds associated with heavy rains (Carballeira *et al.* 1983). Days with wind and rain were considered to be those having average wind speeds of over 5B (>29 km h^{-1}), accompanied by a daytime rainfall >10 mm. These values have been used because of their adverse effect on the sea, affecting light penetrating below the surface layer. This effect probably makes it difficult for shags to catch their prey and/or the prey remain in the sand.

The relationship between mortality and the laying date, brood size and nest site quality was examined each year. A nest site quality index was obtained from a multiple regression model that related accumulated reproductive success from 1994 to 1996 to four descriptive variables of the physical habitat (of the 27 recorded initially). The Physical Quality Index = 1.61 Visibility from Nest + 1.14 Covering - 1.13 Slanted Walls + 0.96 Roof ($R^2 = 0.79$, $n = 128$; Velando *et al.* unpubl. data). 'Visibility from the nest' means the possibility of observation from the nest of access by other Shags or predators (from 1, total visibility, to 4, no visibility). 'Covering' is the number of walls surrounding the nest ledge, and which isolate it from the outside (between 0 and 4). 'Slanted Walls' refers to the number of walls (between 0 an 4) slanted towards the nest (concave) and which surround the ledge where the nest is located (they indicate the degree of drainage in the hollow). The more walls are slanted towards the nest, the greater the possibility of flooding. Finally, 'Roof' is covering of the top part of the nest (from 1, nest or ledge completely exposed, to 3, nest or ledge completely covered).

The effects of the weather on the diet of the European Shag on the Cíes Islands were studied. This was done by comparing the diet in May and June 1995, a year with 'good' weather conditions (few rainy and windy days during the breeding season), with that in May and July 1997, a year with a high number of wet and windy days in May. The diet was determined by examining pellets. The 1995 sampling was part of a broader study on the diet (Velando & Freire 1999), and the analysis presented here was restricted to pellets collected on dates close to those in the 1997 sampling. In 1995 15 pellets were collected on 19 May and 14 and on 17 June; in 1997 18 pellets were collected on 25 May and 18 on 5 July. On the Cíes Islands the consumption of sandeels Ammodytidae has been related to the strategy of group feeding (Velando 1997), a strategy similar to that described by Van Eerden & Voslamber (1995). This paper analyses the relationship between climatic conditions and the presence of feeding groups observed from land and on sea trips in a radius of 2 km around the island.

RESULTS

Significant differences between years were found in the reproductive success of the European Shag on the Cíes Islands (1994 to 1996; median test: $\chi^2_2 = 15.73$, $P < 0.001$), largely due to the interannual variability of chick mortality. In 1994 and 1997, 29% and 34% of the chicks died, respectively, while in 1995 and 1996 the mortality was only 4% and 13%, respectively (Table 1). Chicks were found dead in 1994, 1995 and 1996, in only

Table 1. Mortality of European Shag chicks during the 1994 to 1997 breeding seasons in three subcolonies studied on the Cíes Islands. The percentage of the total number of chicks hatched is given in parentheses. The reproductive success is the number of survivor chicks per nest with eggs.

	1994	1995	1996	1997*	Total
Nests studied	89	93	80	36	262
Chicks hatched	149	174	168	72	497
Reproductive success (chicks/nests)	1.2	1.83	1.83	0.92	
Dead chicks prior to 15 days of age	26	6	10	-	42
	(17%)	(3%)	(6%)	-	(8%)
Dead chicks after 16 days of age	18	2	12		32
	(12%)	1%)	(7%)	-	(6%)
Total dead chicks	44	8	22	25	74
	(29%)	(4%)	(13%)	(36%)	(15%)

* In 1997 only the total number of dead birds was calculated.

Table 2. Periods of high chick mortality in broods of the European Shag on Cíes Islands in each year studied. The number of chicks that died in each period is given in parentheses.

Year	Chicks died	Periods of high mortality	
1994	44	5-22 May (33 chicks)	22 May-6 June (9 chicks)
1995	8	7-18 May (6 chicks)	
1996	22	21-29 April (10 chicks)	14-18 May (10 chicks)

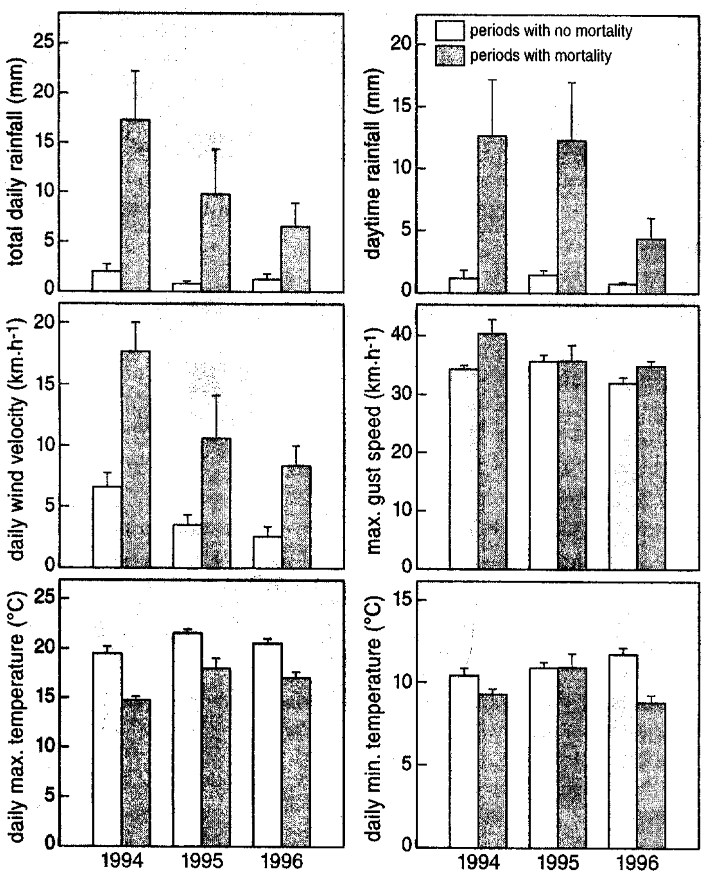

Fig. 1. Rainfall, wind and temperature (mean ± SE) during the chick development period (April to June) in periods of mortality (light shaded bars) and no mortality (dark shaded bars); mortality of chicks <0.5%·day^{-1} in the European Shag on the Cíes Islands. For each of the three years of study the following are shown: daytime and total daily rainfall (in mm), daily mean wind velocity and maximum gust speed (both in km h^{-1}), and daily maximum and minimum temperatures (in °C). Data were provided by the weather station of the Instituto Nacional de Meteorología in Vigo at Peinador Airport.

certain periods (Table 2). High mortality related to the spring rainstorms with southerly winds was recorded in 1997, but as we only visited the nests three times the exact date of death could not be pinpointed (of 72 birds hatched, 25 had died by 30 May).

There were large meteorological differences between the mortality periods in 1994, 1995 and 1996 and the periods of the same years during which there was no mortality (Fig. 1). The mortality periods were characterised by south winds that bring storms and rain showers. During the periods of mortality, the rainfall was significantly heavier than during the rest of the growth period of the chicks, both in terms of rain during the daytime (t-test, 1994 t_{89} = 5.01; 1995 t_{89} = 4.56; 1996 t_{89} =

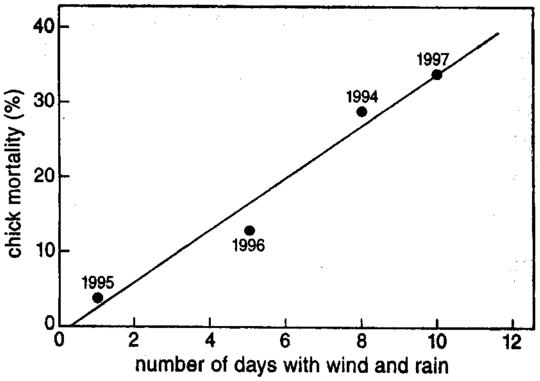

Fig. 2. The relationship between the mortality rate of European Shag chicks during each breeding season on the Cíes Islands and the number of days with wind and rain in May. Stormy days were considered to be those having maximum daily wind gusts of >29 km h^{-1} and daytime rainfall of >10 mm. Meteorological data were provided by the weather station of the Instituto Nacional de Meteorología in Vigo at Peinador Airport. The linear regression y = 3.50x - 1.00 (R^2 = 0.97) is showed.

3.70, $P < 0.001$ in the three years) as well as the total daily value (1994 $t_{89} = 5.85$; 1995 $t_{89} = 5.25$; 1996 $t_{89} = 3.58$, $P < 0.01$ in the three years). The mean wind speed was higher on the days when mortality occurred during the three years (1994 $t_{89} = 3.84$; 1995 $t_{89} = 2.74$; 1996 $t_{89} = 3.49$, $P <$ 0.01 in the three years). The differences in the wind speed of the maximum gusts between the periods were only significant in 1994 (1994 $t_{89} =$ 2.74, $P < 0.01$; 1995 $t_{89} = 1.28$, n.s.; 1996 $t_{89} =$ 1.76, n.s.). In the mortality periods recorded in the three years of study, the maximum temperatures were significantly lower (1994 $t_{89} = 3.62$; 1995 t_{89} = 2.65; 1996 $t_{89} = 2.63$, $P < 0.01$ in the three years), while in the case of minimum temperatures, significant differences were only detected in 1996 (1994: $t_{89} = 1.13$, n.s.; 1995: $t_{89} = 0.05$, n.s.; 1996: $t_{89} = 3.34$, $P < 0.01$).
There was a significant positive correlation between chick mortality and adverse weather conditions, number of days with wind, predominantly southerly, and rainfall in May ($r = 0.984$, $P =$ 0.016, Fig. 2). 1997, the year having the highest mortality, had 10 days of wind and rain, while in 1995 there was only one windy and rainy day in May, and was the year with the lowest mortality (4%).

There were no differences in the mean laying date (days from the beginning of the year) between the nests with mortality and nests in which all chicks survived in 1994 and 1996 (91.2 and 91.7 Julian days, respectively, in 1994 $t_{61} = 0.17$, n.s.; 78.3 and 78.8 days in 1996 $t_{63} = 0.10$, n.s.). Age structure at death in 1994 (n = 44) was 2% between 1 and 7 days, 57% between 7 and 15 days, 27% between 15 and 30 days, and 14 % over 30 days old. In 1995, 6 chicks died before they were 15 days old (75 %) and only two chicks aged 15 and 20 days died. In 1996, 41% of the dead birds (n = 22) were under 15 days old and 59% over 15 days. In 1994 and 1997 (the years showing higher chick mortality rate) the nests affected by mortality had initially larger broods

Table 3. Index of the physical quality of the nest site (mean ± SE; see Methods) in broods of the European Shag on the Cíes Islands for nests with and without chick mortality during the four study years. The sample size (n) are given in each case.

	Nest site index of physical quality			
	with chick mortality	without chick mortality	t-test	P
1994	4.53 ± 0.37 n = 34	4.54 ± 0.37 n = 26	0.01	n.s.
1995	3.98 ± 0.70 n = 6	5.18 ± 0.26 n = 60	1.53	n.s.
1996	4.45 ± 0.51 n = 20	4.88 ± 0.28 n = 49	0.73	n.s.
1997	4.73 ± 0.40 n = 21	5.04 ± 0.35 n = 15	0.53	n.s.

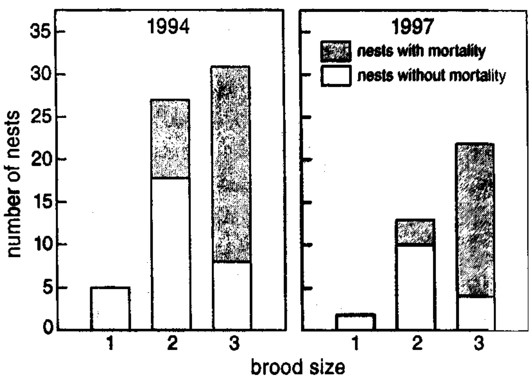

Fig. 3. Distribution of brood size frequency in the European Shag in nests with (light shaded bars) and without mortality (dark shaded bars) on the Cíes Islands in 1994 (left) and 1997 (right).

(median 3 chicks in both years), than those that were not affected (median 2 chicks per brood in both years; Mann-Whitney test, 1994: $Z = 3.68$, $n = 63$; 1997: $Z = 3.5$, $n = 36$, $P < 0.001$ in both years). In 1995 and 1996, however, there were no differences in brood size, with medians in both years of 3 chicks per brood in the nests affected and unaffected by mortality (Mann-Whitney test, 1995 $Z = 0.08$, $n = 66$, n.s.; 1996 $Z = 0.08$, $n = 63$, n.s.). In 1994, 72% of nests with mortality had three chicks and 28% had two. Five nests had one nestling, all of which survived (Fig. 3). In 1997, of 22 nests with three chicks, 18 had mortality (one nestling in 12 nests, two in 5 nests, and in one nest all 3 chicks died). One chick died in three of 12 nests with two chicks. There were only two nests with one nestling each where both survived (Fig. 3). Nest site quality during the four seasons of study was similar in nests affected and unaffected by mortality (Table 3).

The effect of climatic conditions on the diet of the European Shag was analysed by comparing the pellets collected on similar dates in 1995 and 1997 (Table 4). In May 1997 it rained heavily and before the week the pellets were collected there were four days (just before the collection) of wind and rain (with heavy rain mean 129 ± 37). In May 1995 it rained very little, with only one wet windy day (with only 4 mm daytime rain) during the week the pellets were collected. It did not rain during the sample collection at the end of June and during early July 1995 and 1997. In May, 1997 only 4 of 18 pellets collected contained sandeels but in May 1995 sandeels were found in 14 out of 15 pellets ($G = 19.1$, $df = 1$, $P < 0.0001$). The presence of sandeels in May 1997 also differed from their presence at the beginning of July 1997 when 17 out of the 18 pellets examined contained sandeels ($G = 21.1$, $df = 1$, $P < 0.0001$).

From 23 to 26 May 1997 we observed no

Table 4. The frequency of occurrence of each prey taxon in pellets of the European Shag on the Cíes Islands in May and June of 1995 and in May and July of 1997. Days with wind (maximum gust >29 km h^{-1}) and daytime rain (>10 mm) the week (7 days) before pellets were collected are also shown.

	1995		1997	
	May	June	May	July
number of pellets	15	14	18	18
Ammodytidae	93.3	71.4	22.2	94.4
Atherina presbyter	13.3	28.6	72.2	5.6
Symphodus spp.	33.3	28.6	33.3	5.6
Trisopterus spp.	6.7	14.3	22.2	11.1
Chelon labrosus	0.0	0.0	27.8	0.0
Others	13.3	14.3	16.7	11.1
Days with wind and rain in the week	1 (14%)	0 (0%)	4 (57%)	0 (0%)

feeding groups in our trips around the island. From 5 to 11 June, several feeding groups were located every day. In 1995, on each day during the week before the pellet collection dates, feeding groups were frequently seen throughout the day (Velando 1997). The feeding groups were easy to locate, with the group size varying between 300 and 1000 birds moving around the island. On occasions we observed no feeding groups in a radius of 1 km around Cíes Island (winter and in this study), only a few solitary birds were located, the total being less than 50 birds (Velando 1997).

DISCUSSION

This study shows a clear relationship between adverse weather conditions during the period of one month after hatching and chick mortality in the rest of breeding season in European Shags breeding on Cíes Islands. Chick mortality was relatively high in years with more strong winds and precipitation, There was a significant correlation between the number of days with wind and rain in May and chick mortality rate in the total breeding season was found.

Aebischer (1985) showed that rains have a particular effect on medium-sized European Shag chicks (in his study, 72% of the dead birds were between 20 and 37 days of age), and related mortality to nest site quality. In contrast in Cíes Island, 57% of dead chicks were small-sized (between 1 and 15 days of age). The Shags on Cíes Islands breed in hollows left by the falling granite rocks on the slopes of the cliffs: hollows that protect the chicks from adverse weather conditions (Velando *et al.* unpubl. data). In our study, there was no correlation between mortality and the index of the physical quality of the nest site during any of the four years of study. We also found no relationship between laying date and chick morality: age structure was similar in broods with and without mortality. Chick mortality was correlated with periods of wind and rain immediately after hatching. There was, however, a negative effect of brood size: in years with high mortality (1994, 1997), pairs with larger clutches suffered most chick losses. This suggests that chick mortality is related to a decline in food availability. Because pairs with larger-sized broods have to meet higher energy requirements, these adults have to make more feeding trips and so face greater problems in meeting chick food requirements (Pearson 1968; Leger & McNeil 1987). During periods when food is scarce, there may be also be a reduction of brood size, so ensuring the growth and the quality of the surviving chicks (Amundsen & Stokland 1988).

In 1995 sandeels comprised over 70% of their diet during the breeding season, from February to June (Velando & Freire 1999). The capture of sandeels by Shags on the Cíes Islands has been linked to their formation of co-operative groups of Shags of up to one thousand individuals that fish on shallow sand banks (<15 m). The formation of groups may be determined by underwater visibility, which would explain why they carry out their fishing activities in shallow waters, and also why no feeding groups were detected during the wet, windy days in 1997. Cíes Islands are located in the outer area of the Ría de Vigo. Around the island there are larger sandbanks, and, beyond these banks, the sea depth increases rapidly (>30m). Feeding groups were not seen around Cíes Islands in winter, but solitary shags were seen feeding in the inner area of Ria de Vigo, more than 10 km from Cíes Islands (Velando 1997).

The presence of sandeels in the diet varied significantly between May 1995 (good weather year) and May 1997 (bad weather year). In May there were adverse weather events, with a great number of wet, windy days, and only 22% of the pellets collected contained this prey. Moreover, the presence of sandeels also varied significantly between May and July 1997. In July, several feeding groups were located and the presence of sandeels reached 94%, which implies that they were available in areas near the Cíes islands that year. Potts (1969) reported a correlation between eruptive movements and atmospheric conditions, suggesting that prey availability is reduced during periods of bad weather, due to the poor underwater visibility, difficult conditions for flight and because Lesser Sandeels *Ammodytes tobianus* as the dominant prey bury themselves in the sediment. The higher energetic cost of activity during windy conditions has been well documented in other seabirds (Gabrielsen *et al.* 1987, 1991), and in the Shag, the metabolic cost of flapping flight increases with wind speed. Laboratory experiments on Lesser Sandeels, showed that they catch their prey visually (Winslade 1974a b). When light was scarce, the fish remained buried in the sand, and only came out to swim in periods of high light intensity.

Two factors may be involved in the chick mortality of the European Shag associated with wind and rainfall. The first, and probably most important, is food limitation, due to reduced underwater visibility, the greater amount of energy spent in the fishing effort by the parents, and because most prey remain buried in the sediment. The second factor, of less importance, may be the effect of the weather conditions themselves on the health of the chicks.

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SAMENVATTING

Op de Cíes Eilanden (NW Spanje) wordt van jaar tot jaar een aanzienlijke variatie gevonden in het aantal uitvliegende jonge Kuifaalscholvers *Stictocarbo aristotelis*. Deze fluctuatie wordt vooral veroorzaakt door grote jaarlijkse verschillen in kuikensterfte. Door frequente nestbezoeken werd getracht de perioden te achterhalen die voor kuikens klaarblijkelijk kritiek zijn. Al snel bleek dat kuikensterfte vooral optreedt in regenachtige en winderige perioden. Daarom werd de 'kwaliteit' (mate van beschutting) van de verschillende nesten in kaart gebracht en onderzocht in hoeverre er verschillen bestonden in de aanvoer van voedsel naar de kolonie tussen perioden met mooi en slecht (regenachtig, winderig) weer. De aandacht werd vooral gericht op de maand mei, een periode waarin de nog jonge kuikens een snelle groei doormaken. Het bleek dat de jongensterfte in beschutte nesten niet verschilde van die in meer aan weer en wind geëxposeerde nestplaatsen. Het voedsel van de jonge Kuifaalscholvers bestond gedurende het gehele seizoen voor ongeveer 70% uit Zandspiering *Ammodytes* spp. Om deze vis te bemachtigen opereerden de Kuifaalscholvers meestal in grote sociaal vissende groepen. Tijdens een periode met zware neerslag bleek Zandspiering nog slechts in 22% van de braakballen vertegenwoordigd te zijn, terwijl sociaal vissende Kuifaalscholvers in het geheel niet werden opgemerkt. Geconcludeerd wordt dat de kuikensterfte hoofdzakelijk veroorzaakt wordt door ondervoeding als gevolg van een verminderd aanbod van de geprefereerde prooien.

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