

The status and recent breeding performance of the critically endangered Northern Bald Ibis *Geronticus eremita* population on the Atlantic coast of Morocco

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The main wild population of the Northern Bald Ibis *Geronticus eremita* breeds on the Atlantic coast of Morocco in the Agadir region. This paper describes the numbers of breeding pairs over the last two decades, the recent breeding performance, the causes of egg and chick losses and their conservation implications. Since 1980 there has been no overall decline in numbers with, over the last 5 years, 59–74 pairs breeding and a peak prebreeding population of around 220 birds. In contrast with the now extinct Northern Bald Ibis populations in Turkey and elsewhere in Morocco, the birds are present in the Agadir region throughout the year and do not appear to migrate from the area outside the breeding season. Breeding performance is highly variable from one year to the next but does not appear to be related to rainfall in the vicinity of the colonies as has been reported elsewhere. It is suggested that coastal fogs in this region may buffer the adverse impacts of low rainfall and may in part account for the year-round residency of the birds. The main causes of breeding failures have been loss of eggs to predators and, most importantly, poor chick survival as a result of starvation and predation. Conservation action to date has focused on reducing the negative influences on breeding success but it is recognized that for such a long-lived bird adult survival is also likely to be an important limiting factor on the population size.

The Northern Bald Ibis or Waldrapp *Geronticus eremita* once had an extensive breeding distribution from Turkey through North Africa to Morocco, and was even known to breed in the Alps as late as the sixteenth century (Hirsch 1979, Collar & Stuart 1985, Tomlinson 1994, Pegoraro 1996, Pegoraro & Foger 1999). It is now listed as critically endangered (BirdLife International 2000), having disappeared from most of its former range over the last century. In the east of the range, in 2002 a newly discovered but very small population of three pairs occurs in Syria (G. Serra pers. comm.), but otherwise the last remaining wild population at Birecik, southern Turkey, became extinct in 1989 although semi-wild birds remain and breed in the area (Akcakaya 1990, Arihan 1998, 1999). There are still occasional sightings of birds around the Red Sea in Saudi Arabia, Yemen and Eritrea (Hirsch 1979, Brooks 1987,

Brooks *et al.* 1987, Bezzel & Wartmann 1990, Schulz & Schulz 1992). In Algeria, the last remaining colony is thought to be extinct although very little recent information is available (Arhzaf 1993, A. Fellous pers. comm.). The IUCN listing as 'critical' (BirdLife International 2000) is based on the sharp decline in 1996 when there was an unexplained mortality incident (Touti *et al.* 1999), and on the very small area of the actual breeding sites.

Morocco, at the western limit of the former range, now supports the main wild population of the Northern Bald Ibis. However, even here, the bird has declined substantially in numbers and range over the last few decades. It formerly bred at over 40 sites, mainly in the High and Middle Atlas mountains and along the Atlantic coast (Hirsch 1979 and unpubl. obs., Bowden *et al.* 1997). All of the inland colonies have, apparently, now disappeared, leaving the last remaining wild population in the Agadir region of southern Morocco (Brindley *et al.* 1995).

In spite of the precipitous and widespread decline of the Northern Bald Ibis, the causes of this decline

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have remained obscure. Habitat loss, persecution, climate change and the use of pesticides have all been suggested but it has not been possible to demonstrate convincingly that any one of them has been the primary cause (Hirsch 1979, Collar & Stuart 1985). Direct poisoning by pesticides was a key cause of the collapse of the Birecik population (Hirsch 1979, Akcakaya 1990), but other factors are likely to have driven the chronic and widespread decline throughout the former range.

In 1991 the Moroccan authorities designated the Parc National de Souss-Massa (PNSM) (30°05'N, 9°40'W) – a coastal national park covering an area of 33 800 ha specifically to protect the nesting and feeding areas of the Northern Bald Ibis south of Agadir. The other main breeding and feeding area of the Ibis is 50 km north of Agadir, again a coastal strip, in the region of Tamri (30°42'N, 9°50'W) which is a no-hunting area designated as an SIBE (Site d'Interêt Biologique et Ecologique), but with no formal protection. Both areas have very sandy substrates, and are predominantly littoral steppe, which is sporadically used for the unintensified cultivation of wheat and barley. Vegetation consists of sparse cover of perennial shrubs with some growth of annuals in early spring depending on the grazing regime and rainfall. Sheep, goats, donkeys and camels graze much of the area, and another important human activity is fishing from the shore. The aeolianite sandstone cliffs are an important feature, providing inaccessible nesting ledges for the Ibis. The climate is mediterranean, with temperatures varying between 7 and 35 °C and mean annual rainfall between 120 mm in the south and 240 mm in the north. Regular coastal fogs are probably important for the maintenance of the vegetation under what are otherwise arid conditions. There are numerous scattered villages in both areas, but very few asphalt roads, despite the close proximity of the city of Agadir.

In 1994 the Royal Society for the Protection of Birds on behalf of BirdLife International was invited by the PNSM Administration to work with local staff to develop a monitoring programme for the Northern Bald Ibis and to initiate research on the ecology of the species to inform the management plan for the Park (GTZ 1995). This programme began in 1994/95 and continues to evolve with the changing needs and as management implications begin to emerge (Bowden & Aghnaj 1999). This paper describes the numbers and breeding performance of the birds in the Agadir region from 1995 to 1999 and discusses the implications of these findings for current and

future conservation action. This is the first time such information has been published for this critically endangered species.

METHODS

The main breeding colonies of the Northern Bald Ibis are in the PNSM to the south of Agadir but there is also a recently expanded colony on the coast 50 km to the north of the city near the village of Tamri. The two nesting areas are separated by some 100 km (Fig. 1). Outside the breeding season the birds largely roost communally either at the breeding colonies or at a limited number of other sea-cliff sites. At the outset of the project an inventory of all known roost and breeding sites was made by consulting PNSM staff and local villagers. These sites were then visited and the birds counted approximately weekly throughout the appropriate seasons. As the project has developed and our knowledge increased, local wardens have been appointed and trained to cover each of the key sites. By 1999 seven such wardens were employed.

The frequency and quality of our count and other information have improved during the course of the project. For 1995 and 1996 the counts, although regular, were not always co-ordinated on the same day. From 1997 onwards, co-ordinated weekly counts were conducted throughout the year to assess the total numbers of birds in the region. One non-breeding season roost site within the PNSM is particularly important and a warden was employed to make daily counts from autumn 1995 onwards.

During the breeding season the colonies were monitored each day by the wardens. The nesting cliffs, consisting of aeolianite (essentially consolidated sand dune), are extremely fragile and prone to rapid erosion (Fox & Moore 1996). Direct access to the nesting ledges is therefore out of the question because of concerns both for human safety and for the birds. All observations on the nesting birds have consequently been made by telescope from vantage points at ranges of 50–100 m. Care was taken to ensure that this did not disturb the birds, but this meant that it was not always possible to see the contents of all nests throughout the nesting cycle. It was always possible to determine the status of each nesting attempt.

At PNSM, six different nesting sites (A–F; not marked on Fig. 1) over a stretch of 6 km of coastal cliff have been used over the course of the study, although no more than four have been used simultaneously

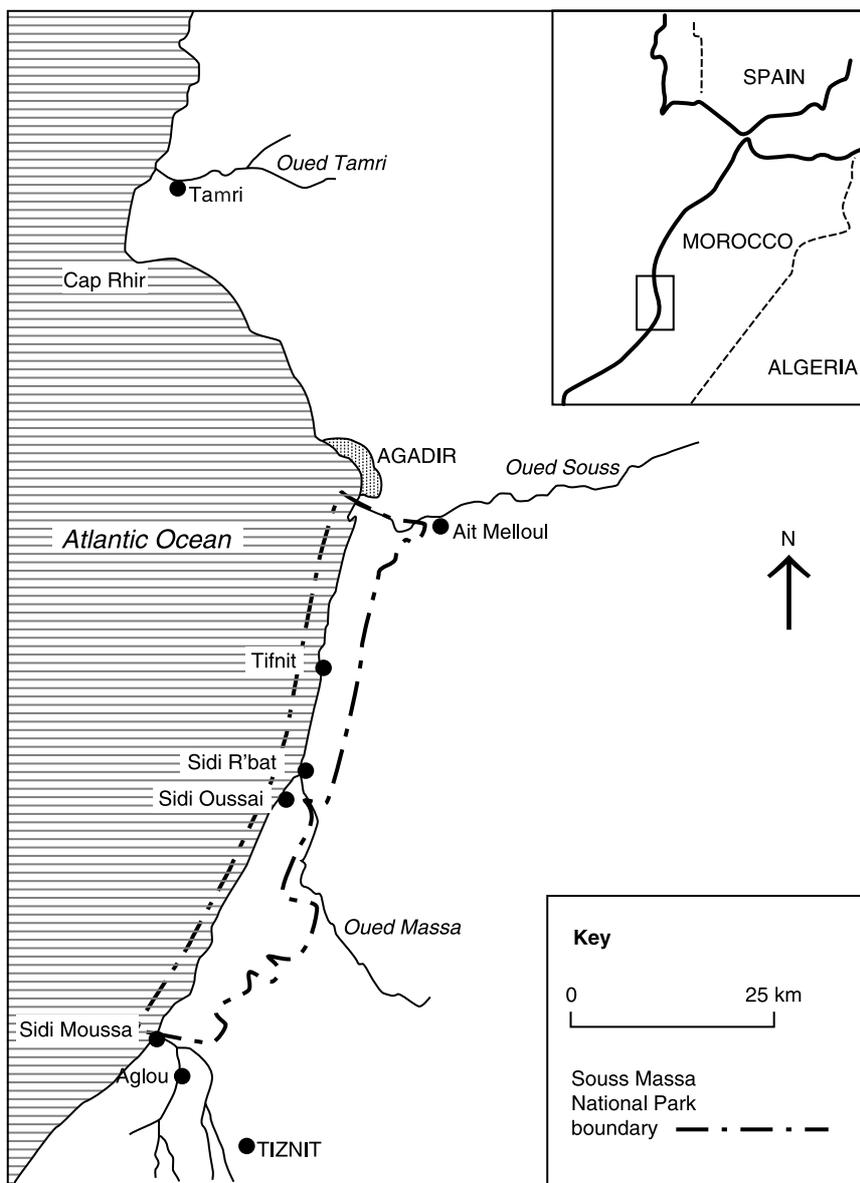


Figure 1. The region of south-west Morocco showing the location of the Souss-Massa National Park and Tamri, the two areas where Northern Bald Ibis breed and are largely resident. Breeding and roosting sites are not marked to minimize the risk of increasing visitor pressure, which can cause serious disturbance to the birds.

in any one year. At Tamri, a single nesting cliff has been used during this study period, although two other nearby sites are known to have been used previously. Inspections by the wardens on nearby areas during the breeding season are carried out each year to check for newly colonized nesting cliffs. For the purposes of the analyses, data from all the PNSM sites have been combined and compared with those from Tamri.

Nesting attempts were identified when adults were seen to carry back material to build a nest, and annotated sketch maps of all nest-sites were made each year. The numbers of pairs laying eggs, and the first egg date, were determined from direct observation of the eggs or of birds incubating, which normally commenced from the first egg. The hatching date of the first egg was determined from the changed behaviour of the adults. In a few cases, in

which only the hatching dates were known, back calculation was used to derive the first egg date assuming an incubation period for the first egg of 28 days (Hirsch 1979; data from clutches observed from laying to hatching in this study $n = 52$, median incubation period 28 days, range 21–59 days). Only when the first egg date could be determined to within 3 days was it included in the analysis.

Breeding attempts that failed during incubation often resulted in very rapid relaying. Although none of our birds was individually marked, the short time interval, and lack of any nest refurbishment between attempts, suggested that the same birds were involved. In assessing overall productivity we have therefore used the data from the last clutch laid in any nest. The probability of relaying after failure during incubation was analysed by logistic regression, with calendar date and period of incubation before failure as the predictor variables.

Each stage of the nesting cycle was analysed separately to identify the key limiting factors. As all nests were observed each day, the simple proportion of nests succeeding to hatching was used to assess incubation success. Hatching success was estimated from the numbers of eggs and small young observed in the nest around hatching time. This was likely to be underestimated as small chicks that hatched and died within 2 days were probably missed. The daily probability of brood reduction was analysed by logistic regression, with days since the start of incubation and first egg date as the predictor variables. The probability of brood reduction rather than daily chick survival was used in this analysis because, with unmarked chicks and asynchronous hatching, it was uncertain which individuals in a multiple brood were the ones actually lost.

Previous work with Northern Bald Ibis elsewhere in Morocco suggests that rainfall is a key determinant of breeding success, with a two-fold higher productivity in wet years than dry years (Robin 1973). We therefore analysed our breeding parameters against daily rainfall data obtained from Tamri village and Sidi R'bat at the mouth of Oued Massa, which are each within 5 km of the main feeding areas for each population, respectively. We correlated first egg date, mean clutch size, overall productivity per pair and chick survival with the total November to March rainfall in the preceding winter.

In May 1996 there was a major mortality incident at PNSM (Touti *et al.* 1999). Initially, sick birds were noticed near one of the PNSM breeding colonies and over the following 2 weeks a total of 21 corpses of

full-grown birds were found and six nestlings died prematurely, presumably the result of losing one or both parents. Counts at the colonies suggested that a total of 38 full-grown birds were lost from the population during this short period. In spite of intensive veterinary investigations in Morocco and the UK the cause of the incident was never determined although, if only by elimination of all other likely causes, avian botulism or an obscure virus remain possibilities (Touti *et al.* 1999). Following this incident it was decided that it would be desirable to provide a source of clean water experimentally near the breeding colonies for the birds to drink and bathe in. Accordingly, a small, shallow 0.3-m² concrete pool was built on the cliff near colony B in 1998 and a further one added near colony E in 1999. The pools were cleaned and topped up with fresh water by the wardens each day and records were kept of the usage by birds. The breeding performance of birds with and without access to these drinking points was compared.

RESULTS

Seasonal movements and total numbers

The results of the coordinated counts at the breeding colonies and roosts from 1994 to 1999 are summarized in Figure 2. Many populations of Northern

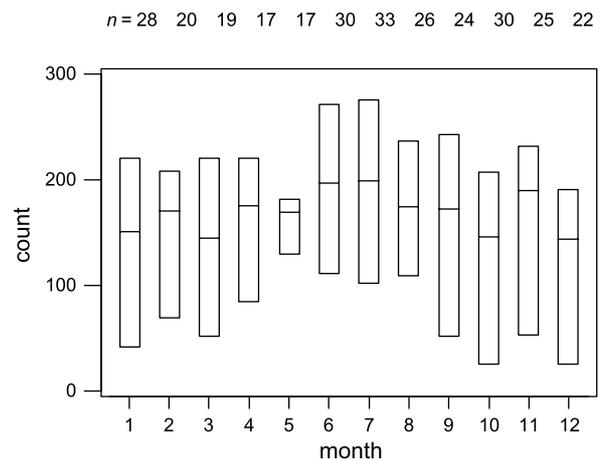


Figure 2. Total counts of Northern Bald Ibis from 1995 to 1999 in the Massa and Tamri regions. Counts from all breeding colonies and known roost sites have been summed. Each diagram shows the median count (X) for each month together with the range over the period. The number of counts for each month is shown at the head of each graph. The counts include both full-grown and recently fledged young birds.

Bald Ibis, including those in the Atlas Mountains and at Birecik, were migratory, leaving the breeding areas in winter. It had been assumed that this was also the case for those breeding on the coast of Morocco, but these data show that there are significant numbers of birds using the PNSM and Tamri areas throughout the year. The general pattern is for stable numbers in the prebreeding and breeding periods, an increase immediately after breeding, and more variable and occasionally low counts at other times. These low counts suggest that the birds may then be using unknown local sites and possibly that some movements outside the region may be taking place.

Counts at the end of the breeding season in late May and June included recently fledged young and consequently were often higher than counts during the rest of the year. However, the birds were more mobile at this time, and some may well have left the area or roosted at unknown sites. For this reason the more consistent prebreeding counts are a more reliable measure of the population level, when almost all of the birds roost at the colonies. These counts show the total population to be around 220 birds in 1999. The number breeding dropped to 59 pairs from 77 after the 1996 mortality. Before 1996, a higher percentage of the birds bred than after the mortality incident. Since then the prebreeding population counts, but not the number of breeding pairs, have risen by 10% per annum, suggesting that numbers are building up, but the younger birds have not yet been recruited to the breeding population.

Outside the breeding season the distribution of roosting birds varies and is not totally consistent between years. Some birds continue to roost at or near the breeding colonies (particularly true at Tamri) but others roost elsewhere. This is particularly so at PNSM where the majority of the birds roost 30 km from the breeding colonies outside the breeding season. Figure 3 summarizes the counts from this site, which is of immense importance with over 80% of the world population of Northern Bald Ibis there at times in the autumn.

The total numbers of nesting pairs and the numbers of young fledged each year from the PNSM and Tamri colonies are shown in Table 1. All available count data, including some previously unpublished records from U. Hirsch and K. Pegoraro, from 1980 onwards have been used in the table. Since 1994 we have used the laying of eggs in a nest as the criterion for a nesting pair although there are always a few pairs that build a nest but do not lay eggs. Note that non-laying pairs were excluded from calculation of

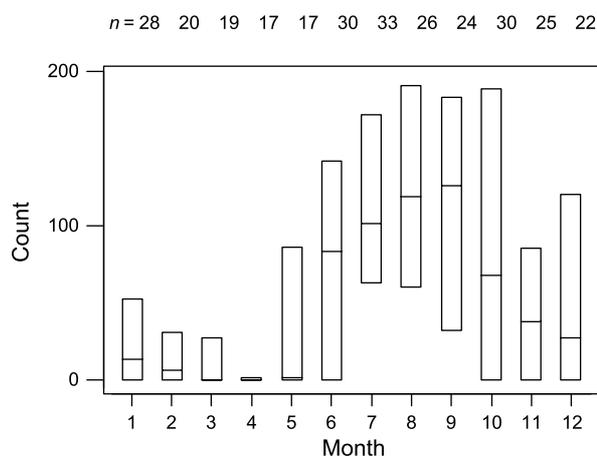


Figure 3. Total counts of Northern Bald Ibis at the main non-breeding roost site within the PNSM for the period 1995–99 (see Fig. 2 for explanation).

the productivity figures (young fledged/pair). As counts in the early years were often made late in the season it is possible that they were underestimates as birds may have already laid eggs, failed and left the colony before the count took place. Table 1 also includes the best estimate of the total prebreeding population based on the peak sum of the coordinated counts between January and early March when counts were most stable. Over the 2-year period for which we have information there is no evidence for any long-term trend in the total number of pairs nesting in the region, although there are large fluctuations from one year to the next ($F_{1,14} = 0.005$, $P = 0.94$). Over the last 5 years there has been a decrease in the numbers at PNSM that has been partially compensated for by an increase at Tamri, supporting the supposition that there is interchange between the two sites.

The sharp decrease in numbers of breeding pairs at PNSM in 1997 appears to have resulted from the mortality incident in May 1996 (Touti *et al.* 1999), and even by 1999 breeding numbers had not recovered to their high level of 1996. It is not known whether similar incidents have occurred in the past, although the large fluctuations in breeding numbers suggest that they may have done so.

First egg dates

The first egg laying dates are summarized in Table 2. With the exception of Tamri in 1995, when early season visits were relatively infrequent, the first egg dates could be determined for most nests. Using the

Table 1. The numbers of breeding pairs and fledged young of Northern Bald Ibis at the PNSM and Tamri colonies from 1980 to 1999. From 1995 onwards the numbers of pairs building nests and not subsequently laying eggs and the total prebreeding (January to mid-March) maximum count of all birds are given.

Year	PNSM				Tamri				Total Pairs that laid eggs	Total Pairs with no eggs	Total prebreeding count
	Pairs that laid eggs	Pairs with no eggs	Total fledged young	Young fledged/pair	Pairs that laid eggs	Pairs with no eggs	Total fledged young	Young fledged/pair			
1980	67	–	–	–	8	–	–	–	75	–	–
1981	48	–	–	–	8	–	–	–	56	–	–
1982	56	–	–	–	12	–	–	–	68	–	–
1983	–	–	–	–	–	–	–	–	–	–	–
1984	34	–	–	–	–	–	–	–	–	–	–
1985	46	–	–	–	10	–	–	–	56	–	–
1986	38	–	33	0.84	3+	–	–	–	–	–	–
1987	38	–	–	–	10	–	–	–	48	–	–
1988	50	–	33–37	0.68	10	–	–	–	60	–	–
1989	48	–	89	1.93	11	–	–	–	59	–	–
1990	49	–	–	–	14	–	–	–	63	–	–
1991	38	–	–	–	–	–	–	–	–	–	–
1992	39	–	48	1.18	9	–	–	–	48	–	–
1993	39	–	20	0.45	10	–	–	–	49	–	–
1994	46	–	44	0.92	19	–	23	1.21	65	–	–
1995	50	2	60	1.20	24	5	13	0.54	74	7	218
1996	54	4	49	0.91	23	5	9	0.39	77	9	223
1997	32	2	22	0.69	27	0	28	1.04	59	2	183
1998	33	3	52	1.58	29	4	25	0.86	62	7	208
1999	32	5	65	2.03	28	4	18	0.64	60	9	220

Table 2. The distribution of first egg dates for nests in the PNSM and Tamri areas from 1995 to 1999. January 1st = day 1. The data include all clutches including those that subsequently failed and their replacements.

Year	PNSM				Tamri			
	<i>n</i>	range	mean	se	<i>n</i>	range	mean	se
1995	31	53–99	67.3	1.7	6	59–76	68.0	3.6
1996	60	56–109	74.6	0.6	24	53–97	71.0	2.4
1997	31	47–94	63.9	1.9	27	49–98	60.8	2.2
1998	35	59–122	79.9	2.5	30	53–98	65.9	1.8
1999	32	59–114	74.4	1.7	28	64–106	77.9	1.5

data from all years there were significant year and year*site effects on mean laying date (year $F_{4,286} = 15.67$, $P < 0.001$; site $F_{1,286} = 3.59$, n.s.; year*site $F_{4,286} = 7.15$, $P < 0.001$); however, these depended on the late laying at PNSM in 1998. If 1998 data were removed from the sample the only significant effect remaining was that of year ($F_{3,239} = 16.43$, $P < 0.001$). So, although the timing of breeding varied by up to 16 days from year to year, it was fairly well synchronized between the two sites in all but one of the five years.

Table 3. The number of nests in each of the PNSM subcolonies (A–F) over the period 1995–99.

Year	A	B	C	D	E	F
1995	6	9	37	0	0	0
1996	7	9	42	0	0	0
1997	7	7	20	0	0	0
1998	12	8	0	1	13	2
1999	13	8	0	0	14	2

Subcolony shifts

The late laying at PNSM in 1998 followed a major shift in breeding site. Until 1998 the main breeding site was colony C (Table 3) but this was abandoned in 1998. The breeding ledges were occupied early in the season as usual but then, for no obvious reason, all the birds left the colony and eventually settled to breed elsewhere. Two new colonies (E and F) were founded and six pairs used new ledges at colony A which had been extended by a team of climbers 5 years previously. The exact cause of these movements is not known but it is possible that it resulted from competition for the nesting ledges with Great

Table 4. Clutch size for PNSM and Tamri in 1995–99. Some clutches are lost during laying and early incubation and are subsequently replaced and incubated. In these cases only the last laid clutch in a particular nest has been included in this sample.

Year	PNSM				Tamri			
	<i>n</i>	range	mean	se	<i>n</i>	range	mean	se
1995	31	1–5	3.16	0.15	1	–	3.00	–
1996	47	2–5	2.87	0.09	5	2–3	2.60	0.25
1997	25	1–3	2.68	0.13	19	2–3	2.95	0.05
1998	10	1–3	2.30	0.22	18	2–3	2.33	0.11
1999	15	2–4	3.07	0.12	28	2–4	2.96	0.06

Cormorants *Phalacrocorax carbo maroccanus* or from some disturbance unseen by the wardens, perhaps at night. The consequence of this colony shift was that egg laying was delayed by around 10 days at PNSM in 1998.

Clutch size

Clutch size could be determined for 63% of the PNSM nests and 54% of those in Tamri. The median clutch size was three in all years and sites except for 1998 when it was two eggs at both PNSM and Tamri (Table 4). At PNSM in 1995 and 1996 there were 13 clutches of four or five eggs. Up to three of these eggs were thought to have resulted from extra females laying an egg in the nest, and the true figure may have been even higher than this. In one of these cases an Ibis was seen to throw eggs out of the nest. No five-egg clutches have been seen since the mortality incident at PNSM in 1996 although there were three instances of four-egg clutches in 1999.

The mean clutch-size did not differ significantly between colonies. It did, however, differ significantly between years (ANOVA on log transformed clutch size; colony $F_{1,199} = 0.00$, n.s.; year $F_{4,199} = 6.36$, $P < 0.001$) being low in 1998. The clutch size declined significantly with first egg date (clutch = $4.27 - 0.020 \times$ first egg day; $F_{1,188} = 39.14$, $P < 0.001$) but there was no significant year effect.

Nesting success

Failures during incubation

Overall 9.1% of clutches were lost during incubation (Table 5) and there was no significant difference in the overall fraction lost between PNSM and Tamri ($\chi^2 = 0.74$, n.s.). In 1997 in PNSM, the numbers

Table 5. Nest failures during incubation. Some clutches are lost during laying and early incubation and are subsequently replaced and incubated. In these cases only the last laid clutch in a particular nest has been included in this sample.

Year	No. of nests	No. of nests failed during incubation (plus no. failed and replaced in parentheses)	Percentage of nests failed
PNSM			
1995	50	3 (3)	6.0
1996	54	2 (7)	3.7
1997	32	10 (3)	31.2
1998	33	3 (4)	9.1
1999	32	3 (0)	9.4
Total	201	21 (17)	10.4
Tamri			
1995	24	2 (0)	8.3
1996	23	1 (1)	4.3
1997	27	1 (1)	3.7
1998	29	4 (1)	13.8
1999	28	1 (0)	3.6
Total	131	9 (3)	6.9

Table 6. The proximate causes of egg losses between 1995 and 1999. The majority of losses are categorized as 'cause unknown'. Only when the loss of the egg or eggs was actually observed has it been listed against a known cause in this table.

	Number of individual eggs lost	
	PNSM	Tamri
Lost – cause not known	43	16
Nest destroyed by Ibis	15	0
Nest destroyed by Raven	5	0
Nest destroyed by Ibis/Raven/gull	2	5
Egg taken by Raven	2	0
Egg taken by Cormorant	2	0
Egg taken by Ibis	0	0
Eggs rolled from nest	4	3
Nest fell from ledge	0	5
Eggs destroyed by fighting Ibis	5	0
Total	78	29

lost, at 31.2%, were significantly higher than in other years combined ($\chi^2 = 14.8$, $P < 0.001$). The partial loss of eggs from clutches was not a significant factor. Over the whole 5 years, single eggs were known to be lost from only seven clutches at PNSM and four at Tamri.

Although nest destruction by other Ibis and Common Ravens *Corvus corax* was observed on several occasions, the majority of such clutches simply went missing with no known cause (Table 6). There is

more evidence of this type of disruption at PNSM than at Tamri. The main cause of the high egg losses at the PNSM colonies in 1997 was from the attentions of a pair of Ravens at one colony. This site suffered the highest levels of egg-loss, and the impact was sufficiently high that measures to control Ravens with territories around the Ibis breeding colonies at PNSM were developed and implemented from 1998 onwards.

Relays after clutch loss

The egg losses above have been calculated for the final attempt at each nest and include no losses that were followed by relays. In fact, for the total of 50 nesting attempts in which the complete clutch was lost there were relays in 20 cases. Logistic modelling showed that the probability of a clutch being replaced depended significantly on the date of failure ($P < 0.001$), with first egg day making no significant additional contribution to the model.

The final model was:

$$\text{probability of relay} = \frac{\exp(a + b \times \text{fail date})}{1 + \exp(a + b \times \text{fail date})}$$

where $a = 13.82 \pm 3.26$ (\pm se) and $b = -0.167 \pm 0.039$ (\pm se). The later the failure, the less likely was a relay, with a 50% chance of relaying when the day of failure was 83 (March 23), about 14 days after the median laying date.

Although early clutch loss was to some extent compensated for by relays, the overall success of relay nests in 1996 and 1997 was lower than the rest (1996, 0.17 chicks/pair from six relays, 0.8 chicks/pair from the rest; 1997, 0 chicks/pair from four relays, 0.91 chicks/pair from the rest). Although this lower success is included in the overall figures for egg and chick loss it is important to recognize that it is a consequence of early clutch loss and replacement.

The data on relays are too sparse to be able to unravel the mechanisms for lower success but overall the clutch size is significantly lower (mean 2.08 ± 0.19 for relays, 2.84 ± 0.04 for the rest; $z = 3.88$, $P < 0.001$) and in 1996 and 1997 the survival of chicks was low (0.12 for relay nests, 0.40 for the rest). The reduction in clutch size was greater than would be expected from the delayed laying date alone (mean delay in laying was 14.5 days, expected reduction in clutch size = 0.29 ± 0.04 sd).

Hatching success

A significant number of losses occur at or around the time of hatching when it is not always possible to

Table 7. The numbers of eggs which, having survived the full period of incubation, were seen to have hatched to produce small live young of 1 or 2 days old. Number of nests observed is the sample of nests for which contents were clearly visible.

Year	No. of nests observed	Eggs	Small chicks	% hatched
PNSM				
1995	36	110	77	70.0
1996	44	126	107	84.9
1997	19	52	46	88.5
1998	9	21	19	90.5
1999	15	45	40	88.9
Total	123	354	289	81.6
Tamri				
1995	3	9	3	—
1996	13	30	26	86.7
1997	18	52	39	75.0
1998	18	44	40	90.9
1999	27	81	71	87.7
Total	79	216	179	82.9

Table 8. The survival of young in the nest from small chicks (2 days old) to fledging.

Year	No. of nests observed	Small chicks	Fledglings	% hatched
PNSM				
1995	37	82	48	58.5
1996	46	112	43	38.4
1997	21	54	22	40.7
1998	28	68	51	75.0
1999	28	78	63	80.8
Total	160	394	227	57.6
Tamri				
1995	15	28	7	25.0
1996	16	35	9	25.7
1997	25	53	28	52.8
1998	25	59	25	42.4
1999	27	71	18	25.4
Total	108	246	87	35.4

attribute them to egg or chick losses (Table 7). Overall around 80% of eggs surviving through incubation resulted in live small young with no significant difference between PNSM and Tamri ($\chi^2_1 = 0.05$, n.s.). Observations in zoos suggest that most of this chick mortality occurs during hatching (Pegoraro 1996), but we cannot determine this from our observations.

Survival of young

By far the greatest losses occur during chick rearing, with only 47.5% of small chicks surviving to fledging (Table 8). Overall the survival of nestlings is higher

Table 9. The proximate causes of the loss of young.

	PNSM	Tamri
Disappeared – cause not known	98	117
Disappeared – suspected predation	0	30
Dead in nest	56	12
Dead below colony	5	5
Fell from nest	4	3
Fell during adult Ibis fight	2	0
Fought with Ibis chick	1	0
Nest fell from ledge	3	1
Trapped, nylon around foot	4	0
Total	173	168

for the PNSM colonies than for that at Tamri ($\chi^2_1 = 10.67$, $P < 0.001$). There is great variation from year to year, with survival being particularly high at PNSM in 1998 and 1999. If these two years are removed from the comparison there is no significant difference between the two sites ($\chi^2_2 = 2.26$, n.s.). The causes of chick losses (Table 9) also differ between the sites, with many chicks dead in the nest at the PNSM colonies and many probably disappearing through predation at Tamri.

The logistic regression of the daily probability of brood reduction showed a significant effect of the days since the first chick hatched in only three colony/years; 1995 and 1997 in PNSM, 1999 at Tamri (Table 10). In all cases the daily probability of brood reduction decreased with days since hatching. Chicks from late nests survived less well in PNSM in 1996 and 1998.

Relation of breeding performance to rainfall

Although the two weather stations were only 80 km apart, there were large differences in rainfall, Tamri

always receiving more than three times the annual rainfall of that at PNSM (Table 11). There were no significant correlations between November to March rainfall and any of the breeding variables (Spearman rank correlations: first egg date $r_{10} = -0.30$, n.s.; clutch size $r_9 = -0.38$, n.s.; productivity per pair $r_{12} = -0.37$, n.s.; chick survival $r_{10} = -0.22$, n.s.) although with data only available for a small number of years this is not a powerful test and is vulnerable to type 2 errors.

Provision of supplementary drinking water

Within a few days of installing the first pool the birds were seen to drink at it, and usage was regular from then on. In 1998 and 1999 the productivity per pair at PNSM was very high, largely through high chick survival (Table 8). To examine whether this was related to the provision of supplementary pools, chick survival at PNSM subcolonies from which birds were seen to use the pools was compared with that at subcolonies distant from the pools. In 1998 chick survival was significantly higher for colonies that used the pools (used pools 36 of 40 chicks survived (90%); away from pools 12 of 24 chicks

Table 11. Total rainfall (mm) for PNSM (Sidi R'bat) and Tamri village for the November to March period leading up to each breeding season.

Year	PNSM	Tamri
1994/95	66	69
1995/96	366	685
1996/97	196	485
1997/98	130	390
1998/99	165	167

Table 10. Summary of logistic models of daily probability of brood reduction in PNSM and Tamri for each of the five years. A stepdown procedure has been used with an initial model including first egg date and days since hatching. The significance of the removal of each variable has been given. For none of the models was there a significant interaction between the variables.

Year	PNSM			Tamri		
	Overall daily probability of no brood reduction	Days since hatching of first egg	First egg date	Overall daily probability of no brood reduction	Days since hatching of first egg	First egg date
1995	0.982	*	n.s.	0.968	n.s.	n.s.
1996	0.962	n.s.	***	0.952	n.s.	n.s.
1997	0.964	*	n.s.	0.982	n.s.	n.s.
1998	0.987	n.s.	*	0.964	n.s.	n.s.
1999	0.987	n.s.	n.s.	0.951	*	n.s.

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

survived (50%); $\chi^2_1 = 4.36, P < 0.05$). However, in 1999, birds from all but one colony were seen to use the pools and no significant difference could be detected (used pools 57 of 72 chicks survived (79%); away from pools all six chicks survived (100%); $\chi^2_1 = 0.11$, n.s.).

DISCUSSION

With only 60 breeding pairs and a total world population of about 220 birds in the wild the Northern Bald Ibis is highly vulnerable. Its dependence on just seven localized breeding cliffs in two areas, its restricted feeding range and gregarious behaviour together with the threat of further mortality incidents such as occurred in 1996 confirm that the species should continue to be listed as 'critical' in the IUCN red list (BirdLife International 2000). The only other species in the genus *Geronticus*, the Southern Bald Ibis *Geronticus calvus*, found in South Africa and Lesotho, is also threatened (classed as 'vulnerable'). The Southern Bald Ibis often nests in smaller colonies and appears to be more adept at exploiting cultivated habitats (Kopij 2001). It also has a much less synchronized breeding season than *G. eremita*, laying eggs over a 3-month period (Kopij 1998), thus allowing further adaptability.

There are few published data on the breeding success of other wild Northern Bald Ibis populations with which to compare our data. For Moroccan birds at inland sites Robin (1973) reported an overall figure of 0.5 chicks/pair in dry years rising to 1.05 chicks/pair in wet years. On this basis our birds appear to be doing reasonably well. However, for the Birecik birds in Turkey the average productivity over the decade before the population became extinct (1977–88) was 1.60 chicks/pair, far higher than for our birds (Akcakaya 1990). In captivity, birds are capable of raising 2–3 young, although this is highly dependent on the husbandry (Bohm 1999a). For the period 1988–1998 Bohm (1999b) reported that 76.4% of eggs hatched in zoos resulted in fledged young which would convert to an overall breeding success of more than two young per pair. Three studies of the closely related Southern Bald Ibis from different areas show productivity figures of between 0.29 and 0.84 chicks/pair (Allan 1985, Manry 1985, Kopij 1998), again lower than the average in the present study.

Given the range of causes of egg and chick losses observed over this 5-year period it is probably not surprising that we found no obvious relationships

between productivity and rainfall and certainly not the strong relationship reported by Robin (1973). However, *df* was only 9 or so and all correlations were negative. Even in 1995 when the winter rainfall was exceptionally low (Table 11), the productivity at PNSM was reasonably high. This may provide a clue to one of the reasons for the persistence of this coastal population of Northern Bald Ibis in a period when all other colonies have been lost. The coastal region around Agadir experiences sea fogs throughout the year. It has been shown elsewhere that coastal desert vegetation and arthropod communities depend heavily on the moisture provided by fogs (Seely 1979, Tigar & Osborne 1997). It could well be that the fogs around Agadir act as a buffer for the Ibis in dry years and prevent productivity collapsing in the way that it did in such years at inland colonies.

The loss of eggs to Common Ravens is to some extent compensated for by relaying but in 1998 it became so prevalent that it was a serious threat to the overall productivity of the PNSM birds. Before then, although Ravens were present, they had not been a major problem to the Ibis. It is not clear whether the Ravens have changed their habits or simply increased in numbers. There are no data on trends in Raven numbers at PNSM but the rapidity with which territorial birds are replaced (on the two occasions when Ravens were killed, they were replaced within 2 days) suggests that there are substantial numbers of non-breeding birds in the area. It is possible that Ravens are now attracted to the vicinity of the breeding colonies by the rubbish left by the increasing numbers of rod and line fishermen using the cliffs. However, we cannot rule out the possibility that the problems arose simply because one or two individual Ravens learned to take Ibis eggs.

The poor survival of young from hatching to fledging is the main limitation to the productivity of the Ibis. Some of the young appear to be lost to predators although we have no direct observations to support this. At Tamri, the loss of chicks is generally at night and a Pharaoh's Eagle Owl *Bubo ascalaphus* has twice been seen to approach and land on the Ibis breeding ledges late at night and seems likely to be at least partially responsible for the lower productivity there. Other chicks die in the nest or simply disappear, suggesting starvation as corpses can easily drop into the sea below, unobserved, while there is a good chance that predation events would have been observed by the wardens. Nocturnal chick losses, however, remain a source of uncertainty, and more attention is planned to investigate this. In

zoo-bred birds, strong sibling rivalry within broods (Pegoraro 1996) results in the death of some chicks. In wild birds this would lead to the loss of the weakest chicks during periods of food shortage. It would be expected that brood reduction would be more likely when the chicks were young or for late nests when food was less available. However, the analysis of daily brood reduction probabilities provided only weak evidence for this, with days since hatching being a significant predictor in only three colony/years out of 10, and first egg date in only two out of 10. The two years in which there was a significant effect of first egg date both had exceptionally late nests. In 1998 at PNSM laying was delayed by the shift to new colony sites, whilst in 1996 there was no obvious reason, although intraspecific competition for nest ledges may have been important as numbers peaked in that year.

The mortality incident in 1996 was a serious setback for the population and the lack of a clear diagnosis of the cause is a major limitation for any remedial action. On the basis that either poisoning or botulism was probably involved, steps have been taken to work with the local villagers to avoid accidental misuse of poisons and to ensure that safe fresh water is available for drinking. This was one reason why water points were provided on an experimental basis near the breeding colonies. There has also been some discussion of whether water available for drinking might be an important factor influencing chick survival. Although it is known that at some former breeding sites there was often no available water source (U. Hirsch unpubl. data), and that the birds often go all day without drinking, water availability could still affect the birds by restricting foraging areas or prey types. The higher chick productivity at PNSM in 1998 and 1999 did coincide with the provision of controlled water points beside the colonies, but further trials are needed to verify whether this was simply the result of chance or some other factor.

Preliminary data on the foraging areas used by the birds during the breeding season in 1998 and 1999 showed that they were feeding closer to the colonies than in previous years. This could have been because a ready supply of drinking water near the colonies allowed them to exploit the area more easily. Alternatively, because the fallow fields in these areas were more vegetated in the years following abnormally high rainfall in 1996 (which was more than double the average figure) there would have been more prey available (Aghnaj *et al.* 2001). The greater vegetation

cover would imply higher densities of prey such as beetles and lizards in these fields, although the situation is complicated by the decisions of farmers on whether to cultivate such areas in a given year, cultivation leading to a much reduced prey base (Bowden *et al.* 1997, Aghnaj *et al.* 2001).

Northern Bald Ibis populations in Turkey and the Atlas mountains were forced by cold conditions to abandon their breeding areas in winter and migrate or disperse to warmer areas, the Turkish birds apparently wintering as far south as the Red Sea. One of the key factors in the final demise of the Birecik colony was the low return rate of birds from their wintering areas in at least the last decade of the existence of the wild population (Akçakaya 1990). Although some of the birds from coastal Morocco may be migratory and there may well be some juvenile dispersal, it is clear from the counts that the majority remain in the region for most of the year. Although some birds are apparently missing from September to November we still have no evidence that there is any consistent migration out of the region.

Although none of the birds is individually marked, the co-ordinated counts have shown a number of cases in which there must have been interchange between the Tamri and PNSM populations. However, we still have no information on the degree of movement of breeding birds or gene flow between the two populations.

It would appear that at least in the first two years of this study there was a shortage of nest-sites at the main colony in PNSM. The incidence of four- and five-egg clutches and a higher level of observed disputes between birds suggest a surplus of birds that were unable to find their own nest-site. What is surprising is that these birds did not make the break from the main group and found a new colony. The fact that new colonies (E and F) were established in 1998 shows that other sites were always available, as there is no evidence that these were unsuitable in previous years. It is possible that there are important benefits in staying and breeding synchronously, which inhibit the establishment of new colonies for this colonial species.

In 1993 a team of volunteer climbers extended the nesting ledges at one of the key colonies in PNSM, and in 1998 these were used for the first time, holding six additional nests. Given the indications of overcrowding in 1996, more such work will be needed to ensure that adequate space is available in existing colonies. Individual sites can collapse as

a result of erosion of the cliff base (Fox & Moore 1996).

In 1997 an Action Plan for the conservation of the Northern Bald Ibis in the Agadir region was agreed with the authorities (Bernecker & Ribí 1998). Many of the actions are already underway, and their outcomes are described in this paper. The continued monitoring of numbers and breeding success is clearly vital as is the protection of the key breeding and roost sites from disturbance and development. The wardens, who are all from the local villages, as well as collecting this information, also have a key role in promoting the importance of the Ibis to the local populace (Bowden 1998). Given that the birds spend most of the year in the PNSM and Tamri areas, and that they are often in very close association with local villages and villagers, the programme to raise the profile of the birds and to find ways in which the villagers can benefit from their continued conservation (Bernecker & Ribí 1998) is vitally important.

Most actions to date have focused on the breeding performance of the birds, but with such a long-lived species, survival rates are likely to be extremely important in determining population trajectory. Factors such as the extent and quality of foraging habitat and the severity and frequency of chance mortality incidents are likely to be particularly important.

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