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Contribution of research to conservation action for the Northern Bald Ibis *Geronticus eremita* in Morocco

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Summary

The Northern Bald Ibis or Waldrapp *Geronticus eremita* is a species of arid semi-deserts and steppes, which was formerly widely distributed as a breeding bird across North Africa, the Middle East and the European Alps. Just over 100 breeding pairs now remain in the wild at two sites in Morocco whilst two further wild pairs remain in Syria. There is also a population in Turkey, which is maintained for part of the year in captivity, and a large captive population in zoos. The species is classified by IUCN as 'Critically Endangered', the highest threat category. The wild population has grown during the past decade, which represents the first evidence of population growth in the species' recorded history. Conservation action in Morocco has contributed to this recovery. A large part of the contribution of research to conservation action has been to establish and document the value of simple site and species protection. Quantitative assessments of the importance of sites for breeding, roosting and foraging have helped to prevent disturbance and the loss of sites to mass-tourism development. Wardening by members of the local community have reduced disturbance by local people and others and increased the perceived value of the birds. Monitoring has suggested additional ways to improve the breeding status of the species, including the provision of drinking water and removal and deterrence of predators and competitors. These actions have been evaluated by subsequent testing. Steppe and two-year fallows were shown to be the key feeding habitats, and maintaining such non-intensive land uses in future may present major management challenges. The recovery in the Souss-Massa region remains precarious because the population is concentrated in a few places where adverse changes are possible. However, it could provide opportunities for natural extension of the range to formerly occupied sites further north in Morocco.

Introduction

The Northern Bald Ibis *Geronticus eremita* is a species of arid semi-deserts and steppes, which formerly bred through North Africa and the Middle East and even as far north as the European Alps. It has just one congener, the Southern Bald Ibis *G. calvus*, which occurs in grasslands of Southern Africa and is classified as 'Vulnerable' by IUCN (Manry 1985, Barnes 2000, Gaynor *et al.* 2003, IUCN 2008). The decline in range and population of the Northern Bald Ibis is relatively well documented and perhaps one of the longest on record for birds. The species was present over four thousand years ago in Egypt and was assigned its own hieroglyphic symbol. The last colony in Egypt disappeared in about 1900 (Collar and Stuart 1985). It was widespread in the European Alps but numbers dwindled until it finally disappeared over four hundred years ago (Pegoraro 1996). Populations across the Middle East (Syria and Turkey) and northwestern Africa (Morocco and Algeria) persisted for longer, but sustained declines brought them to the verge of extinction by the 1980s and 1990s. As a result, the Northern Bald Ibis is globally categorised as 'Critically Endangered', the highest threat category, (IUCN 2008). The known wild breeding population was at its lowest point, 59 breeding pairs, in 1997 (Bowden *et al.* 2003). Currently, just over 100 breeding pairs are known.

Because 400 years have elapsed since the extinction of the Northern Bald Ibis in the European Alps, its causes are uncertain. However, they are likely to have included over-hunting, particularly of nestlings, habitat loss and possibly climate change. By the 20th century, the remaining distribution was split into western and eastern sub-populations, which are now genetically if not morphologically distinct (Pegoraro *et al.* 2001, Broderick *et al.* 2001). Both populations were largely migratory. The Moroccan and Algerian birds were thought to winter as far south as Southern Morocco and Senegal, whilst the eastern populations of Turkey and Syria were thought to winter in Ethiopia and Eritrea. In the early 20th century, both western and eastern populations declined gradually, but this accelerated during the 1950s and 1960s. The reasons are not fully understood, but there are records of hunting incidents and collecting for zoos that apparently wiped out whole colonies in Morocco and Algeria. Contamination with the organochlorine pesticide DDT led to depression of breeding performance (Hirsch 1979, Parslow 1973) and had a disastrous impact on the last Turkish population at Birecik. DDT poisoning may also have affected other populations during this period, but probably went undocumented. We suspect that another important cause of population declines in the 20th century was the conversion of steppe-like foraging habitats, used extensively for grazing and shifting cultivation, into more intensively managed farmland. The species' requirement for a large area of steppe or fallow land, rich in prey, close to undisturbed, safe cliffs for breeding and roosting is an important limiting factor today.

Background

Ecology of the species

The Northern Bald Ibis is a gregarious species. It usually forages in flocks for animal prey taken from the ground surface and vegetation. Its food includes lizards and a wide range of invertebrate and other animal prey. Unlike many ibis species, it rarely forages in wetlands, preferring drier steppe-like habitats. It usually breeds in dense colonies on ledges or in cavities on vertical cliff faces. Similar sites are used for communal roosts. The resulting concentration into a few small areas makes the surviving populations vulnerable to adverse local changes. Recent studies indicate that the remaining population in southern Morocco is largely resident (Bowden *et al.* 2003), with a high proportion of birds remaining in the area throughout the year. The tiny breeding population in Syria has recently been shown to winter in Ethiopia (Lindsell *et al.* in press).

Early conservation efforts

The plight of the Northern Bald Ibis was recognised in the 1970s, when the World Wildlife Fund (WWF) became involved and Udo Hirsch led conservation efforts in both Turkey and Morocco. In Turkey, the programme was successful in reviving the traditional and cultural values of the bird in the town of Birecik, the location of the only surviving colony. However, encroachment by human dwellings onto the ibis nesting ledges continued. Although part of the colony was shifted to a secure site nearby, this was not enough to prevent extinction of the wild migratory population in 1989 (Akcakaya 1990). A semi-wild population has been maintained at the nearby site, which provides an important opportunity for the future re-establishment of a fully wild population. However, it will be difficult to restore the former migratory pattern. The Birecik birds were thought to be the last remnant of the Eastern population of the species, but in 2002, a small wild population was discovered near Palmyra in Syria (Serra *et al.* 2003), which currently stands at just two breeding pairs (Serra and Peske 2007).

An assessment of the conservation status of the ibis in Morocco in the 1970s and 1980s, led by WWF, revealed that the Middle Atlas and High Atlas colonies had probably declined too far to recover. Just one breeding area in Morocco seemed to offer any hope - the Souss-Massa region, south of Agadir. Mohammed Ribi and Udo Hirsch led a concerted effort to secure the designation of this zone as a protected area. The Moroccan Government responded very positively by creating the Souss-Massa National Park, which was officially designated in 1991. The Park had a number of biodiversity and ecosystem objectives, including the protection and conservation of the Northern Bald Ibis. Symbolically the species was adopted as the logo of the Park. Sadly, as predicted by the original WWF project, the Northern Bald Ibis colonies in the Atlas Mountains were extinct by 1990 so that the only remaining breeding colonies in the whole of North Africa were on the southern Moroccan coast. These were the colonies in the Souss-Massa region and, in addition, a few birds breeding outside the National Park, near the coastal village of Tamri, 60 km north of Agadir.

The designation of Souss-Massa National Park was timely given the growing pressure for development in the area and the Park has already provided a crucial framework for the implementation of protection measures. In 1993, the Park director, Mohammed Ribi and the Moroccan Water and Forests Directorate approached BirdLife International (BLI) to instigate research to identify measures needed to manage and conserve the ibis population. An initial three-year research programme was developed with the RSPB, the UK BirdLife Partner. This provided the main technical input to Park management plans (Bernecker and Ribi 1998, El Bekkay *et al.* 2007) and the international species action plan (Jimenez-Armesto *et al.* 2006). The relationship between BLI and the Park has continued with SEO the Spanish BirdLife partner now taking the lead. The programme has developed to include the management recommendations from the research but has also broadened to include sustainable development initiatives within the National Park. These actions have been initiated by SEO/BirdLife and the Park itself, attracting funding from a range of European donors, including the Spanish Aid Agency (AECI), Canary Islands Government, Territori i Paisage Foundation and EuroNature, together with further support from GTZ, the German Technical Assistance. These are led and managed by SEO/BirdLife and the National Parks Service, under the Water and Forests (Eaux et Forêts) High Commission, successfully collaborating with local communities.

The research programme in Morocco

Previous assessments, most notably by Collar & Stuart (1985), suggested that effective control of persecution by humans and pesticide use were required for the conservation of the Northern Bald Ibis. However, it was thought that these two actions might not safeguard the ibis population in and near the Souss-Massa National Park on their own. Therefore, a research and monitoring programme was designed to develop detailed management recommendations.

Monitoring breeding population size and performance

There are two main areas used by Northern Bald Ibis in Morocco; the Souss-Massa National Park to the south of Agadir and an area around the village of Tamri, 60 km to the north (Figure 1). We devised monitoring protocols for both areas and first employed local fishermen as wardens in 1995 to carry them out. This had the result of sensitising local populations to the significance of the birds and helped to defuse suspicions that would have surrounded the activities of staff from outside the area. As far as possible, competent and respected individuals from the villages closest to the ibis colonies were recruited.

During the breeding season (February to May) the wardens watch the breeding colonies for most of each day and complete daily recording sheets that are submitted to the Park headquarters. These document the course of each nesting attempt and its outcome. This allows a

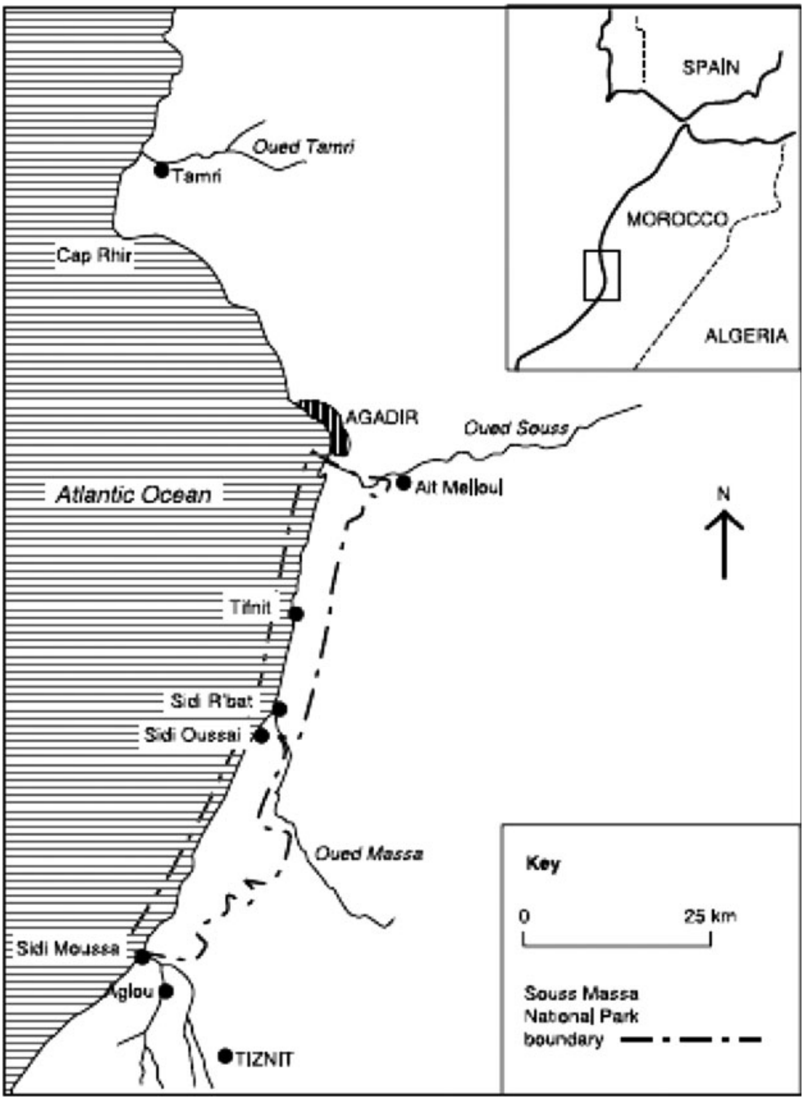

Figure 1. The region of South-west Morocco showing the location of Souss-Massa National Park, and Tamri, the two areas where Northern Bald Ibis are largely resident.

quick response by the wardens (or if necessary the Park authorities) to any significant problems that arise at the breeding sites. The results of the wardens' colony monitoring, combined with earlier information (from Bowden *et al.* 2003), indicate a decline in the breeding population until 1993, followed by a brief increase until 1996 (Table 1). After a marked decline in 1997 (see below), the positive trend resumed. The breeding population stood at 105 pairs in 2007, about twice that of 1993. A feature in recent years has been the increasing numbers of nests at Tamri compared with relative stability at the Souss-Massa National Park colonies (Table 1). At the same time, breeding success (1994–2006 mean fledged young per pair) has been consistently higher in Souss-Massa National Park: 1.38 ± 0.14 (SE) than at Tamri: 0.86 ± 0.09 (SE).

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Table 1. The numbers of breeding pairs and fledged young of Northern Bald Ibis at the Souss-Massa National Park and Tamri colonies from 1980 to 2006. Data from 1994 onwards are from standardised monitoring carried out by wardens. Before that some counts may be underestimates. From 1995 onwards the total pre-breeding (January to mid-March) maximum count of all full-grown birds is given.

Year	Souss-Massa National Park (PNSM)			Tamri			Total	Total pre- breeding count	Breeding birds as % of pre-breeding total
	Pairs that laid eggs	Total fledged young	Young fledged / pair	Pairs that laid eggs	Total fledged young	Young fledged / pair	Pairs that laid eggs		
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	60	1.20	24	13	0.54	74	218	67.9
1996	54	49	0.91	23	9	0.39	77	223	69.1
1997	32	22	0.69	27	28	1.04	59	183	64.5
1998	33	52	1.58	29	25	0.86	62	208	59.6
1999	32	65	2.03	28	18	0.64	60	220	54.5
2000	35	62	1.77	30	44	1.47	65	238	54.6
2001	38	23	0.61	28	19	0.65	66	280	47.1
2002	42	45	1.07	31	17	0.55	73	249	58.6
2003	44	59	1.34	46	51	1.11	90	230	78.3
2004	45	102	2.27	49	65	1.32	94	284	66.2
2005	40	72	1.80	51	40	0.78	92	315	58.4
2006	43	74	1.72	41	31	0.59	95	258 (?)	73.6
2007	50	81	1.62	55	61	1.10	105	344	61.0

Identifying causes of breeding failure

The wardens record possible disturbance at the breeding colonies in the form of approaches by birdwatchers and local fishermen. These have the potential to cause abandonment of a colony, depending on the full scale and circumstances, but may also attract more local people to frequent the sites if tourists (potential sources of income) become regular visitors. The wardens have very successfully changed the behaviour of local fishermen and other villagers, but it is the outsiders who probably present the greater and growing concern (Table 2). Most such visitors are intercepted and leave before any disturbance has taken place, but some (such as the paragliders) made a serious impact before they could be removed. Persuading irresponsible birdwatchers to avoid disturbing the area is, perhaps surprisingly, not always easy. Records are also kept of any natural incidents that might affect breeding productivity. For instance, the loss of eggs in one sub-colony in the Souss-Massa National Park to Common Ravens *Corvus corax* was identified and quickly dealt with by killing three problem birds and, in one case, scaring them from nesting

Table 2. Potential human disturbance events recorded during the breeding season at the Souss-Massa and Tamri colonies by the wardens between 2000 and 2007.

Souss-Massa National Park.

	2000	2001	2002	2003	2004	2005	2006	2007
Birdwatchers (1–3 people)	2	3	–	–	2	1	1	–
Birdwatchers (larger group)	1	–	1	–	–	–	4	–
General tourists (1–3 people)	–	–	–	–	5	1	2	3
General tourists (larger group)	1	–	–	–	1	1	2	4
Fishermen	–	1	–	–	1	–	–	–
Photographer	–	–	–	–	–	–	1	2
Paragliders	–	–	–	–	–	–	1	

Tamri.

	2000	2001	2002	2003	2004	2005	2006	2007
Birdwatchers (1–3 people)	5	8	4	6	3	10	8	12
Birdwatchers (larger group)	5	5	3	2	4	6	4	15
General tourists (1–3 people)	11	2	13	5	3	10	18	12
General tourists (larger group)	9	1	2	4	1	8	11	5
Fishermen	1	2		2	–	–	–	–
Photographer	–	3	1	–	–	5	2	1
Falcon hunters	1	–	–	–	–	–	–	–

sites within 200 m of the ibis colonies. Similarly, destruction of ibis nests and displacement of breeding birds by Great Cormorants *Phalacrocorax carbo* was observed. This has been successfully dealt with by disturbing any cormorants that started nest-building at regular ibis nest-sites using a laser pointer directed at the cormorants' feet to disturb them (and not the nearby ibis) on a moonless night.

There is considerable aggression between breeding pairs of ibis and occasional intrusions by non-breeding birds. Such interactions are a significant cause of egg loss and nest destruction. At least 18.7% of the 9.1% of eggs lost between 1994 and 1999 were destroyed because of interactions between ibises (Bowden *et al.* 2003). In addition, many nests failed for unknown reasons and it is quite possible that many of these are also due to conspecific interactions. This finding suggested that reducing competition for nest sites might be an effective intervention to reduce breeding failures. This might be the case even though large vacant breeding ledges are available at past breeding sites which have been abandoned. There appear to be strong social pressures, which make pairs very reluctant to establish new colonies. For this reason, attempts were made to provide more ledges in prime locations at existing colonies. In preparation for this, the characteristics of nesting ledges and the erosion processes involved in maintaining them were assessed and evaluated (Fox and Moore 1996). Nest ledges were then extended at a favoured sub-colony by expert volunteer climbers. This was carried out in the non-breeding season and space for 12 new nests was created. Five of the new sites were eventually used four years later, but so were other natural ledges at the same sub-colony that had been available throughout. We concluded that the artificial extension of nest ledges was unlikely to be effective.

Identifying causes of mortality of full-grown birds

The most notable major event discovered by the wardens was a significant mortality incident during the breeding season in May 1996 when 41 adult and first-year birds were found dead or dying within the Park (Touti *et al.* 1999). The detected losses represented 18% of the pre-breeding count that year and the 18% fall in this count in 1997 suggests that most of the deaths were detected (Table 1). This event would probably have gone undetected before the monitoring was in place. The cause of the incident was never established, but several candidates were excluded and, based upon the epidemiology, possible likely causes were considered to be a mosquito-borne pathogen, such as West Nile Virus, or toxicity (Cunningham 2001). There had been unusually high rainfall immediately prior to the event which may have been an indirect factor. Some of the dead birds were found near to a stagnant freshwater pool in the Park and this was a key motivation for the provision of safe fresh water near to the breeding colonies. This later proved to be an important way of enhancing breeding productivity (Smith *et al.* in press) and is treated in more detail later in this paper.

Monitoring the total population throughout the year

Outside the breeding season, the birds roost largely on sea cliffs away from the breeding colonies, often concentrated at one site with upwards of 300 individuals (75% of the world population) roosting on one small section of cliff. The wardens monitor these roost sites, counting the birds and providing protection against accidental or deliberate disturbance. The pattern of year-round counts shows that a large fraction of the ibis population remains in the Agadir region throughout the year (Bowden *et al.* 2003). The percentage of full-grown birds counted in roosts at the beginning of the breeding season that subsequently breed has fluctuated between 47% and 78%. Following the mortality incident in 1996, this fraction decreased until 2001 but then increased (Table 1). A possible explanation for this pattern is delayed recruitment of immature birds into the breeding population following the loss of breeding birds in 1996. Since 2002 the percentage breeding has increased towards the levels before the mortality incident. This is additional evidence that availability of nest sites has not limited the breeding population over the last decade.

Locating foraging areas

Flocks of ibis flying from colonies and roosts were followed in a vehicle to their foraging grounds and the exact locations marked on copies of aerial photos. To avoid bias, groups to be followed were selected at random on any particular day with tracking taking place on one day per week. The open nature of the terrain allowed flocks to be tracked reliably such that only 4% of attempts to follow flocks completely failed. The birds were followed to the feeding areas but, if they were lost from view en route, the observer stayed at the last known location for up to an hour to await the appearance of a subsequent group that could then be followed using the same method.. In most cases when a flock was lost, the later group of birds ended up joining the earlier one at the feeding ground. For the 4% of cases where birds were not successfully followed, any locations on that date were excluded from the main analysis. The problem of losing birds arose almost exclusively in one area north of Tifnit where vehicle access was challenging, making it more difficult to keep up with the birds. Hence, the map of foraging areas detected in this way is reasonably unbiased but may under-represent usage in the extreme north of the park (Figure 2). The foraging range is large, varying somewhat between seasons and years, but the great majority of feeding areas lie within the National Park although patchily distributed. Detailed examination shows that some areas are used regularly, but others only occasionally. A similar approach has been adopted in the Tamri region to define the area used by feeding ibis flocks as a basis for its protection.

These data have been crucial in providing evidence that commercial developments in certain areas in and around Souss-Massa National Park would be harmful to Northern Bald Ibis. For instance, proposals, most notably since 2001, for a major tourism development on a small area of

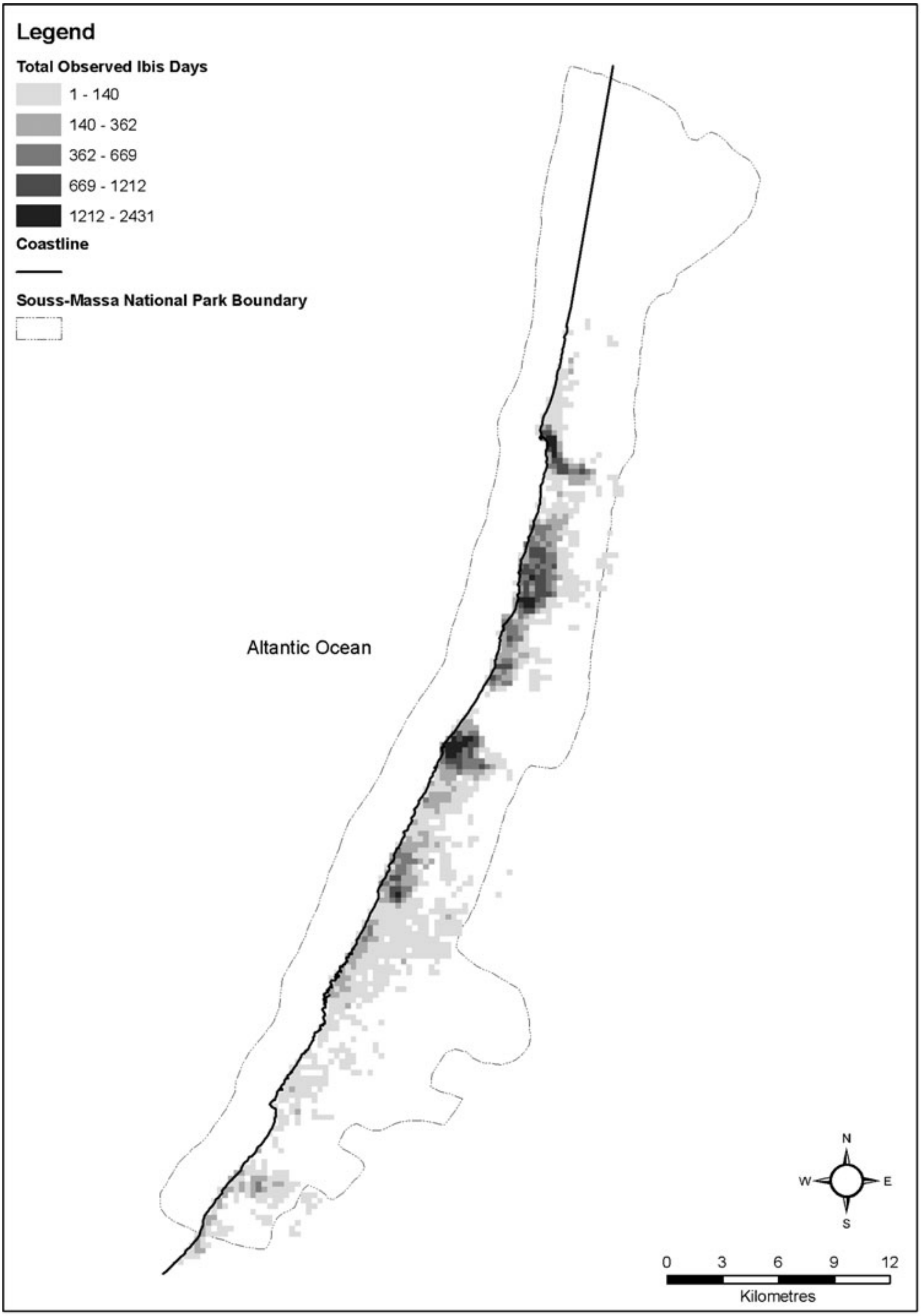

Figure 2. Map of utilization for foraging by Northern Bald Ibis of 300 m x 300 m squares in Souss-Massa National Park in 1995 – 2005.

non-designated land within the Park have been greatly modified to avoid conflicts with the ibis that feed there. Proposals for a power station close to the Tamri site were rejected in 2007 with the adjacent ibis feeding areas cited as a key reason, even though the area itself had no official designation. Neither of these interventions would have been successful without the foraging range data. The National Park and Moroccan authorities have used the results from this work to exert considerable influence locally and the ibis feeding areas in the Tamri Region have been defined within the Regional Development Plan (Lahlou *et al.* 1999) adopted since 2001.

Characteristics of preferred foraging areas

The feeding areas used by the birds are subject to traditional land uses of grazing and irregular cultivations for cereals. The land can be broadly classified as semi-natural steppes with sparse cover of perennial and annual vegetation, cultivation, and fallow areas of various ages gradually reverting to steppe. The extent of cultivation of the coastal zone is irregular depending on the winter rainfall and other local socio-economic factors in particular years. All areas are subject to some level of grazing. It is important to understand how these habitats and the processes that maintain them interact to provide suitable conditions for the ibis. Otherwise, changes in land use could reduce the area of suitable foraging habitat. Land use maps were made for areas of Souss-Massa National Park within 5 km of the coast, which is the distance within which all foraging grounds lay. It was not always possible to distinguish steppe from long-unused fallows and so these categories were merged before analysis. Although the full range of cultivated areas, fallows of different ages, and steppe are all used by the birds at different times, older fallows and steppe habitats are used to a greater degree than would be expected from their area, relative to that of recent fallows and cultivated land (Table 3).

Another analysis of foraging habitat preference used satellite imagery and sample 'ground truth' vegetation data (percent cover and species composition) to characterise the vegetation of the Souss-Massa National Park (Rice 2002; Rice *et al.* 2002). The mapped data on ibis foraging locations were then used in combination with this remotely-sensed vegetation map, the soils map and distances from villages, the coast and roost sites to build a model of utilisation of the land by ibis (Rice 2002). The best model was able to predict successfully 80% of the positive locations. Preferred foraging areas were characterised by an over all vegetation cover of about 30% dominated by annual and perennial herbs as opposed to sub-shrubs (Rice *et al.* 2002).

Diet analysis

Knowledge of ibis diet was considered important in order to understand their preference for certain types of land cover. Faecal analysis showed that *Acanthadactylus* lizards and adult

Table 3. Foraging habitat use by Northern Bald Ibis within Souss-Massa National Park in relation to availability. The results are derived from systematically following birds from their roosts and breeding cliffs to feeding areas in 1994/95. All the foraging birds were located within 5 km of the coast so available habitat has been estimated for this zone using a habitat map available for the Park (Benabid *et al.* 1994). Densities of flocks and birds are accumulated values over the whole survey period. Flocks were significantly more likely to be found on steppe/old fallows than expected from the relative area of this habitat ($\chi^2_1 = 22.6$, $P < 0.001$). An equivalent test for bird numbers is inappropriate because of non-independence.

	Steppe/old fallows	Cultivations/recent fallows
Area in km^2 (%)	15.11 (17.0)	74.54 (83.0)
No of independent ibis flocks	18	22
Ibis flocks km^{-2}	1.19	0.30
Total number of foraging ibis	944	2,086
Ibis km^{-2}	62.5	28.0

tenebrionid beetles were the main food items, along with a wide range of invertebrate prey, including snails (Mollusca), spiders (Araneae), various insect larvae and others (Table 4). There was a small but significant difference between seasons in the relative contributions of the prey fragments in the samples with a higher proportion of beetle remains in the breeding season ($\chi^2_3 = 16.2$, $P < 0.005$) However, conclusions based upon counts of prey remains can be misleading because prey differ in the proportion that can be detected from remnants in the faeces, the number of key fragments differs between animals (in particular, each beetle has two mandibles but each lizard has 26 vertebrae) and because the average body mass of prey varies enormously. In captive Northern Bald Ibis fed on known diets (Gruar 2000), the proportion of individual tenebrionid beetle mandibles recovered and identified by faecal analysis was 0.45, whereas that for individual lizard vertebrae was only 0.013. In the same experiment the wet mass of the beetles fed to the birds was 0.92 g (SD = 0.52, $n = 90$) whereas that of the lizards was 4.5 g (SD = 2.5, $n = 8$). Combining the figures from Table 4 with those for detectability and wet mass shows clearly that, in both seasons, the lizards are contributing 8–10 times more mass to the diet than the beetles. However, these conclusions depend critically on the values for the detectability of the prey fragments in the faecal samples. There is still considerable uncertainty in these figures, particularly for the lizard vertebrae, and further work on captive ibis is in progress to address this.

Effect of land management on food availability

Surveys of *Acanthadactylus* lizards and beetles were carried out in areas with different land use to determine its effects on the density of important ibis prey. In the case of lizards, the proportion of 85 m transects on which at least one lizard was seen was used as the measure of abundance. All transects were walked during the middle part of the day when preliminary investigations showed that lizards are active and detectability is relatively stable. The number of adult beetles caught in pitfall traps per 3-day trapping period was used as an index of beetle abundance. Each pitfall was a 66 mm diameter plastic beaker set into the ground and containing a small quantity of 70% ethanol with a drop of detergent (Aghnaj 1996).

In Souss-Massa National Park, the probability of seeing a lizard on a transect was higher on steppe than on cultivated land and intermediate on fallows (Table 5). Logistic regression of presence/absence of lizards on habitat type and season showed significant effects of habitat type but no effect of season (likelihood ratio tests; habitat $\chi^2_2 = 74.6$, $P < 0.001$; season $\chi^2_1 = 0.04$, $P = 0.84$). At Tamri, the probability of seeing a lizard on a transect was also higher on steppe

Table 4. The diet of Northern Bald Ibis on the Atlantic coast of Morocco. The results of faecal analysis of samples collected within The Souss-Massa National Park and in the Tamri area north of Agadir from 1996 to 2001. Approximately 10 samples were collected for each month of the year and the total numbers of key prey fragments identified in the faeces are given in the table (see text for details of the conversion of these figures into the relative contribution to the diet). The breeding period corresponds to February to May inclusive and the non-breeding period June to January. Only prey occurring in large numbers or with large mass are included in the table – Reptilia, Coleoptera and the larvae of Coleoptera and Lepidoptera. In addition, the following other items were identified in the samples but contributed little to the overall diet either because of low numbers or low mass; Mollusca, Formicidaea, Heteroptera, Diptera, Scorpiones, Dictyoptera, Araneae.

Period	Number of faecal samples	Number of lizard vertebrae	Number of beetle mandibles	Number of beetle larvae mandibles	Number of Lepidoptera larvae mandibles
February– May (breeding)	31	104	194	6	32
June – January (non-breeding)	82	413	442	20	94

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Table 5. The probability of an observer detecting a lizard in 1994/1995 in Souss-Massa National Park in relation to habitat type and season. The proportion of 100 pace (85 m) transects on which at least one lizard was detected is shown for the ibis breeding season (March) and the winter (December to January). Confidence intervals in the table are based upon binomial proportions.

	Breeding season	95% CI	Non-breeding season	95% CI
Cultivations (n = 186)	0.194	0.140 – 0.253	0.183	0.129 – 0.242
Fallows (n = 75)	0.253	0.160 – 0.360	0.200	0.120 – 0.293
Steppe (n= 258)	0.450	0.388 – 0.512	0.461	0.399 – 0.523

than on cultivated land and bare sand (logistic regression, likelihood ratio test; $\chi^2_5 = 31.5$, $P < 0.001$) (Table 6; Aghnaj 1996, Aghnaj *et al.* 2001). It was also found that the probability increased with the age of fallows (logistic regression, likelihood ratio test; $\chi^2_2 = 16.1$, $P < 0.001$); with lizards being about 60–70% as likely to be seen on fallows two or more years old as they are on steppe. The vegetation cover was estimated at each transect and there was a clear positive relationship between vegetation cover and the probability of seeing a lizard (probability of seeing a lizard = 1/(1 + exp (2.37– 0.074*veg cover%). Logistic regression, likelihood ratio test; $\chi^2_1 = 8.95$, $P < 0.001$). Inclusion of a quadratic term in the regression did not give a statistically significant improvement to model fit ($\chi^2_1 = 3.33$, $P = 0.06$). Hence, there is little evidence for an optimum vegetation density for lizards.

The impacts of habitat and management on the numbers of beetles are less clear. In Souss-Massa National Park, there was no clear difference in beetle abundance among habitats (Table 7). Two-way analysis of variance of log(X + 1) transformed numbers per trap showed a significant effect of season but not of habitat ($F_{2,826} = 0.863$, $P = 0.422$; season $F_{1,826} = 8.95$, $P = 0.003$). At Tamri, there were actually higher numbers of beetles trapped in cultivation than on steppe (Table 8). One-way analysis of variance of log(X + 1) transformed numbers per trap showed a significant effect of habitat ($F_{4,145} = 9.23$, $P < 0.001$). This difference between sites could well

Table 6. The probability of an observer detecting a lizard at Tamri during the ibis breeding season in relation to habitat and age of fallows. The probability of detecting a lizard in the course of a 100 pace (85m) transect is shown, with confidence intervals based upon binomial proportions.

	Probability	95% CI
Bare sand (n = 36)	0.028	0 – 0.063
Cultivation (n = 102)	0.029	0 – 0.069
1 year fallow (n = 102)	0.029	0 – 0.069
2 year fallow (n = 99)	0.162	0.09 – 0.24
2+ year fallow (n = 102)	0.186	0.12 – 0.26
Steppe (n = 93)	0.269	0.18 – 0.37

Table 7. The abundance of beetles in Souss-Massa National Park in relation to habitat and season. The mean numbers of beetles trapped per 3 days in pitfall traps set at randomly selected points are shown. All beetle species were included, but the sample was dominated by Tenebrionidae. Means and confidence intervals are back transformed from logs of (count +1).

	November - December	95% CI	March	95% CI
Cultivations	3.28 (n = 144)	2.55 – 4.14	5.64 (n = 162)	4.75 – 6.67
Fallows	4.50 (n = 69)	3.12 – 6.34	4.78 (n = 60)	3.29 – 6.78
Steppe	4.11 (n = 178)	3.28 – 5.10	5.99 (n = 219)	4.91 – 7.26

Table 8. The abundance of beetles at Tamri in the ibis breeding season in relation to habitat and time since cultivation of fallows. The mean numbers of beetles trapped per 3 days in pitfall traps set at randomly selected points are shown. The means and confidence intervals were back transformed from log (count +1).

	Mean catch	95% CI
Cultivation (n = 34)	21.9	17.4 – 27.5
1 year fallow (n = 30)	11.8	9.8 – 14.3
2 year fallow (n = 29)	16.3	13.0 – 20.3
2+ year fallow (n = 30)	13.0	9.3 – 18.1
Steppe (n = 27)	9.3	6.7 – 10.2

be related to the scale of cultivation in the two areas. In Souss-Massa National Park, cultivations, when they occur, tend to be large scale, mechanised and field based. By contrast, in Tamri they are small scale and by hand with the crops often sown around and amongst perennial steppe vegetation. Poisson regression of the number of beetles caught per trap at Tamri on vegetation cover indicates a quadratic relationship ($\log_e$(beetle numbers) = 2.49 + 0.063* veg cover% − 0.0011*(veg cover%)^2; χ^2_2 = 23.0, $P < 0.001$, likelihood ratio test corrected for overdispersion). This indicates an optimum vegetation cover for beetles of 28%.

After cultivations, the second most important factor in the maintenance of the semi natural steppe habitats is grazing. The steppes and fallow areas are grazed by village herds of sheep and goats and occasionally by the camels of nomads. This maintains a very open structure. For instance, in Souss-Massa National Park, the mean vegetation cover of the coastal zone (largely steppe and old fallows) in spring 1994 was 27.7 ± 2.0 (1 SE)% (Aghnaj 1996) of which 21.1% consisted of annual plant species. This is close to the optimum for beetle abundance. However, it has proved to be very difficult to collect any systematic data on the grazing levels in the park because such investigations are likely to be viewed with suspicion by local people.

The overall effects of cultivation and grazing on food availability for ibis remain uncertain. Removal of grazing and cultivation would result in an increase in steppe-like habitats, with higher vegetation cover than at present. However, it is likely that this would result in a lower abundance of beetles than in grazed and cultivated habitats. Lizard abundance might increase with less land use, but surveys on experimental areas of steppe from which grazing was excluded would be needed to test that. Vegetation cover might become too high for them beyond the range currently seen. Finally, removal or reduction of grazing and cultivation might adversely affect the ability of ibis to walk through the vegetation and detect prey. Overall, maintenance of an extensive agricultural system that creates mosaics of two-year or more fallows and steppe habitats with a moderate level of grazing seems to be a satisfactory way to maintain ibis foraging habitat. Achieving this land use pattern presents a challenge, but is a key element for the future management of the park.

Provision of supplementary water

The proximity of some of the dead birds found in the 1996 mortality incident to a stagnant water source, probably used for drinking, prompted the testing of the provision of fresh water close to breeding colonies as a way to reduce potential risks to the birds from contaminated water. However, the results indicated beneficial effects beyond those of avoiding infrequent catastrophes. We provided small drinking pools (one per colony or group of colonies) near the breeding colonies. The birds very quickly used these and, following initial trials, over a five year period we experimentally provided water points to about half of the Souss-Massa National Park colonies and did not provide them to the other half. The provision of water points was switched between years to exclude site effects. A detailed analysis is presented in Smith *et al.* (in press), but breeding success (young fledged per pair) was much higher at colonies with water points than those without. The scale of the effect varied among years, being particularly marked in dry years. Since 2003 the provision of water at all colonies has been part of the wardens' duties and the breeding success has been consistently high, particularly in the Souss-Massa National Park. The mechanism of the effect has not been determined but it seems plausible that birds provided with water have more time to attend the nest and forage because they do not have to spend time flying to other scarce water sources.

Discussion

In the last decade, the world population of the Northern Bald Ibis has shown a sustained increase for the first time in history. However, there are still only about 100 breeding pairs. The actions on the ground in Morocco have contributed to this recovery. These have been, most notably, wardening, the prevention of building construction and human disturbance, the provision of accessible water close to the breeding sites, and selective deterrence and removal of predatory and competitive species. The programme of detailed monitoring and research has been an essential source of guidance and scientific justification for the National Park to support their implementation of these measures. The studies ensured that the Park staff were able to exert considerable influence at the higher levels within the administration. The research has provided the basic knowledge required by the Souss-Massa National Park to fulfill its objectives.

Although it cannot now be proved, we strongly suspect that intensification of land use may have been a factor in the historical decline of the Northern Bald Ibis in much of its former range. Our findings of the key importance of lizards in the diet and that steppe habitats and two-year and older fallows hold far higher lizard densities than cultivations and young fallows is of major significance for defining the management objectives in the National Park and Tamri. The grazing regimes are also extremely important and, although we have been able to develop an understanding of the vegetation cover needed by ibis and their prey, we have been unable quantify the levels of grazing necessary to achieve this. However, it is absolutely clear that maintaining the current non-intensive land use systems in the Souss-Massa National Park and Tamri will be an ongoing challenge in the face of growing human population pressures and agricultural intensification,

It is of considerable interest that the increase in the Northern Bald Ibis numbers in Morocco has been brought about by simple, small scale methods. These have been funded largely by core NGO funds from RSPB and SEO/BirdLife. It is a constant source of frustration that implementing the key measures needed, for example the functioning and employment of the locally based wardens can be unappealing to the international funding agencies.

The work in Morocco remains essential, but has become part of a wider programme for the conservation of the Northern Bald Ibis. The recently rediscovered birds in Syria are the subject of a monitoring and conservation programme. Progress is being made in increasing the numbers of semi-captive birds in Birecik. In addition there are behavioural studies led by the Konrad Lorenz Institute and a number of projects to establish free flying birds from captive stock. A major development in recent years has been the formation of IAGNBI (International Advisory Group for Northern Bald Ibis) in 1999 which has taken a key role in bringing together the teams working on the wild birds with those in the zoo community.

The conservation status of Northern Bald Ibis is still precarious, bearing in mind the concentrated, colonial and social nature of the birds. For instance, at certain times over 70% of the world population concentrate at a single small roost-site. The cause of the 1996 mortality has not been determined despite numerous tests and efforts, and could potentially recur. The two pairs persisting in Syria appear to be the last remaining birds of the far more precarious eastern wild population, and lessons from Morocco are already important in informing actions there. Large captive populations persist in zoos, which have a Moroccan founder population, and release trials in Austria and Spain involve these birds. In addition, there are eastern birds in a semi-wild state at Birecik in Turkey as well as a very small number in Turkish zoos. Although there is considerable progress with developing viable reintroduction methods, such programmes are inevitably costly, come with their own risks of failure, and are problematic for formerly migratory populations (Bowden *et al.* in press). From the recent trend of recovery in the Souss-Massa region, there is now a realistic prospect that former colony sites further north in Morocco

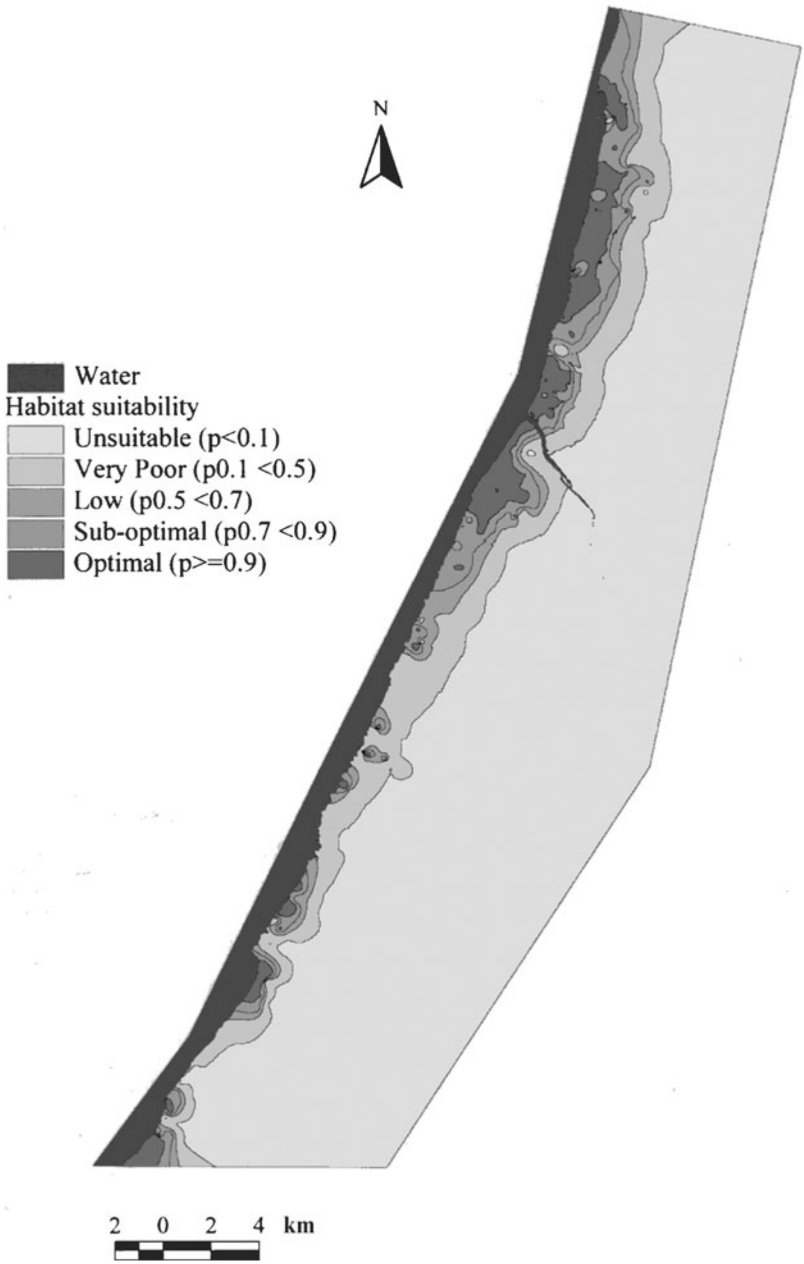

Figure 3. Map of modeled suitability for foraging by Northern Bald Ibis of part of Souss-Massa National Park (see text for details; from Rice *et al.* 2003). The extreme north of the park was excluded from the analysis because of the lack of clear satellite imagery from the area.

may be naturally recolonised. It is essential to maintain high productivity to maximize the chances of this occurring. Future efforts can build on the understanding that has been gained in the Souss-Massa region to look into the necessary measures needed to maintain the suitability of a selection of those former sites, and this is an area that should be looked into further in the near future.

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