White Stork (*Ciconia ciconia*) Migration Studies : Basic Research Devoted to Conservation Measures

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Abstract

As an inhabitant of open terrain, tolerant of human activities, the White Stork was able to follow the historical expansion of agricultural areas, and for a long time the species benefited from the wet pastures and riparian meadows thus created. But as early as the 19th Century its populations began to decline, owing primarily to the draining of wetlands, the creation of a network of high-voltage wires and the like. There are two major groups of White Storks in Europe, eastern and western. In the case of the western storks (which migrate to West Africa *via* Gibraltar), the populations of entire countries died out and have now been replaced by semi-domesticated storks. The eastern White Storks (migrating to East Africa *via* Israel) have been affected. Here we describe research to establish scientific bases for a comprehensive plan to protect these birds according to the "Bonn Convention." Modern methods such as satellite tracking, Magnetic Resonance Imaging and a combination of field and lab studies were applied initially to clarify the migration mode and staging biology of White Storks. Migrating from Central Europe to northeastern Africa, they cover about 4600 km in an average of 19 days, usually travelling daily in flights of ca. 250 km. Prior to the first outward phase, as far as NE Africa, they build up hardly any fat stores, and they probably lose weight on the journey as they feed only moderately to sporadically. This rapid outward migration with little need for special stopover sites will make it relatively easy to secure their future migration through the Near East by international treaties as proposed by the "Bonn Convention".

Key words : Bird conservation, Bird migration, Satellite tracking, White Stork

1. The White Stork as a Species under Threat

Unlike the Black Stork (*Ciconia nigra*), which inhabits large forested regions, the White Stork is a bird of the open countryside. It also lacks the shyness of its black congeneric, so that as humans converted forests to cultivated land in the Middle Ages, the White Stork progressively invaded these settlements. In particular, wet meadows in riparian lowlands became its most important habitat, where its reproduction rate was highest. As early as the 19th Century, however, stork populations began a continuous decline, chiefly related to the increase in the human population and the accompanying industrialization and restructuring of agriculture. The main factors were and are the melioration of wetlands, the use of former meadows for growing crops such as maize, the proliferation of high-voltage wires in the countryside, and the construction of factory chimneys high enough to act as stork traps. The storks have also been increasingly hunted on their migration routes and in their winter quarters, and negatively affected by biocides. This long-term population trend has been documented in greater detail than for any other bird species, by five internationally coordinated White Stork censuses throughout the entire distributional area (1934, 1958, 1974, 1984, 1994/1995). In four countries the free-living White Stork populations have meanwhile disappeared : Belgium in 1895, Switzerland in 1950, Sweden in 1955 and Holland in 1991. In 1997 only 3 breeding pairs remained in Denmark, out of about 4000 in the 19th Century (Fig. 1). The 1984 census showed the following balance : of the ca. 120,000 breeding pairs still in existence, about 100,000 were "eastern storks" (which migrate into eastern African winter quarters by detouring around the eastern Mediterranean Sea through Israel and Egypt), and only about 20,000 belonged to the western group, which migrates by way of Gibraltar to winter quarters in western Africa. The number of western storks had fallen by about 20% overall from 1974 to 1984, with an almost 40% decline in the northern part of their breeding area and a decline of about 17% in Spain and Portugal. During the same period the eastern storks declined by "only" about 12%. The census of 1994/1995 showed diminished White Stork populations in 22 countries of Europe and northern Africa, a stable population in one country and an increase in numbers in only four countries (reviewed by Rheinwald *et al.* 1989, Biber *et al.* 1994, Berthold 2000).

Distinctly different approaches have been made to conservation of the White Stork in the eastern and western parts of its range. In view of the dramatic decline and in some countries extinction of wild populations of the western storks, the measures that had been taken to protect them appeared useless or were no longer applicable ; therefore in the 1940s, programs were initiated to raise the storks in captivity, with the aim of eventually reintroducing them into the

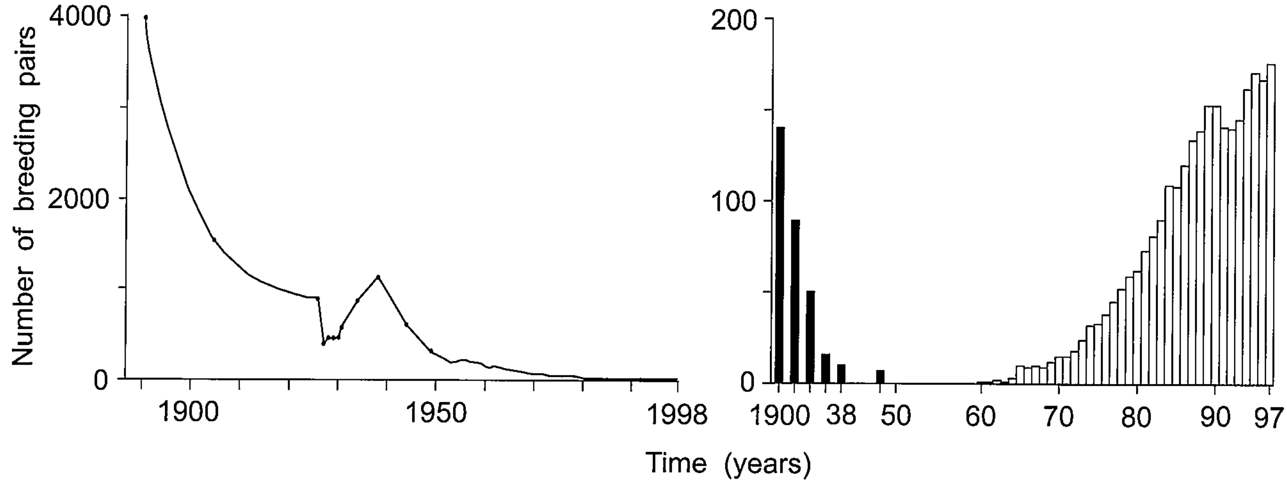

Fig. 1 Left : the decline of the White Stork population in Denmark since the end of the last century (Skov 1999, Berthold 2000). Right : decline of the White Stork population in Switzerland (until its extinction in 1950) and development of a re-introduced population since 1960 (Boettcher-Streim 1990-1997, Berthold 2000)

wild. This method (Bloesch 1989), first practiced in Switzerland, was rapidly extended to France, Germany and onward as far as Scandinavia, and since 1960 thousands of semi-domesticated breeding pairs have been settled in the region of the western storks (Fig. 1). Most of these birds spend the whole year in the breeding grounds, where they are fed during the winter ; their offspring mostly migrate away, but only a few return. For the eastern storks the procedure has been different. Because they are still relatively numerous, and the 1994/1995 census even revealed some population gains, it was decided to develop far-reaching ideas for conservation in various areas. Our investigations, described further below, fall into this category.

2. Conservation Concepts

Because its reputation as the bringer of babies has made the White Stork one of the most popular of all birds, efforts to protect it go back to pre-World War II years. At first they were concentrated almost exclusively on preserving suitable habitats in breeding grounds, providing nesting opportunities and reducing the number of birds killed by electrocution and collisions with high-voltage wires or by accidents with factory chimneys, etc., by erecting suitable shields. Not until later was attention also paid to the migration routes and winter quarters, where the losses - though difficult to quantify - are certainly considerable. It has been estimated that in the eastern populations alone, 2-3% of the storks (ca. 15,000 individuals) annually fall victim to hunters. The main dangers to storks during migration and in the winter quarters have been assigned to five categories, primarily by Schulz (1997). Here, again, habitat destruction is at the forefront, mainly involving the desiccation of wet areas and the construction of plantations, etc., closely coupled to severe reduction of the food supply, especially in regions where attempts are made to eliminate agricultural pests such as locusts. Next most important are marked climatic changes. The Sahel drought, in particular, has had devastating consequences since the end of the 1960 s : direct, in that habitats are lost owing to extensive desertification, and indirect through overgrazing of drought-stricken areas by disproportionately large herds of domestic animals. Third, there are also exposed electrical lines on the migration route and in the winter quarters - for instance, in Sudan and South Africa - which cause a substantial number of deaths by collision and electrocution. Following the hunting mentioned above, a fifth highly influential factor is undoubtedly the use of biocides, certainly inasmuch as they reduce the numbers of one of the main animals on which the overwintering storks feed - the migratory locust. The extent to which biocides are also significant in poisoning the storks directly has not yet been established with reliable data.

Following the 1972 UN conference in Stockholm, a conservation agreement was worked out that in 1983 came into force in international law as the "Convention on the Conservation of Migratory Species of Wild Animals" (CMS or "Bonn Convention") ; today it comprises about 60 member states. This convention is concerned with all aspects of the conservation of threatened species, including the need for research. In practice the Convention implements "Regional Agreements" with respect to particular animal species or species groups, with countries in which threatened species are to be especially protected. The most important of these so far is the "Agreement on the Conservation of African-Eurasian Migratory Waterbirds" (AEWA), which also includes the White Stork (Müller-Helmbrecht and al-Janabi 1999). Because the White Stork is an especially endangered species that can serve as a guide for dealing with others, an additional agreement is planned : the "Trittstein (Stepping-stone) Project" in the Near East, intended to ensure a safe migratory passage from central and eastern Europe to Sudan. It is our task to provide the basic scientific information needed for this project.

The work comprises precise analysis of the spatiotemporal process of migration, of resting behaviour, of the ecology of staging and of migration energetics including food requirements during the journey.

3. Previous White Stork Migration Studies

The White Stork, together with the Starling (*Sturnus vulgaris*) and some raptors, is among the pioneer species with which Mortensen began scientific bird ringing 100 years ago in Denmark. Once Thienemann had institutionalized this approach in 1903, following the establishment of the first bird research station, the "Vogelwarte Rossitten" in Germany, the White Stork became one of the main target species of bird ringing (Berthold 2000). By now about 300,000 White Storks have been ringed, and the ring recovery rate is high : approximately 35,000 recoveries have been made. These provide a classical example of bird ringing and have brought to light a unique picture of migration (Fig. 2) : the Mediterranean Sea is almost completely avoided by the for-

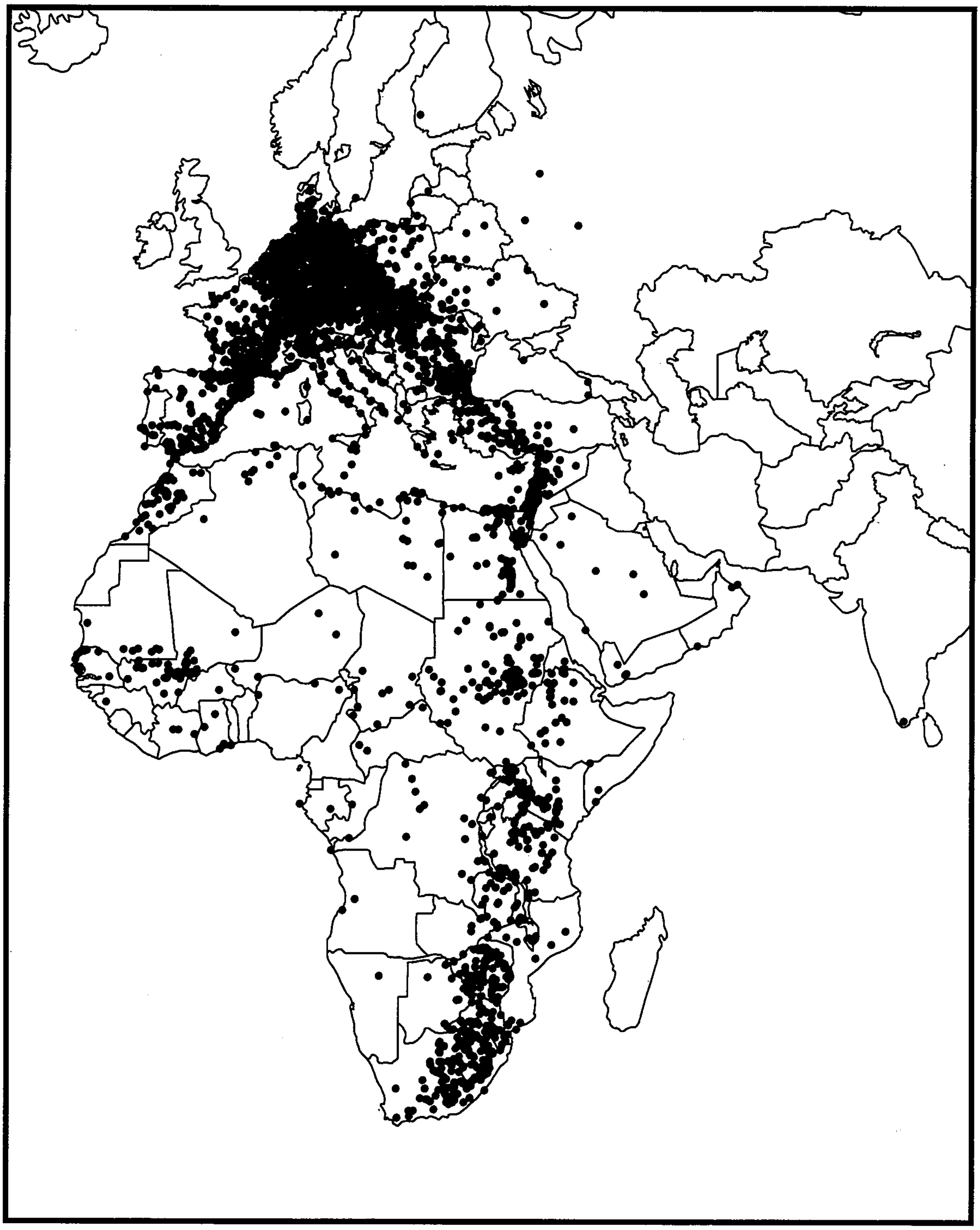

Fig. 2 The ca. 35,000 ring recoveries made for the White Stork, one of the pioneer species of scientific bird ringing, in the last 100 years. Most importantly, they map the two main migration routes : those of the "western storks" past Gibraltar to western Africa, and of the "eastern storks" through Israel to eastern and southern Africa

mation of a migration divide in the central European breeding grounds, so that the western storks migrate by way of Gibraltar into winter quarters in western Africa, whereas the eastern storks pass through Isreal to northeastern Africa and in some cases as far as the southern tip of South Africa.

Despite the enormous duration of the ringing efforts, 100 years, and the relatively large number of recoveries, the data are still far from sufficient to answer crucial questions in the analysis of migratory and resting behaviour that we have been asked to accomplish. Schüz (in Schüz *et al.* 1971) summarized the results obtained from ring recoveries with respect to migration velocity and stopover duration as follows : "On the whole storks allow themselves more time for the outward journey than for the return, so that to cover a distance of about 10,000 km they travel a daily average of about 120 km in autumn and 150 km in spring. Because relatively long stopovers are inserted when a suitable site is reached, the actual daily rates are in part much lower, and in part much higher. Furthermore, the rule does not apply to the entire migration : in late summer, when it is dry, the storks migrate more rapidly through the Near East than they do in spring, when the higher precipitation provides more food and makes it more appealing to spend time there" (translation). This description and similar statements by some other authors are too vague to suggest a conservation plan for the regions through which the migrants pass. Among the facts we need to know are : how long the daily flights in specific regions are and how broad their inter - and intraindividual scatter is, how often and how long the birds rest on the way, whether stopover periods serve to replenish energy reserves, and if special regions with a particularly abundant food supply are specifically sought out for this purpose, whether the young storks are guided by older birds on the outward trip, and whether the storks form flocks that stay together throughout the journey, as a prerequisite for successful migration. No satisfactory answer to any of these questions can be derived from the results of ringing. Hence for this study, from the outset, we had in mind a new, extremely promising method : satellite tracking. We were able to introduce this method in Europe in 1990, applying it successfully to Bewick's Swan (*Olor bewickii*) and the Griffon Vulture (*Gyps fulvus*). When smaller transmitters became available in 1991, we began using satellite tracking for the White Stork. Later other modern methods were also employed for this study, most importantly Magnetic Resonance Imaging.

4. Satellite Tracking of White Storks

Since 1991 our satellite tracking studies have been largely focussed on the White Stork (Fig. 3), with the result that by the breeding season of 2000 we had been

Fig. 3 Two White Storks travelling along the eastern route towards the Mediterranean region. To their backs are attached mini-transmitters for satellite tracking, the antennae of which are visible in the picture (photo by Bisch)

able to track a total of 82 individuals, 75 of which were in the eastern group of interest here. Of these 75 birds, a total of 23 individuals were followed throughout their journeys from the breeding grounds in eastern Germany (14 : 7 adults, 7 juveniles) and Poland (9 adults) into the northern African regions in Sudan and Chad ; the locations of 21 of these birds were recorded daily, and those of the remaining two on at least every second day. In the case of 5 storks the outward migration was tracked several times (four, three and in 3 cases two times), so that 31 complete records of individual migrations to northeastern Africa are available. Of the remaining 52 birds, 40 were tracked over considerable stretches of the outward route. Ten of the storks that proceeded on from the staging areas in Sudan and Chad during the autumn were tracked into southern Africa, some of them as far as the southernmost tip (Fig. 4). The longest distance over which a White Stork was tracked was more than 24,000 km (outward plus homeward), and the highest number of locations pinpointed in a given round trip was 1890.

The results so far obtained from satellite tracking of storks are many and, in particular, crucial for the conservation project. A new, important staging area was discovered quite unexpectedly, despite a century of intensive ringing of storks : western Sudan and Chad. Whereas the ring recoveries were made almost entirely in eastern Sudan, the few further west being regarded as strays, over half of our locations indicate storks aiming for western Sudan and Chad, and one

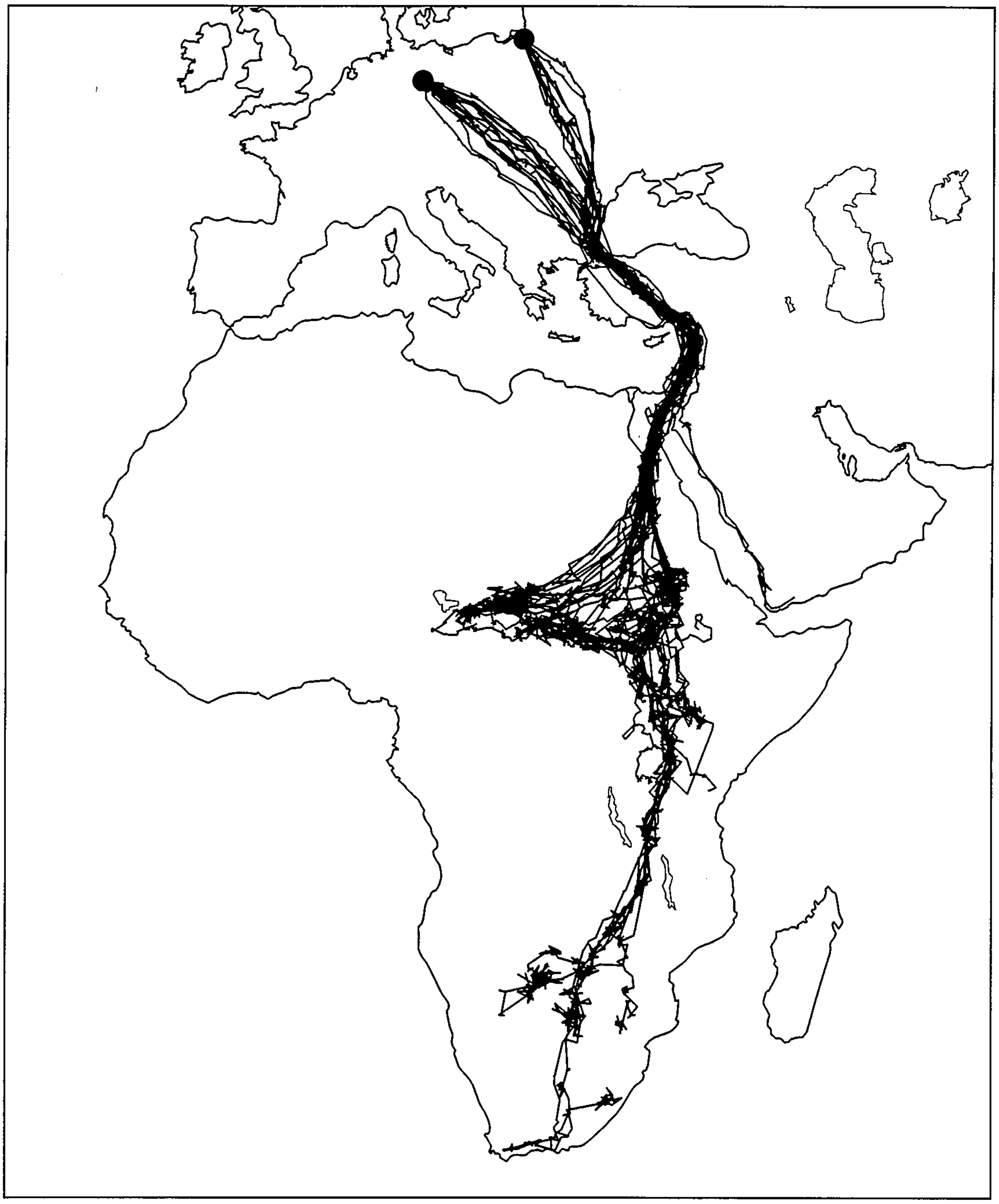

Fig. 4 Thirty routes of White Storks during migration from central and eastern Europe, determined by satellite tracking. The routes are grouped close together at first, as far as NE Africa, and from there spread out towards central or southern Africa

even as far west as Nigeria (Fig. 4). Because the birds stay for weeks in these western regions, it is urgent to include these regions in the conservation project - and a prerequisite for that is on-site investigation of the conditions in the main areas occupied. The explanation for western Sudan and Chad having previously been overlooked is undoubtedly that the local population has not been reporting recoveries, for religious and other reasons (reviewed by Berthold *et al.* in press b).

The most important finding from tracking relates to the mode of migration through the Near East. Nineteen of the 23 storks tracked from the breeding grounds into the staging areas in northeastern Africa (see above) travelled with very little delay, and covered the ca. 4,600 km to 18° latitude in only 18.9±2.95 (13-24) days. Nine of these birds migrated daily, flying for 8-10 hours from morning to afternoon ; 10 interposed brief rest stops on the way, with a duration of 2.6±1.35 (1-4) days. Only 4 of the 23 tracked storks took distinctly longer : 27-66 days. We know from direct observation that one of these birds had problems with flying for long periods at a time, while another had joined a group of injured old storks and might have stayed longer in resting areas on their account.

It can be concluded from these data that the endogenous program for migration of White Storks into the staging areas in northeastern Africa is evidently set for nearly continuous flight periods daily, or almost every day, and that when a stork does take a longer rest, lasting more than a few days, it is probably for external reasons. Furthermore, in combination with on-site observations our tracking studies showed that although the White Storks are gregarious migrants, they fly not as families or fixed groups but rather in flocks with a composition and size that frequently change, depending on what the situation happens to be (aggregations, as temporary chance conjunctions, Berthold 1998).

5. Ecophysiological Studies

Whereas observers have had an idea of the migration speed and daily stages of the eastern storks for some time now (see reference to Schüz above), there was essentially no useful information about resting behaviour, staging ecology or the birds' energy balance during migration. Moreau (1972) noted, "Nothing is known about the accumulation of fat by these storks," and that continued to be the case for decades. Hall *et al.* (1987) observed a unique body-weight cycle of storks from the western population that were kept in aviaries : their weight was low during the migration periods and reached a peak in midwinter. But it remained an open question whether this finding also applied to the eastern storks and, indeed, whether it typified free-living storks at all (Berthold *et al.* in press c).

If one wants to find out more about the resting behaviour and staging ecology of migratory birds, ring recoveries are not likely to be of much help. Rings, of course, are recovered from individuals left stranded on the ground, and one of the reasons for their difficulties might well be a failure to behave as they should during staging. To attack questions in the fields of staging biology and energy balance, we took two approaches. The first was to select particular

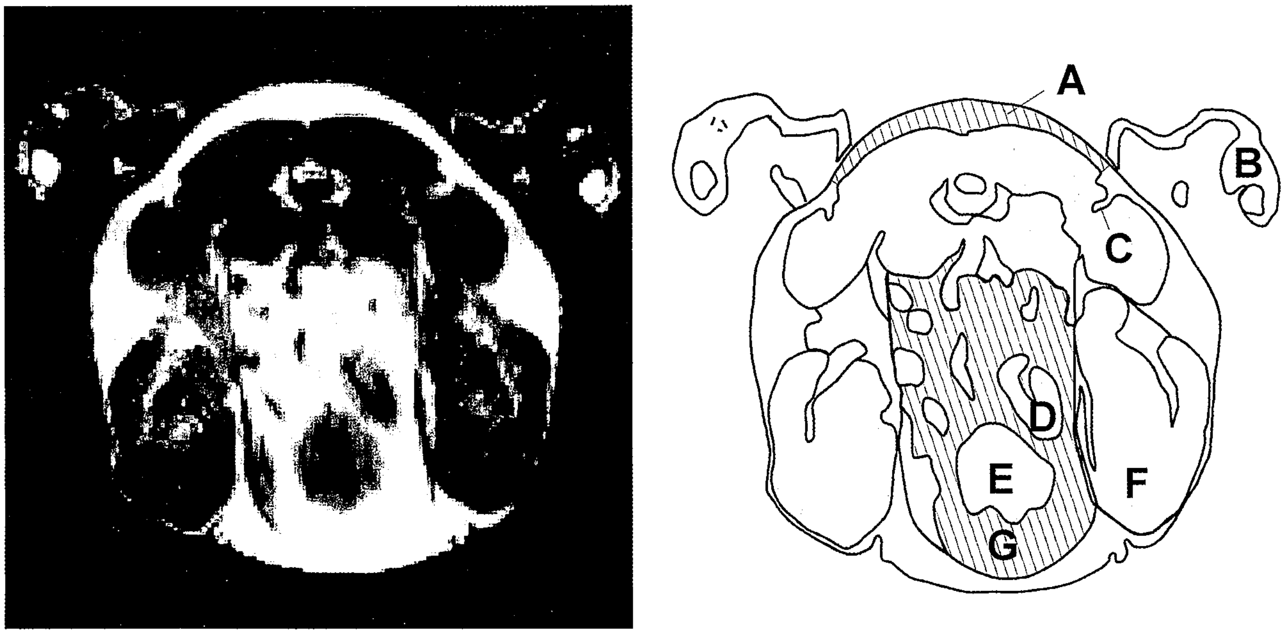

Fig. 5 Left : virtual dorsoventral cross section through a White Stork at the level of proventriculus and gizzard (see right), produced by Magnetic Resonance Imaging. The higher the water content of a tissue, the brighter it appears in the image. Right : explanation of the imaged body parts. A (hatched) : cutaneous/subcutaneous fat depots, in the region measured for quantitative fat determination, B : wings, C : site of attachment of air sacs, D : proventriculus, E : gizzard, F : thigh musculature, G (shaded) : visceral fat deposits in the abdominal body cavity (Berthold *et al.* in press a)

storks equipped with transmitters for satellite tracking and follow them in cars and small airplanes, so as to examine the staging biology of individuals that had been shown by continuous tracking to be capable of migrating successfully. The second was to collect weight and fat-deposit data from storks kept in aviaries and compare this with samples taken from conspecifics living in the wild.

In research for a dissertation, M. Kaatz and co-workers tracked 35 transmitter-bearing storks from eastern Germany and Poland into the Mediterranean region, where altogether more than 200 resting sites chosen by the storks were investigated (Kaatz in press). For another dissertation, v.d. Bossche (in press) carried out a similar study on storks passing through Israel. In our institute we kept 12 hand-raised White Storks of the eastern population, from Sachsen-Anhalt, in a large aviary where in winter the photoperiodic conditions of the natural winter quarters were simulated. For 15 months the body weight and fat deposition of these birds were monitored to obtain a complete annual cycle. The fat content of the living birds was measured in a pilot study by means of approximately monthly Magnetic Resonance Imaging (MRI) and combined computed tomography (Fig. 5). With this method the volumes of the cutanous/subcutanous and visceral fat depots (in cubic centimetres) can be determined very accurately, as has been established by comparisons with the values obtained by dissecting out and weighing the adipose tissue of a number of bird species (reviewed by Berthold *et al.* in press a). In addition, Magnetic Resonance Spectroscopy was used to obtain a series of measurements of the fat content of the breast muscles, in search of evidence of intramuscular fat deposition such as is typical of many other species of migratory birds (Berthold 2000).

The main results of our ecophysiological studies are as follows. The storks in the aviaries had relatively low weights in both migration periods (outward and return) and their fat deposits were correspondingly small (Fig. 6). They also gave no sign during migration periods of the hyperphagia characteristic of other migratory bird species. These results, obtained under experimental conditions, agree well with those of field observations. As described above, these storks make almost uninterrupted flights to northeastern Africa, normally taking very few days off to rest, so they have little opportunity for intensive feeding. Even during their hours on the ground during migration days, no evidence was found of hyperphagia that could promote migratory fat deposition. On the contrary : the moderate food intake observed in eastern Europe seems just enough to support everyday energy consumption. As the birds approach the Mediterranean Sea, their feeding becomes progressively more opportunistic and sporadic, and in Israel, where sometimes more than 100,000 White Storks pass through at the same time, practically no food at all is eaten. The body weights measured in the field are also consistent with this interpretation : about 3,400 g in eastern Germany just before the outward flight (the same as

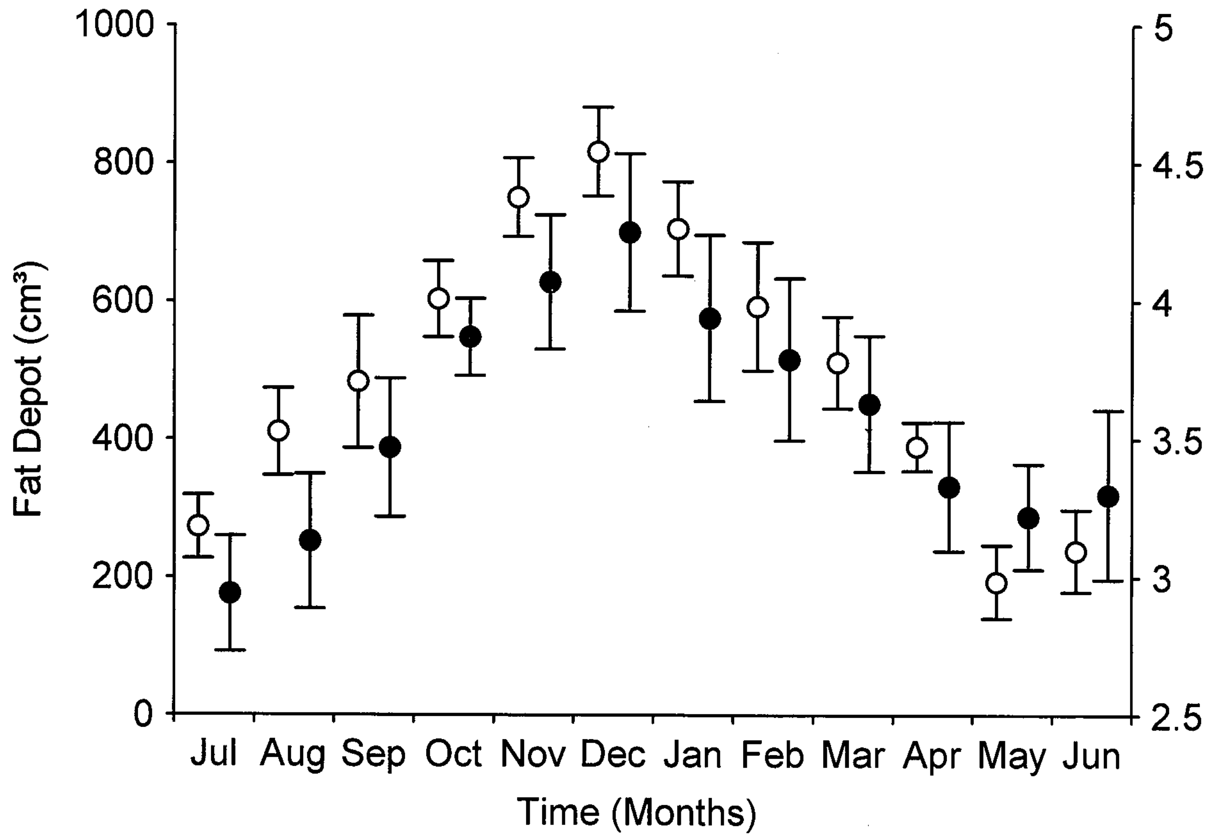

Fig. 6 Annual cycle of body weight (black dots, means and standard deviations) and of abdominal fat deposition (white circles) experimental white storks as determined by Magnetic Resonance Imaging (Berthold *et al.* in press c)

the weight of our experimental birds at the corresponding time; Fig. 6) and about 3,000 g in Israel (see review by Berthold *et al.* in press c).

6. Conclusions and Results Regarding Conservation Measures

The combined field-and-laboratory study of White Storks, employing modern methods such as satellite tracking, Magnetic Resonance Imaging and MR Spectroscopy, has brought to light a new migration mode, which has only been hinted at in previous descriptions. We have called it the MSOM type - from "mostly travelling every day", "seldom inserting whole-day rests", "opportunistically feeding", and "developing moderate or no fat depots". It contrasts with the two main types of migratory birds previously known, the ILHB type (for intermittently migrating) and NNHB type (nonstop migrating; for details see Berthold *et al.* in press c).

According to our findings, the typical White Stork migrating on the eastern route, from eastern Germany or Poland, flies every day until it has reached its North African staging area (18° latitude or beyond); thus it covers the ca. 4,600 km in about 19 days, on each of which it has flown an average of ca. 250 km. For such a stork to rest for a whole day, or several, is the exception, and such behaviour seems to be brought about more by external circumstances than by the endogenous migration program. During this nearly uninterrupted migration the storks evidently exhibit neither hyperphagia nor pronounced migratory fat deposition - whether in the interior of the body, in the skin, or in the breast muscles. On the contrary: they tend to lose a certain amount of weight, because of feeding only opportunistically or not at all until they reach their staging areas. In this regard, the data obtained from storks kept in aviaries agree very well with samples and observations from the field. This special migration mode of the White Stork makes it relatively simple to implement the above-mentioned "Trittstein Project" as far as the outward journey is concerned. For practical purposes, it will be sufficient to ensure that the storks have resting sites on the eastern route and are protected from hunters and not chased away or otherwise disturbed; there is no need to make accessible, or to create, highly nutritive feeding sites. However, the storks migrating back to the breeding grounds might face different problems. The studies by v.d. Bossche (in press) have shown that homeward-bound White Storks search intensively for food in Israel, unlike those on the outward journey. This could be a matter of specific hunger for proteins, to build up protein reserves in preparation for laying eggs after arrival in the breeding grounds. Such protein reserves, which are evidently essential for successful reproduction of White Storks, might formerly have been accumulated by feeding on migratory locusts in Africa (Dalinga & Schoenmakers 1989). But now it often happens that pest-control efforts have severely reduced this food source, as well as others (Bairlein 1991). To answer these questions further, targeted investigations of free-living storks during the homeward migration period will be needed. It is also necessary to check whether storks living free in their African winter quarters reach a midwinter peak in weight and fat depots like that observed in our aviary storks. There is some evidence that they do (Berthold *et al.* in press c), but as yet no convincing documentation. The buildup of fat stores in winter could be an adaptation of the storks to extremely variable local conditions, which often make it necessary to migrate over considerable distances within the African continent. As winter approaches, if the living conditions for storks that have stopped in Sudan and Chad deteriorate as a result of drought and food shortages, the birds are often forced to move on to Kenya or even further through Tanzania, Zimbabwe and Botswana into more southern regions, until they find a place where the food supply is adequate. The endogenous program might allow for acquiring a winter fat depot to support travel over these enormous distances, through regions that are in part extremely inhospitable. This aspect deserves further investigation. But for now the most important goal is to put the findings outlined here into practice soon by implementing bilateral international treaties within the framework of the "Bonn Convention." In concrete terms, this means creating rest zones for the storks, and securing their existence by the appropriate legal means, from central and eastern Europe through the countries of the Near East to northeastern Africa. The preparations for this have already been begun by the Federal Office for Conservation in Bonn as part of the "Trittstein Project".

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(Received on 30 Aug., 2000, Accepted on 4 Dec., 2000)