Temporal and Spatial Pattern of Nocturnal Bird Migration across the Western Mediterranean Sea Studied by Radar

Diploma Thesis by

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Content

Pictures:

I

General Introduction

Migratory birds have to cross or circumvent two vast areas, the Sahara Desert and the Mediterreanean Sea, during their migratory journey between their breeding areas in Europe and their wintering areas in Africa. A lot of day migrants such as raptors, herons and storks avoid crossing the Mediterranean Sea and concentrate at the Straits of Gibraltar and Bosporus. But most birds migrate by night and until recently relatively little was known about how and to what extent these night migrants cross the Mediterranean Sea and the Sahara. It was supposed that they fly on a more or less broad front across the Mediterranean and the Sahara during night and day (Moreau 1972, Curry-Lindahl 1981). Early radar and visual observations gave no evidence for concentrations along the shortest routes, such as Gibraltar, Sicily or Malta (Casement 1966) and many surveillance radar studies suggested no deviations in tracks when birds flew across coastlines (Eastwood 1967). In recent years however, field observations have shown that mountain ridges can lead to local concentrations of the migratory stream (Bruderer 1996) and that coasts can influence the flight behaviour of migrants (Alerstam, 1977). It was argued that at least some of the birds maintained their temporal pattern of flying by night and resting during the day even over a large ecological barrier such as the Sahara (Biebach et al. 1986, Bairlein 1988). Therefore, the Swiss Ornithological Institute carried out a study supported by the Swiss National Science Foundation, where bird migration across the western Mediterranean was investigated in autumn 1996 and spring 1997. The aim of this study was to find out if the the migratory stream occurs over a broad front across the Mediterranean Sea and if islands such as the Balearic Islands, in particular the coastlines, influence the migratory stream. Two tracking radars were operated, one on the southern tip of the island Mallorca, the other near Malaga at the coast on the Spanish mainland. Moon and infrared observations along the French and Spanish coast provided additional information over a larger scale.

This diploma thesis was part of the project. It focused on the temporal and spatial pattern of nocturnal bird migration over Mallorca during the spring season as recorded by radar. The thesis was divided into two themes which were analysed and discussed in detail:

1) the temporal and seasonal schedule of the migration intensities and
2) the direction, speed, and potential recruiting areas of the migrants.

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II

Diurnal and Seasonal Schedule of Spring Migration over Mallorca

Summary

The diurnal and seasonal schedule of nocturnal bird migration over Mallorca in spring was investigated by means of a tracking radar. The diurnal course showed two phases of high activity with a gap in between. The take-off phase on the island started shortly before sunset and lasted for 2 to 4 hours. The peak intensity was reached within one hour after sunset. The main mass of birds from Africa arrived on Mallorca eight hours after sunset. On average at least one third of the migrants landed soon after crossing the coast every night. This pattern is supported by a fair correlation between the number of birds arriving during the night and the number of birds taking off the next evening. This correlation suggests short resting periods of only one day. Among all tracked birds the proportion of birds with a passerine-type wing-beat pattern was almost 50% at the beginning of April and decreased to 18% by the end of May. The proportion of birds with a continuously flapping wing-beat pattern stayed approximately constant, while the proportion of birds with a swift-type wing-beat pattern increased from 6% to more than 40% over the same period. The temporal variation in the number of birds was high, presumably due to different weather conditions. The diurnal pattern showed that the take-off was confined to a short period after sunset and that the main mass of birds landed somewhere in North Africa before crossing the Mediterranean Sea.

Keywords

bird migration, Mediterranean, Mallorca, temporal pattern, seasonal pattern, take off, landing, spring

Introduction

Every year in Europe about 5 billion birds (Moreau 1972) leave their breeding areas in autumn and migrate to Africa in order to spend the winter in regions which offer more favourable environmental conditions. In spring they return to Europe to make use of the abundant food for raising their broods. On their migratory journey they either circumvent the Mediterranean or cross it (Bruderer & Liechti in press). Those making the shortcut across the sea between southern France and the Algerian coast have to fly a distance of about 600 km without the possibility to land. The eastern and western straits, Bosporus and Gibraltar, are famous for their massive concentrations of day migrants such as raptors, herons and storks. But most species migrate by night and until recently relatively little was known about how and to what extent these night migrating birds cross the Mediterranean and the Sahara. Early radar and visual observations indicated no concentrations at the narrows of Gibraltar, Sicily or Malta (Steinbacher 1954, Moreau 1961, Casement 1966,). It was supposed that the birds crossed the Mediterranean on a broad front and that the migrants performed non-stop flights over the Sahara and in autumn even directly over the Mediterranean without landing (Moreau 1972, Curry-Lindahl 1981, Lövei 1989). In recent years, however, it was shown that mountain ridges can lead to local concentrations and deviations from the migratory stream (Bruderer & Jenni 1990, Bruderer 1996, Liechti et al. 1996) and it was argued that at least some of the birds maintained their temporal pattern of flying by night and resting during the day even over a large ecological barrier such as the Sahara (Biebach et al. 1986, Bairlein 1988, Biebach et al. 1991). This schedule was maintained in the Negev desert in southern Israel (Bruderer 1994). A recent review of bird migration across the Mediterranean, including radar, infrared and moon watching data, showed considerable concentration of nocturnal bird migration to the east and west of the Mediterranean Sea and a high degree of separation between diurnal and nocturnal migration in spring and autumn (Bruderer & Liechti in press).

From previous studies in different parts of Europe and North America it is known that migration starts prior to or within the first hour after sunset and reaches a peak of migratory activity 1 to 4 hours after sunset (Parslow 1968, Hebrard 1971, Bolshakov 1975, Alerstam 1976, Richardson 1978, Dolnik 1987, Biebach et al. 1991, Åkesson et al. 1996, Bruderer 1997, Liechti et al. 1997). But it is not well known how long the take-off phase is. Studies in which radio transmitters were attached to birds showed that some birds took off much later in the night (Cochran et al. 1967, Åkesson et al. 1996, Moore & Aborn 1996).

In this paper, I would like to present the seasonal course and the exact time schedule of nocturnal bird migration over Mallorca. Owing to the unique geographical situation which the island offers and the radar site near the southern coast, it was possible to investigate the timing and length of the take-off phase. Because the birds could not take off from the sea, the actual take-off by birds in the small area around and south of the radar could be monitored. The birds which had taken off in North Africa arrived only later in the night, after crossing a distance of 300 km over water. By means of the observed temporal pattern of migration it will be shown: 1) Whether the take-off phase is confined to the beginning of the night or whether birds take off at any time throughout the night; 2) Whether the birds adhere to the pattern of migrating by night and resting during the day, even when crossing a large ecological barrier such as the Mediterranean Sea. Then the local schedule of migration can be used to show if non-stop flights over the Mediterranean and the Sahara are the prevailing strategy or if most birds take advantage of the possibility to land and refuel in North Africa before crossing the Mediterranean Sea.

Materials and Methods

This radar study was conducted in spring 1997 on the island of Mallorca, Spain. The radar was located in the south of the island (39°18´ N, 3°4´ E) 20 m above sea level next to the Salines de Salobrar about 8 km NW and 2 km NE from the southern coast (fig. 1). The radar used was an X-band (3.3 cm wavelength) tracking

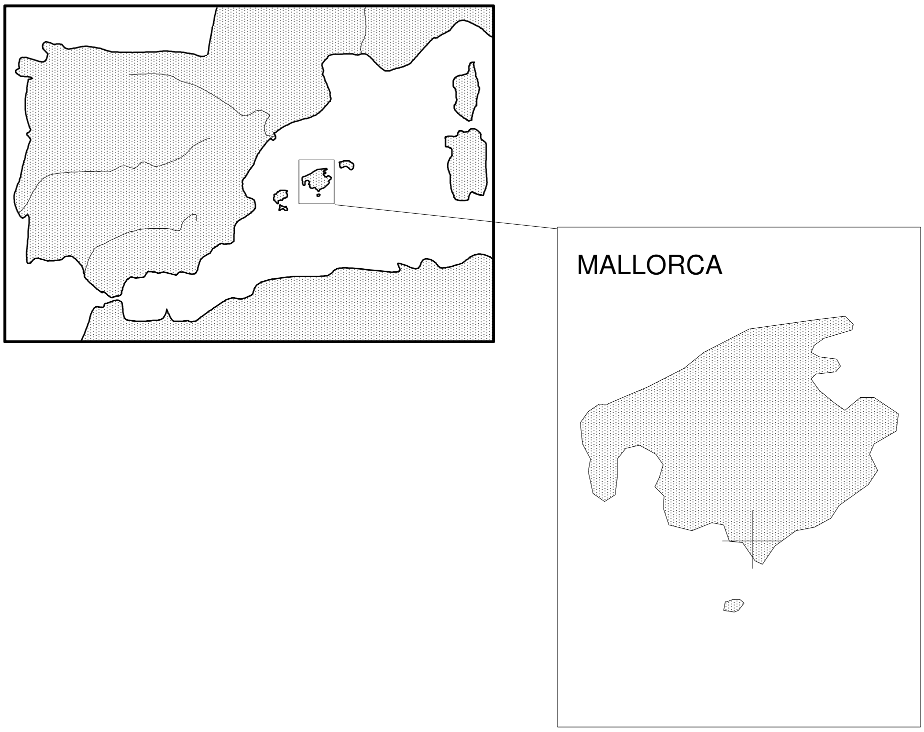

Fig. 1. Map of the western Mediterranean. The radar site is marked with a cross.

radar with 2.2° nominal beam width, 150 kW peak pulse power and 0.3 µs pulse length. Data was obtained on 64 nights between 24-03-97 and 26-05-97. Every half hour from 20:30 h to 04:30 h and every hour from 05:30 h to 11:30 h a quantitative measurement of the spatial distribution was made by conically scanning within a half-sphere of 4 km radius. All time indications are local summer time, which is UTC + 2 h.

From 13-04-97 to 26-05-97 at the same site a second radar was operated, which automatically made the quantitative measurements every 10 minutes, 24 hours a day. With these measurements, the density of the birds was calculated as number of birds·km^{-3} according to the procedure described by Bruderer et al. (1995).

During the time between two measurements, the operator manually locked on single targets to register their flight tracks for 40 s each. The wind was measured by tracking a meteorological balloon up to at least 4 km height above ground level at noon and then every 4 hours. By combining the data of the wind measurements with the tracking data of the birds (e.g. ground speed, vertical speed, altitude and track), heading and air speed were calculated. The fluctuations of the radar signal (echo-signatures) allowed the identification of wing-beat patterns, which were classified into 4 groups (Bloch et al 1981):

CF: continuously flapping birds, corresponding mainly to wader-/waterfowl-type birds, but also to continuously beating swifts and others

IF: intermittently flapping birds, corresponding mainly to passerines

SW: swifts (apus)

UD: undetermined pattern; flocks, bats, insects, echoes interfering with ground clutter

For the present analysis I worked with two datasets. For the period from 27-03-97 to 13-04-97, I used the data from the first radar (N = 14 nights); from 13-04-97 to 26-05-97, I also took the measurements from the second radar (N = 35 nights). For those times when data from both radars was available, I took the average of the two. In the analysis some nights are lacking due to missing measurements or technical problems.

In order to express the temporal pattern quantitatively, I wrote a computer program in Access Basic (appendix). It went through all measurements of the densities one by one and calculated the following: 1) the maxima and minima of the density curve over time. In the case of the first radar, a value was defined as a maximum if the two measurements before and the two measurements after were smaller than the actual value, and as a minimum if they were larger. For the second radar, the definition of a maximum or a minimum was slightly different, because more measurements were available. In that case a value was defined as a maximum if all values one hour before and one hour after it were smaller, and as a minimum if they were larger; 2) the duration was calculated as the time between two minima; 3) the sum of all densities from one minimum to the next was computed and used to calculate the MTR (Migration Traffic Rate = theoretical number of birds crossing a front of one kilometre per hour, Lowery 1951. Originally one mile).

All measurements from one minimum to the next will be referred to as a phase. The phase from the first minimum around sunset to the following minimum was considered to be the take-off phase (TP), characterised by one maximum in between. All the phases from this second minimum onwards to the first minimum which followed after the last maximum before sunrise were defined as the night phase (NP). A special case occurred when the density after the take-off phase remained low and no maximum could be detected between two minima. In such cases the night phase was defined to start at the minimum before the next maximum after the minimum of the take-off phase. By multiplying the MTR with the length of the night phase or the take-off phase and weighting it with the proportion of tracks with wing-beat classes of CF and IF, the number of birds arriving or leaving the area south and around the radar per front of one kilometre was calculated. For this entity the term weighted Migration Traffic (MT) will be used.

Results

Diurnal schedule

Nocturnal migration showed two more or less distinctive phases separated by a gap, caused by the lack of migrants taking-off from the sea. The first phase consisted of birds departing from the island; the second phase of those arriving from North Africa later in the night. In the relatively short gap only few birds were recorded (fig. 2, for figures and time tables of all nights separately, see appendix). The take-off phase began on average 13 ± 25 min before sunset (standard error of the mean SE = ± 4 min, N = 49 nights), reached the maximum only 64 minutes later (mean M = 51 ± 13 min, SE ± 2 min) and came to an end 200 ± 62 min after sunset (SE = ± 9).

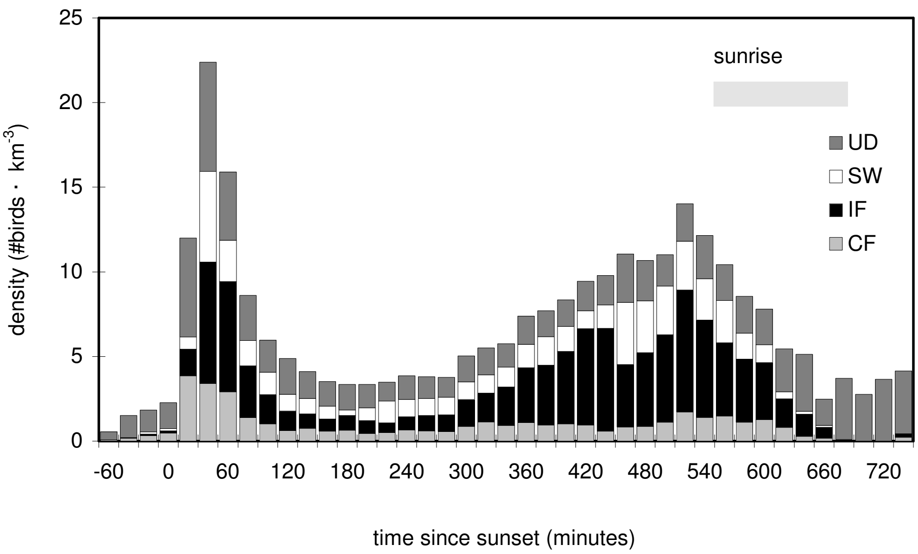

Fig. 2. Temporal pattern of the mean densities per time interval. Proportions of wing-beat classes were calculated relative to the number of tracked birds per time interval. The densities resulted from measurements with conical scanning. UD = undetermined tracks, SW = swifts, IF = intermittent flapping, CF = continuously flapping.

The relationship of the take-off phase to sunset and civil twilight (sun 6° below horizon) over the observation period is shown in figure 3. At this latitude the civil twilight bears a constant relationship to the time of sunset. The time when nocturnal migration began was clearly related to the time of sunset (or civil twilight), as was

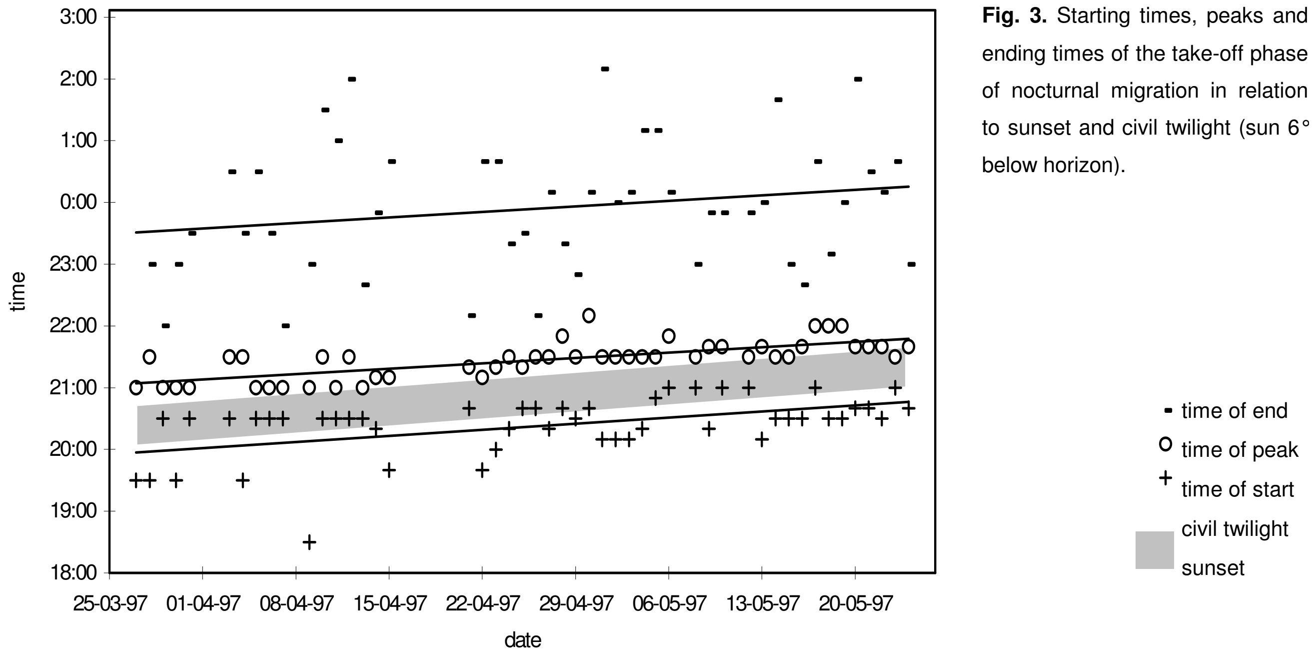

Fig. 3. Starting times, peaks and ending times of the take-off phase of nocturnal migration in relation to sunset and civil twilight (sun 6° below horizon).

true for the time of the peak of the take-off phase. Even the widely scattered end of the take-off phase was related to sunset. Therefore I used the time of sunset as a reference and not the local time.

The between-nights variation of the arrivals from North Africa was quite large. This was not surprising, considering the birds had crossed 300 km of open sea and encountered different wind situations. The fastest birds arrived on average 229 ± 81 min after sunset on Mallorca (SE = ± 12 min, N = 49 nights). The main mass of birds did not reach the island until 256 minutes later than the fastest birds (M = 485 ± 94 min, SE = ± 13 min). On average 8 ± 59 min after sunrise the night phase was over (M = 8 min, SD =, SE = ± 8 min).

The average proportion of the classes CF + IF in the take-off phase was 43%; in the night phase it was 52%. The proportions of the CF and the IF in the night phase showed a bimodal distribution, where the highest proportions of 70% during the first peak and 63% during the second peak occurred (fig. 2). Around sunrise the proportions of CF, IF and SW decreased, while the proportion of UD increased. The take-off pattern of the CF around sunset was significantly different from that of the IF (Mann-Whitney U = 126, $p < 0.046$, N = 20), which indicates that the CF started earlier than the IF. The proportions of the classes CF and UD in the take-off phase were significantly greater than in the night phase (Mann-Whitney U Test, $U_{CF} = 826$, $p < 0.008$, N = 49, $U_{UD} = 725$, $p < 0.001$, N = 49). For the proportion of IF and SW the opposite was true ($U_{IF} = 791$, $p < 0.004$, N = 49, $U_{SW} = 858$, $p < 0.015$, N = 49).

Seasonal course

The seasonal course of migratory intensity is shown in figure 4. The weighted MT fluctuated heavily from day to day. As a rough picture the overall weighted MT ($MT_{TP} + MT_{NP}$) showed a steep increase from the beginning of April to mid-April, then slowly declined by the end of May. The highest weighted MT occurred between mid-April and the beginning of May. The weighted MT in the night phase showed greater fluctuations and was in general higher than in the take-off phase, except for 12 nights.

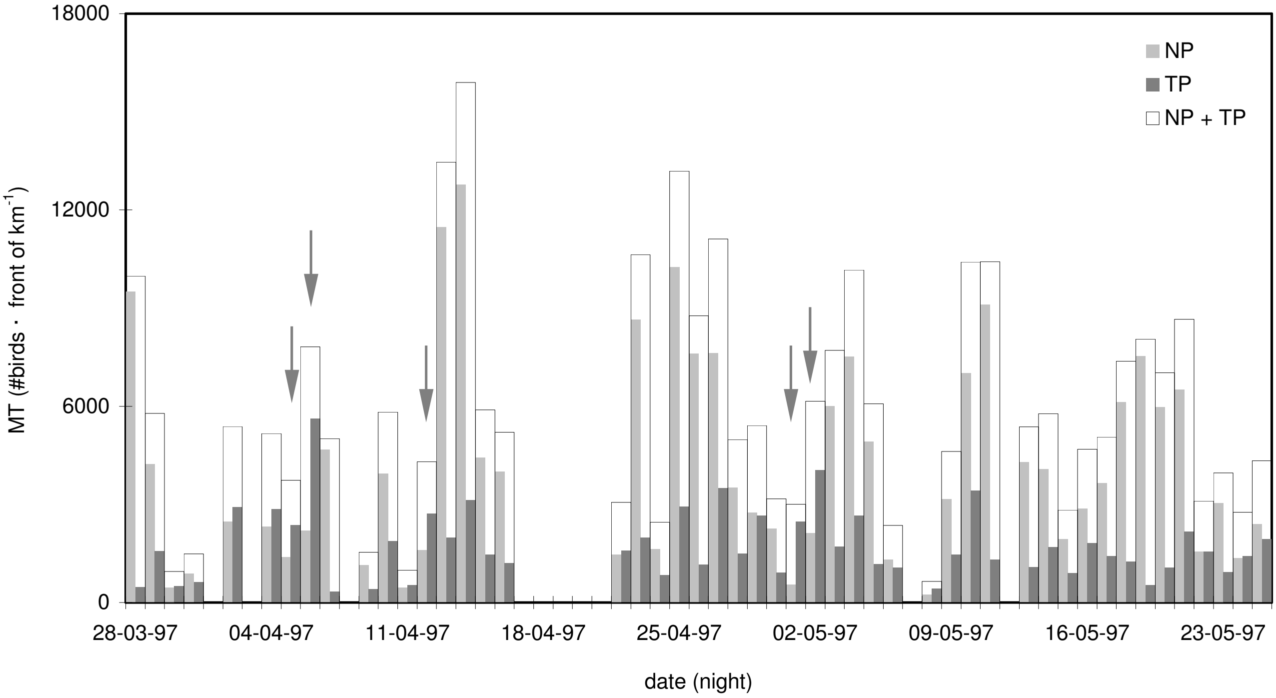

Fig. 4. Seasonal pattern of the weighted migration traffic of 49 nights (MT = migration traffic, NP = night phase, TP = take-off phase, NP + TP = sum of NP and TP). Arrows indicate nights where the MT of the TP was much higher than the MT of the NP (nights with mass departures).

To investigate the changes in the temporal course and the composition of the migration throughout the season, the quantitative and the qualitative data were grouped into four periods (fig. 5). Early in the season the migration consisted mainly of IF (48%), only few SW were tracked (8%), the proportion of CF was intermediate (15%) and the proportion of the UD was 29%. From the first period to the last period the proportion of SW increased to 43%. Correspondingly, the proportion of IF decreased steadily to 18%. The proportion of CF and of UD remained approximately at the original level, suggesting that their absolute number increased slightly towards May due to the high increase of SW patterns. The increased number of swifts in May led to the disappearance of the clear separation of the night phase from the take-off phase, because the Swifts slept in the air and thereby increased the densities between the two phases.

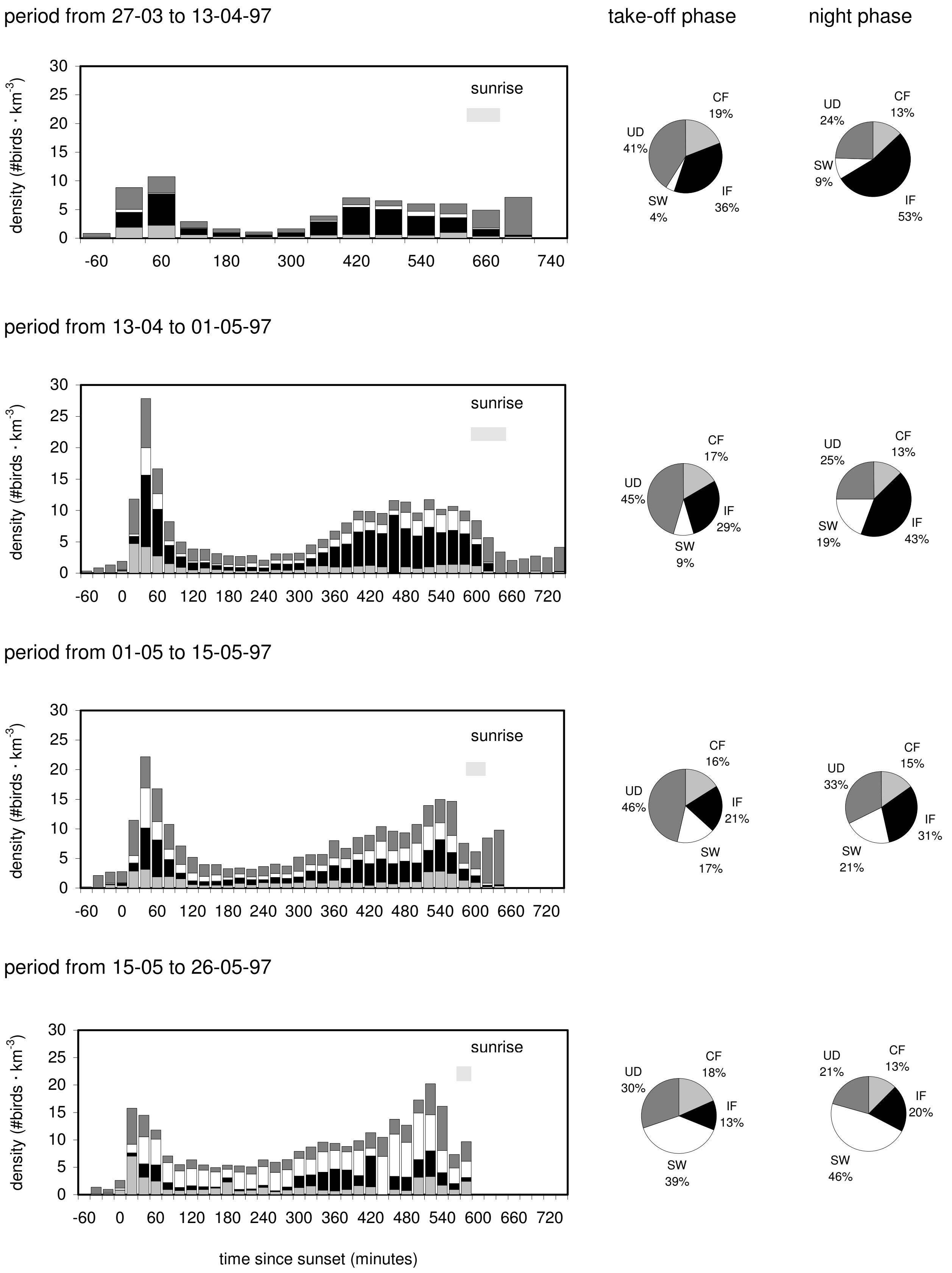

Fig. 5. Temporal patterns of the mean densities per time interval and pie charts of the proportions of wing-beat classes grouped into four periods. CF = continuously flapping, IF = intermittently flapping, SW = swifts, UD = undetermined tracks.

Stop or non-stop?

The median of the vertical speed remained approximately constant over time (fig. 6). But about 60 minutes before sunrise the range of the negative values increased drastically, with some birds having vertical speeds of more than -15 $m \cdot s^{-1}$. From 120 minutes to 240 minutes after sunrise the range returned to the same values.·

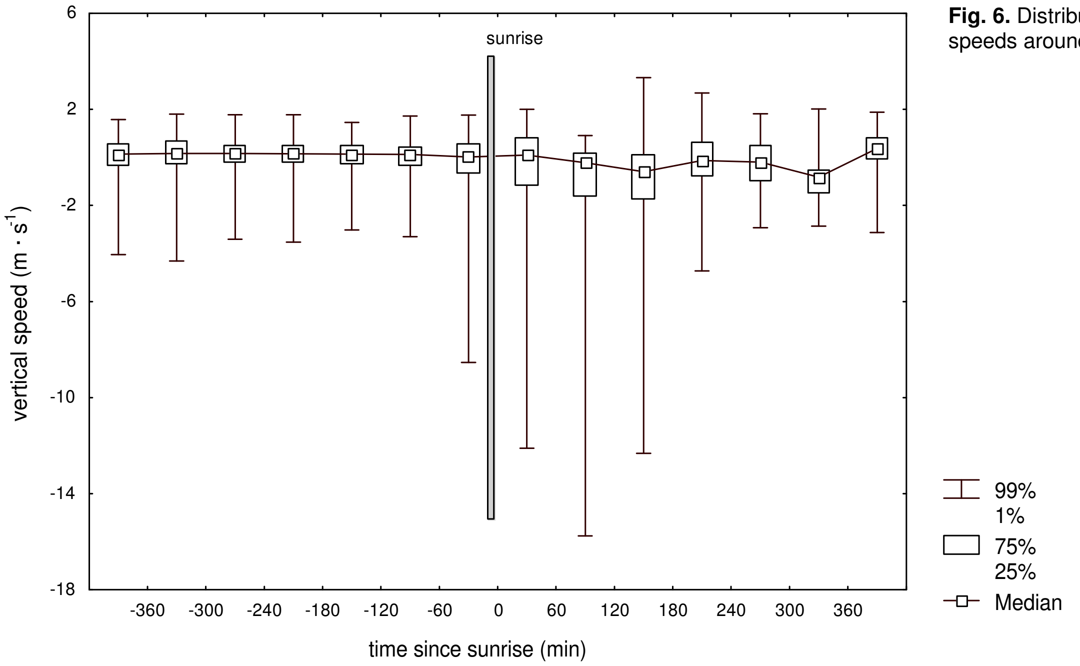

Fig. 6. Distribution of vertical speeds around sunrise.

The high number of birds taking off every evening from the island suggests that a lot of birds must have landed during the night (and day?) before. With the MT of the take-off phase and the night phase it was possible to estimate the proportion of landed birds. Two estimations will be given, indicating a lower and higher limit of the actual proportion. For the lower limit I assumed that we did not measure the birds twice, once when they arrived from North Africa during the night and once when they departed from the island during the take-off. Thus one can think of the proportion of landed migrants as: $MT_{TP} \cdot (MT_{NP} + MT_{TP})^{-1}$, which came to 27% (average of 49 nights). For the upper limit I assumed that the measurements of the take-off phase included the same birds as in the night phase. The proportion of landed birds was then calculated from the weighted MT as: $MT_{TP} \cdot MT_{NP}^{-1}$, which came to 37% (N = 49 nights). The actual quantity presumably lies somewhere in between, but certainly nearer to the 27%, because 1) it is very unlikely that we measured a bird twice and 2) it was possible that during the day some birds still arrived from North Africa and landed unmeasured south of the radar.

If the birds which landed stayed only until the next evening, the number of birds that arrived during the night (during the night phase) should correlate with the number of birds departing the next evening (fig. 7). But in a

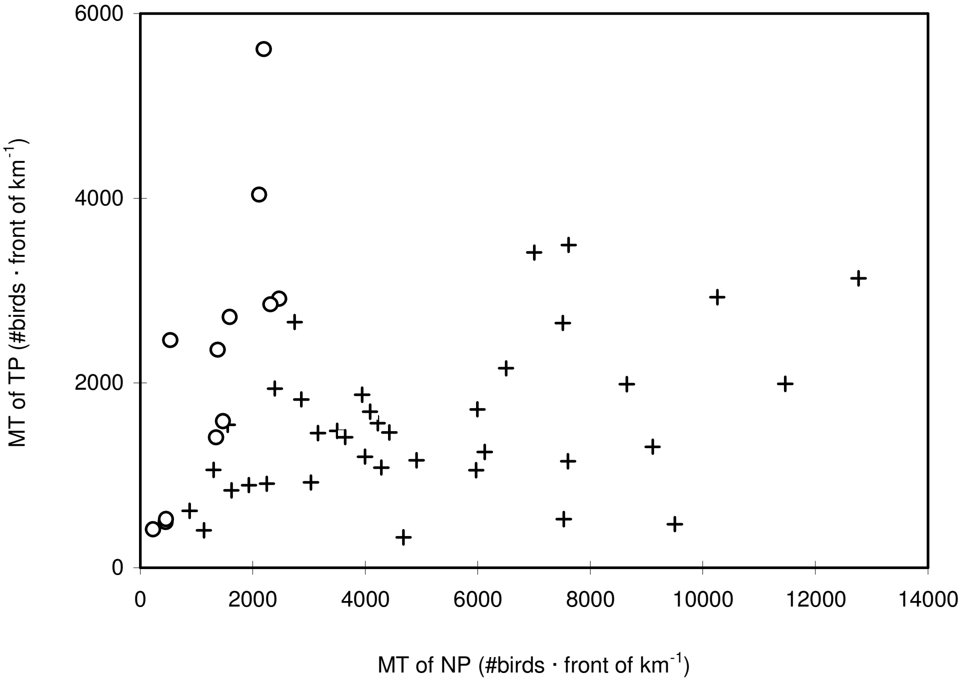

Fig. 7. Correlations between the weighted MT of the night phase and the take-off phase. Open circles for 12 nights, where the weighted $MT_{TP} > MT_{NP}$ (corresponding to nights with mass departures after nights with bad weather conditions), crosses for 37 nights where the weighted $MT_{TP} < MT_{NP}$.

first step no significant correlation between the MT of the night phase and the take-off phase was found (Spearman R = 0.2389, p = 0.0983, N = 49). But by dividing all nights into two groups where the weighted MT of the take-off phase was greater than that of the night phase. Where the weighted MT of the take-off phase was smaller, the correlation within both groups became highly significant ($R_{TP > NP} = 0.8951$, $p < 0.001$, N = 12 and $R_{TP < NP} = 0.4520$, p = 0.0107, N = 35).

Discussion

The take-off phase on Mallorca started shortly before sunset, which is at least half an hour earlier than reported in other papers (for a summary of take-off times see table 2 in Åkesson et al.1996). It is not clear if this is a relevant difference or just a matter of method, because the methods compared are widely different and sometimes very crude in determining the take-off time. Surveillance radars in particular might miss the first departures (example Fig. 8. in Gauthreaux 1971, where the first birds seemed to be cut off.). If the decision of a bird to take off is related to light intensity, then this variation in take-off times could be an effect of relating the take-off times to sunset (instead of light intensity itself), because light intensity around sunset depends on the time of year and geographical latitude and it varies with local weather and cloud conditions. Species with a continuously flapping wing-beat pattern departed earlier than the passerines. This has already been described by Bruderer (1997). Richardson (1979) found general take-off times of shorebirds of even more than one hour before sunset.

The peak intensity of the take-off phase was reached within one hour after sunset and the whole take-off phase lasted only 2 to 4 hours. Published data on the exact duration of the take off-phase is scarce. It has been reported that migratory activity declined during the later part of the night and ceased more or less before sunrise (Alerstam 1976, Bruderer 1994, Bruderer 1995). But this does not really show the length of the take-off phase, because birds which had taken off further from the observation site flew over the observation site later in the night. Using data from a ceilometer study with visual observations of migrants taking off (Hebrard, 1971), I calculated a mean duration of the take-off phase of 83 ± 29 minutes. Gauthreaux (1971) reported a take-off pattern which is very similar in shape to the one of the present analysis. The duration was at least 4 hours but the data in the presented graph is not arranged according to sunset, probably increasing the duration of the take-off time. Parslow (1968) inferred from his own data that the take-off phase could be as short as 10 minutes. But studies in which radio transmitters were attached to the birds showed that some birds took off much later in the night (Cochran et al. 1967, Åkesson et al. 1996, Moore & Abborn 1996). These studies, however, are very limited in the number of tracked birds and might only be valid for the observed species and could therefore not be taken as the general pattern. Furthermore, the late take-off times were not observed directly but inferred from not relocating the birds the next day. It can not be excluded that the handling of the birds influenced the decision of the birds to take off. Nonetheless, they can indicate that there could be differences in the take-off times between species and latitudes.

The radar situated at the southern tip of Mallorca offered a special opportunity to investigate the time period during which the migrants took off, because the area south of the radar site was very limited in size (approximately 65 km^2). The data was based on a high number of observed migrants and lasted over several days. It is evident that the take-off on Mallorca was confined to 2 to 4 hours after sunset and that the take-off times and take-off peaks were related to sunset. Even the widely scattered ending times of the take-off phase were related to sunset.

The high number of birds taking off south and around the radar site every evening reflected a high attractiveness of the island. The temporal pattern suggested that on average at least one third of the birds which arrived on Mallorca landed, especially around sunrise (and probably during the first morning hours). The birds which did not land and continued to fly over the radar site before sunrise still had a flight of more than one hour to cross the island. According to an infrared study in the north of Mallorca most migrants did not fly out to sea after sunrise (Holzgang pers. comm.). Therefore, the proportion of birds which landed on the whole island must have been much higher than one third.

It is generally assumed that most migrants cross the Mediterranean in one non-stop flight. Based on their physiology it is estimated that birds can easily fly distances of 400 - 600 km without landing (Biebach 1992). In spring the competition for good breeding sites, which may simply depend on who arrives first at the breeding grounds, and the possibility to raise additional broods could create a strong pressure to be back as early as possible. This could result in a more rapid migration than in autumn (Safriel & Lavee 1988). Why then should the birds land instead of covering the whole sea-crossing in one flight? Possible reasons include: 1) The risk of depleting energy reserves by omitting a possibility to land and refuel could be high, especially if some migrants already had low energy reserves when they left the coast in North Africa. 2) The selection for flying by night must be stronger than selection for time minimising. This could explain why the vertical speeds on Mallorca suddenly became more negative around sunrise, indicating that landings could be a reaction to increasing light intensity. The present results showed that in spring a non-stop flight over the Sahara and the Mediterranean Sea is not the case for most birds. The pattern with two waves and a gap in between showed that the birds had landed in North Africa before crossing the Mediterranean Sea. This is consistent with the findings of Bairlein (1988) and Biebach et al. (1991) suggesting that an unknown proportion of birds uses an intermittent strategy when crossing the Sahara. Also Moreau (1961) supposed that in spring the Atlas Mountains in North Africa could offer good resting sites because of the Mediterranean climate with its rainy season in winter and spring. It can of course not be excluded that some birds flew over the Mediterranean non-stop, but they were quantitatively not relevant.

The declining proportions of passerine type wing-beat frequencies and the highest migration intensities between mid-April and the beginning of May was in agreement with the findings of Finlayson (1992) at Gibraltar, where the highest densities of trans-Saharan migrants occurred in April and to a lesser extent in May. The highest densities of the pre-Saharan migrants in Gibraltar were recorded already in February and March and were even higher than the density of the trans-Saharan migrants in April. But the densities on Mallorca were low in the last third of March. This could indicate that the pre-Saharan migrants either did not cross the Mediterranean in large numbers and instead circumvented it or they had already passed in February or during the first two thirds of March. The second possibility is highly probable, because Bruderer & Liechti (in press) recorded highest densities of autumn migrants over Mallorca during the passage of pre-Saharan migrants in October.

Trapping was carried out on Cabrera, a small island SSW of the radar site from 16-04 to 15-05-1993 (Montemaggiori et al. 1993). The seasonal peak of the number of captures was in the beginning of May, which was later than the seasonal peak of the radar data in mid-April. This difference could be an indication that trapping on an island is biased if the species differed in their decision to land at the first occasion while flying over the sea. The most frequently trapped night migrants on Cabrera were the following species, which might also be represented in the passerine-type wing-beat class: Pied Flycatcher (*Ficedula hypoleuca*), Spotted Flycatcher (*Musciapa striata*), Willow Warbler (*Phylloscopus trochilus*), Redstart (*Phoenicurus phoenicurus*), Whinchat (*Saxicola rubetra*), Whitethroat (*Sylvia communis*) and Garden Warbler (*S. borin*). Wader species were not captured. For examples of possible species see observations of Kestenholz & Peter (1998).

During the whole observation period, migration intensity fluctuated heavily from night to night. This variation was much higher in the night phase than in the take-off phase. A possible explanation could be that the island functioned as a buffer for the number of birds. The variability in the number of birds in the night phase could be a consequence of the weather in northern Algeria, whereas the number of birds in the take-off phase could be more influenced by the local weather situation on Mallorca itself. The migrants which arrived in the second half of the night had only left the coast in north Africa and continued their migration over the sea when winds were not too unfavourable. In contrast, the migrants on Mallorca would take off irrespective of winds and land again later when winds were too bad to continue migration.

In some nights (especially from 03-04 to 06-04 and 01-05 to 02-05) more birds departed from the island than arrived during the night before. This is explainable by an accumulation of birds and a following mass departure. The high number of departing birds in the nights from 03-04 to 06-04 could be a consequence of the high number of birds which arrived in the night of 28-03 and almost no departures in the evenings of the two following nights. The same situation holds true for the nights from 01-05 to 02-05, which followed after the nights from 25-04 to 27-04 with very high numbers of arriving birds. Both mass departures took place after an evening with very strong opposing winds with velocities of more than 10 $m \cdot s^{-1}$ in migration direction. This was in the same magnitude as the birds own airspeed (part B of diploma thesis), probably keeping them on the ground (data from wind measurements at 20:00 h). This buffer effect seems to be the reason why no direct correlation between the number of birds in the night phase and the number of birds in the take-off phase was found. Two groups were created, one in which the weighted MT in the take-off phase was higher than in the night phase, the other in which it was lower. Then the correlation within both groups became highly significant. This suggests that a lot of birds stayed only for a short time, probably not more than one day. This is supported by findings of Gauthreaux (1971), Biebach et al. (1986), Safriel & Lavee (1988), Kuenzi et al. (1991) and Moore & Aborn (1996), where the stopover times of most birds were usually not longer than one day. Another explanation of these mass departures could be that in the preceding nights most migrants arrived after sunrise on Mallorca. They immediately landed unmeasured south of the radar site and were therefore not included in the night phase, thereby increasing the number of birds taking off the next evening.

The daily course of migration was not included, because the measured densities during the day were not reliable due to the following reasons: 1. Local birds, which became active soon after sunrise, could not be separated from migrating birds. These were mostly Yellow-legged Gulls (*Larus cachinnans)*, which could be visually observed up to great heights almost every day, circling over the radar site in large flocks. This increased the number of birds in the air during the day to values much larger than during the night, although the gulls were the only birds around on most days.

Tracking was often continued into the day until 12:00 h. The decline of the density and of the proportion of tracks with a songbird or continuously flapping wing-beat pattern around sunrise showed that the birds did not continue to fly over the island after sunrise (although the decline of the density and the increase of the proportion of undetermined tracks around sunrise may have been to some extent due to building flocks and not to landing). Furthermore, it was possible to check the tracked bird visually with a telescope. But we could not detect single migrating birds or flocks. This indicates that migration across Mallorca is confined to the night. It cannot be excluded that some birds still arrived on the island during the day and landed undetected in front of the radar if they were flying at very low altitudes and/or landed very quickly. It seems that the main mass of birds followed the pattern of migrating by night and resting during the day. The birds did not continue to fly across Mallorca during the day, which would have forced them to fly another 300 km over water, taking them to the southern coast of France.

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III

Direction, Speed and Origin of Spring Migrants Arriving on Mallorca: Why did Nocturnal Migrants Arrive in a Wave?

Summary

Direction and speed of nocturnal bird migration was investigated with a tracking radar over Mallorca in spring 1997. The mean flight direction was 18° during take-off and 10° during the arrivals from North Africa. The average ground speed of the migrating birds was 12 $m \cdot s^{-1}$. Birds with a passerine-type wing-beat pattern had a more than 2 $m \cdot s^{-1}$ higher ground speed than birds with an uninterrupted wing-beat pattern. Nocturnal migrants from Africa arrived in a wave at different times in the second half of the night. This pattern occurred because most migrants did not fly non-stop over the Sahara and the Mediterranean Sea, but landed somewhere in North Africa. With the direction and speed of the migrants during the arrivals, it was possible to calculate the potential previous take-off areas for each night. The distribution of the take-off areas suggested that the migrants were not predominantly concentrated along the coast before they crossed the sea. Instead they departed, at least in some nights, from different places further inland in the Atlas Highlands. Some migrants could even have departed south of the Atlas mountains. It seems likely that the migrants, after having crossed the Sahara, landed as soon as they detected the first potential resting areas around dawn. Those migrants finding themselves still over the Sahara continued their flights until they reached promising habitats in the Atlas highlands increasing the number of migrants there but not near the coast.

The island seemed to have no important concentration effect in attracting migrants from different directions.

Keywords

bird migration, Mediterranean, flight speed, air speed, flight direction, stopover, north Africa, radar, recruiting areas, intermittent flight strategy, Sahara

Introduction

The knowledge about the Paleartic-African bird migration system was discussed in comprehensive reviews by Moreau (1961, 1972). But the incomplete data available at that time was difficult to handle, particularly because quantitative data on flight behaviour and volume of migration were lacking. He concluded that most autumn migrants flew non-stop over the Mediterranean Sea and the adjacent Sahara Desert on a broad front. On the birds' journey back to the breeding grounds, the Atlas mountains and the coastal region in the western part of the Mediterranean offered good resting areas in spring because of the rainy season during the preceding winter. A more recent review of bird migration across the Mediterranean, including infrared and moon watching data, showed considerable concentration of nocturnal bird migration to the east and west of the Mediterranean Sea and a high degree of separation between diurnal and nocturnal migration in spring and autumn (Bruderer und Liechti in press).

In central Europe autumn migration occurs on a broad front with basic directions around SW (Bruderer 1997). Moonwatching (Liechti et al. 1996) and observations by radar (Bruderer & Jenni 1990) have shown that in the area of the Alps most of the migrants are deflected by the mountains towards WSW. In northern Italy and southern France the main directions are even more westerly. Over the Iberian Peninsula the general flow of migrants takes place on a more NNE-SSW axis. The migrants flying over the Mediterranean Sea had more southerly directions (Bruderer & Liechti 1998a). Until now, reliable quantitative data of flight directions and flight speeds of nocturnal migrants across the western Mediterranean Sea in spring has been lacking. First indications of directions were given in an early radar study by Casement (1966) suggesting directions around NE; while some more recent data suggests mainly NNE directions (Rivera & Bruderer 1998).

The temporal pattern of nocturnal bird migration on Mallorca showed that the take-off time was confined to 3 hours after sunset. Migration intensities increased again in the second half of the night, after a period when only few birds were recorded. The gap occurred because no birds could have taken off from the Mediterranean Sea. The pattern showed that most birds did not fly non-stop over the Mediterranean Sea, but must have landed somewhere in North Africa after having crossed the Sahara Desert (diploma thesis part A).

This paper presents data about directions and speeds of nocturnal migrants arriving at Mallorca in spring. Information about directions and speeds is used as a basis to calculate potential recruiting areas of the migrants in North Africa. Two possible distributions of the potential resting areas previous to Mallorca will be presented and the following questions will be discussed: 1) Where did the migrants come from? On the one hand the migrants could have taken off from only a narrow strip along the coast leading to a wave in arrivals on Mallorca. On the other hand they could have departed from anywhere in North Africa. 2) Was Mallorca an important stepping stone or just an accidental stopover site? If the island attracted birds, this would imply a higher scatter of directions during the arrivals compared to the departures and an increase in scatter and possibly a shift in the general migration direction towards the end of night.

Materials and Methods

This radar study was conducted in spring 1997 on the island of Mallorca, Spain. The radar was located in the south of the island (39°2´ N, 3°4´ E) 20 m above sea level next to the Salines de Salobrar about 8 km NW and 2 km NE from the southern coasts (fig. 1). The radar used was an X-band (3.3 cm wavelength) tracking

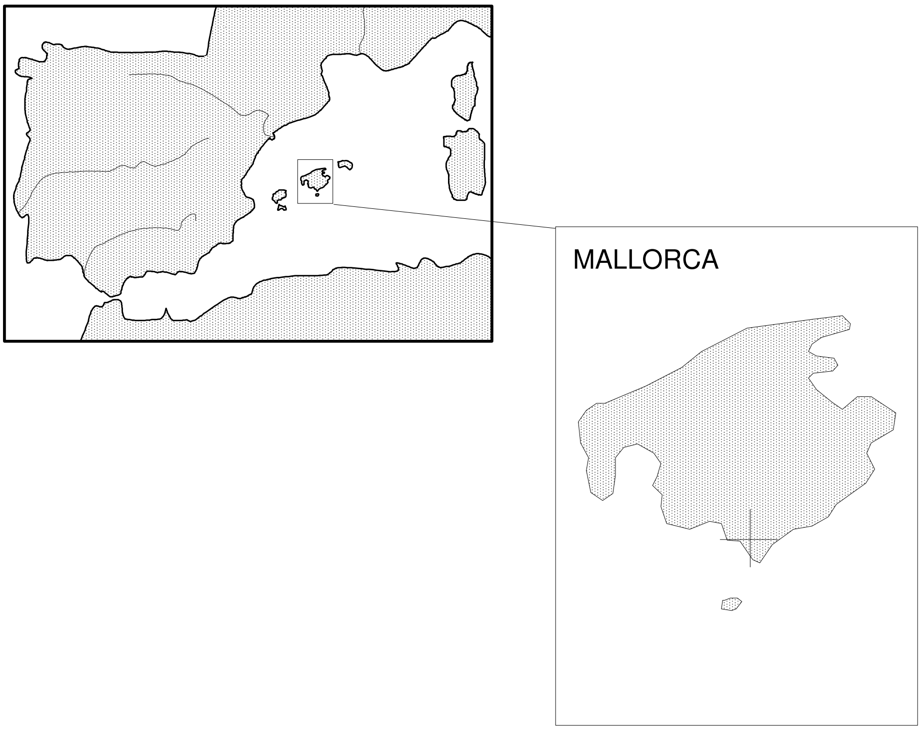

Fig. 1. Map of the western Mediterranean. The radar site is marked with a cross.

radar with 2.2° nominal beam width, 150 kW peak pulse power and 0.3 µs pulse length. Data was obtained on 64 nights between 24-03-97 and 26-05-97. Every half hour from 20:30 h to 04:30 h and every hour from 05:30 h to 11:30 h a quantitative measurement of the spatial distribution was made by conically scanning within a half-sphere of 4 km radius. All time indications are local summer time, which is UTC + 2 h.

From 13-04-97 to 26-05-97 at the same site a second radar was operated, which automatically made the quantitative measurements every 10 minutes, 24 hours a day. With these measurements, the density of the birds was calculated as number of birds·km^{-3} according to the procedure described by Bruderer et al. (1995). During the time between two measurements, the operator manually locked on single targets to register their flight tracks for 40 s each. The wind was measured by tracking a meteorological balloon up to at least 4 km height above ground level at noon and then every 4 hours. By combining the data of the wind measurements with the tracking data of the birds (e.g. ground speed, vertical speed, altitude and track) heading and air speed were calculated. The fluctuations of the radar signal (echo-signatures) allowed the identification of wing-beat patterns, which were classified into 4 groups (Bloch et al 1981):

CF: continuously flapping birds, corresponding mainly to wader-/waterfowl-type birds, but also to continuously beating swifts and others

IF: intermittently flapping birds, corresponding mainly to passerines

SW: swifts (apus)

UD: undetermined pattern; flocks, bats, insects, echoes interfering with ground clutter

For the present analysis only tracks were considered that fell either into the take-off phase or the night phase (= period of time in the second half of the night during which the arrivals from North Africa occurred) of every night. To quantify the number of migrants arriving on Mallorca the weighted Migration Traffic (MT) was calculated: The weighted MT is the Migration Traffic Rate (MTR = theoretical number of birds crossing a front of one kilometre per hour, Lowery 1951. Originally one mile) multiplied by the duration of the night phase or take-off phase, weighted with the proportion of CF and IF of all tracks during the corresponding phase (for definitions of terms see part A of diploma thesis). Only the CF and IF were used, because they were the best defined and predominant groups.

Standard deviations (s) of angles (Φ) were calculated as $s = [2 \cdot (1 - r)]^{-½}$, where r is the length of the mean vector $r = ([n^{-1} \cdot \sum(\text{Cos } \Phi)]^2 + [n^{-1} \cdot \sum(\text{Sin } \Phi)]^2)^{-½}$ according to Batschelet (1981). The distribution of speeds within groups was not always normal. But according to the central limit theorem, which states that as sample size increases, the means of samples drawn from a population of any distribution will approach the normal distribution (Sokal and Rohlf 1995), it was possible to use the t - test.

Calculation of potential recruiting areas

In order to calculate the coordinates of the potential take-off areas previous to Mallorca, the following assumptions were made in a first step (model 1): 1) The birds had a constant track when they flew over the Mediterranean; 2) The ground speed of the birds was constant during the sea crossing; 3) The take-off schedule in North Africa was similar to the one measured on Mallorca. The assumptions 1) and 2) implied no large changes in wind speed and wind direction during the sea crossing. For every night phase an average ground speed (Vg) and flight direction (Rg) were calculated from the tracking data of targets with a CF or IF wing-beat pattern (tracks with a wing-beat pattern of SW or UD were excluded). The time from 50 min after sunset (average time after sunset, where the maximum intensity of the take-off from Mallorca occurred) to the time of peak intensity during every night phase was taken as the flight duration (t) of the migrants. The rectangular coordinates (x, y) were obtained by $x = \cos(Rg) \cdot Vg \cdot t$ and $y = \sin(Rg) \cdot Vg \cdot t$

The number of migrants arriving on Mallorca is indicated by the size of the circles, where the radius is proportional to the weighted MT. The area covered by the circles is not related to the actual swize of the take-off areas. Nights with negligible numbers of arrivals (MT < 2500) were excluded from the analysis due to overproportional contamination with local birds.

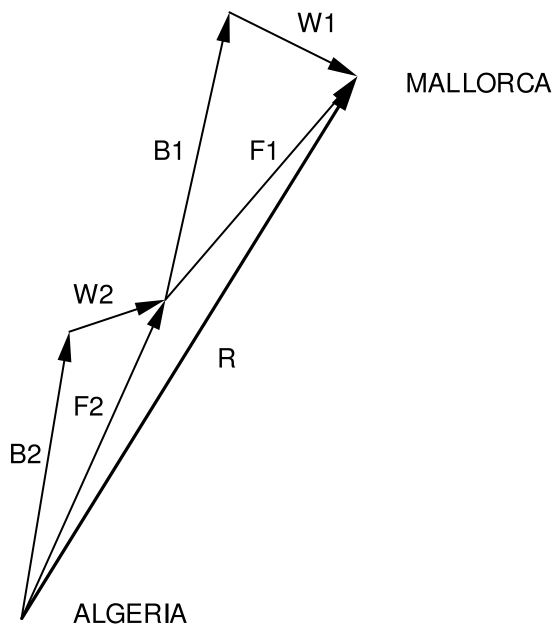

Fig. 2. Calculation of the flight vectors (F) for model 2 from the bird's original vectors (B) and the wind vectors (W). It was assumed that the migrants flew half of the time with winds over Algeria (W2), the other half with winds over Mallorca (W1). The resultant vector (R) is determined by F1 + F2.

In a second step the coordinates of the previous take-off areas were calculated taking into account the different winds over Mallorca and northern Algeria (model 2). It was assumed that 1) the migrants chose the altitude with the highest tailwind component; 2) they had a constant air speed and heading during the whole flying time; 3) half of the time they flew with winds measured over northern Algeria; the other half with winds measured over Mallorca. This model shows the maximum possible distance to the previous take-off areas. By vector addition, two flight vectors (F1 & F2) were calculated from the birds' original vectors (B) and the wind vectors (W1 & W2), which were combined to give the resultant vector (R) (fig. 2). The birds' original vectors (B) were determined by an average heading (Ra) of 8.73° and an average air speed (Va) of 11.70 $m \cdot s^{-1}$. The wind vectors (W1 & W2) were obtained from the wind speed and wind direction at the altitude with the highest tailwind component (TW1 & TW2). Data from our own measurements at the radar site was used to calculate W1. For W2 data from a meteorological station at Dar-El-Beida (36°7' N, 3°3') near Algiers was taken. The tailwind components (TW1 & TW2) for choosing the appropriate wind speed (Vw1 & Vw2) and direction (Rw1 & Rw2) were calculated in relation to the birds' general flight direction (average of all headings). The tailwind components were determined up to a height of 4000 m by $\max(TW_i)$, where $TW_i = \cos(Rw_i - 8.73°) \cdot Vw_i$. The index i stands for the different altitudes.

Results

Directions

To allow easy comparison, the directions presented are calculated as proportions of number of tracks per 10° interval to the total number of tracks, because the directions of the night and take-off phases are based on different numbers of tracks. The headings of the birds during take-off (fig. 3) were around N (Ra = 12 ± 68°, r = 0.30). The tracks were shifted to NNE (Rg = 18 ± 68°, r = 0.30) and some of the birds flew SW. The grouping into the wing-beat classes revealed that the southwesterly movements took place mainly within the SW and CF. (note: the area of the polygons itself has no meaning, e.g. the headings and tracks do not necessarily have the same area).

The birds which arrived after having crossed the Mediterranean (fig. 4) mainly flew N (Rg = 10 ± 57°, r = 0.50). Their headings did not seem to be different from the tracks (Ra = 9 ± 53°, r = 0.57). Within the class of the IF tracks and headings were highly concentrated around the mean (Rg = 5 ± 41°, r = 0.74, Ra = 6 ± 35°, r = 0.81, N = 3863). The CF and the UD were less concentrated, and the SW showed the highest scatter. The CF and the UD also comprised birds flying more to the ENE. Overall, the differences in directions between the take-off and the night phase were only marginal. In general, the tracks and headings of the migrants during take-off seemed to be more easterly and showed slightly higher scatter than those during the night phase (for details see table 1). During take-off, tracks were shifted more to the NNE than the headings, whereas during the night phase tracks and headings were similar. Within the IF, no significant difference between the mean heading of the take-off phase and the night phase could be found (Watson-Williams $F_{1,5013}$ = 0.008, $p > 0.75$), the same was true for the mean tracks ($F_{1,5013}$ = 1.385, $p > 0.6$).

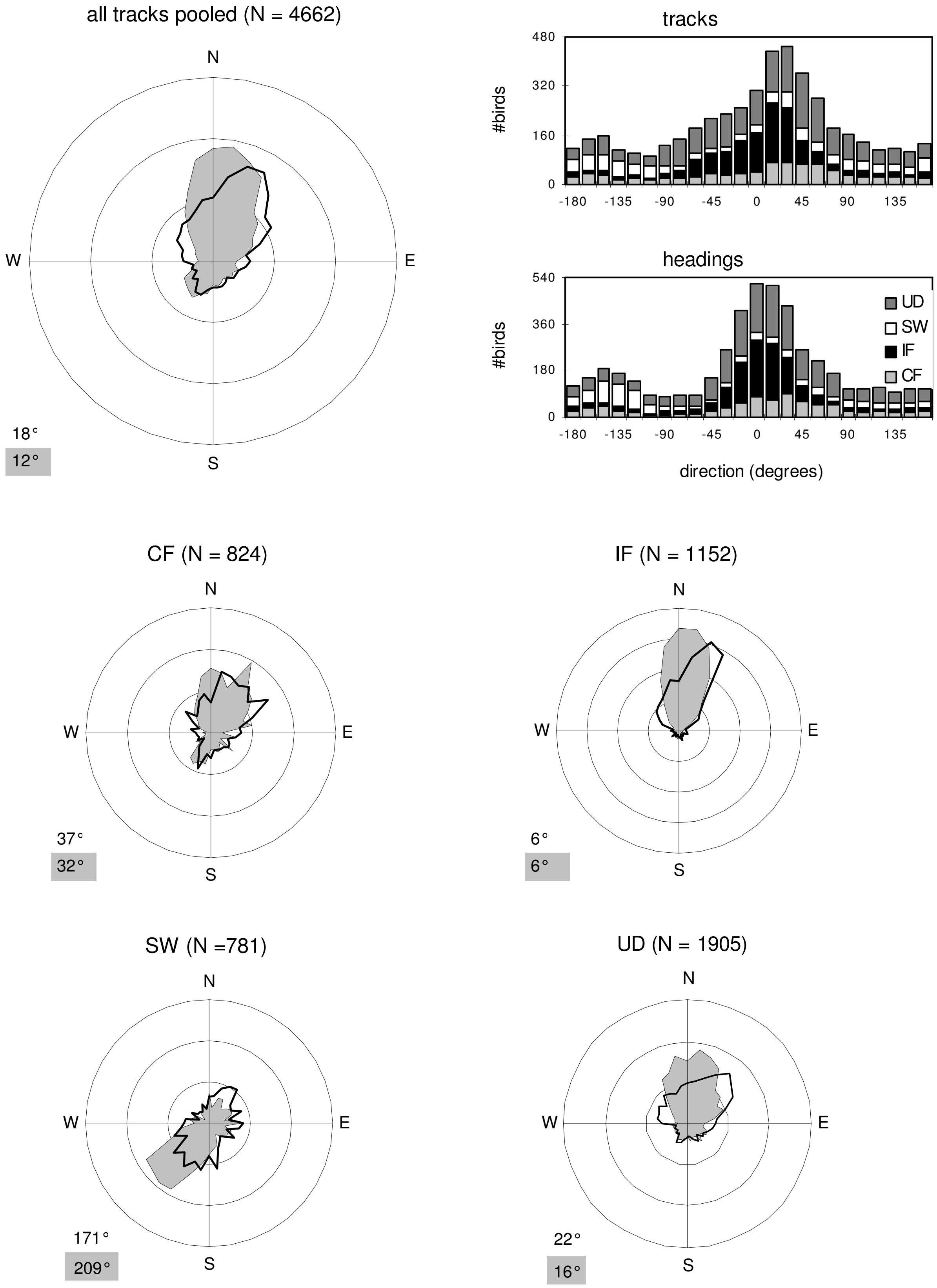

Fig. 3. Distributions of tracks (solid line) and headings (shaded) of the pooled tracks and of different wing-beat classes during the take-off phase. One circle corresponds to 4%. Mean directions are indicated for each polygon. CF = continuously flapping, IF = intermittently flapping, SW = swifts, UD = undetermined tracks.

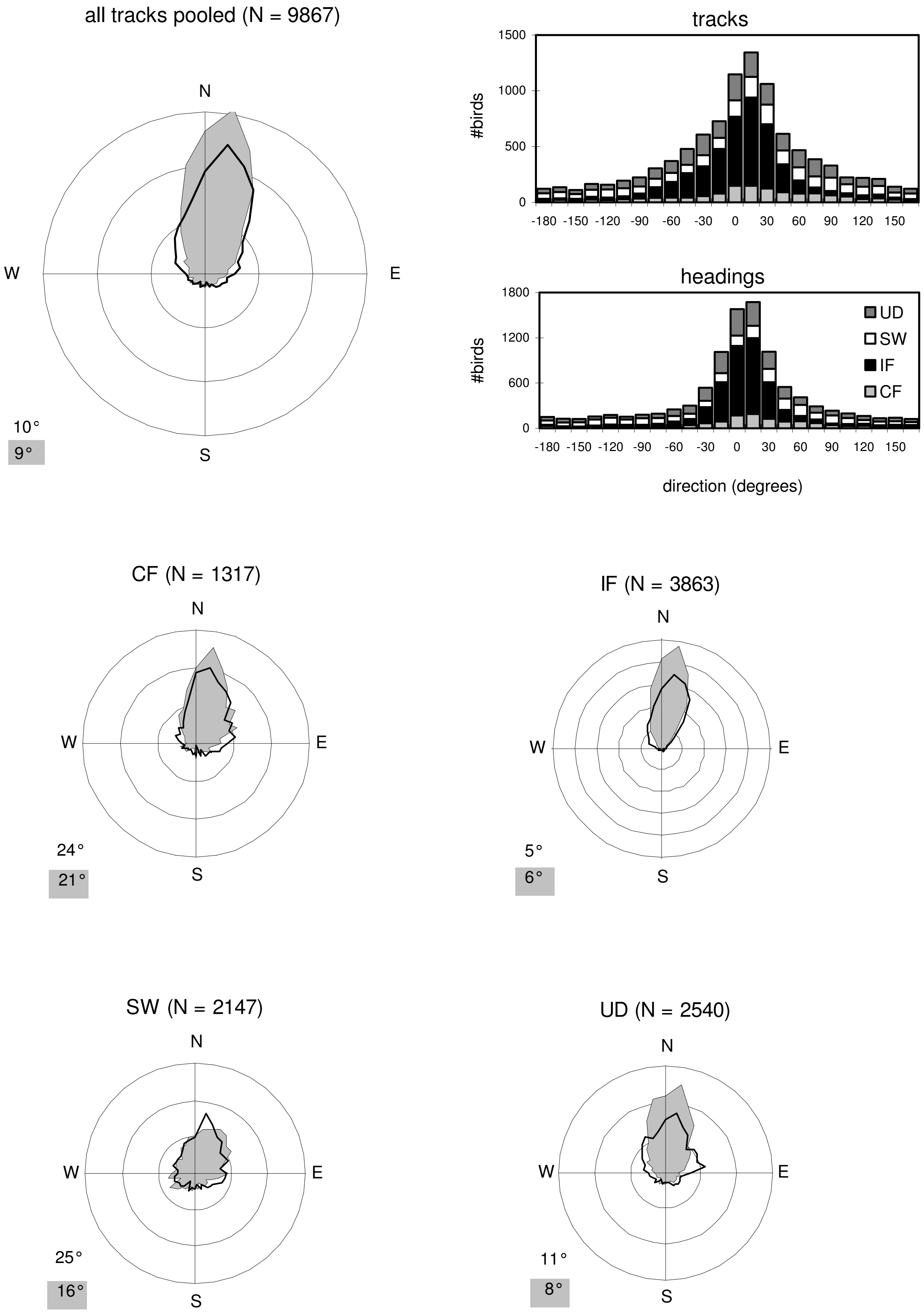

Fig. 4. Distributions of tracks (solid line) and headings (shaded) of the pooled tracks and of different wing-beat classes during the night phase. One circle corresponds to 4%. Mean directions are indicated for each polygon. CF = continuously flapping, IF = intermittently flapping, SW = swifts, UD = undetermined tracks.

	wing-beat class	Rg (°)	rRg	Ra (°)	rRa	#birds
take-off phase	CF	37 ± 69	0.28	32 ± 67	0.31	824
	IF	6 ± 51	0.61	6 ± 46	0.67	1152
	SW	171 ± 77	0.10	209 ± 70	0.27	781
	UD	22 ± 67	0.31	16 ± 63	0.39	1905
night phase	CF	24 ± 61	0.44	21 ± 57	0.51	1317
	IF	5 ± 41	0.74	6 ± 35	0.81	3863
	SW	25 ± 70	0.26	16 ± 70	0.25	2147
	UD	11 ± 64	0.38	8 ± 57	0.50	2540

Table 1. Tracks and headings of the different wing-beat classes during the take-off phase and night phase.

Speeds

The average ground speed of all tracked birds during the night phase was 11.6 ± 5.8 $m \cdot s^{-1}$ (N = 9867), whereas their calculated average air speed was lower 10.2 ± 4.0 $m \cdot s^{-1}$. If the SW and DU were excluded, the average ground speed increased to 13.4 ± 5.6 $m \cdot s^{-1}$ (N = 5180), whereas the calculated average air speed of 11.7 ± 3.5 $m \cdot s^{-1}$ remained almost the same The ground speeds of the birds were distributed over a wide range. Almost 10% of all tracked birds had a ground speed of more than 20 $m \cdot s^{-1}$ indicating high wind support. The average ground speed of birds with a passerine-type wing-beat pattern was significantly higher than the average ground speed of birds with an uninterrupted wing-beat pattern (Student's t-test, $t = 10.07$, $p < 0.00001$, for details and differences between wing-beat classes see table 2).

wing-beat class	ground speed ($m \cdot s^{-1}$)	air speed ($m \cdot s^{-1}$)	#birds
CF	11.9 ± 6.4	10.8 ± 4.1	1317
IF	13.9 ± 5.3	12.0 ± 3.2	3863
SW	8.2 ± 5.0	8.9 ± 2.6	2147
DU	10.8 ± 5.3	8.2 ± 4.7	2540

Table 2. All means of ground and air speeds between groups were significantly different; $p < 0.00001$

Potential recruiting areas

The distribution of the potential previous take-off areas calculated according to model 1 is shown in figure 5. Most take-off areas lay almost S of Mallorca within a sector of 194 ± 17°. Arrivals from the Spanish mainland were never recorded. The take-off areas seemed to be aggregated in two large areas. One about 40 km off the Algerian coast, the other at least 100 km further inland in the Atlas Mountains. The remaining take-off areas in nights with low migration intensities were projected onto the sea, but seemed at least to follow a line along the coast.

Fig.5. Distribution of the potential previous take-off areas of 31 nights calculated according to model 1 (see methods). Filled circles for nights, which were discussed in more detail (see results). A = 14-04-97, B = 23-04-97, C = 11-05-97.

To check if the assumptions of no large changes in wind speed and wind direction during the sea crossing were reasonable, the wind direction and wind speed at the radar site from the height interval 1200 - 1400 m at 04:00 h were compared with sondage data from Dar El Beida (36°25“ N und 3°25“ E) at 850 hPa and at 23:00 h (In four evenings the measurements at 17:00 h were used, because the measurements at 23:00 h were lacking). Both correlations showed strong scatter (fig. 6), but were nonetheless highly significant

(Spearman Rank Correlation of tailwind component R = 0.471, p < 0.001, of sidewind component R = 0.491, p < 0.001, N = 49 and circular correlation of the wind directions r = 0.421, p < 0.001, N = 49).

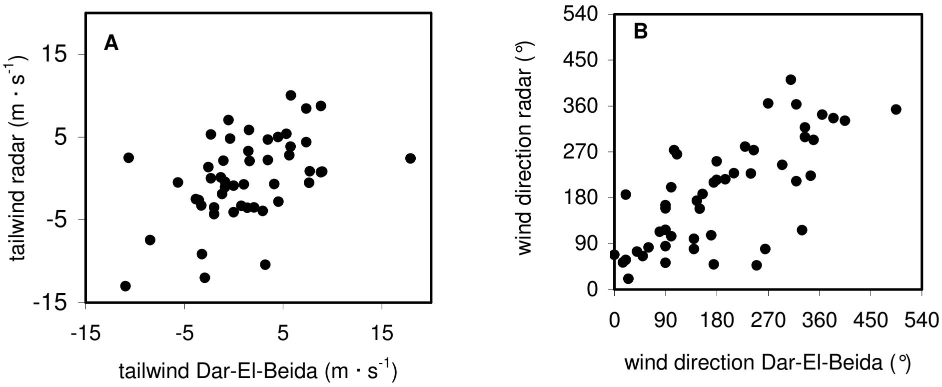

Fig. 6. (A) Comparison of tailwind component at Dar-El-Beida and at the radar site. (B) Comparison of wind directions at the two sites.

The distribution of the potential take-off areas as calculated according to model 2 is shown in figure 7. Most take-off areas moved further inland and shifted from SSW to SW compared to model 1. The scatter in

Fig. 7. Distribution of the potential previous take-off areas of 31 nights calculated according to model 2 (see methods). Filled circles for nights, which were discussed in more detail (see results). A = 14-04-97, B = 23-04-97, C = 11-05-97.

directions decreased slightly (201 ± 5°) and the two concentrations seemed to be even more obvious. In general both distributions were similar. When wind influence was excluded and only the average air speed, the average heading and the flight times were used to calculate the previous take-off areas, in 17 nights out of 46 (37 %) the migrants would not have been able to cover the distance to cross the sea without wind assistance in the time period from their assumed take-off in North Africa to their measured arrival on Mallorca. Three nights with high migration intensities were chosen to illustrate the temporal schedule and wind assistance in more detail (see appendix for figures of temporal patterns for all nights).

A) In the night of the 14-04-97 the influx of the migrants commenced 4.5 hours after sunset and reached its maximum 3 hours later. Thereafter the densities decreased and migration ended 7 minutes after sunset (fig. 8 A). 68% of all targets showed a passerine-type wing-beat pattern, 12% an uninterrupted wing-beat pattern, 9% of the birds were swifts and 11% of all tracks were undetermined (N = 271). This resulted in a weighted MT of 12768 birds (weighted MTR = 1964). The mean ground speed of the CF and IF during the night phase was 14.1 ± 3.4 m·s^{-1} (N = 215). The mean flight direction was 12 ± 34° and the tracks were highly concentrated around the mean (r = 0.82, N = 215). The projection according to model 1 suggests that the migrants took off mainly from the coast (fig. 5). Opposing winds from NW prevailed on Mallorca during the arrivals, but at least at some altitudes the migrants could find some good tailwind support from SSE (maximum of 6.2 m·s^{-1} at 500 m, fig. 8 A). The migrants actually made use of these winds (fig. 8 A). Winds near Algiers from WNW during take-off were opposing, too. Best tailwinds occurred at 850 hPa from SSE (maximum 4.6 m·s^{-1}, fig. 8 A). Thus, if the birds maintained their heading of 9° and made use of the good tailwinds (according to model 2), they could have taken off from more than 100 km inland (fig. 7).

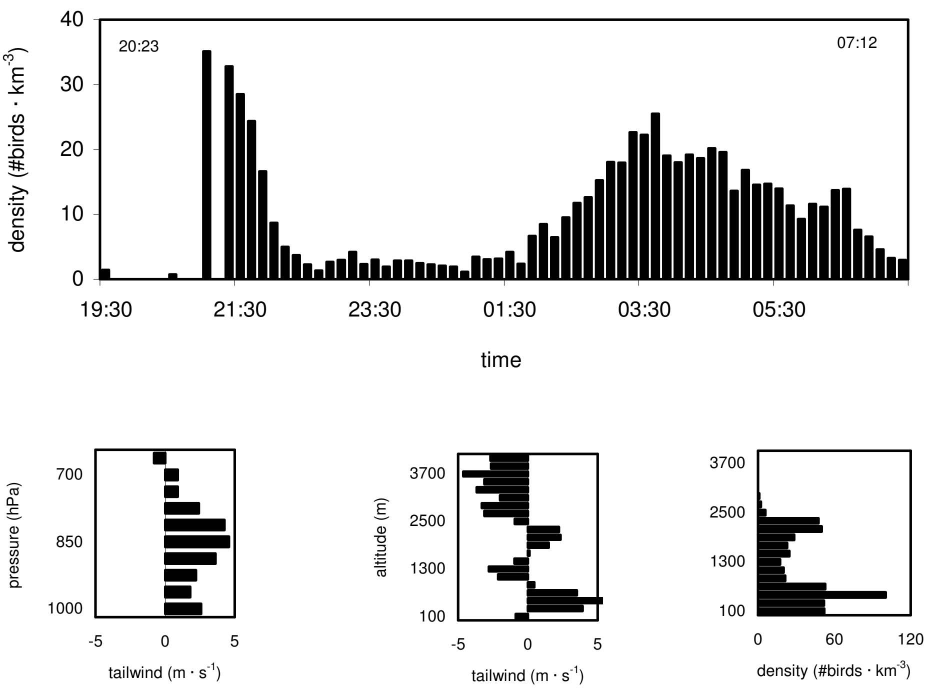

Fig. 8 A. Temporal pattern and height distribution of densities from measurements with conical scanning. Time of local sunset is indicated to the upper left and of sunrise to the upper right. Altitudinal information about wind speeds in general migration direction from a meteorological station near Algiers and from the radar site.

B) Migration densities on the 23-04-97 increased rapidly 7 hours after sunset, which was more than 2.5 hours later than the beginning of the night phase on the 14-04-97. The maximum density was reached within 2 hours. By 40 minutes after sunrise migration intensity was low again (fig. 8 B). Most of the targets belonged to the IF (55%), 9% to the CF, 8% to the SW and 28% to the UD (N = 278) resulting in a weighted MT of 8647 birds (weighted MTR = 1235). The migrants were flying north (Rg = 0° ± 44°, r = 0.70) with an average ground speed of 13.4 ± 3.4 m·s^{-1} (N = 179). On Mallorca the migrants had to deal with strong crosswinds from E at low altitudes changing into crosswinds from W at higher altitudes. During take-off in Algiers only weak crosswinds from WSW to WNW dominated. Nevertheless, the migrating birds could have found some tailwind support at appropriate flight levels, which they obviously did (fig. 8 B). The potential take-off area lay

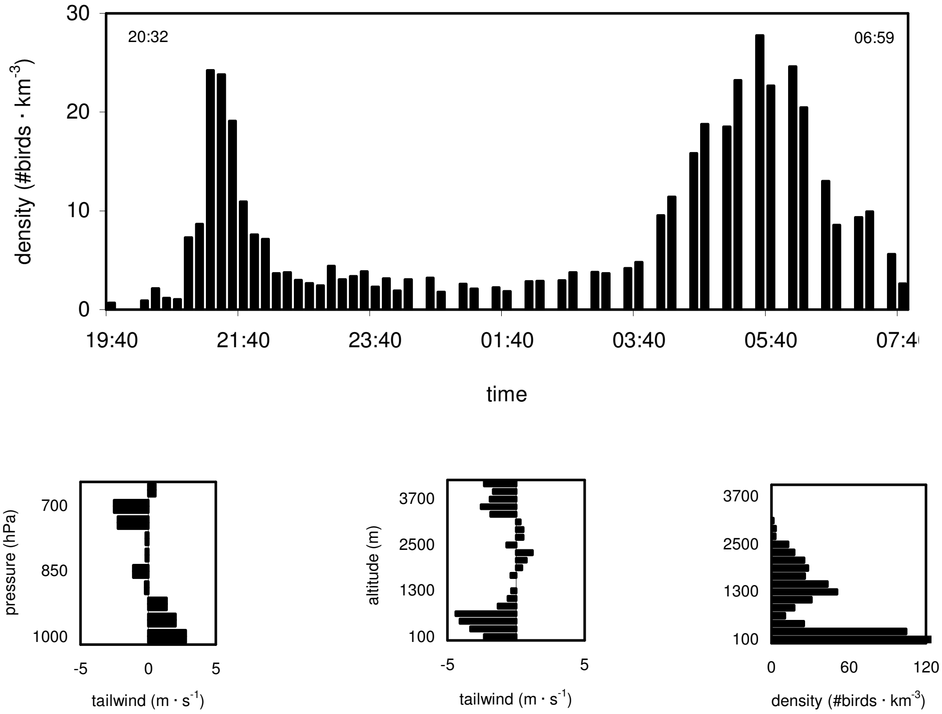

Fig. 8 B. Temporal pattern and height distribution of densities from measurements with conical scanning. Time of local sunset and sunrise is indicated to the upper left respectively to the upper right. Altitudinal information about wind speeds in general migration direction from a meteorological station near Algiers and from the radar site.

more than 100 km inland in the Atlas Mountains. With the assumptions of model 2, the migrants would have taken off more or less at the same distance from Mallorca, but the resting area would have been much more to the W at the coast (fig. 7).

C) In the night of the 11-05-97 the first migrants arrived 4 hours after sunset on Mallorca. Maximum density was reached 3.5 hours later. From then on, the density remained rather high. Nocturnal migration faded out 22 minutes after sunrise (fig. 8 C). More than one third of the migrants were swifts (35%), decreasing the weighted MT to 9107 (MTR = 1271, unweighted MT = 22861, unweighted MTR = 3190), although the measured densities were very high. The proportion of continuously flapping birds was also high (17%), whereas the proportion of songbirds was rather low (22%). The migrants had to fly quite high to take advantage of the good wind assistance from SW over Mallorca. In Algeria good tailwinds occured, too (fig. 8 C) The birds' average ground speed was 18.9 ± 9.0 m·s^{-1} and the birds were flying NNE (Rg = 20 ± 42°, r = 0.73, N = 98). Most migrants had taken off some 130 km inland in the Atlas Mountains. If they had always flown at altitudes with the highest tailwind, they could have taken off more than 230 km inland (fig. 7).

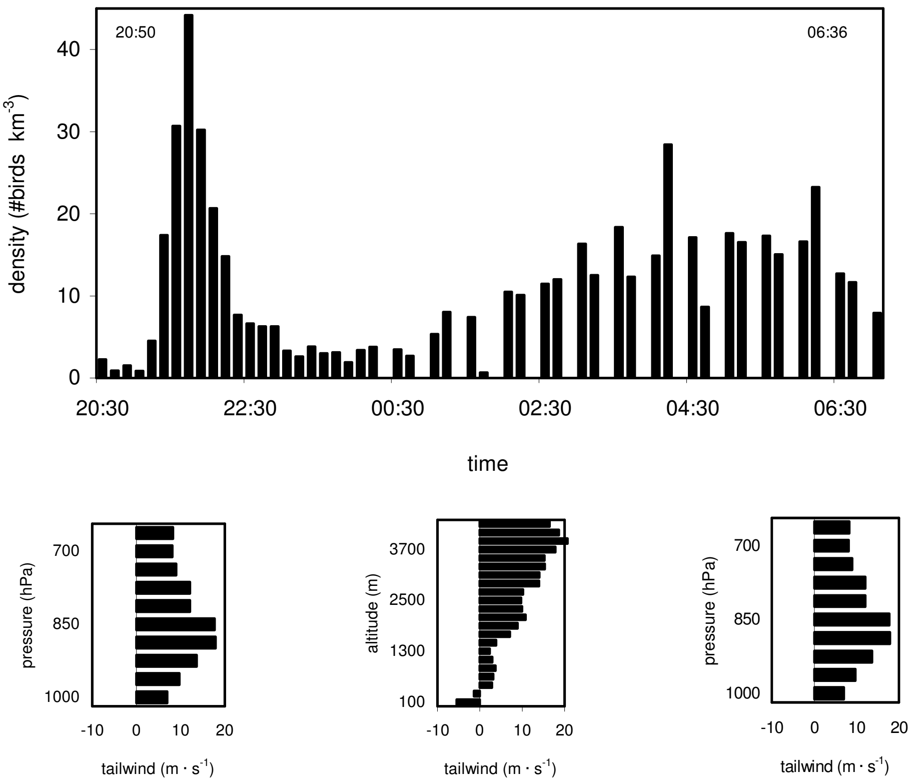

Fig. 8 C. Temporal pattern and height distribution of densities from measurements with conical scanning. Time of local sunset and sunrise is indicated to the upper left respectively to the upper right. Altitudinal information about wind speeds in general migration direction from a meteorological station near Algiers and from the radar site.

Discussion

Directions

Directions during the arrivals on Mallorca were almost north and highly concentrated. Hilgerloh (1991) measured a general direction of 6° at the Straits of Gibraltar. Bruderer et al. (1996) also found flight directions around 13° in a preliminary infrared study at the NE coast of Mallorca. But Casement (1966) reported flight directions more to NE for the western Mediterranean Sea. If the migrants generally flew NE instead of N, the sea crossing from Morocco to the Camarque would be roughly 1.5 times longer than from Algiers to the Camarque, which means about 23 hours of flight compared to 18 hours (with an average ground speed of 12 m·s^{-1}). Flight directions in southern France are NNE (Hilgerloh et al. 1992, Rivera & Bruderer 1998). Lathy (1979) observed NNE arrivals across the sea but NE and E departures in the Camarque area. This suggests that migrants shift their flight direction after crossing the Mediterranean Sea to reach on average the general NE direction prevailing in central Europe.

Tracks and headings during take-off were different, whereas tracks and headings during the arrivals from North Africa were more or less the same. Migrants took off from Mallorca with winds from any direction leading to the observed scatter and the difference between tracks and headings. In contrast, the migrants which arrived in the second half of the night had only left the coast in north Africa and continued their migration over the sea when winds were not too opposing. The birds flew downwind over the sea. As a consequence, directions during the night phase were highly concentrated and the tracks were not different from the headings.

Most of the swifts and some of the birds with a continuous wing-beat pattern flew SW during take-off. This can be explained by local bird movements. The swifts preferred to go for roosting flights over the sea rather than over land. The southwesterly movements, which took place within the CF were Yellow-legged gulls (*Larus cachinnans*), which were visually observed flying out to sea every evening probably to sleep on Cabrera, a small island southwest of Mallorca.

Speeds

The classes CF and IF together, had an average air speed of 11.7 ± 3.5 $m \cdot s^{-1}$, which was almost equal to the 11.5 $m \cdot s^{-1}$, whereas the average ground speed of 13.4 ± 5.6 $m \cdot s^{-1}$ was higher than the 12.4 $m \cdot s^{-1}$ measured above the Arava Valley in Israel in spring (Liechti & Bruderer 1995). In general the ground speed of the migrants was slightly higher than the air speed. This difference was more pronounced in the IF, where the ground speed was almost 2 $m \cdot s^{-1}$ higher than the air speed. This suggests either a prevalance of tailwinds during the considered season, a selectivity of the migrants for nights or altitudes with good tailwind, or any combination of these possibilities. The second and third possibilities seem highly probable. A bird which migrates selectively during nights with favourable wind conditions can speed up its flight on average by 30% in the Mediterranean (Liechti & Bruderer 1998b). In Israel the migrants chose flight altitudes with best tailwinds (Bruderer et al. 1995).

The swifts had quite a low ground speed (8.2 $m \cdot s^{-1}$). Bruderer & Weitnauer (1972) found ground speeds of 6.4 $m \cdot s^{-1}$ for non-migrating and 11.1 $m \cdot s^{-1}$ for migrating individuals. This suggests that a lot of the swifts tracked were locally roosting individuals. This is also seen in their SW directions during take-off, as most of the swifts preferred to fly out to sea for their roosting flights.

Why did nocturnal migrants arrive in a wave?

The temporal pattern of nocturnal migration densities on Mallorca in spring clearly showed a short take-off phase followed by a gap. Thereafter, the densities increased again and nocturnal migration ended around sunrise (diploma thesis part A and appendix). This second wave occurred at different times during the night. It was interpreted to result from most migrants landing somewhere in North Africa after crossing the Sahara Desert before flying over the Mediterranean Sea. Otherwise the migrants would have flown over the island all night (and day) long.

Coastlines can influence flight behaviour of migrating birds (Schüz 1971, Alerstam 1977). On the Spanish coast near Malaga and on Mallorca the proportion of reverse migration increased during the course of the night. The migrants tended to shift their direction along the E-W-leading coast near Malaga (Bruderer & Liechti 1998b). If the disposition of migrants to cross a large ecological barrier depended on the diurnal schedule, more and more migrants would land in the vicinity of the Mediterranean Sea at the Algerian coast towards morning instead of still flying out to sea. This would lead to a concentration of migrants at the coast, which could explain the wave observed on Mallorca during the night. Calculation of flight distances per night revealed, however, that the recruiting areas often lay far inland. The distributions of take-off areas, especially in model 2, showed that many waves did not originate from a concentration at the coast. Instead, it is very likely that the take-off areas lay further inland in the Atlas highlands. It seems that the migrants, after having crossed the Sahara, are prone to land whenever they detect potential resting areas around dawn. The migrants finding themselves still over the Sahara continue to fly until they reache promising habitats in the Atlas highlands increasing the number of migrants there but not near the coast. Some of the take-off areas in nights with low migration intensities were projected onto the sea, but seemed at least to follow a line along the coast (model 1). A possible explanation could be that the migrants found flight altitudes with better tailwind support over northern Algeria than over Mallorca. This seems highly probable, because in model 2, where winds over northern Algeria were included, these take-off areas moved onto the land.

The take-off areas seemed to be aggregated in two large areas in both models. Was this just coincidence or did these regions attract a higher number of migrants? To answer this question direct radar observations in the Atlas Mountains would be needed. Nevertheless an inspection of maps showed an impressive correspondence with the river system of the Cheliff and the highlands of the Scotts suggesting that there could be real geographical reasons for an aggregation of resting areas.

Take-off areas are represented by circles, which indicate by their size the number of birds arriving on Mallorca. The circles show where most birds came from, but the area covered does not correspond to the actual size of the region from which the migrants took off. The temporal pattern of arrivals on Mallorca suggested that along the region from the take-off areas to the coast the number of birds must have decreased. It seems likely that the length of the time period when the migrants arrived on Mallorca (e.g. the time from the beginning to the maximum of the night phase), was not only caused by actual differences in distance between the birds taking off in North Africa, but was also determined by variation in ground speed and take-off time among the migrants. Therefore, this decrease in numbers from the take-off area to the coast, would have been much more pronounced than suggested by the actual temporal pattern on Mallorca.

Did the island attract migrants?

Tracks during the arrivals were very concentrated around the north. This was also reflected by the high mean vector lengths especially within the class of the IF. Mean vector lengths of 0.74 for 3863 tracks and of 0.81 for the headings are very high. The night phase did not show the higher scatter in directions than the take-off phase as would be expected if the island attracted migrants. Also, a shift in mean directions of the classes CF and IF during the night phase within three time periods was not found. In some nights arrivals from more western or eastern directions occurred. These were nights with strong crosswinds from the corresponding directions and the MT was reduced. There is evidence that migrants compensate for wind drift over land, but only partly over sea (Alerstam & Petterson 1976). It seems likely that the migrants were drifted by the wind rather than oriented to reach Mallorca in those nights. Therefore, the distribution of take-off areas should not necessarily be interpreted to mean that migrants took off every night only in the area represented by the corresponding circle (e.g. that east and west to it there were no birds). In general, I propose that the migrants take off from anywhere over the whole Atlas Mountains with a more or less constant heading around N. With calm wind conditions or with lack of crosswinds, migrants which took off south of Mallorca in North Africa reach the island. All other migrants further to the east and west will miss the island and bypass it. With crosswinds migrants from south of Mallorca miss the island, while the migrants from the corresponding direction of the crosswind reach the island.

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IV

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Appendix

Time Tables of all take-off and night phases

Explanations of column titles:

begin:	beginning of night phase (time of minimum)
DenBeg:	density (#birds · km^{-3}) at beginning of night phase
TimeMax:	time of maximum
DenMax:	density at time of maximum
End:	end of night phase (time of minimum)
DenEnd:	density at end of night phase
MDen:	mean density of whole night phase
MTR:	migration traffic rate (#birds · front of km^{-1} · h^{-1}), not weighted with wing-beat classes
MT:	migration traffic (#birds · front of km^{-1}), not weighted with wing-beat-classes

Take-off phases

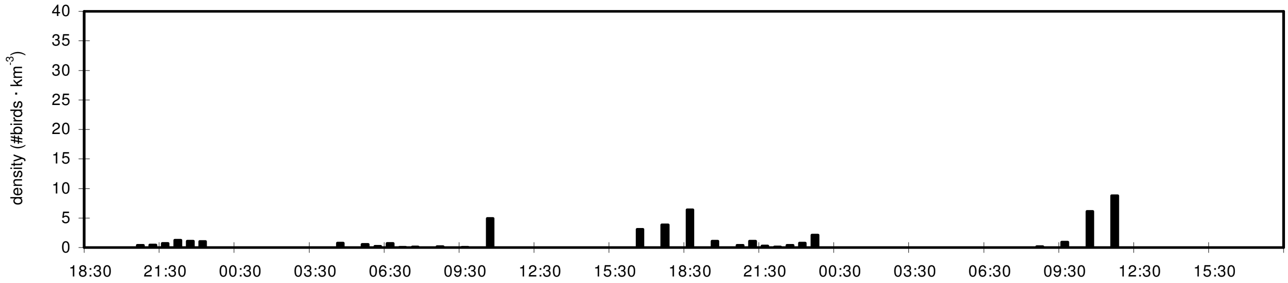
Date	Begin	DenBeg	TimeMax	DenMax	End	DenEnd	MDen	MTR	MT
27.03 to 28-03-97	19:30	1	21:00	10	0:30	0	3	420	2101
28-03-97	19:30	1	21:30	5	23:00	0	2	238	834
29-03-97	20:30	1	21:00	19	22:00	3	10	1098	1647
30-03-97	19:30	1	21:00	4	23:00	1	2	175	612
31-03-97	20:30	1	21:00	8	23:30	0	3	298	893
03-04 to 04-04-97	20:30	0	21:30	15	0:30	0	4	569	2276
04-04-97	19:30	1	21:30	27	23:30	1	13	1063	4252
05-04 to 06-04-97	20:30	4	21:00	18	0:30	2	8	868	3471
06-04-97	20:30	3	21:00	63	23:30	2	22	2268	6804
07-04-97	20:30	2	21:00	5	22:00	0	3	478	716
09-04-97	18:30	0	21:00	4	23:00	0	1	331	1492
10-04 to 11-04-97	20:30	0	21:30	45	1:30	0	9	950	4749
11-04 to 12-04-97	20:30	1	21:00	9	1:00	1	3	363	1632
12-04 to 13-04-97	20:30	1	21:30	29	2:00	3	12	1350	7424
13-04-97	20:30	1	21:00	35	22:40	1	16	1928	4178
14-04-97	20:20	0	21:10	85	23:50	2	16	1590	5564
15-04 to 16-04-97	19:40	0	21:10	29	0:40	2	6	857	4285
21-04-97	20:40	1	21:20	9	22:10	1	5	543	815
22-04 to 23-04-97	19:40	1	21:10	24	0:40	2	6	904	4519
23-04 to 24-04-97	20:00	1	21:20	45	0:40	1	9	1164	5433
24-04-97	20:20	0	21:30	14	23:20	0	4	609	1826
25-04-97	20:40	1	21:20	22	23:30	1	6	1299	3681
26-04-97	20:40	0	21:30	15	22:10	1	6	1384	2077
27-04 to 28-04-97	20:20	0	21:30	43	0:10	5	13	1898	7277
28-04-97	20:40	0	21:50	27	23:20	2	8	966	2576
29-04-97	20:30	0	21:30	51	22:50	4	13	2065	4819
30-04 to 01-05-97	20:40	1	22:10	6	0:10	2	4	497	1741
01-05 to 02-05-97	20:10	1	21:30	26	2:10	2	7	1044	6262
02-05-97	20:10	1	21:30	65	0:00	4	13	1996	7653
03-05 to 04-05-97	20:10	1	21:30	32	0:10	4	10	1623	6490
04-05 to 05-05-97	20:20	2	21:30	22	1:10	2	8	1492	7210
05-05 to 06-05-97	20:50	0	21:30	7	1:10	0	2	537	2326
06-05 to 07-05-97	21:00	0	21:50	36	0:10	1	11	2277	7209
08-05-97	21:00	0	21:30	3	23:00	0	2	375	751
09-05-97	20:20	1	21:40	39	23:50	1	10	1617	5660
10-05-97	21:00	1	21:40	44	23:50	2	12	2447	6933
12-05-97	21:00	5	21:30	21	23:50	2	7	1169	3311
13-05 to 14-05-97	20:10	0	21:40	24	0:40	3	6	1304	5868
14-05 to 15-05-97	20:30	6	21:30	42	1:40	2	10	1542	7970
15-05-97	20:30	2	21:30	19	23:00	2	6	924	2311
16-05-97	20:30	0	21:40	25	22:40	4	9	1631	3534
17-05 to 18-05-97	21:00	0	22:00	20	0:40	1	8	1381	5064
18-05-97	20:30	1	22:00	20	23:10	2	8	1409	3758
19-05-97	20:30	0	22:00	13	0:00	1	6	1087	3806
20-05 to 21-05-97	20:40	0	21:40	14	2:00	9	11	1502	8010
21-05 to 22-05-97	20:40	0	21:40	14	0:30	4	7	1096	4200
22-05 to 23-05-97	20:30	0	21:40	12	0:10	3	6	921	3378
23-05 to 24-05-97	21:00	0	21:30	9	0:40	1	4	639	2343
24-05-97	20:40	1	21:40	24	23:00	4	11	1492	3481

Night phases

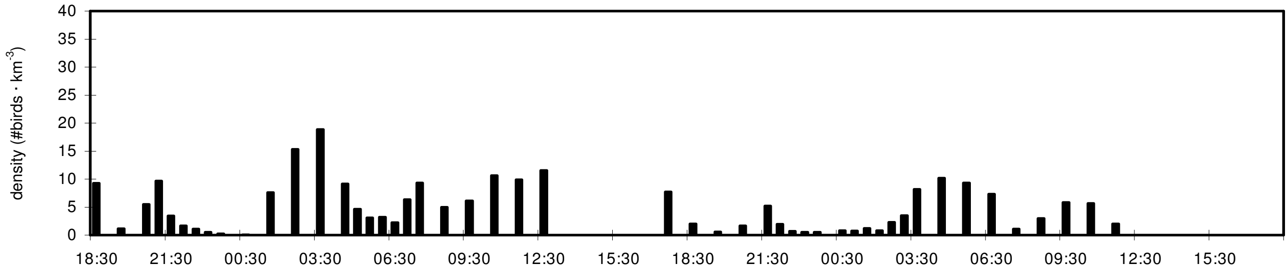
Date	Begin	DenBeg	TimeMax	DenMax	End	DenEnd	MDen	MTR	MT
28-03-97	0:30	0	03:30	19	8:30	5	7	1475	11797
28-03 to 29-03-97	23:00	0	04:30	10	7:30	1	4	656	5579
30-03-97	4:30	1	05:30	2	7:30	0	1	174	521
30-03 to 31-03-97	23:00	1	23:30	2	7:30	1	1	136	1154
31-03 to 01-04-97	23:30	0	04:30	6	5:30	3	2	389	2336
04-04-97	0:30	0	06:30	10	8:30	1	4	570	4564
05-04-97	2:00	1	03:30	8	6:30	4	4	644	2900
06-04-97	0:30	2	06:30	12	7:30	1	4	507	3547
06-04 to 07-04-97	23:30	2	04:30	12	7:30	0	7	862	6896
07-04 to 08-04-97	22:00	0	02:30	6	6:30	0	3	708	6019
09-04 to 10-04-97	23:00	0	02:30	6	8:30	0	3	683	6493
11-04-97	1:30	0	04:30	2	8:30	1	1	141	985
12-04-97	2:30	1	04:30	7	7:30	3	4	660	3301
13-04-97	2:00	3	05:30	32	9:30	5	15	2387	17902
14-04-97	0:50	1	03:40	26	7:20	3	12	2465	16020
14-04 to 15-04-97	23:50	2	05:30	18	9:10	2	6	895	8356
16-04-97	0:40	2	03:40	14	7:30	2	6	1121	7661
22-04-97	0:30	1	06:30	9	9:00	1	2	382	3247
23-04-97	0:40	2	05:30	28	7:40	3	10	1918	13429
24-04-97	2:00	1	06:30	10	7:30	2	4	697	4180
24-04 to 25-04-97	23:20	0	03:30	27	7:10	6	10	1917	15020
25-04 to 26-04-97	23:30	1	04:30	20	7:00	3	7	1498	11238
27-04-97	0:10	0	03:30	12	6:40	4	7	1729	11238
28-04-97	0:10	5	04:30	10	7:00	2	8	1123	7674
28-04 to 29-04-97	23:20	2	06:00	11	8:00	0	4	710	6155
30-04-97	22:50	4	05:00	10	7:00	2	6	1053	8602
01-05-97	1:40	1	06:10	8	7:10	1	4	397	2185
02-05-97	2:10	2	05:30	13	7:00	1	7	1108	5357
03-05-97	0:00	4	05:30	24	7:00	2	12	2150	15049
04-05-97	0:10	4	05:40	21	7:10	3	11	1991	13936
05-05-97	3:10	3	06:00	17	6:40	5	8	1821	6375
06-05-97	1:10	0	04:00	4	4:40	2	2	960	3359
07-05-97	0:10	1	06:10	16	7:30	2	8	1219	8937
08-05 to 09-05-97	23:00	0	05:30	10	7:30	6	3	552	4692
10-05-97	1:30	1	05:40	19	8:00	7	8	1779	11566
10-05 to 11-05-97	23:50	2	04:10	28	7:00	8	12	3190	22861
12-05 to 13-05-97	23:50	2	02:30	9	6:10	4	6	1380	8741
14-05-97	0:40	3	04:10	13	5:00	8	9	2127	9217
15-05-97	1:40	2	06:00	13	6:40	3	6	1019	5093
15-05 to 16-05-97	23:00	2	06:00	26	7:00	4	11	1989	15910
16-05 to 17-05-97	22:40	4	02:30	11	5:00	1	7	1634	10346
18-05-97	0:40	1	05:40	28	7:00	12	8	2211	14004
18-05 to 19-05-97	23:10	2	05:40	31	6:10	10	12	3144	22006
20-05-97	0:00	1	05:30	15	6:10	10	7	2218	13678
21-05-97	2:00	9	06:00	26	7:00	1	15	4043	20213
22-05-97	0:30	4	06:00	21	6:10	4	9	1485	8413
23-05-97	0:10	3	05:40	23	6:10	5	11	1928	11567
24-05-97	0:40	1	03:40	7	4:00	4	4	968	3225
24-05 to 25-05-97	23:00	4	23:30	9	5:30	4	5	935	6075

Figures with densities of all nights

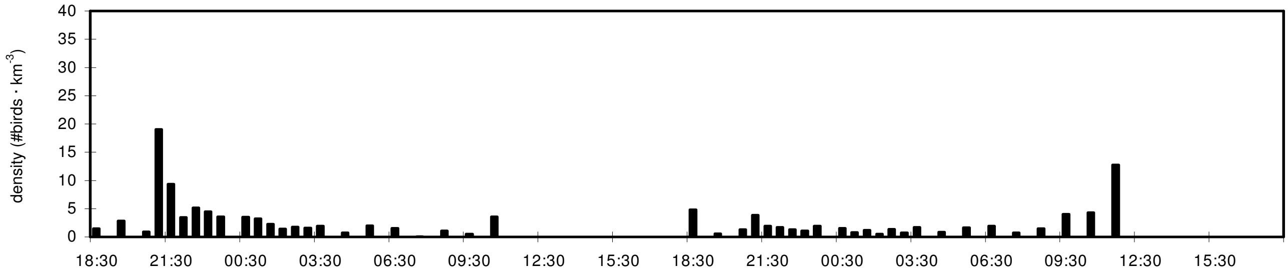
25-03 to 27-03-97



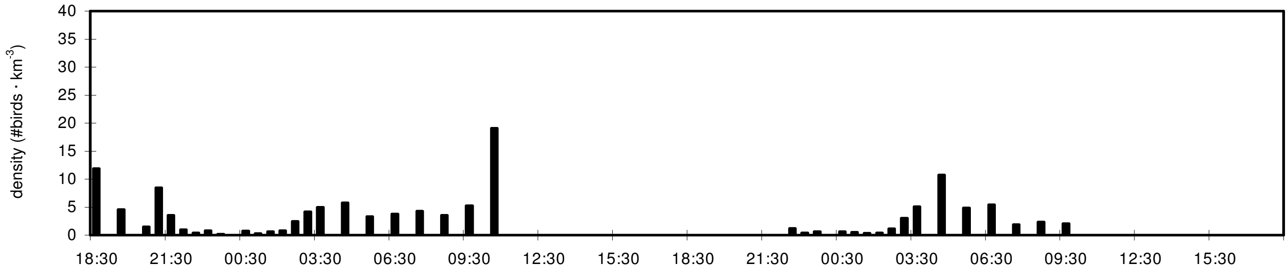
27-03 to 29-03-97



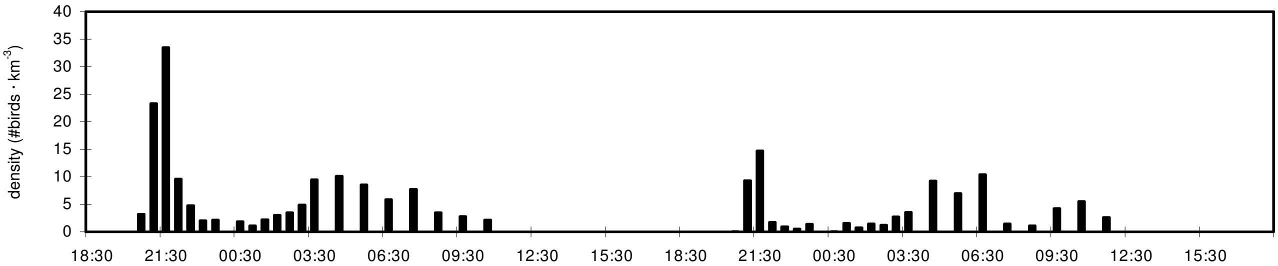
29-03 to 31-03-97

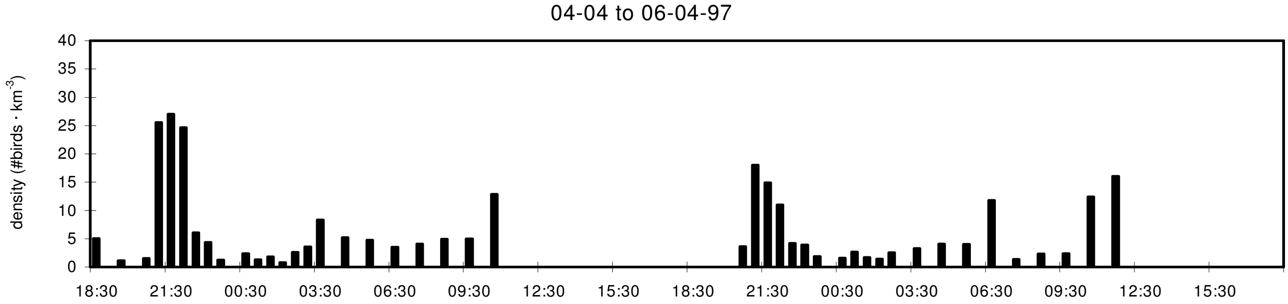


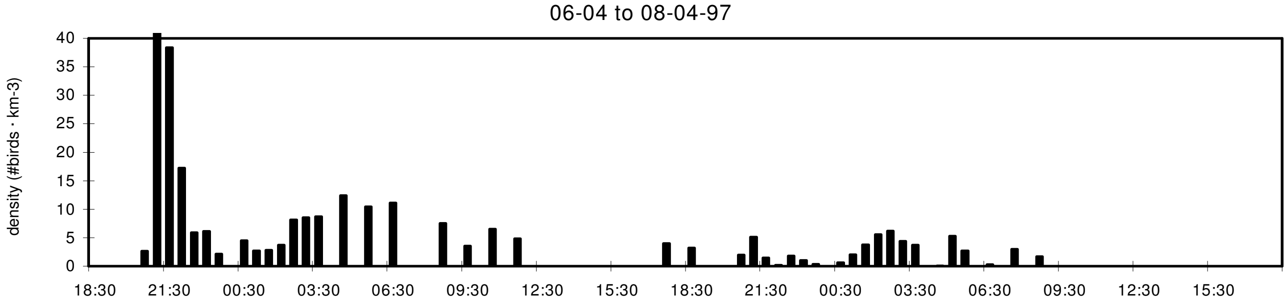
31-03 to 02-04-97

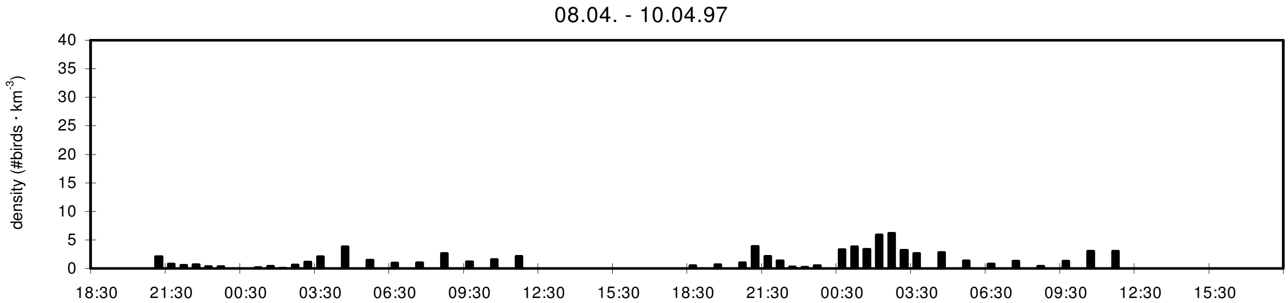


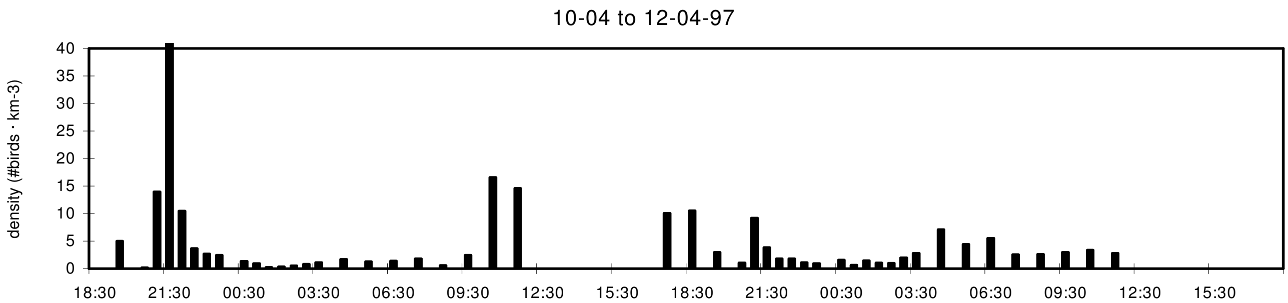
02-04 to 04-04-97

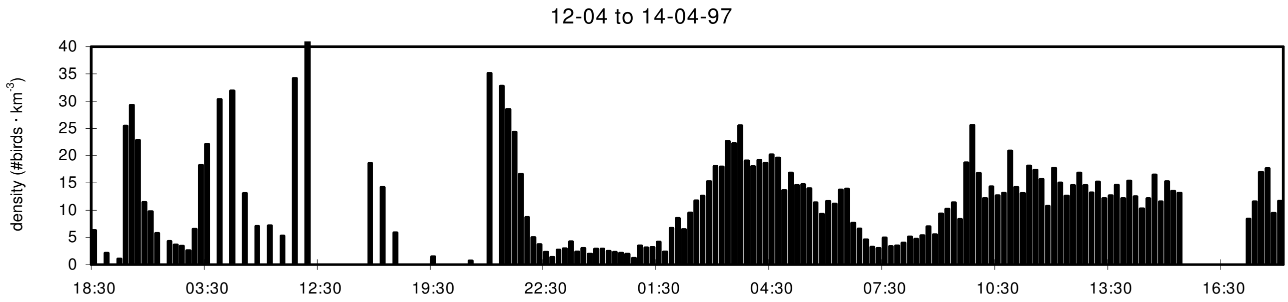


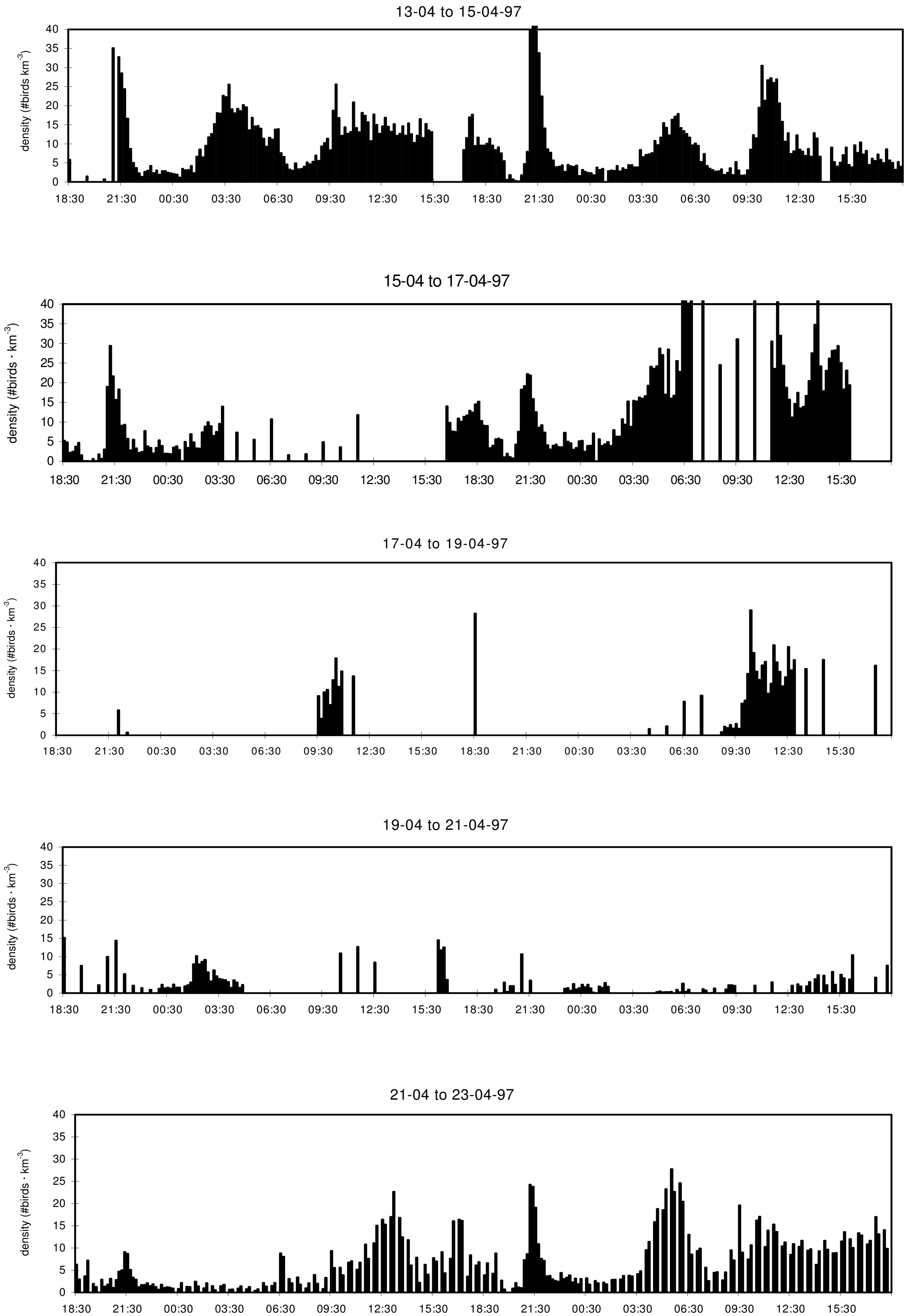

04-04 to 06-04-97
density (#birds · km^{-3})
0
5
10
15
20
25
30
35
40
18:30
21:30
00:30
03:30
06:30
09:30
12:30
15:30
18:30
21:30
00:30
03:30
06:30
09:30
12:30
15:30

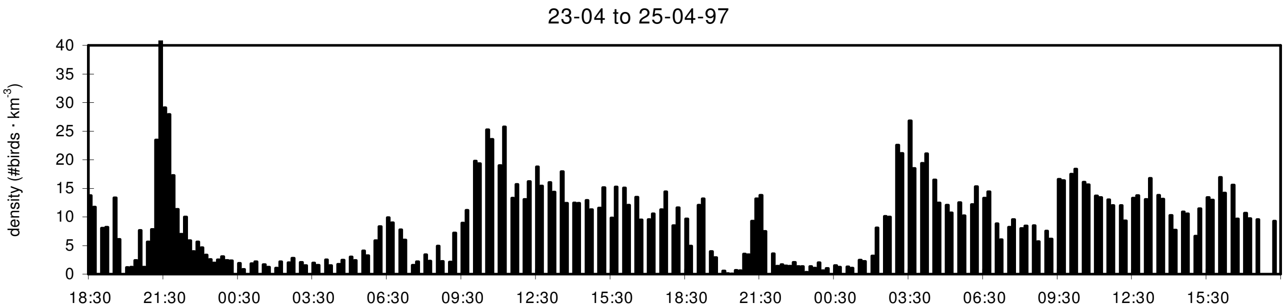

06-04 to 08-04-97
density (#birds · km-3)
0
5
10
15
20
25
30
35
40
18:30
21:30
00:30
03:30
06:30
09:30
12:30
15:30
18:30
21:30
00:30
03:30
06:30
09:30
12:30
15:30

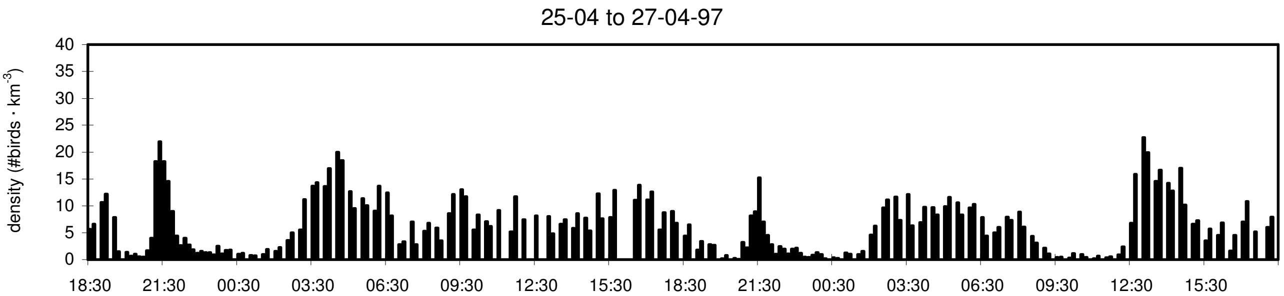

08.04. - 10.04.97
density (#birds · km^{-3})
0
5
10
15
20
25
30
35
40
18:30
21:30
00:30
03:30
06:30
09:30
12:30
15:30
18:30
21:30
00:30
03:30
06:30
09:30
12:30
15:30

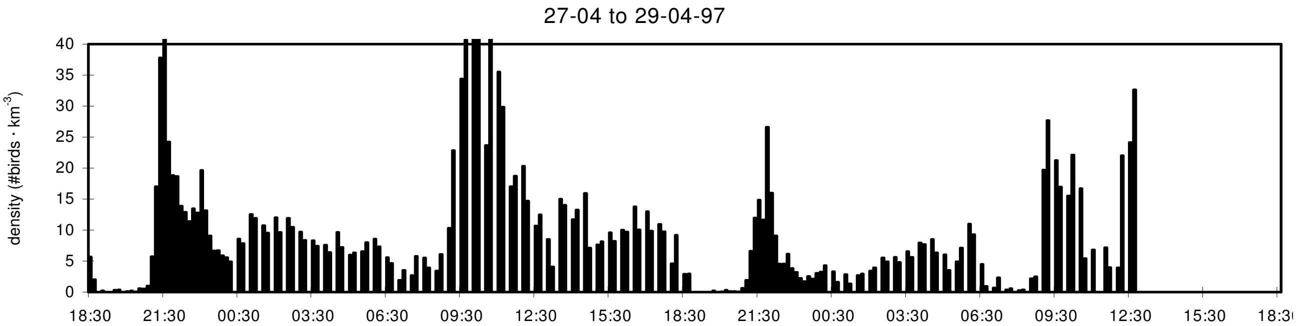

10-04 to 12-04-97
density (#birds · km-3)
0
5
10
15
20
25
30
35
40
18:30
21:30
00:30
03:30
06:30
09:30
12:30
15:30
18:30
21:30
00:30
03:30
06:30
09:30
12:30
15:30

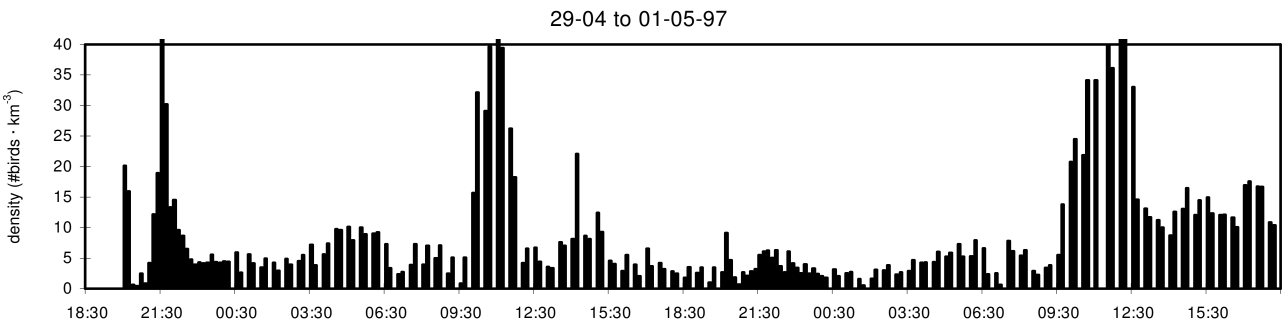

12-04 to 14-04-97
density (#birds · km^{-3})
0
5
10
15
20
25
30
35
40
18:30
03:30
12:30
19:30
22:30
01:30
04:30
07:30
10:30
13:30
16:30

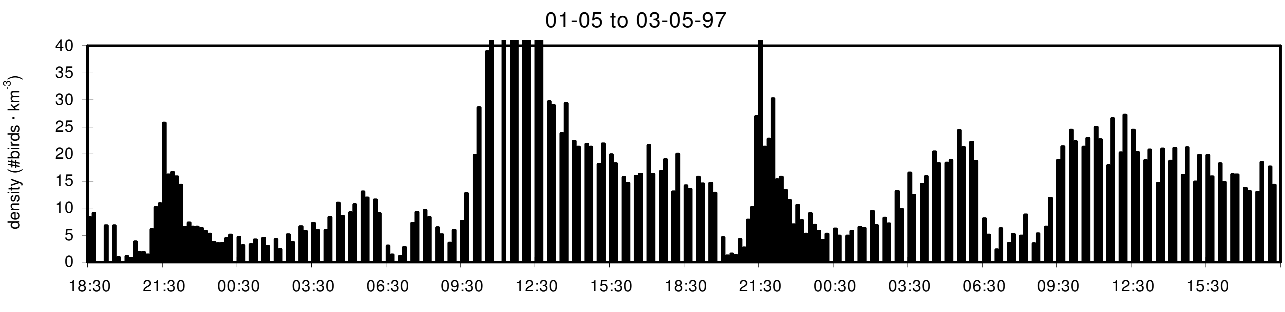

13-04 to 15-04-97
15-04 to 17-04-97
17-04 to 19-04-97
19-04 to 21-04-97
21-04 to 23-04-97
density (#birds · km^{-3})
0
5
10
15
20
25
30
35
40
18:30
21:30
00:30
03:30
06:30
09:30
12:30
15:30

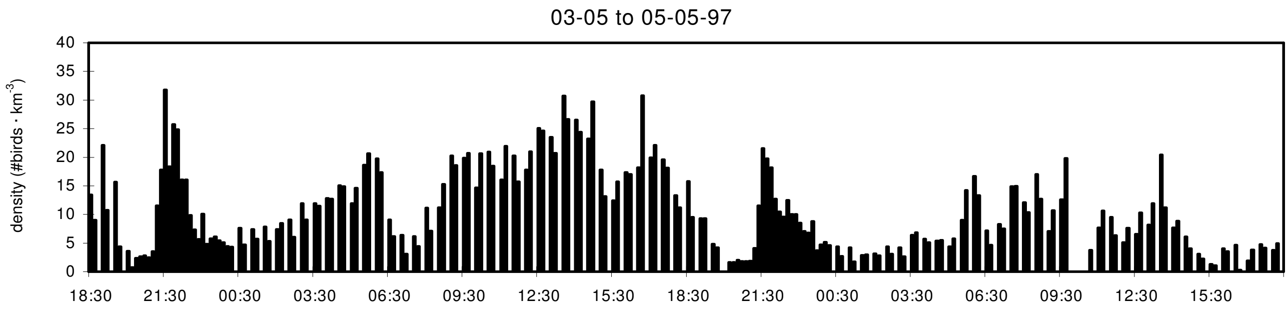

23-04 to 25-04-97
density (#birds · km-3)
0 5 10 15 20 25 30 35 40
18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30 18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30

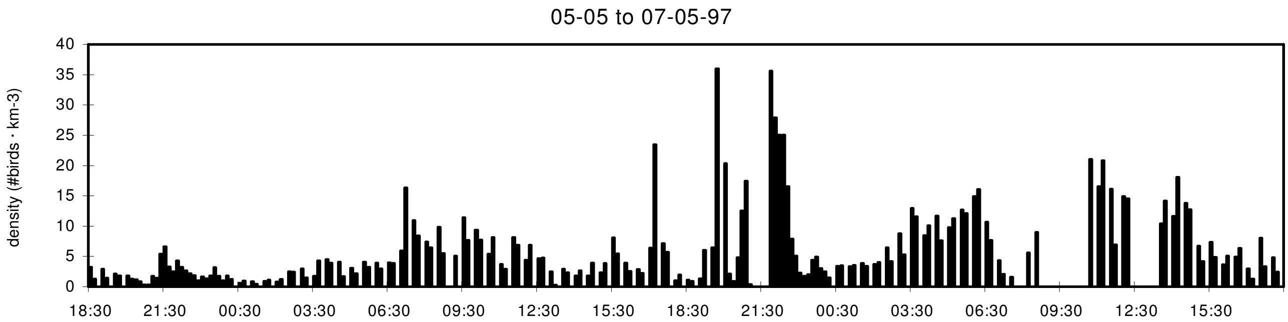

25-04 to 27-04-97
density (#birds · km-3)
0 5 10 15 20 25 30 35 40
18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30 18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30

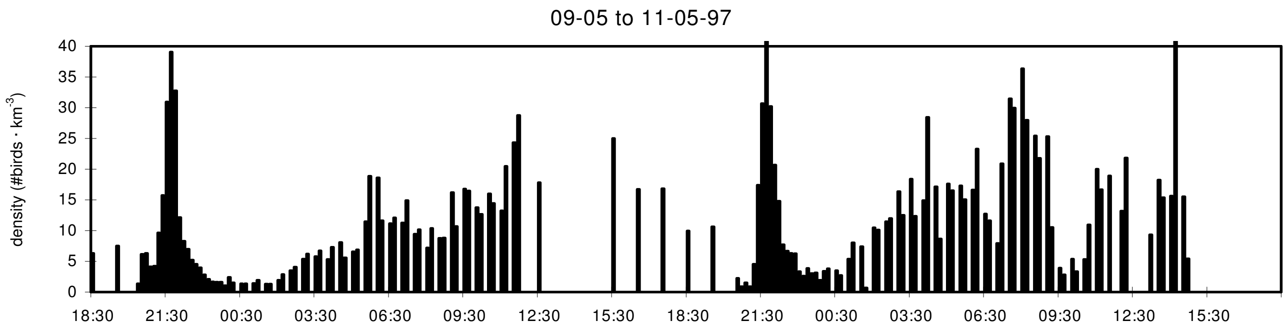

27-04 to 29-04-97
density (#birds · km-3)
0 5 10 15 20 25 30 35 40
18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30 18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30

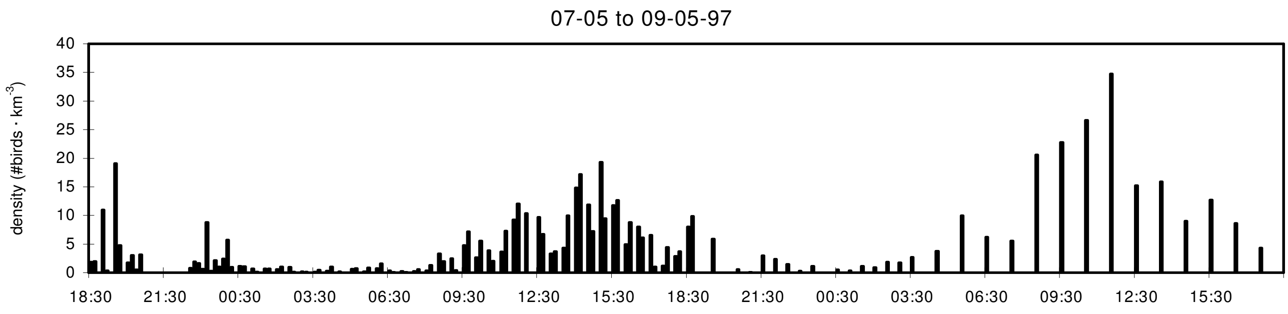

29-04 to 01-05-97
density (#birds · km-3)
0 5 10 15 20 25 30 35 40
18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30 18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30

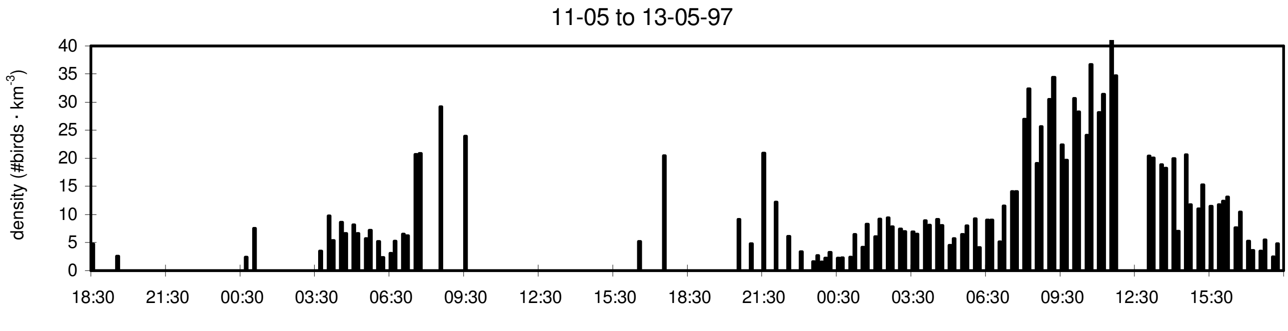

01-05 to 03-05-97
density (#birds · km-3)
0 5 10 15 20 25 30 35 40
18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30 18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30

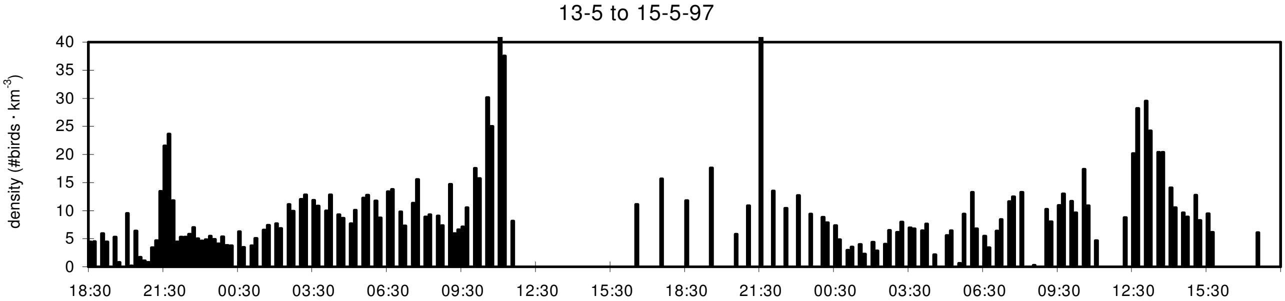

03-05 to 05-05-97
density (#birds · km-3)
40
35
30
25
20
15
10
5
0
18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30 18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30

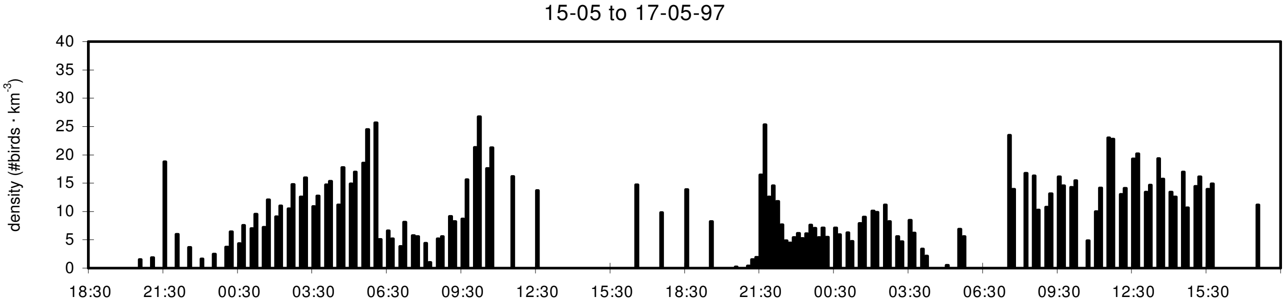

05-05 to 07-05-97
density (#birds · km-3)
40
35
30
25
20
15
10
5
0
18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30 18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30

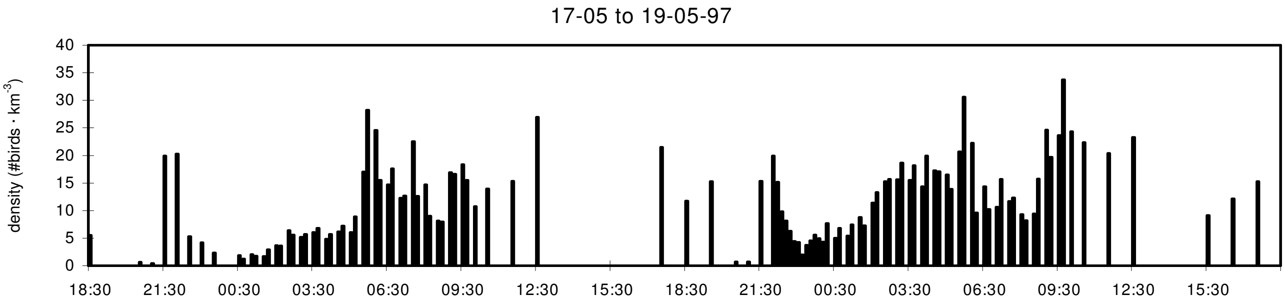

09-05 to 11-05-97
density (#birds · km-3)
40
35
30
25
20
15
10
5
0
18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30 18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30

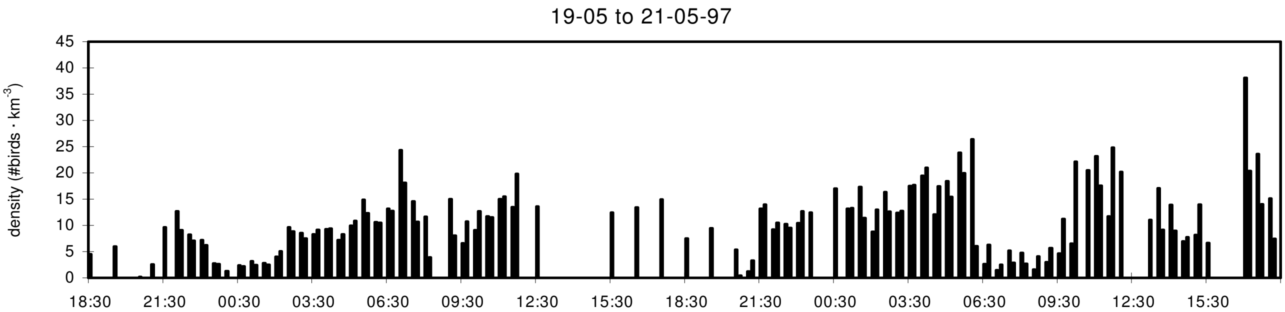

07-05 to 09-05-97
density (#birds · km-3)
40
35
30
25
20
15
10
5
0
18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30 18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30

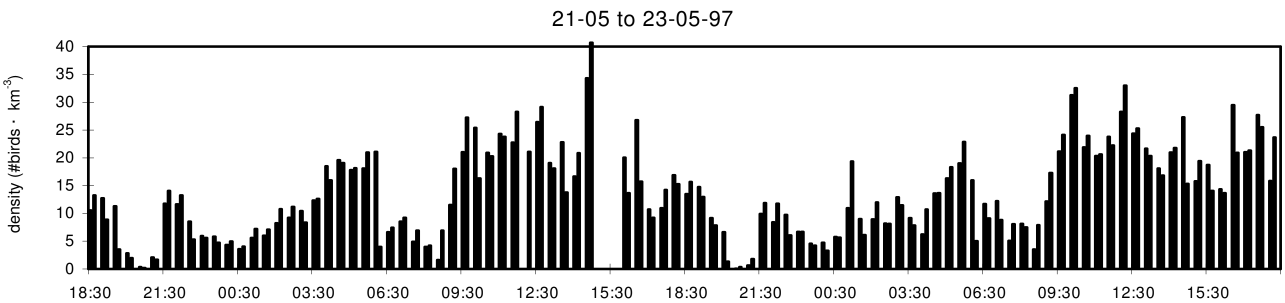

11-05 to 13-05-97
density (#birds · km-3)
40
35
30
25
20
15
10
5
0
18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30 18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30

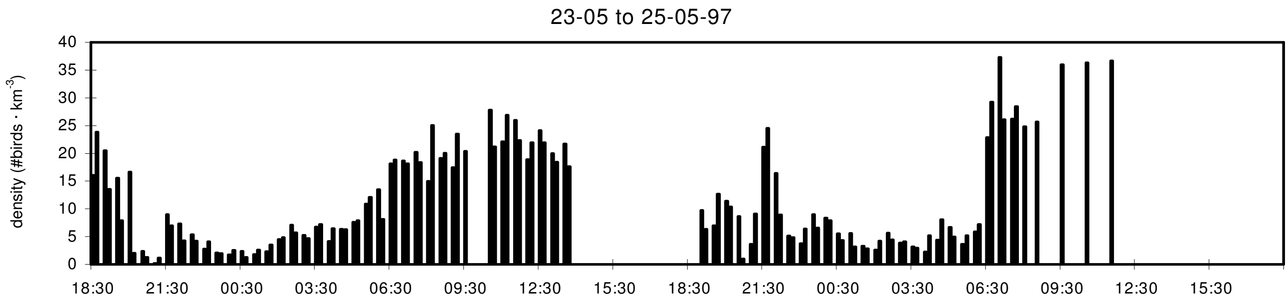

13-5 to 15-5-97
density (#birds · km-3)
40
35
30
25
20
15
10
5
0
18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30 18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30

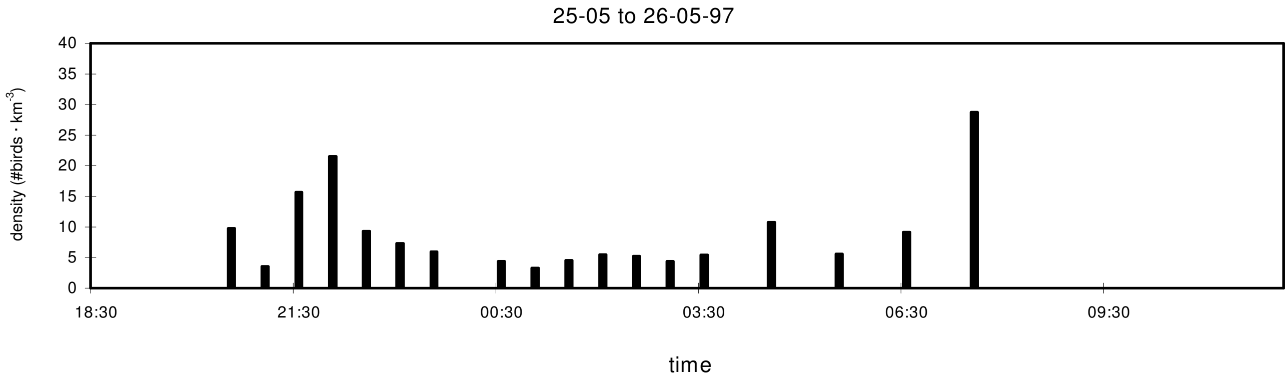

15-05 to 17-05-97
density (#birds · km-3)
40
35
30
25
20
15
10
5
0
18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30 18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30


17-05 to 19-05-97
density (#birds · km-3)
40
35
30
25
20
15
10
5
0
18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30 18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30


19-05 to 21-05-97
density (#birds · km-3)
45
40
35
30
25
20
15
10
5
0
18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30 18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30


21-05 to 23-05-97
density (#birds · km-3)
40
35
30
25
20
15
10
5
0
18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30 18:30 21:30 00:30 03:30 06:30 09:30 12:30 15:30





Access Basic Module for analysing the temporal schedule of the densities

The whole Access Basic Module consists of several procedures. The steps and procedures are listed below:

Sub auswert	1. Sub doublettenmitteln	
	2 . Function TabelleMaximaanlegen	
	3. Function TabelleMinimaanlegen	
	4. Sub Maximaberechnen	4.1 Function Maximumschonvorhanden
	5. Sub Minimaberechnen	5.1.Function Minimumschonvorhanden
Sub start	1. Sub TabelleStartphaseanlegen	
	2. Sub Startphase	

Sub **auswert** ()

```
Sub auswert ()
   Dim aktuelleDB As Database
   Dim MD As Recordset
   Dim MDMaxima As Recordset
   Dim MDMinima As Recordset
   Dim MDStart As Recordset
   Dim MDPhase As Recordset
   Dim Kriterum As String
   Dim Tabellenname1 As String, Tabellenname2 As String
   MsgBox ("Die Datensätze der Tabelle -BC97 MD pro Messung sortiert- werden analysiert")
   Set aktuelleDB = DBEngine(0)(0)
   Set MD = aktuelleDB.OpenRecordset("BC97 MD pro Messung sortiert", DB_OPEN_DYNASET)
   MsgBox ("Datensätze von B97 und C97 gleicher Zeit werden gemittelt")
   Doublettenmitteln MD
   Tabellenname1 = TabelleMaximaanlegen()
   If Tabellenname1 = "" Then
      Exit Sub
   Else
      Tabellenname2 = TabelleMinimaanlegen()
      If Tabellenname2 = "" Then
```

```
            Exit Sub
        Else
            Set MDMaxima = aktuelleDB.OpenRecordset("" & Tabellenname1 & "", DB_OPEN_DYNASET)
            Set MDMinima = aktuelleDB.OpenRecordset("" & Tabellenname2 & "", DB_OPEN_DYNASET)
            MsgBox ("Maxima und Minima werden gesucht und in die neuen Tabellen " & Tabellenname1 & " und
" & Tabellenname2 & " geschreiben")
            Maximaberechnen MD, MDMaxima
            Minimaberechnen MD, MDMinima
            MsgBox ("Anschliessend bitte: 1. Abfrage BC97 Minima anfügen ausführen 2. Prozedur Start
           ausführen. ")
        End If
    End If
End Sub
```

```
Sub Doublettenmitteln (MD As Recordset)
    Static DatumZeitVergleich(1 To 2) As Double
    Static NEchosVergleich(1 To 2) As Integer
    Static MDenVergleich(1 To 2) As Double
    Dim MDenneu As Double
    Dim NEchosneu As Integer
    Dim i As Integer, j As Integer
    Dim Code As Integer
    On Error GoTo Fehler_abfangen3
    MD.MoveFirst
    Do While MD.EOF = False
        For i = 1 To 2
            DatumZeitVergleich(i) = MD!DatumZeit
            NEchosVergleich(i) = MD!Nechos
            MDenVergleich(i) = MD!MDen
            MD.MoveNext
        Next i
        If DatumZeitVergleich(2) = DatumZeitVergleich(1) Then
            MDenneu = (MDenVergleich(2) + MDenVergleich(1)) / 2
            NEchosneu = (NEchosVergleich(2) + NEchosVergleich(1)) / 2
            MD.MovePrevious
            MD.MovePrevious
            MD.Edit
                MD!MDen = MDenneu
                MD!Nechos = NEchosneu
                MD!site = "B97 " & "C97"
            MD.Update
            MD.MoveNext
            MD.Delete
            MD.MoveNext
        Else
            MD.MovePrevious
        End If
    Loop
Fehler_abfangen3:
        'Fehler tritt auf, wenn Schleife versucht 5 Datensätze einzulesen und
        'der 5. letzte Datensatz schon erreicht wurde (EOF Problem)
        Exit Sub
End Sub
```

```
Function TabelleMaximaanlegen () As String
    Dim DB As Database
    Dim Tabelle1 As TableDef
    Dim Tabellenname1 As String
    Dim Feld As Field
    Dim Ergebnis As Integer
On Error GoTo Fehler_beheben
    Set DB = DBEngine(0)(0)
    Tabellenname1 = InputBox$("Bitte geben Sie einen Namen für die 1. Tabelle ein", "1. Tabelle erstellen",
```

```
    "BC97 Maxima")
    If Tabellenname1 = "" Then
        MsgBox "Analyse wird abgegrochen"
        TabelleMaximaanlegen = ""
        Exit Function
    Else
        Set Tabelle1 = DB.CreateTableDef("" & Tabellenname1 & "")
        Set Feld = Tabelle1.CreateField("Datum", DB_DATE)
        Tabelle1.Fields.Append Feld
        Set Feld = Tabelle1.CreateField("Maximumzeit", DB_DATE)
        Tabelle1.Fields.Append Feld
        Set Feld = Tabelle1.CreateField("Code", DB_INTEGER)
        Tabelle1.Fields.Append Feld
        Set Feld = Tabelle1.CreateField("MDen", DB_DOUBLE)
        Tabelle1.Fields.Append Feld
        Set Feld = Tabelle1.CreateField("NEchos", DB_INTEGER)
        Tabelle1.Fields.Append Feld
        Set Feld = Tabelle1.CreateField("NNr", DB_DATE)
        Tabelle1.Fields.Append Feld
        Set Feld = Tabelle1.CreateField("Site", DB_TEXT)
        Tabelle1.Fields.Append Feld
        TabelleMaximaanlegen = Tabellenname1
        DB.TableDefs.Append Tabelle1
    End If
Exit Function
Fehler_beheben:
    Ergebnis = MsgBox("Es ist schon eine Tabelle mit dem Namen " & Tabellenname1 & " vorhanden. Alte
Tabelle wird gelöscht", 49, "löschen")
    If Ergebnis = 2 Then
        Exit Function
    Else
        DB.TableDefs.Delete "" & Tabellenname1 & ""
    End If
    Resume
End Function
```

Function **TabelleMinimaanlegen** () As String

```
    Dim DB As Database
    Dim Tabelle2 As TableDef
    Dim Tabellenname2 As String
    Dim Feld As Field
    Dim Ergebnis As Integer
On Error GoTo Fehler_beheben2
    Set DB = DBEngine(0)(0)
    Tabellenname2 = InputBox$("Bitte geben Sie einen Namen für die 2. Tabelle ein", "2. Tabelle erstellen",
    "BC97 Minima")
    If Tabellenname2 = "" Then
        MsgBox "Analyse wird abgebrochen"
        TabelleMinimaanlegen = ""
        Exit Function
    Else
        Set Tabelle2 = DB.CreateTableDef("" & Tabellenname2 & "")
        Set Feld = Tabelle2.CreateField("Datum", DB_DATE)
        Tabelle2.Fields.Append Feld
        Set Feld = Tabelle2.CreateField("Minimumzeit", DB_DATE)
        Tabelle2.Fields.Append Feld
        Set Feld = Tabelle2.CreateField("Code", DB_INTEGER)
        Tabelle2.Fields.Append Feld
        Set Feld = Tabelle2.CreateField("MDen", DB_DOUBLE)
        Tabelle2.Fields.Append Feld
        Set Feld = Tabelle2.CreateField("NEchos", DB_INTEGER)
        Tabelle2.Fields.Append Feld
        Set Feld = Tabelle2.CreateField("NNr", DB_DATE)
        Tabelle2.Fields.Append Feld
```

```
      Set Feld = Tabelle2.CreateField("Site", DB_TEXT)
      Tabelle2.Fields.Append Feld
      DB.TableDefs.Append Tabelle2
      TabelleMinimaanlegen = Tabellenname2
   End If
Exit Function
Fehler_beheben2:
   Ergebnis = MsgBox("Es ist schon eine Tabelle mit dem Namen " & Tabellenname2 & " vorhanden. Alte
   Tabelle wird gelöscht", 49, "löschen")
   If Ergebnis = 2 Then
      Exit Function
   Else
      DB.TableDefs.Delete "" & Tabellenname2 & ""
   End If
   Resume
End Function
```

Sub **Maximaberechnen** (MD As Recordset, MDMaxima As Recordset)

```
   Static MDenVergleich(1 To 15) As Variant
   Static Zeit(1 To 15) As Variant
   Dim Datzeit As Variant
   Dim DatumZeit As Double
   Dim Differenz2 As Single, Differenz1 As Single
   Dim i As Integer, j As Integer, k As Integer
   Dim Wert As Integer
   Dim Lesezeichen1 As String, Lesezeichen2 As String
   Dim test As String
On Error GoTo Fehler_abfangen2
   MD.MoveFirst
   Do While MD.EOF = False
      i = 0
      Differenz2 = 0
      Do Until Differenz2 >=                 'Datensätze in Array einlesen, bis vom ersten zum letzten 2 Stunden
      verstrichen sind
         i = i + 1
         MDenVergleich(i) = MD!MDen
         Zeit(i) = MD!DatumZeit
         If i = 2 Then
            Lesezeichen1 = MD.Bookmark      'Lesezeichen1 beim 2. Array-Datensatz setzen
         End If
         MD.MoveNext
         Datzeit = MD!DatumZeit
         Differenz2 = (DateDiff("n", Zeit(1), Datzeit)) / 60
      Loop
      i = i + 1
      MDenVergleich(i) = MD!MDen             'Dichte und DatZeit des letzten Datensatzes in Array abspeichern
      Zeit(i) = MD!DatumZeit
      Lesezeichen2 = MD.Bookmark             'Lesezeichen2 beim letzten Datensatz des Arrays speichern
      If i > 4 Then                          'überprüfen, ob mindestens 5 Werte für Berechnung des Maximum zur
      Verfügung stehen
         Differenz1 = 0                      'zu Array-Datensatz wechseln, der mind. 1 Std vom ersten entfernt ist
         Do Until Differenz1 = 1
            For j = 2 To i
               Differenz1 = (DateDiff("n", Zeit(1), Zeit(j))) / 60
               If Differenz1 >= 1 Then
                  Exit Do
               End If
            Next j
         Loop
         k = 0
         Do Until k = i                      'prüfen ob Maximum
            k = k + 1
            If MDenVergleich(j) < MDenVergleich(k) Then
```

```
                Wert = 0
                Exit Do
            Else
                Wert = 1
            End If
        Loop
        If Wert <> 0 Then
            MD.Bookmark = Lesezeichen2
            Do
                If MD.DatumZeit = Zeit(j) Then
                    Exit Do
                End If
                MD.MovePrevious
            Loop

            test = Maximumschonvorhanden(MD)
            If test = "nein" Then
                MDMaxima.AddNew             'Maximum in Tabelle schreiben
                    MDMaxima!Datum = MD!Datum
                    MDMaxima!Maximumzeit = MD!DatumZeit
                    MDMaxima!MDen = MD!MDen.Value
                    MDMaxima!Nechos = MD!Nechos
                    MDMaxima!NNr = MD!NNr
                    MDMaxima!site = MD!site
                MDMaxima.Update
            End If
        End If
        MD.Bookmark = Lesezeichen1          'Beim nächsten Datensatz fortfahren
    Else
    MDMaxima.AddNew
        MDMaxima!site = "zuwenig Werte"
    MDMaxima.Update
        MD.MoveNext
    End If
  Loop
Fehler_abfangen2:
    'Fehler tritt auf, wenn Schleife versucht weitere Datensätze einzulesen und
    'der letzte Datensatz schon erreicht wurde (EOF Problem)
    Exit Sub
End Sub

Function Maximumschonvorhanden (MD As Recordset) As String
  Static y As Integer               'verhindert, dass y nach beenden der Funktion wieder 0 gesetzt wird
  Static Kriteriummax(1 To 2) As Double
  y = y + 1
  Kriteriummax(y) = MD!DatumZeit
  If Kriteriummax(2) = Kriteriummax(1) Then
    Maximumschonvorhanden = "ja"
  Else
    Maximumschonvorhanden = "nein"
  End If
  If y = 2 Then
    y = 0
  End If
End Function

Sub Minimaberechnen (MD As Recordset, MDMinima As Recordset)
  Static MDenVergleich(1 To 15) As Variant
  Static Zeit(1 To 15) As Variant
  Dim Datzeit As Variant
  Dim DatumZeit As Double
  Dim Differenz2 As Single, Differenz1 As Single
  Dim i As Integer, j As Integer, k As Integer
```

```
    Dim Wert As Integer
    Dim Lesezeichen1 As String, Lesezeichen2 As String
    Dim test As String
    On Error GoTo Fehler_abfangen4
    MD.MoveFirst
    Do While MD.EOF = False
      i = 0
      Differenz2 = 0
      Do Until Differenz2 >= 2              'Datensätze in Array einlesen, bis vom ersten zum letzten 2 Stunden
      verstrichen sind
        i = i + 1
        MDenVergleich(i) = MD!MDen
        Zeit(i) = MD!DatumZeit
        If i = 2 Then
          Lesezeichen1 = MD.Bookmark      'Lesezeichen1 beim 2. Array-Datensatz setzen
        End If
        MD.MoveNext
        Datzeit = MD!DatumZeit
        Differenz2 = (DateDiff("n", Zeit(1), Datzeit)) / 60
      Loop
      i = i + 1
      MDenVergleich(i) = MD!MDen            'Dichte des letzten Datensatzes in Array abspeichern
      Zeit(i) = MD!DatumZeit                'DatZeit des letzten Datensatzes in Array abspeichern
      Lesezeichen2 = MD.Bookmark            'Lesezeichen2 beim letzten Datensatz des Arrays speichern
      If i > 4 Then                         'überprüfen ob mind. 5 Werte für Berechnung des Minimums zur
Verfügung stehen
        Differenz1 = 0                      'zu Array-Datensatz wechseln, der 1 Std vom ersten entfernt ist
        Do Until Differenz1 = 1
          For j = 2 To i
            Differenz1 = (DateDiff("n", Zeit(1), Zeit(j))) / 60
            If Differenz1 >= 1 Then
              Exit Do
            End If
          Next j
        Loop
        k = 0
        Do Until k = i                      'prüfen ob MDenvergleich(j) ein Minimum ist
          k = k + 1
          If MDenVergleich(j) > MDenVergleich(k) Then
            Wert = 0
            Exit Do
          Else
            Wert = 1
          End If
        Loop
        If Wert <> 0 Then                   'Minimum zu aktuellen Datensatz machen
          MD.Bookmark = Lesezeichen2
          Do
            If MD.DatumZeit = Zeit(j) Then
              Exit Do
            End If
            MD.MovePrevious
          Loop
          test = Minimumschonvorhanden(MD)
          If test = "nein" Then
            MDMinima.AddNew                 'Minimum in Tabelle schreiben
              MDMinima!Datum = MD!Datum
              MDMinima!Minimumzeit = MD!DatumZeit
              MDMinima!MDen = MD!MDen.Value
              MDMinima!Nechos = MD!Nechos
              MDMinima!NNr = MD!NNr
              MDMinima!site = MD!site
            MDMinima.Update
```

```
            End If
        End If
        MD.Bookmark = Lesezeichen1          'Beim nächsten Datensatz fortfahren
    Else
        MDMinima.AddNew
            MDMinima.site = "zuwenig Werte"
        MDMinima.Update
        MD.MoveNext
    End If
  Loop
Fehler_abfangen4:
    'Fehler tritt auf, wenn Schleife versucht Datensätze einzulesen und
    'keine neuen mehr vorhanden sind (EOF Problem)
    Exit Sub
End Sub
Function Minimumschonvorhanden (MD As Recordset) As String
  Static x As Integer                   'verhindert, dass x nach beenden der Funktion wieder 0 gesetzt wird
  Static Kriteriummin(1 To 2) As Double
  x = x + 1
  Kriteriummin(x) = MD!DatumZeit
  If Kriteriummin(2) = Kriteriummin(1) Then
    Minimumschonvorhanden = "ja"
  Else
    Minimumschonvorhanden = "nein"
  End If
  If x = 2 Then
    x = 0
  End If
End Function
Sub Start ()
  Dim aktuelleDB As Database
  Dim MD As Recordset
  Dim MDMaxima As Recordset
  Dim MDMinima As Recordset
  Dim MDStart As Recordset
  Set aktuelleDB = DBEngine(0)(0)
  Set MD = aktuelleDB.OpenRecordset("BC97 MD pro Messung sortiert", DB_OPEN_DYNASET)
  Set MDMaxima = aktuelleDB.OpenRecordset("BC97 Maxima", DB_OPEN_DYNASET)
  Set MDMinima = aktuelleDB.OpenRecordset("BC97 Minima", DB_OPEN_DYNASET)
        MsgBox ("Startphase wird analysiert und in die Tabelle BC97 Start geschrieben")
        TabelleStartphaseanlegen
        Set MDStart = aktuelleDB.OpenRecordset("BC97 Startphase", DB_OPEN_DYNASET)
        MDMinima.Filter = "site <> ""zuwenig Werte"""
        Set MDMinima = MDMinima.OpenRecordset()
        MDMinima.Sort = "Minimumzeit"
        Set MDMinima = MDMinima.OpenRecordset()
        Startphase MD, MDMinima, MDStart
        MsgBox ("Analyse beendet")
End Sub

Sub TabelleStartphaseanlegen ()
  Dim DB As Database
  Dim TabellePhase As TableDef
  Dim Feld As Field
  Dim Tabellenname As String
  Dim Ergebnis As Integer
  Set DB = DBEngine(0)(0)
  Tabellenname = "BC97 Startphase"
  Set TabellePhase = DB.CreateTableDef("" & Tabellenname & "")
  Set Feld = TabellePhase.CreateField("Datum", DB_DATE)
  TabellePhase.Fields.Append Feld
  Set Feld = TabellePhase.CreateField("NNr", DB_DATE)
  TabellePhase.Fields.Append Feld
```

```
   Set Feld = TabellePhase.CreateField("Zeitvon", DB_DATE)
   TabellePhase.Fields.Append Feld
   Set Feld = TabellePhase.CreateField("MDenvon", DB_SINGLE)
   TabellePhase.Fields.Append Feld
   Set Feld = TabellePhase.CreateField("Zeitbis", DB_DATE)
   TabellePhase.Fields.Append Feld
   Set Feld = TabellePhase.CreateField("MDenbis", DB_SINGLE)
   TabellePhase.Fields.Append Feld
   Set Feld = TabellePhase.CreateField("Densum", DB_SINGLE)
   TabellePhase.Fields.Append Feld
   Set Feld = TabellePhase.CreateField("Dauer", DB_SINGLE)
   TabellePhase.Fields.Append Feld
   Set Feld = TabellePhase.CreateField("AnzMess", DB_INTEGER)
   TabellePhase.Fields.Append Feld
   DB.TableDefs.Append TabellePhase
End Sub

Sub Startphase (MD As Recordset, MDMinima As Recordset, MDStart As Recordset)
   Dim Anzahl As Integer
   Dim Datzeit As Variant
   Dim Datum As Variant
   Dim Datumvon As Variant
   Dim Datumbis5Prozent As Variant
   Dim MDensum As Single, MDen As Single
   MD.MoveFirst
   MDMinima.MoveFirst
   Datzeit = MDMinima!Minimumzeit
   Do While MD!DatumZeit <> Datzeit          'MD zum 1. Minimum bewegen
      MD.MoveNext
   Loop
   Do While MDMinima.EOF = False
      Datum = MD!Datum
      Datumvon = MD!DatumZeit
      MDenvon = MD!MDen
      Datzeit = MDMinima!Minimumzeit
      MDensum = 0
      Anzahl = 0
      Do Until MD!DatumZeit = Datzeit
         MDen = MD!MDen
         MDensum = MDensum + MDen          'Dichtesumme berechnen
         Anzahl = Anzahl + 1               'Zähler für Anzahl Werte die für Densum berücksichtigt wurden
         MD.MoveNext
      Loop
            MDStart.AddNew
               MDStart!Datum = Datum
               MDStart!NNr = MDMinima!NNr
               MDStart!Zeitvon = Datumvon
               MDStart!MDenvon = MDenvon
               MDStart!Zeitbis = MDMinima!Minimumzeit
               MDStart!MDenbis = MDMinima!MDen
               MDStart!Densum = MDensum
               MDStart!Dauer = DateDiff("n", Datumvon, MDMinima!Minimumzeit)
               MDStart!AnzMess = Anzahl
            MDStart.Update
      MDMinima.MoveNext
   Loop
End Sub
```