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Spatial and seasonal variation in nocturnal autumn and spring migration patterns in the western Mediterranean area: a moon-watching survey

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Abstract – Nocturnal autumn and spring migration patterns around the western half of the Mediterranean sea were investigated simultaneously in different countries by means of an improved moon-watching method. This report is based on over 6000 individual observations reported by up to 160 volunteer observers from 45-62 sites (depending on season and weather), and the data were collected and analysed by the Swiss Ornithological Institute. Intensities and directions of migration are presented for the full-moon periods of autumn 1996, 1998 and spring 1997. In autumn, westerly directions of migration prevailed in northern Italy, shifting towards SW along the French Mediterranean coast and to SW-SSW on the Iberian peninsula, with deviations and scattered directions near relevant topographical features. In autumn, migration intensities were high in northern Italy, slightly lower along the Mediterranean coast and reached again high values across the Iberian peninsula, while low intensities occurred in central Italy and on the islands. In spring, directions of migration were around NE-NNE in all areas, and the intensities were more evenly distributed over the observation areas than in autumn, suggesting that spring migration occurs on a broader front than autumn migration. Relatively strong NE-NNE migration in northern Italy suggests arrivals from the sea and direct crossing of the Alps. Intense spring movements across the Mediterranean and Adriatic sea are indicated by intense migration across the central part of the Italian peninsula.

Riassunto – *Variabilità spazio-temporale della migrazione notturna in primavera e in autunno nel Mediterraneo occidentale: una indagine condotta mediante osservazioni dei migratori contro il disco lunare*. La migrazione notturna autunnale e primaverile è stata studiata simultaneamente in diversi paesi del Mediterraneo centro occidentale utilizzando la tecnica del *moon-watch*. Lo studio scaturisce dall'analisi di oltre 6000 osservazioni raccolte da più di 160 volontari in 45-62 siti (numero variabile in base a stagione e condizioni meteorologiche). I dati sono stati raccolti ed analizzati dalla Stazione ornitologica svizzera di Sempach. Intensità e direzione di migrazione sono stati indagati nei periodi di plenilunio autunnale 1996 e 1998 e primaverile 1997. In autunno, nell'Italia settentrionale il flusso migratorio era diretto prevalentemente verso W, verso SW lungo le coste francesi e verso SW-SSW nella penisola iberica, con deviazioni e dispersioni nella direzione in vicinanza di importanti elementi topografici. In autunno, le intensità di passaggio erano alte nell'Italia settentrionale, un po' inferiori lungo le coste mediterranee e nuovamente alte nella Penisola iberica. Basse intensità sono state invece riscontrate nell'Italia centrale e nelle Isole. In primavera le direzioni di migrazione erano orientate in ogni area per lo più verso NE-NNE e le intensità erano distribuite in modo più uniforme che in autunno, suggerendo che la migrazione primaverile avvenga su un fronte più ampio. L'intensità relativamente elevata osservata verso NE-NNE nell'Italia settentrionale suggerisce che ci sia un arrivo di migratori dal mare e l'attraversamento diretto delle Alpi. Un intenso movimento primaverile attraverso il Mediterraneo e l'Adriatico è dimostrato dalla forte migrazione trasversale sopra l'Italia centrale.

The Mediterranean sea is one of the largest ecological barriers for birds migrating from their European breeding areas to their African wintering grounds. The extent to which the course of nocturnal bird migration might be modified by this barrier has often been discussed, but the lack of quantitative data on the spatial variation of this secretive part of migration prevented reaching a general agreement. Some authors proposed that nocturnal migrants cross the sea on a broad front with no topography-induced concentrations (Casement 1966, Moreau 1961, Curry-Lindahl 1981, Lövei 1989). By contrast, ringing recoveries (Zink 1973, 1977, 1985) show important funnelling of directions towards the western and eastern edges of the Mediterranean. Moreover, recent moonwatch and infrared observations conducted at several sites showed a large-scale westward concentration of autumn

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migrants in northern Italy, high migratory intensities along the SE coast of Spain, mainly SSW migration in southern Spain, and important deviations according to topographical features (Rivera and Bruderer 1998, Liechti and Bruderer 1999).

Migration across the Mediterranean islands occurs regularly (Sultana and Gauci 1982, Thibault 1983, Iapichino and Massa 1989). Large scale co-ordinated catching efforts on many Mediterranean islands provided information on differences in species specific passage areas and time schedules of various spring migrants (Spina *et al.* 1993, Pilastro *et al.* 1998). However, a quantitative comparison between the volume of migration on an island and on the mainland was only possible in a recent radar study comparing the passage on Mallorca with that at the Malaga coast (Bruderer and Liechti 1999).

The aim of this paper is to provide an overview of the spatial and seasonal variation in densities and directions of nocturnal autumn and spring migration within the western Mediterranean, based on simultaneous moon-watch observations. The main questions addressed are: 1) is there a uniform broad front migration all over the region, or do we find local and regional differences in the intensity and/or direction of migration? 2) if there are concentrations and/or deviations, do they change within and between seasons? In other words: are there differences between pre-Saharan (short-distance) and trans-Saharan (long-distance) migrants or between strategies adopted by migrants during spring and autumn migration, respectively?

METHODS

Moon-watching

More than 100 years ago, moon-watching emerged as a method for the observation of on-going nocturnal migration (Scott 1881, Chapman 1888). Later, Lowery (1951) revived the method, Bolshakov (1985) improved it by estimating the distance of the birds from the observer according to their silhouette size, and Liechti *et al.* (1995) correlated these relative sizes with the corresponding distances measured by pencil-beam radar. Flight directions are determined by recording for each bird where it enters and leave the disk of the full moon, taking an imaginary clock-face as a reference. Comparison between the size of the bird's silhouette and the moon crater Tycho provides a size class that can be associated with a certain distance from the observer (according to radar calibration); this allows estimating the flight altitude according to the elevation of the moon. The method supplies reliable data for individual birds flying up to 1.5 km altitude in clear nights around the full-moon period. A broader description of the methods to calculate flight directions, flight altitude and migratory intensity is given in Liechti *et al.* (1996a). Unfortunately, this method does not provide much information about species composition, and heavily depends on weather conditions.

Observation sites and periods

The database comprises the full-moon periods of two autumn and one spring season. Part of the data from autumn 1996 and spring 1997 had already been analysed by Bruderer and Liechti (1999). These data are here complemented by considerable data sets that were received later and by the complete autumn period of 1998. Observations were carried out by 160 volunteer recorders at 62 sites in autumn 1996, by 89 recorders at 45 sites in spring 1997 and by 95 observers at 55 sites in autumn 1998. To obtain a general view of the migration behaviour in selected areas and to reduce site-specific variation, neighbouring sites (within about 30 km radius in regions with a dense network of sites, up to 50 km in regions with few sites) were pooled into directional diagrams (Fig. 1). Thus, we present data for 19 areas in autumn 1996, 19 in spring 1997 and 22 in autumn 1998. Observations started two to three nights before and finished two to three nights after full moon. However, most observers did not perform observations during all possible nights. Altogether, we obtained information on 235 observation nights (sum of all nights at the different sites) in autumn 1996, on 138 nights in spring 1997 and on 149 in autumn 1998. The total observation time for all three periods pooled was more than 740 h.

We excluded all observations reported when the moon elevation was below 15° due to the difficulties to calculate reliable flight directions (Liechti *et al.* 1996a). Eventually, the number of individual bird observations included in the analysis was 2991 birds for autumn 1996, 1181 for spring 1997 and 1882 for autumn 1998. Due to reasonably good matching of the observed directions between months, we combined the data in two autumn and one spring map. No data were available from Spain for autumn 1998. To compare

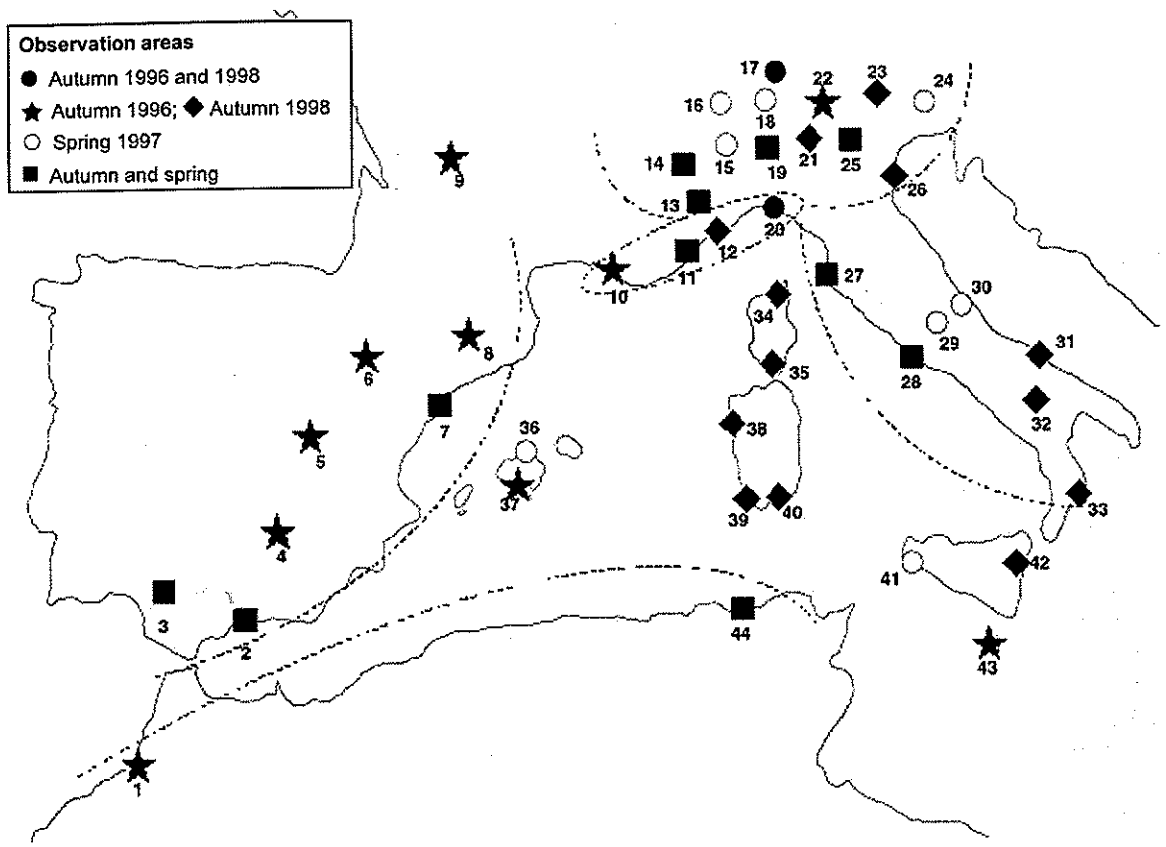

Figure 1. Observation areas in autumn 1996/1998 and spring 1997. An area may comprise several neighbouring observation sites. The identification numbers of the observation areas are reported (same as text). Dotted lines indicate the boundaries of the regions named under Fig. 2. - *Aree di osservazione; autunno 1996/1998 e primavera 1997. Ogni area comprende molte località di rilevamento vicine. La numerazione delle aree è la stessa di quella contenuta nel testo. Le linee trattegiate indicano i confini delle regioni.*

seasonal variation in migratory intensity in different countries, we divided the observation areas into 6 main regions: (1) North Africa, (2) Iberian peninsula, (3) French and north Italian Mediterranean coast, (4) northern Italy, (5) central and southern Italy, (6) Mediterranean islands (Fig. 1).

Migratory intensity is reported as the Migration Traffic Rate (MTR = number of birds crossing a front of 1 km perpendicular to the principal direction of migration in 1 hour) and is expressed as individuals/kmh (Liechti *et al.* 1995).

RESULTS

Spatial variation of autumn migration intensity

The overall average MTR of all areas and season was 727 birds/kmh in autumn 1996, and 603 birds/kmh in autumn 1998 (with no data from Spain). The average MTRs per region in 1996 compared to the overall average are: 0.9 for northern Italy, 0.8 for the Mediterranean coast, 1.4 for the Iberian peninsula, 0.5 for the Italian peninsula, 0.2 for the Mediterranean islands and 2.9 for the African coast in Morocco in 1996. For 1998, it was 1.7 for northern Italy, 0.7 for the Mediterranean coast, 0.7 for the Italian peninsula, 0.3 for the Mediterranean islands and 0.9 for northern Africa (Algeria). Migration intensity was characterised in both autumn seasons by marked day-to-day variations in all regions (Fig. 2).

In northern Italy, high MTR values were recorded in September, with a maximum density of 1300 birds/kmh (1996) and 1700 birds/kmh (1998). In 1996, along the Mediterranean coasts, MTR was lower than that recorded in northern Italy, except for a few nights (Fig. 2a). In 1998, an unexpectedly high intensity was observed on 8 October along the northern Adriatic coast (area 26), with an MTR of 5500 birds/kmh and an equally unexpected prevailing NW direction.

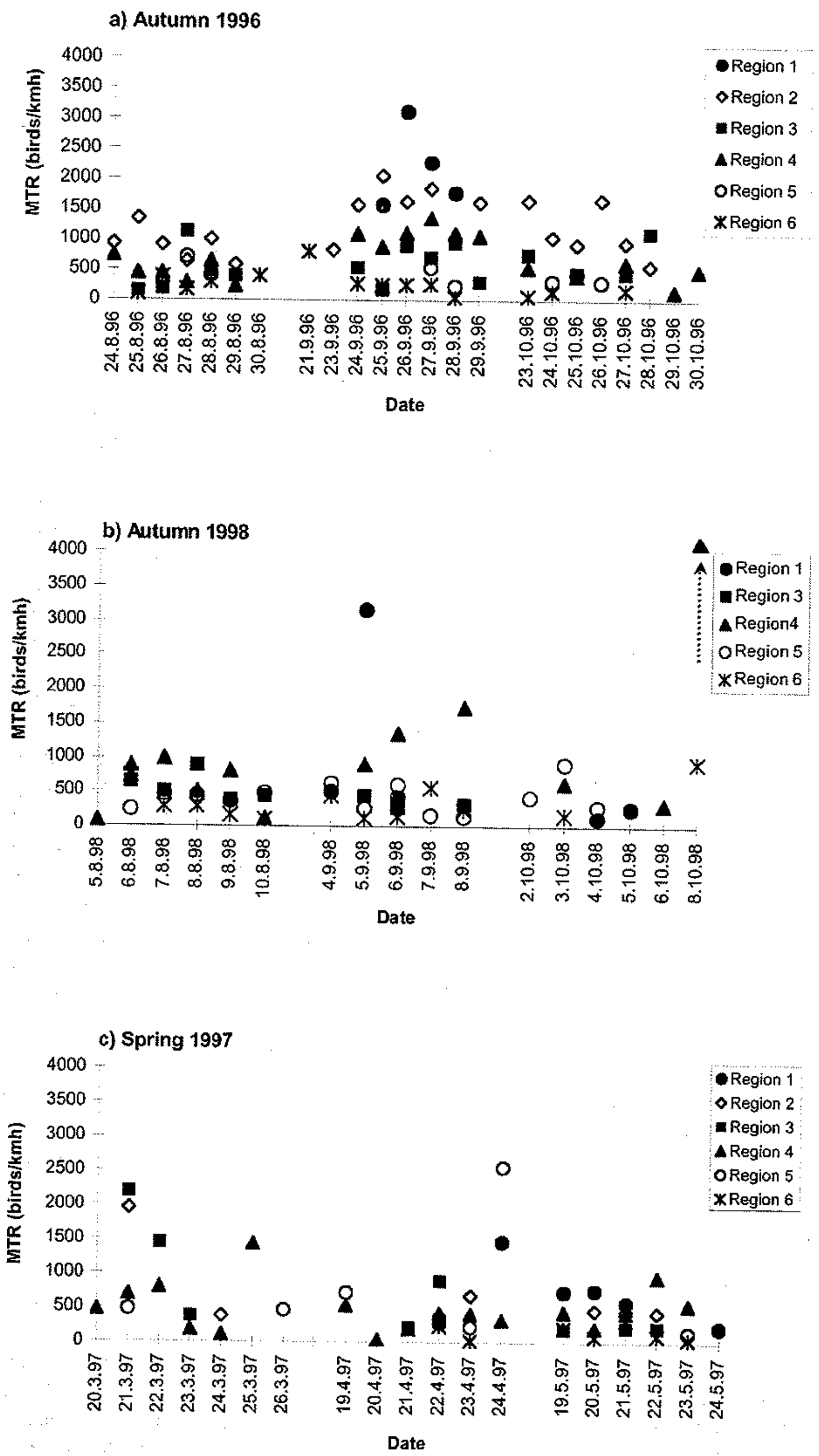

Figure 2. MTR per night and region in (a) autumn 1996, (b) autumn 1998 and (c) spring 1997. A region comprises several observation areas. Region 1 = Africa, 2 = Iberian Peninsula, 3 = French and Italian Riviera, 4 = Northern Italy, 5 = Italian Peninsula, 6 = Mediterranean islands. - *MTR per notte e regione, autunno 1996, autunno 1998 e primavera 1997. Una regione comprende diverse aree di osservazione. Regione 1 = Africa, 2 = Penisola iberica, 3 = Riviera francese ed italiana, 4 = Italia settentrionale, 5 = Penisola italiana, 6 = Isole del mediterraneo.*

In Spain, MTRs of over 1000 birds/kmh were recorded already in August. The highest MTR values were observed in September, with a nightly maximum MTR of 2050 birds/kmh. During the last full-moon period, MTR values declined, but still reached values higher than 1000 birds/kmh on three nights. MTRs on the Italian peninsula were low in the only area available for 1996 (area 28). Two years later, MTRs were slightly higher but usually below 1000 birds/kmh. Densities on the Mediterranean islands were even lower (maximum 800 birds/kmh in 1996, 900 in 1998, Fig. 2a,b). In Morocco (Fig. 3, area 1) we found high densities in September, with an MTR of more than 3000 birds/kmh.

Flight directions during autumn migration

Overall, birds were directed towards W-SW in both autumn seasons, with changes of direction near topographical features and seasonal differences in the concentration of flight directions. In 1996, birds were clearly directed to the W in northern Italy, with a change to the SW close to the Alps and along the Mediterranean coast (Fig. 3). In 1998, when the full moon period was in the first part of the month, flight directions in northern Italy (areas 17, 21, 23 and 25) were heavily scattered, but the other areas confirmed the westerly tendencies of 1996 (Fig. 4). Most migrants flying towards W-SW in northern Italy follow the Mediterranean coastline towards the Iberian peninsula. Along the French and Italian Riviera (areas 10, 11, 12, 20), we always observed a marked scatter of flight directions (Fig. 3, Fig. 4). On the Iberian peninsula, as compared to Italy and the Mediterranean coast, flight directions were more concentrated towards SW-SSW during the whole autumn season (with the exception of the coastal area 7, Fig. 3).

On the Italian peninsula, flight directions along the Tyrrhenian coast (areas 27 and 28) varied between S and SW, indicating that birds migrated towards the open sea. At the Adriatic coast (area 31, Fig. 4), migrants flew to the SSW, crossing the Italian peninsula towards Sicily. In area 33 (Ionian sea, coast of Calabria, Fig. 4), migrants were directed to the SW and NE, respectively, flying along the coastline. On all islands, flight directions were highly scattered (Fig. 3, 4), with the exceptions of a clear preference for a SSW direction on Malta and for a SE direction in southern Corsica (area 35). In Morocco (Fig. 3), migrants were directed towards S-SW. In 1998, we had an observation area in Algeria (Fig. 4), but flight directions for this area were unclear.

Spatial variation of spring migration intensity

In spring 1997, the overall mean MTR was 614 birds/kmh. Average intensity was 0.9 times the overall MTR on the Iberian peninsula, 1.0 in northern Italy, 1.0 along the Mediterranean coast, 1.3 in the Italian peninsula, 0.2 on the Mediterranean islands and 1.0 along the African coast in Algeria. While the mean intensities showed a rather homogeneous distribution, night-to-night variation was high in all regions (Fig. 2c).

In eastern Algeria (area 44), high MTR (with 1400 birds/kmh) was observed on 24 April. During May, MTR was lower, but was still higher than in the others regions. On the Iberian peninsula, we found a high migratory intensity in March (the main passage time of pre-Saharan migrants) and a marked decrease in April and May. The highest intensity was found as early as on 21 March, with an MTR of 1950 birds/kmh close to Sevilla (area 3). In April and May, the MTR was always below 1000 birds/kmh at all Spanish sites. In the same March period as in Spain, highest densities were also measured in area 11 at the Mediterranean coast, with densities of more than 2000 and 1400 birds/kmh in two nights (Fig. 2c). Such high intensities were no longer reached during April and May. In northern Italy, the highest MTR was also recorded in March, with an intensity of 1437 birds/kmh (Fig. 2c). In April, intensities were lowest over this region, although slightly higher MTR values were observed in some nights during May. The situation along the Italian peninsula was rather different, since highest intensities were found in April across this region (Fig. 2c). On 24 April, average intensities of 2217 birds/kmh and 1419 birds/kmh were observed in mainland central Italy (area 29) and close to the Adriatic coast (area 30), respectively. The few observations from the Mediterranean islands (areas 36, 41) show low MTRs during the whole observation period.

Flight directions during spring migration

In spring (Fig. 5), migrants were generally directed towards NNE, with deviations to the NW and NE. Flight directions didn't change within the season and flight directions were more concentrated than in

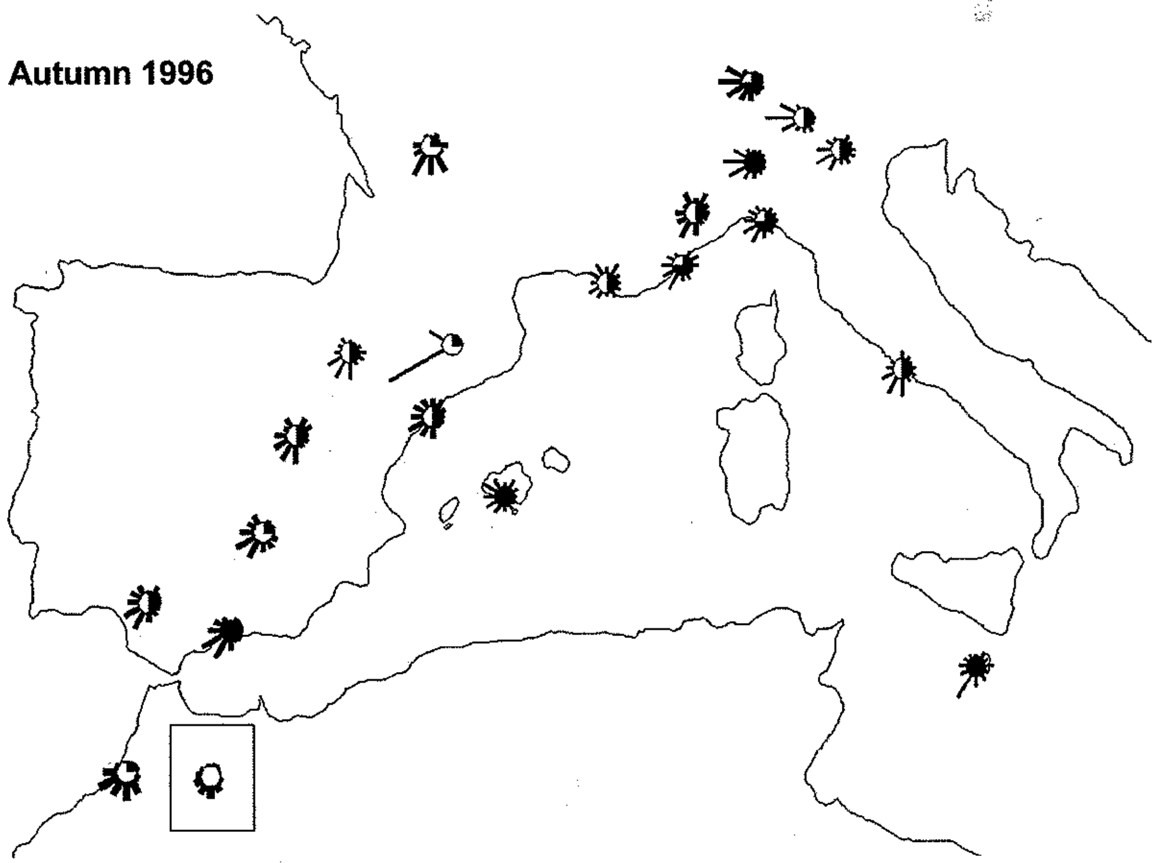

Figure 3. Summarised directional distribution per area in autumn 1996. Increasing width of the bars in the directional diagrams indicates four classes of migratory intensities: width 1 (MTR <=500 birds/kmh), width 2 (MTR <=1000 birds/kmh), width 3 (MTR <= 2000 birds/kmh), width 4 (MTR >2000 birds/kmh). The length of a single line indicates the relative migratory intensity. Observation time in each area is indicated by 4 classes: (observation time <=500 minutes), (observation time >500 and <=1000 minutes), (observation time >1000 and <= 1500 minutes), (observation time >1500 minutes). - *Distribuzione direzionale cumulativa per area nell'autunno 1996. La dimensione delle barre nell'aerogramma indica quattro classi di intensità di migrazione: 1 (MTR <=500 individui/kmh), 2 (MTR <=1000 individui/kmh), 3 (MTR <= 2000 individui/kmh), width 4 (MTR >2000 individui/kmh). La lunghezza delle barre indica l'intensità relativa di migrazione. I tempi di osservazione in ogni area sono indicati in 4 classi : (tempo di osservazione <=500 minuti), (tempo di osservazione >500 e <=1000 minuti), (tempo di osservazione >1000 e <= 1500 minuti), (tempo di osservazione >1500 minuti).*

autumn. Whereas migrants along the southern coast of the Iberian peninsula (area 2) were clearly oriented towards NE, flight directions in area 3 and 7 were scattered from NNW to the ENE.

In northern Italy, directions were not the opposite of the westerly autumn directions. Migrants showed a clear preference for the NNE and scatter was reduced compared to autumn migration. On the Italian peninsula, in three out of four observation areas, migrants were directed towards NE (areas 27, 28, 30), whereas most migrants in area 29 shifted to NW (along the mountain ranges of the Apennine). On Mallorca (area 36), some migrants were directed NW (towards the continent), others E (towards Menorca) and only a few towards NE (the delta of the Rohne), whereas on Sicily migrants were mainly oriented towards NNE.

DISCUSSION

This study provides an overview of simultaneously acquired quantitative data of nocturnal autumn and spring migration for a large portion of the western Mediterranean region. It is obvious that moon-watch data are confined to narrow temporal windows and are, therefore, subject to biases due to local topographical and meteorological condition. Interpretation has to take this into account, and comparison with data obtained from other sources is particularly important. From these data, the overall picture of nocturnal autumn migration in south-western Europe can be summarized as follows: in northern Italy, westward migration predominates, shifting south-

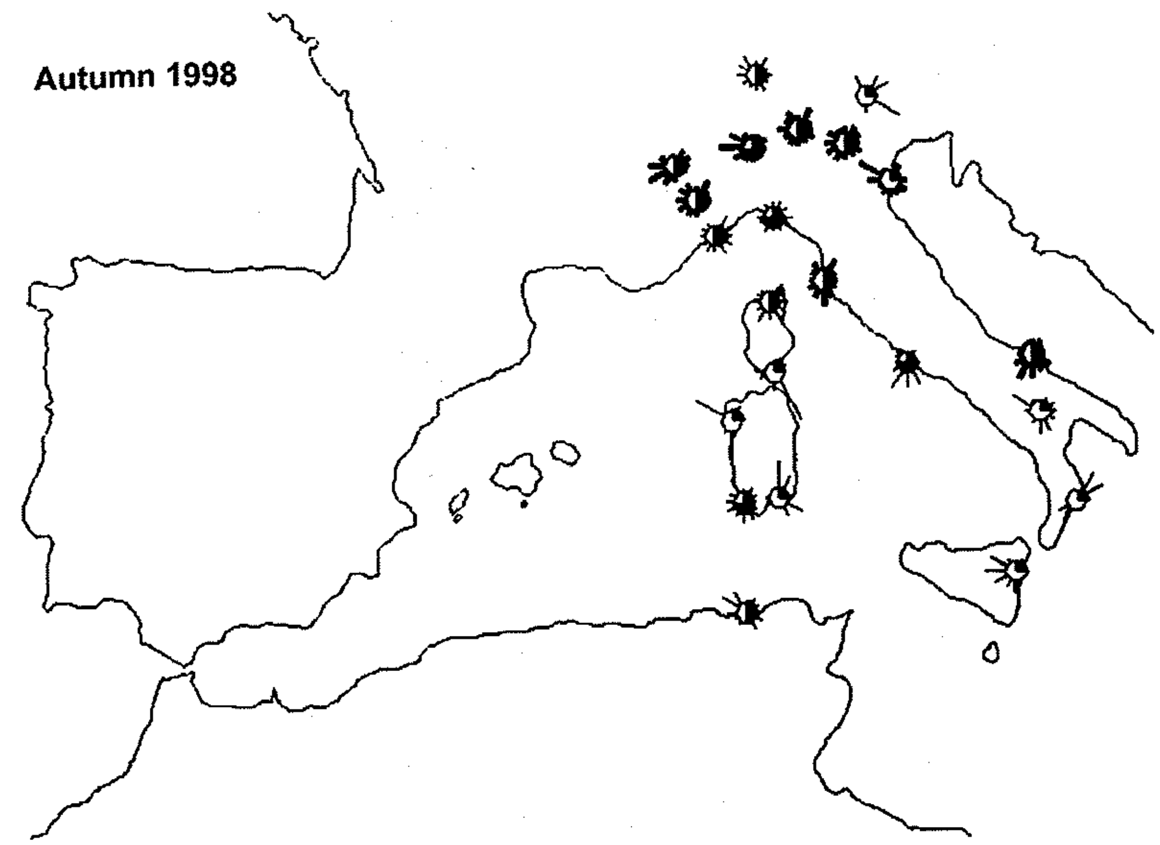

Figure 4. Summarised directional distribution per area in autumn 1998 (see legend to Fig. 3 for details). - *Distribuzione direzionale cumulativa per area nell'autunno 1998 (vedi legenda della Fig. 3 per dettagli).*

westward along the Mediterranean Alps and the French Mediterranean coast, while in south-western France southerly directions prevail. Thus, migration funnels towards the Iberian peninsula, resulting in a high density of migrants directed towards SW-SSW in Spain. Autumn migration across the Italian peninsula and the islands is rather weak. In spring, migrants seems to cross the western Mediterranean on a broad front, with reduced densities in Spain, but relatively dense migration across central Italy. Flying directions are generally NNE, even in northern Italy, where the migrants are approaching the Alps.

Variations in migratory intensity within and between seasons

Reported intensities of autumn migration were highest in Spain and in north-western Africa, followed by those in northern Italy. Areas with generally high passage indicate relatively low intensities in early and late August (representing the beginning of trans-Sahara migration), slightly higher densities in early September and highest MTRs during the available late September observations, partly capturing the main passage of trans-Saharan migrants. In early October, passages over the Italian peninsula were similar to those recorded in September, while those over NW Africa were low, representing the fading of trans-Saharan migration. The data from late October suggest a strong migration of pre-Saharan migrants (e.g. *Turdidae* species), with higher densities over the Iberian peninsula.

In spring, the passage of medium- and short-distance migrants from North Africa starts in February and peaks in March in the Mediterranean area (Finlayson 1992). With our March observations, we covered the last part of the movements of pre-Saharan migrants from North Africa, whereas the later observation periods concern the migration of trans-Saharan migrants (Finlayson 1992, Bruderer and Liechti 1999).

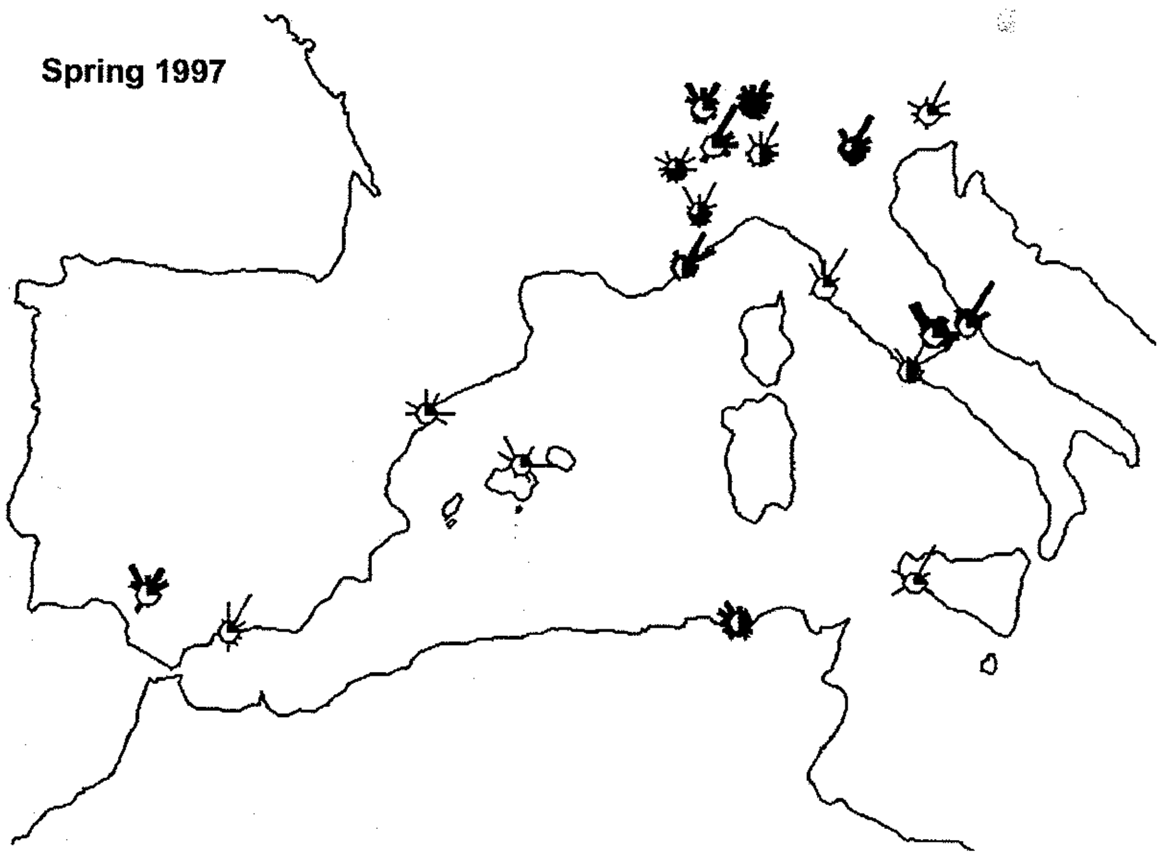

Figure 5. Summarised directional distribution per area in spring 1997 (see legend to Fig. 3 for details). - *Distribuzione direzionale cumulativa per* area primavera 1997 *(vedi legenda della Fig. 3 per dettagli).*

Large-scale shifts in direction and adjustments to topography

The observed SW-SSW directions in the southern part of the Iberian peninsula corroborate earlier observations (Hilgerloh 1989, Rivera and Bruderer 1998, Bruderer and Liechti 1998), revealing a gradual shift in the average direction of the migratory stream from SW in central Europe (Bruderer 1997), WSW along the northern border of the Alps (Bruderer 1996, Liechti *et al.* 1996a) and even W in upper Italy (Liechti *et al.* 1996b), to SW-SSW in southern Spain (Rivera and Bruderer 1998). However, the proposed endogenously controlled SE shift of directions towards the West African savannas, suggested to occur somewhere in the western Mediterranean or in western North Africa (Gwinner and Wiltschko 1978), does not take place before crossing the Mediterranean sea. Even in Morocco migrants were concentrated along the coast and directed to the S-SW, so also in this area no shift to the SE was recognizable.

Besides the observed large-scale funnelling of autumn migration towards the Iberian peninsula and the shifts along the northern and southern borders of the Alps, there are other obvious adjustments of directions to topographical features such as mountain chains and coastlines. Our study shows strong directional scatter in most coastal areas, some migrants heading out to the sea, others inland, and usually a slightly increased proportion along the coast, even if the coast led them towards a seasonally inappropriate direction, such as near Marseilles (area 10). Rivera and Bruderer (1998) emphasized variation according to the local or regional course of the coasts. In particular, they showed concentrated and heavy southward migration along the southward leading coast in south-eastern France and equally strong migration along the south-westward leading coasts of north-eastern Spain. They also report southward migration for the southward leading coasts in south-western France and Portugal.

On the other hand, our data show that spring migrants crossing the Italian peninsula, pay almost no attention to the Adriatic and Tyrrhenian coasts, which they cross at about right angles with NE-NNE directions. Even more, it is rather surprising that the migrants get deviated towards NW (and SE) by the mountain ridges of the Apennines in central Italy.

In contrast to autumn, spring migrants maintain NNE directions throughout south-western Europe. This occurs also in northern Italy, where most birds seem to be able to cross the Alps directly. These prevailing NNE directions are consistent with other, locally restricted studies on flight directions (Hilgerloh 1991, 1992, Liechti *et al.* 1996b, Rivera and Bruderer 1998). However, the idea of a broad-front NNE migration across the western Mediterranean basin is challenged to a certain extent by the low intensities observed on the islands Mallorca and Sicily. On Sicily (area 36) the low density may be explained by the lack of appropriate departure areas to the south; birds from the Tunisian or Libyan coast (with an expected flight time of 9 to 10 hours) would not have reached the study site at the time of the observations. On Mallorca, observations were conducted early at night, when the birds taking off in the central and southern part of the island should have reached the study site.

Observations on islands are in any case peculiar, because they will only show migration if the distance and direction from the available departure areas allow the birds to arrive at the observation site during the time interval available for moon-watching. In spite of the fact that this condition seemed to be fulfilled during the autumn observations on most islands, some reservations with respect to the available data is advisable. For example, in autumn 1996, on Mallorca, the observers saw just the final part of the departure from the North of the island and probably birds arriving from Menorca.

Sea crossing and loop migration

During the main migration of trans-Saharan migrants in autumn, migratory intensities observed on the mainland reached a maximum, while on the Italian peninsula and on the islands intensities were low. This impression of autumn migrants flying a detour around the western Mediterranean sea is corroborated by a full season of simultaneous radar observations on Mallorca and on the Spanish mainland near Malaga (Bruderer & Liechti 1999). Even birds from the south-eastern parts of Europe (e.g. from former Yugoslavia) prefer flights through northern Italy and along the Riviera to reach the Iberian peninsula instead of crossing the Adriatic and Tyrrhenian Sea. In spring, more birds are expected to risk a sea crossing in order to be on their breeding grounds as fast as possible (Schüz 1971, Zink 1973 - 1983). In spite of incomplete data from spring, our moon-watch observations seem to support this time-minimising hypothesis. Intensities of spring migration were lower in Spain and northern Italy than in autumn, but higher across the central parts of the Italian peninsula. NNE flight directions in northern Italy indicate arrivals from the sea and continuation across the Alps. On the other hand, our few spring data from the islands provide no support for increased sea crossing in spring. Some supports come from mist netting data (Pilastro *et al.* 1998), showing that many migrants alight on the islands after long sea crossings, continue across the Tyrrhenian sea and cross the Italian peninsula afterwards.

Besides time minimising, other hypotheses might be put forward to explain why migrants risk a sea crossing in spring. After the winter rains in the Mediterranean, food availability along the northern border of the African continent and in the Atlas mountains is at favourable levels (Alerstam 1990). This may allow migrants to refuel after the Sahara crossing and before departing for a sea crossing (but see Pilastro and Spina 1997, where they state that migrants arriving in Italy do not significantly fatten in north Africa). Recent observations in the western Sahara (own studies in 2003 and 2004) suggest that migration is more concentrated along the West African coast in autumn, while many migrants seem to return form the savannas on a broad front. These indications of migratory routes differing between autumn and spring support the idea of loop migration (Zink 1973, Alerstam 1990), a behaviour which is up to now not recognized as a feature occurring on a broad scale, but is known for some species, such as common quail *Coturnix coturnix* (Schifferli 1960), barn swallows *Hirundo rustica* (Schüz 1971), red-backed shrikes *Lanius collurio* (Schüz 1971) and pied flycatchers *Ficedula hypoleuca* (Curry-Lindahl 1981, Pilastro *et al.* 1998).

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