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PREDICTING REGULARITY OF BIRD MIGRATION IN GLOBAL BOTTLENECK AREAS, ON A DAILY, SEASONAL AND YEARLY SCALE, AND ITS IMPLEMENTAION IN ISRAEL AIR FORCE AND CIVILLIAN FLIGHT.

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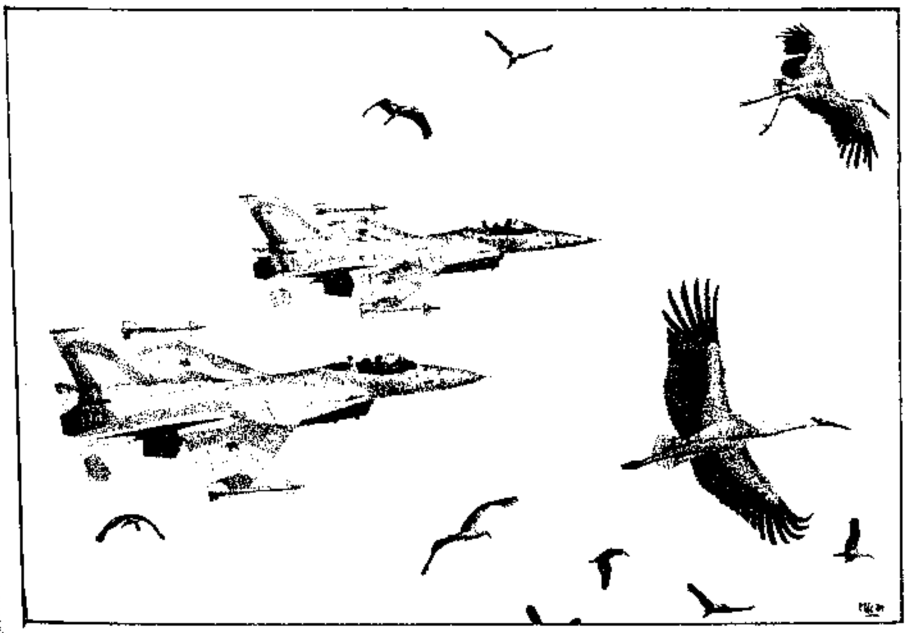
ABSTRACT

The strategic location of Israel, at the junction of three continents, makes it a "bottleneck" area into which significant portions of the world populations of soaring birds converge. This study used a combination of five different methods to gather data, with each method complementing and confirming the data from the others. The appearance times of migrating raptors and storks was found to be very precise (±3.5-±4.92 days). Variations in migration routes on a daily, seasonal and yearly scale were also found to be very regular. The results of this study have been implemented in the Israel Air Force and in the civillian flight system. Procedures for limiting flights during the migration seasons have reduced the average yearly damage to aircraft by 88% compared to the past, while permitting low altitude flights during days with light migration.



INTRODUCTION

Despite its small size, Israel is strategically located at the junction of three continents. As a result, Israel is a "bottleneck", into which all or a large part of the world populations of certain soaring species converge, during spring and autumn. The combination of its unique location and small size, facilitates studying a number of basic migration phenomena, which cannot be followed in breeding or wintering grounds. The only other similar site in the world is in Panama.

Although many migration surveys had been carried out before the early 1980's, there were still many gaps in the existing knowledge of the subject. The surveys had concentrated on a number of limited areas, using conventional optical equipment, so that only a fraction of migration was covered on a horizontal and vertical section. There was no systematic reference to the subject of climatic conditions and their influence on migration.

The concentration of an extremely large mass of soaring birds in the limited air space over Israel, creates a severe flight safety problem for Israel Air Force aircraft and their pilots. The analysis of damage caused by birds between 1972-1983 showed that hundreds of accidents had occurred. Many of these were serious (damage exceeding 1/2 million dollars), several aircraft crashed and one pilot was killed. 74% of the accidents occurred during migration months. Total losses reached tens of millions of dollars.

The objective of this study was to examine if any yearly or seasonal regularity exists in the numbers of birds passing over, times of passage and length of passage time over Israel. The possibility of regularity in daily and seasonal migration routes and altitudes was also checked as well as migration velocity. The influence of various climatic and biological factors on this system was studied. All this in order to examine the possibility of predicting changes and applying the conclusions of the study in the Israel Air Force, in order to avoid injury to pilots and save large amounts of money for the national security budget.

METHODS

Five different data gathering methods were used for this research:

1. **Ground Observer Network** - Dozens of studies have tracked migration with small numbers of observers at 2–3 key observation points. In this study, for the first time ever, ground observers were placed along a **broad front**: 25 observation points were placed across the country, along 75 kilometers, during several migration seasons. More than 150 experienced birdwatchers logged about 224,000 observation hours.

2. **Light Aircraft Tracking** – This method proved excellent for locating principal migration routes, their altitudes and counting flocks per time and distance units, and very efficient on "peak" migration days. Additional flights were carried out to confirm the radar distinctiom ability (see method 5). Twenty-nine flights totalling 83:40 hours were carried out.

3. **Motorised Glider** – This method enabled continous flying, up to 11.5 hours, with the same flock, as well as exact mapping of the migration route, altitude, flock progress rate, climbing and gliding in thermals. One hundred and seventy–three flights totalling about 720 hours were carried out. This was the first time motorised glider migration tracking was used in the Middle East. No study using a motorised glider to systematically follow migrating flocks for such long periods of time had been done up to now, both in the number of flight hours and the number of tracking days.

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4. **Unmanned Aircraft (Drones)** - This method enabled tracking single flocks for about 150 kilometers with constant documentation of the flock by video camera. Nineteen flights were carried out. To the best of our knowledge, this is the first biological study ever to make use of this military instrument for research.

5. **Radar** – A radar screen at the Ben-Gurion International Airport surveillance radar was permanently available during the migration seasons. This enabled constant tracking during all hours of the day. The cloud radar of the Shaham Company followed migration regularly only during one season. Its use was terminated due to technical problems. A total of 8125 radar tracking hours were carried out. This is the first time radar was used to follow soaring bird migration in the Middle East in general, and in Israel specifically.

Most migration tracking research has been limited to one method, and only a minority combined two methods simultaneously, such as a combination of radar and ground observers (Evans & Lathbury, 1973) or light aircraft and radar (Pennycuick, Alerstam & Larsson, 1979). In our study, we have developed, for the first time, to the best of our knowledge, research based on a **combination of five methods** for data gathering from one migration system, with each method complementing, at least partially, the deficiencies of one of the others. At the same time this enabled confirmation of data gathered by one method by one of the other methods. The development of several paraliell research methods allowed for integration between the various methods. The radar could, for example, take over from the motorised glider for a short period of time, to enable refuelling and rest; it could then direct the glider to the exact position of the flock it had left to continue tracking.

The statistical analysis in this research is based on 9 autumn migration seasons for raptors and 4 for storks and pelicans. During spring migration raptors were followed in Eilat for 6 years and storks for 4 in the western Negev.

RESULTS

Comparison of our results to data in the relevant literature, proves, that the data for species whose total population or most of it passes through "bottleneck" areas, provides relatively reliable estimates of **minimal population size**. The numbers counted during migration are sometimes higher by an **order of magnitude** than data from existing studies (Leshem,1991).

In order to examine long-term regularity in major migrating species appearance, the weighted average day of arrival was calculated for all the years of the study, as well as the date by which half of the population had passed by over Israel, the average peak day and the average arrival percentage for each species on the peak day. The results show that it is possible to predict the appearance days of various raptor species with a precision of ±1.35 to ±3.12 days in autumn and ±1.92 to ±4.92 days in spring ($P<0.001$). The arrival of storks can be predicted with a precisi on of ±3.78 days in autumn and ±5.46 days in spring. The rest of the data examined was found to be statistically significant, but for some the time span was broader. The conclusion reached was that it is possible to predict appearance times of the various species.

Comparison of arrival percentages on the peak day for a number of raptor species shows, that the passage percentages in autumn for flocking species are greater than for non-flocking species (17.1%-30.1% and 9.0%–15.6% respectively). In spring, the difference between flocking and non–flocking species is even greater: 27.7%–46.0% and 8.3%–12.0% respectively. Intra-specific comparison shows, that for many of the species the arrival percentage on the peak day is higher in spring than in autumn. This is probably the adult population, hurrying to return to its breeding grounds in spring, therefore moving in more concentrated waves. Thus an inverse relation between the arrival percentage on the peak day and age of sexual maturity is found: 46% of the the Levant Sparrowhawk, population, which reaches sexual maturity in its first year, passes over during the peak day compared to 17.7% of the Steppe Eagle population, which reaches sexual maturity at age 5. In non-flocking species the situation is similar, although in less concentrated waves.

The regularity of passage time period length was examined for each of the species migrating over Israel. Analysis of the data shows, that those species flying over in large numbers tend to flock and pass over during the shortest time periods. Thus, 90% of the populations of the five species which flock in autumn, pass over during 13-20 days, compared to five non–flocking species which pass over during 24–35 days. The only exception to this rule is the White Pelican (Pelecanus onocrotalus), whose passage time period is long (114 days in autumn), despite it being a true flocker. The reason seems to be that this species flocks during the breeding season as well, populating very broad breeding grounds (between 22–85 longitude), with each breeding colony reaching its nesting sites as independent units. Accordingly, we find, that this is the only flocking species that has no peak days on which more than 10% of the population fly over, and whose weighted average day of arrival is the least statistically significant of all flocking species (12.39 days).

Despite all the above, in non-flocking species, which have a longer passage time period, the weighted average arrival day is very exact, within a span of 1.8 to 2.85 days only, in the 4 non-flocking species analysed in this study (Booted Eagle Hieraeetus pennatus, Short–toed Eagle Circaetus gallicus, Egyptian Vulture Neophron percnopterus and Marsh Harrier Circus aeruginosus). These four species also arrive with a high time overlap in autumn and spring, and there is a possibility that what we see here is inter–specific flocking of non–flocking species (they were also observed migrating in common thermals).
The spring migration wave is longer than the autumn one in most birds of prey and storks. In many of the species passage time in spring is almost double that in autumn.

Flocking and non–flocking species passing over Israel were compared according to their wintering grounds and type of food. The data shows, that all nine flocking species overflying Israel, migrate south of the Sahara and some of them reach South Africa. They feed at least partially on exothermic prey. Three of the 4 non–flocking species which are commoner: Booted Eagle, Egyptian Vulture and Short–toed Eagle also feed on heterothermic prey and migrate south of the Sahara. Only the Marsh Harrier is an "intermediary species", wintering both north and south of the Sahara, and feeding accordingly on birds and mammals. A number of species feeding on endothermic prey do not flock, and accordingly do not migrate south of the Sahara. This phenomenon is parallelled in New World raptors (Mindell, 1985).

Comparison of the weighted arrival day of different species according to their chronological order of appearance in autumn, shows distinct regularity in the order of arrival according to the type of prey they feed on – from insect eaters to reptiles, fish and finally mammal eaters. **During spring migration the picture is reversed**, and the first to pass are those feeding on endothermic prey and the last the insect eaters. This phenomenon shows the close relation and dependence between migration times and the availability of prey, whose activity varies with changes in weather, with exotherms disappearing first in autumn and returning first in spring.

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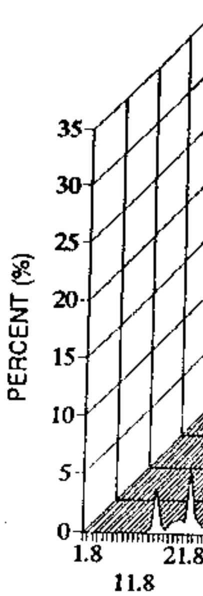


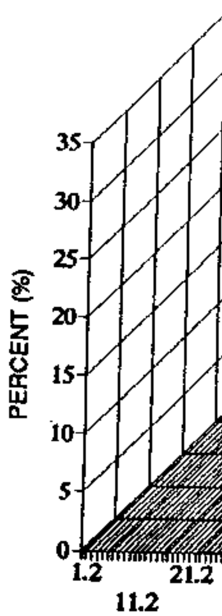
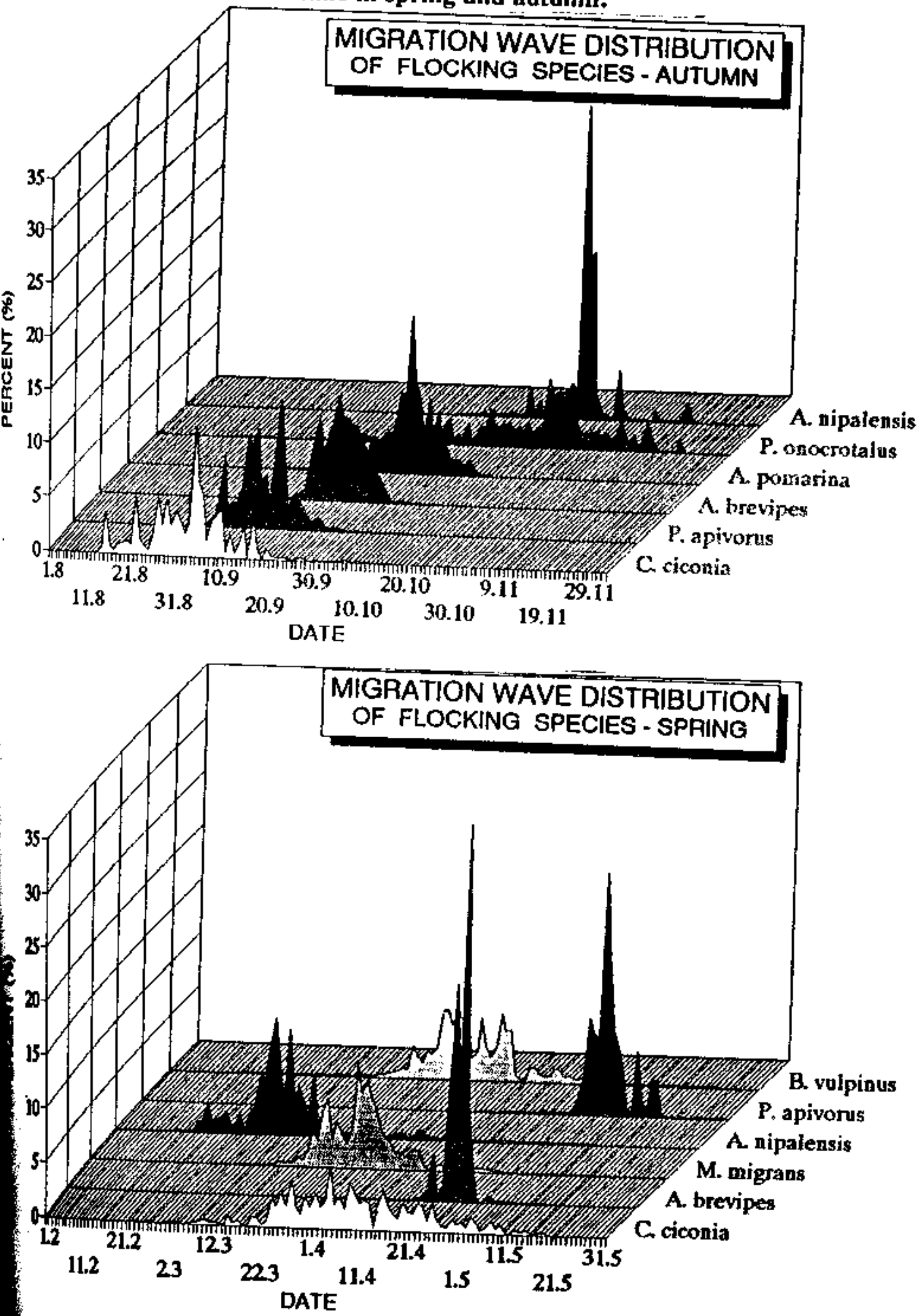
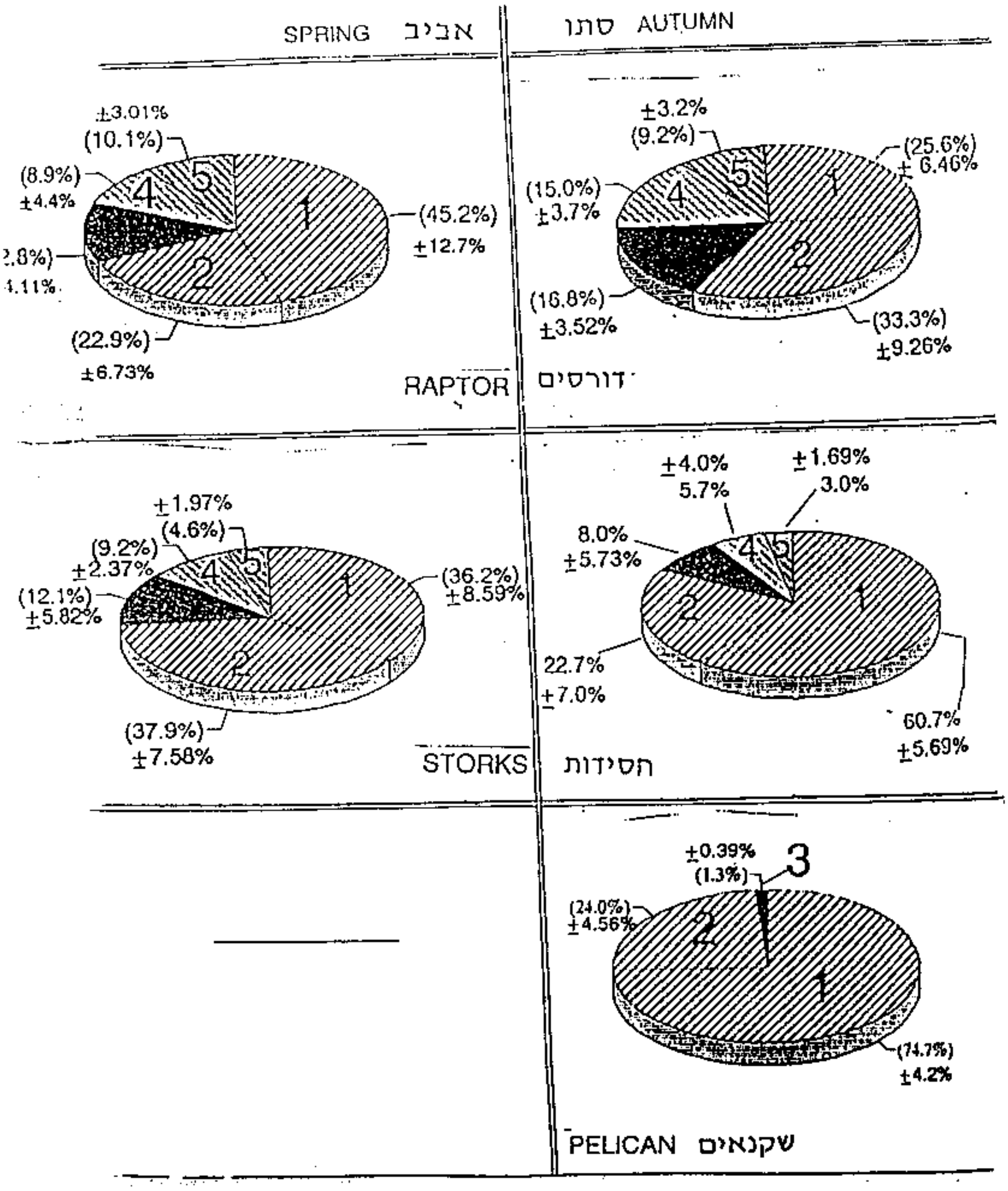


Fig. 1: Percentage of the total population of each flocking species passing over each day. This figure provides a total picture of flocking species distribution in time in spring and autumn.



Five degrees of magnitude were determined to describe the intensity of daily migration: 1 - 0-1000 birds per day, 2 - 1000-5,000, 3 - 5,000-10,000, 4 - 10,000-20,000 and 5 - 20,000-200,000.

<u>Fig. 2</u>: Mean migration magnitude per day in autumn and spring



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Examination of daily raptor migration magnitude during autumn and spring shows (fig. 2), that only in 19% and 24% of the days respectively is there high magnitude migration (10,000–200,000 birds per day), in 12.1% and 16.8% of the days medium magnitude migration (5,000–10,000 birds per day) and in 58.9% and 68.1% of the days migration is sparse (0–5,000 birds per day). Storks show less days with peak magnitude than raptors (13.7% and 13.8%), and pelicans have no days with heavy migration.

The distribution of daily migration magnitude is important biologically to differentiate between the migration patterns of different bird groups (pelicans, storks and raptors). No less important is its significance in the applications of the conclusions of this study by the Israel Air Force. BPZ (Bird Plagued Zone) regulations, which prevent fighter aircraft flying at low altitudes during the migration seasons, have been formulated as a result of this study The migration magnitude distribution shows that low altitude flights are possible during the migration seasons on days when the magnitude is 1, or with a calculated risk, on magnitude 2 days. The data presented shows, that in autumn fighter aircraft can fly at low altitudes 25.4%–58.9% of the time and in spring 42.5%–68.1% of the time. Since soaring bird migration occurs during 6 to 7 months a year, this information is of great operational importance for the IAF.

Migration axis movements on a daily scale

Based on data from the ground observer network, the motorised glider and radar photo sequences from the Ben–Gurion International Airport surveillance radar, it may be seen that the migration axis which passes west of the mountains and parallell to the Mediterranean coast in autumn is deflected at the beginning of the day from east to west for 10–25 kilometers, depending on weather conditions and flock roost locations. Towards 10:00–11:00 the daily breeze blowing from the sea influences the migration axis, which is slowly deflected back to the east. The west–east drift is greater in the data of the Northern Valleys Survey and shorter in the Cross–Samaria Survey due to variations in topography.

In the Eilat Mountains wind flow plays a similar role, but due to the topography of the southern Arava Valley, which causes a change in wind direction, the axis moves during the day in a north- south direction.

Fig. 3: Photo sequence (1-6) - West-east daily fluctuations in Lesser Spotted Eagle (Aquila pomarina) autumn migration as seen on the Ben-Gurion radar (27.9.88).

Photo 1: 09:13 - Lesser Spotted Eagles after leaving roost, 14 km east of the coast.

Photo 2: 10:50 - The Lesser Spotted Eagles on a western axis, 8.5 km east of the coast.

Photo 3: 11:35 - The Lesser Spotted Eagles drift 13 km east of the coastline.

Photo 4: 12:06 - The Le Spotted Eagles 19.3 km east o coastline.

Photo 5: 13:34 - The Spotted Eagl 20.4 km east coastline.

Photo 6: 14:13 - The Spotted Eagl 23.3 km east coastline.

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Photo 4: 12:06 - The Lesser Spotted Eagles drift 19.3 km east of the coastline.

Photo 5: 13:34 - The Lesser Spotted Eagles drift 20.4 km east of the coastline.

Photo 6: 14:13 - The Lesser Spotted Eagles drift 23.3 km east of the coastline.

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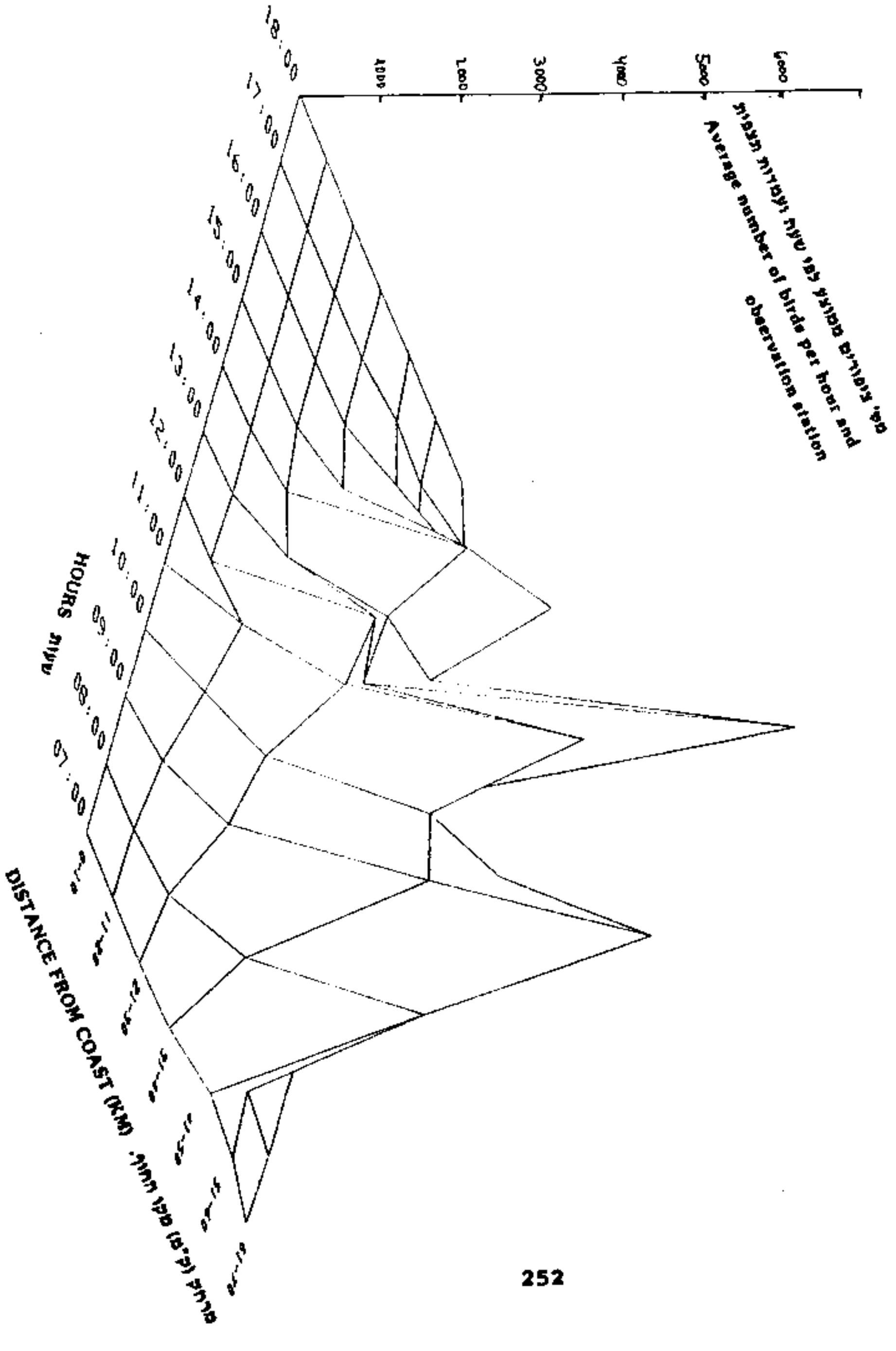
Fig. 4: Honey Buzzard (Pernis apivorus)"isobars" along the Northern Valleys axis in autumn.

This is a three-dimensional illustration portraying the daily average of 29 observation days in which a large number of Honey Buzzards passed over during three survey years (1988–1990).

Z–axis – number of birds

Y–axis – distance from the coast

X–axis – hours of the day



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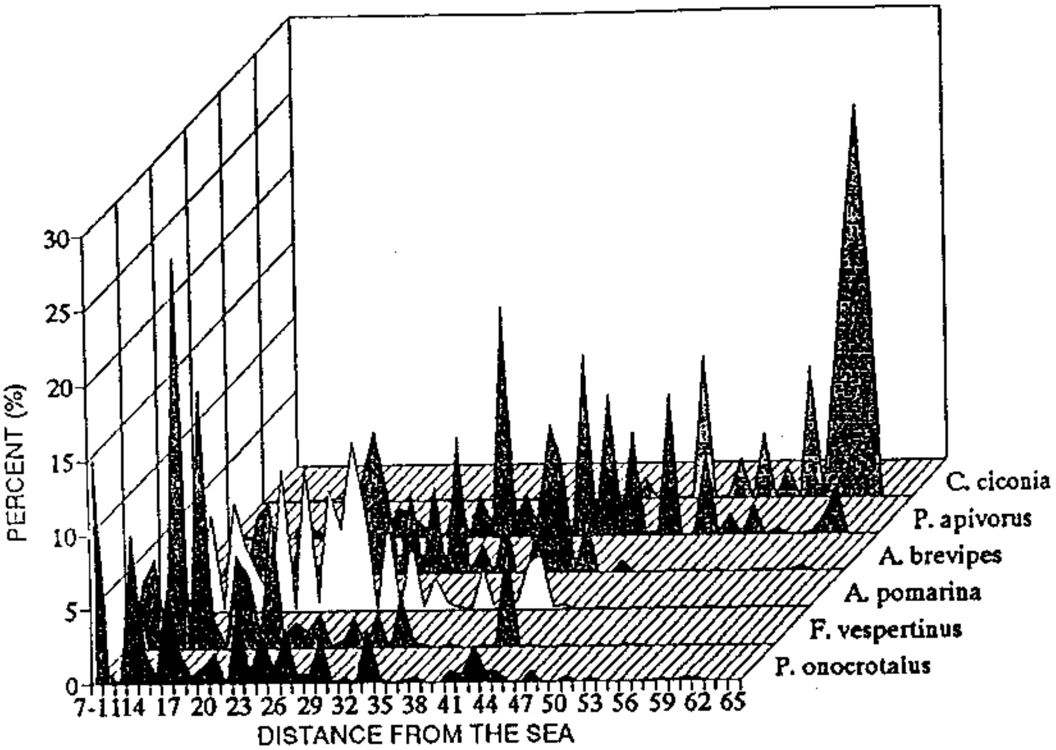
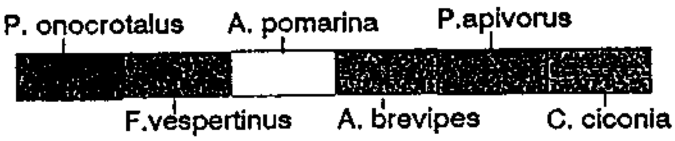
Migration axis movements on a seasonal scale
In the Northern Valleys survey seasonal variations in the horizontal migration axis are very obvious. Between 1987–1990 data on stork and pelican passage was also gathered during the whole autumn migration season. Fig. 5 illustrates the distribution of six flocking species arrival times as a function of distance from the coast. Below, the data for 90% passage and average peak day for each species appears.

The data clearly shows an inverse relation between arrival time of flocking species and average distance from the coast. Storks, the first to appear, migrate along the most easterly axis. As the arrival date becomes later, the axis drifts west towards the coastline. Pelicans, the last to appear, migrate along the most westerly axis. Glider data shows, that pelicans, along the Kfar Kassem – cross-Samaria line, and further south in the Gaza area, concentrate almost completely in the west, at ranges of 5–10 km from the coast.

Fig 5: Seasonal variations in the horizontal migration axis for six species – Northern Valleys autumn migration survey.





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7/11-18/9	13/10-25/9	5/10-21/9	26/9-14/9	14/9-30/8	12/9-16/8	תאריכי מעבר 90% מהאוכלוסייה (Appearance 90% population)
26/10	3/10	1/10	21/9	7/9	21/8	יום שיא ממוצע (Mean peak day)

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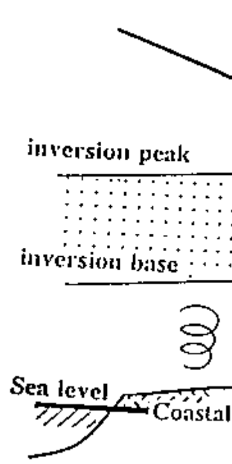
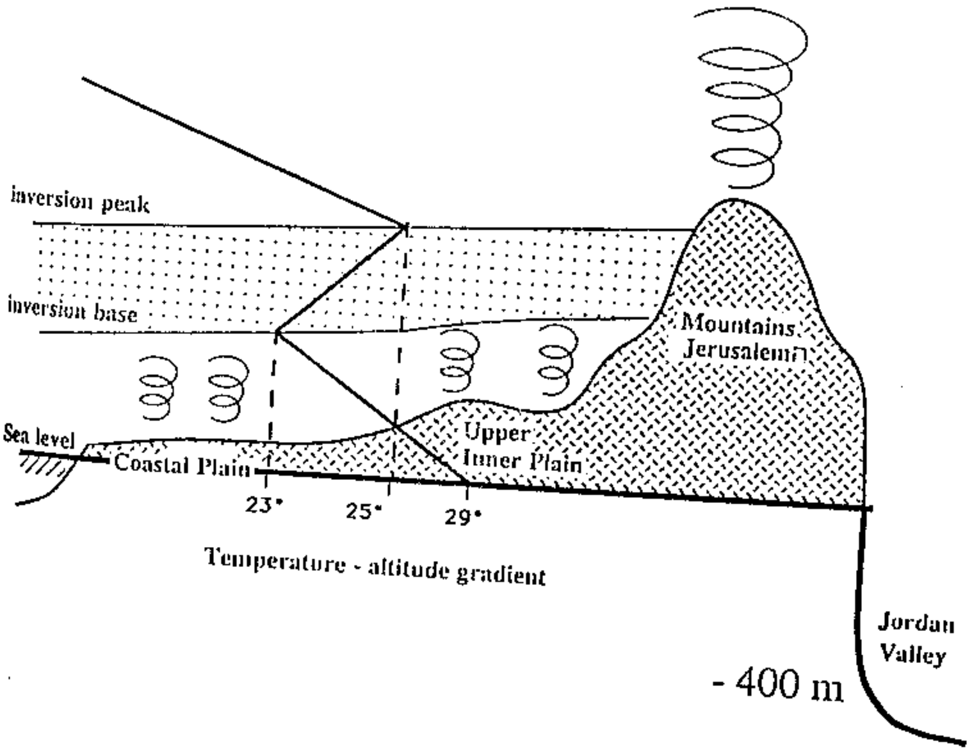


Fig. 5 portrays movements of the migration axis during the season, which starts in August in the east (storks) and eventually moves principally to the western part of the country (Lesser Spotted Eagles, Red-footed Falcons and Pelicans). Climate plays a major role in determining seasonal fluctuations:

In summer, the weather is dominated by a sub-tropical high, which prevails along the entire African coast up to our area (a regional barometric high), combining with the Persian trough in its southern part. The hot, dry air which comes from the Persian Gulf, cools off when it reaches the Mediterranean and absorbs moisture. The cool sea air creates and inversion in the temperature-altitude gradient - the marine inversion.

This inversion creates a stable layer, in which the temperature increases with altitude instead of decreasing (1C for each 150 m.). As a result good conditions for thermals develop, and as can be seen in fig. 6, the eastern area is the most appropriate for migration, and therefore all migration in August converges in the east.

Fig. 6: Scheme of the inversion on a west-east section (noon - August) The thick' diagonal line represents the temperature-altitude gradient.



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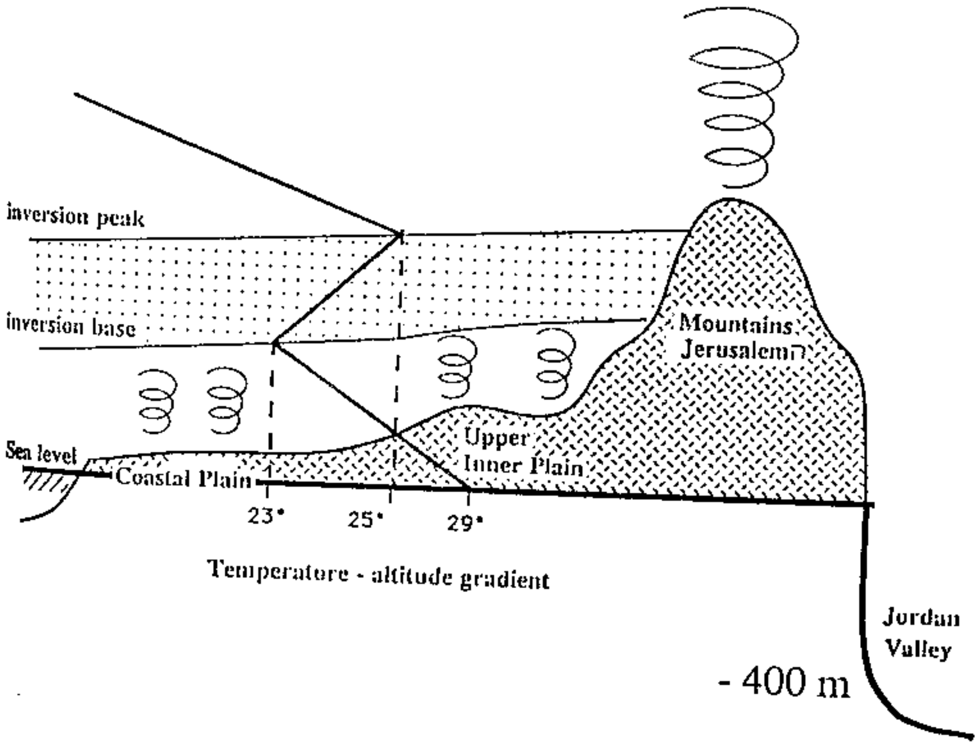
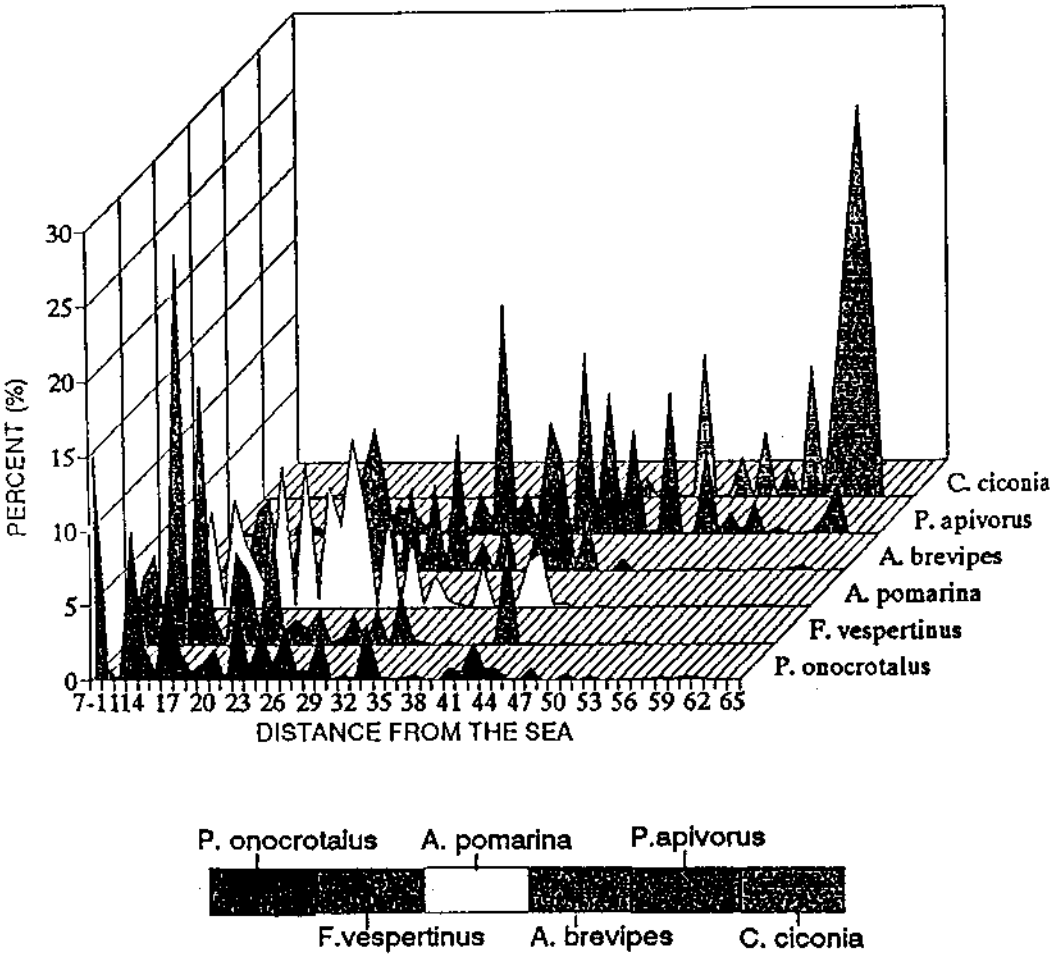


Fig 5: Seasonal variations in the horizontal migration axis for six species – Northern Valleys autumn migration survey.



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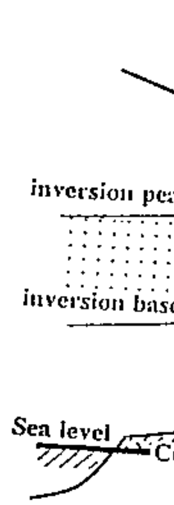

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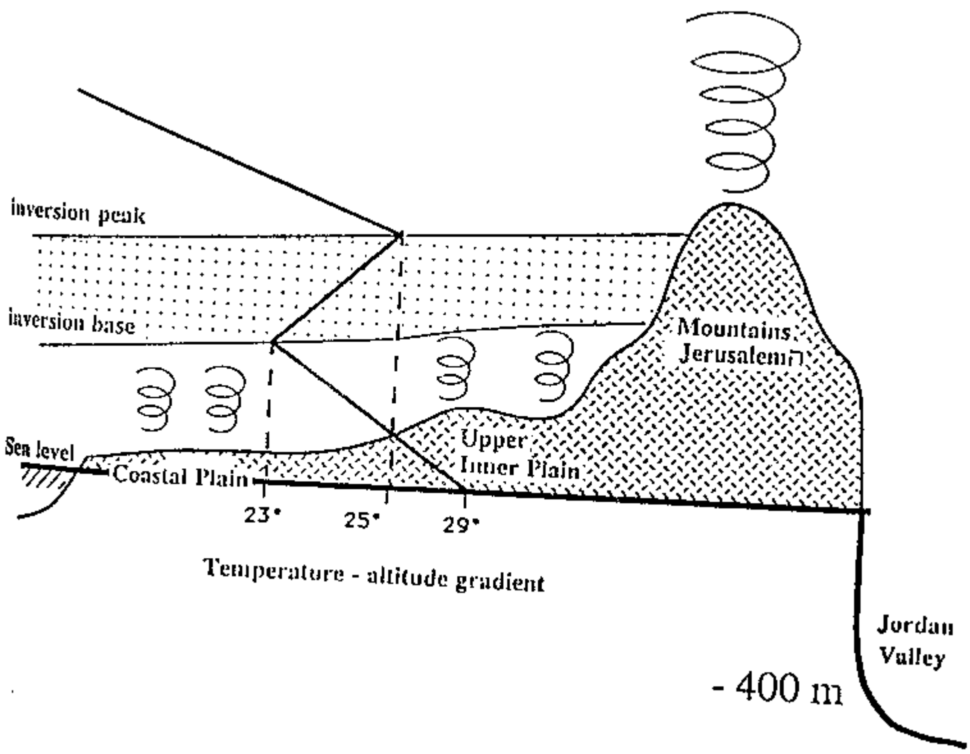
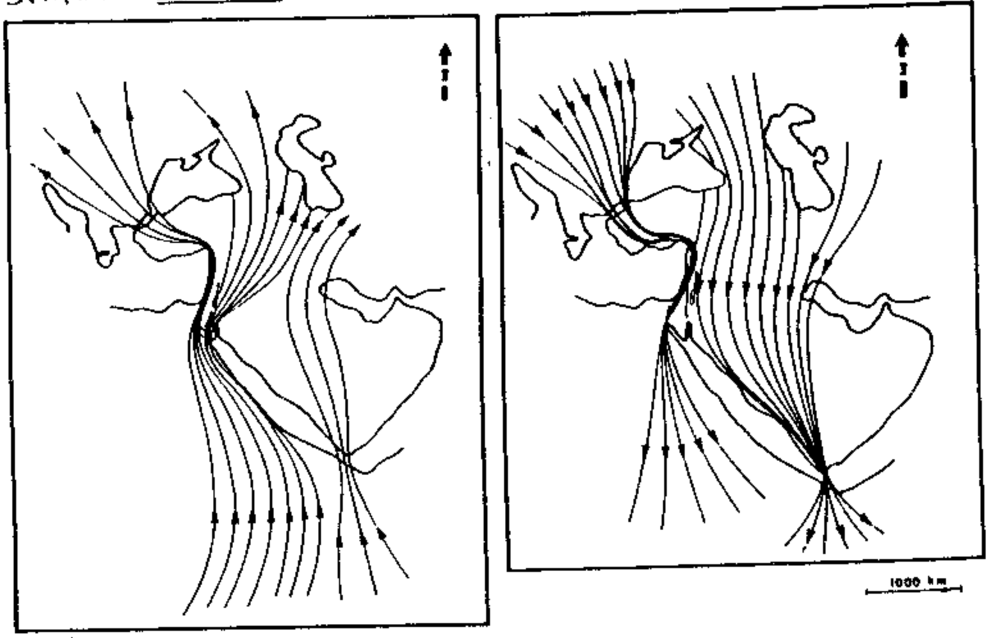


In September the Persian trough gradually recedes, replaced by the Red Sea trough which comes from the south. Temperature differences between sea and land decrease, the inversion influence gradually diminishes, disappearing completely in October. At the same time the migration axis moves from east to west. About half of the stork population which returns north in spring during March and April, when summer weather conditions are still absent, and no inversions exists, migrates accordingly along the western axis over the western slopes of the mountains (unlike in autumn when storks are absent).

Variations in migration magnitude between spring and autumn on a global scale
There are significant differences in the migration magnitudes of the various soaring bird species over Israel in autumn and spring. For example: only one species, the Steppe Eagle (Aquila nipalensis) flies over the Eilat Mountains in autumn, compared to massive migration of more than 30 species in spring; in autumn White Storks (Ciconia ciconia) pass over only along the Jordan Valley axis, whereas in spring about half the population also passes over the western edge of the central mountain range; Honey Buzzards fly along the Western Route in large numbers in autumn, while concentrating almost totally in the Eilat Mountains in spring, and so forth. The reason for the variation in different species appearance is related to their global migration routes, between breeding and wintering grounds, in relation to the Red Sea which they avoid crossing, thus following different routes in autumn and spring (fig.7). The breeding grounds range of different species in relation to the location of Israel (35 longitude) is an additional factor determining different migration routes over Israel in spring and autumn.

Fig. 7: Migration flow scheme in spring and autumn (Yom Tov' 1988)



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MPLEMENTATION OF THE STUDY RESULTS IN THE ISRAEL AIR FORCE AND CIVILLIAN FLIGHT SYSTEM

a. Study of **variations in daily migration magnitude** made it possible to develop a real-time warning system based on the ground observer network and the radars at Ben-Gurion International Airport. On evenings when light migration was observed, low altitude flights were approved even at the height of the migration season. If, at any time, heavy migration was spotted by the observers or radar, low altitude flights were immediately cancelled, and pilots returned to BPZ regulations in effect during the migration season. This procedure permitted about 35% of low altitude training flights to take place during the height of the season.

b. The **preciseness of migration wave arrival times** allowed prediction of arrival and departure times of flocks in advance, as well as preparation according to organised flight procedures in the IAF and civillian flight.

c. **Migration axis movements** were known in advance as a result of this study, making it possible to open and close flight areas accordingly during the migration seasons. The regularity in daily axis movements permitted real-time warnings to IAF base control towers and other elements.

This is the seventh year BPZ regulations during migration seasons have been in effect. The number of bird-aircraft collisions has been reduced by 81.8% compared to the period before these regulations, and average annual damage has declined by 88%.

The following account proved to be an excellent test case for examining the efficiency of the various systems developed in this study:

a. On 5.9.91 a giant flock of White Storks (47,000) passed over Israel. The flock was located at 10:40 by one of the ground observer teams west of Bet She'an in the Jordan Valley. Between 10:40-10:50 the first mass of 9,000 storks passed over, followed immediately by a second mass of 38,000, between 10:51–11:20.

b. The team co-ordinator (James Smith from England) immediately informed the survey head (Dan Alon) via the portable military radio transmitter, who then called the Bird Center at the Ben-Gurion radar on the car phone.

c. The controller at Ben-Gurion immediately changed to a 60 mile scale, instead of the usual 30, rating the stork mass. He then reported its exact position to the Israel Air Force and continued systematically tracking the flock along the eastern axis (west of the Jordan Valley) up to the central Negev.

d. At the same time the control unit of the IAF located the flock because of its size, and commenced transmitting constant warnings to aircraft. while continuing to follow the flock for 6 hours, until 17:00. The tracking was documented on video, until the flock disappeared in the vicinity of Jabel Ya'alek in central Sinai, where it probably landed to roost.

By using the data from this study from which we knew that storks usually take off in the morning at about 8:00, and that their flight velocity in the first two hours is slower than during the rest of the day, we calculated that the storks had covered about 75 kilometers until the moment of discovery. This would agree with a roost in the Hula Valley, which is known to be a preferred spot, the night before. From the moment the flock was located until it disappeared from the IAF radar screen near Jabel Ya'alek, the storks covered a distance of 310 km. This would bring the total distance covered in continuous migration during one day to 385 km.

The continuous tracking with a combination of two radars and ground observers confirms the conclusions of this study and provided reliable real-time warnings to IAF aircraft along most of the country.

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