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Turtle Dove Spatial Patterns: habitats and migrations

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1. Introduction

1.1. About turtle doves' migration in general and in Cyprus

The European turtle dove (*Streptopelia turtur*) is a long-distance, trans-Saharan migratory species that breeds across much of Europe and winters primarily in the Sahel region of sub-Saharan Africa. Studies using geolocators and satellite telemetry have identified three main migratory flyways used by the species: a western route through Iberia and Morocco, a central route via Italy and Tunisia, and an eastern route passing through the Balkans and the eastern Mediterranean (Marx, Körner-Nievergelt & Quillfeldt, 2016). Turtle doves winter mainly in the western Sahel and the Mali–Niger Inner Delta, where they rely on post-harvest seed availability and water sources (Eraud *et al.*, 2013).

Tracking data showed a migration movement, whereby birds return to Europe in spring on a different route than that used in autumn (Eraud *et al.,* 2013; Lormée *et al.,* 2016). Most migratory movements occur at night, and typically use multiple stopover sites for refueling before crossing ecological barriers such as the Sahara and the Mediterranean (Lormée *et al.,* 2016; Barboutis *et al.,* 2023). Arrival to European breeding areas happens between April and May, while departure toward African wintering grounds begins in September (Marx et al., 2016).

Cyprus is located along the eastern flyway and plays an important role as a stepping-stone stopover site for birds migrating between Europe and Africa (Roth, 2008;). Cyprus also holds a small local breeding population that stays on the island year-round, mainly in agricultural mosaics and open woodland habitats. During autumn migration, many turtle doves pass through Cyprus on the way to their wintering sites in Africa.

The island is also notable for its regulated hunting season, which targets turtle doves during their post-breeding migration. The hunting period lasts 15 days from early September, typically coinciding with the species' southbound passage. Hunting is permitted on Wednesdays and Sundays in designated zones, with a much more restricted set of areas available during other weekdays. Each licensed hunter is allowed to harvest up to six birds per day and a maximum of twelve birds for the entire season. Furthermore, hunters are legally required to record their harvests through the Artemis mobile application, while the national hunting quota is capped at 13,500 individuals or until the 15-day period concludes (Game and Fauna Service, 2024).

During the European Turtle Dove International Action Plan conference, Cyprus was urged to impose a complete hunting ban in line with the conservation measures adopted by other European Union member states. However, citing long-standing cultural traditions associated with turtle dove hunting, Cyprus opted not to implement a full prohibition. Instead, the Cypriot authorities pledged to enforce stricter regulations and to initiate systematic population monitoring using GSM-based tracking tags to collect data on migratory behavior and hunting impact. This compromise was accepted within the framework of the action plan as a transitional step toward adaptive management and evidence-based conservation (European Commission, 2018; Game and Fauna Service, 2024).

Overall, the available evidence showcases Cyprus's dual importance as both a breeding site and a key migratory stopover for the European turtle dove. However, the overlap between migration and hunting activity, coupled with its unique exemption under the action plan, continues to raise conservation concerns given the species' ongoing population decline across Europe (Eraud *et al.,* 2013; Marx *et al.,* 2016).

1.2. Limitations, biases, and gaps in what we know about Turtle-dove migration

Most of the studies carried out so far on turtle doves are from ringing data, which are flawed. The samples are very small, and most birds are never recovered. These data often yield biased results, as not all countries have equally extensive ringing and reporting systems, and some do not report their findings at all (Marx *et al.* 2016). Additionally, most capturing takes place in terrains with ideal conditions for trapping, making it extremely likely that birds from more difficult areas experience different migration routes and behavior based on their resources. Moreover, other studies rely on birdwatching surveys, which have multiple limitations (same birds counted twice, human error, birds migrating at night, and uncertainty about where the birds come from). Lastly, many countries, especially in Africa and the Middle East, are not cooperating with the European turtle dove policy.

Even though recent technological developments have improved our understanding of turtle dove behavior and migration, notable limitations, biases, and knowledge gaps are still present. Currently, most studies and data collection have been based on ringing recoveries, a method known to produce misleading results, very low return rates, and geographic inconsistencies (Marx *et al.* 2016; Schumm *et al.* 2021). Most of the birds that are ringed are never recovered. This is largely due to a lack of cooperation with neighboring countries, less developed ringing systems in those countries, and the fact that for a bird to be recovered, it almost certainly needs to be shot by hunters (Marx *et al.* 2016). As a result, the data overrepresent countries with strong monitoring infrastructure while underrepresenting large portions of the species' range.

Capture bias is also a major issue that negatively influences the validity of the results, as most ringing or tagging efforts are made in areas where trapping has a high probability of success — typically in agricultural and semi-open landscapes with high bird densities. This selective sampling can distort the actual activity of the population as a whole and its migratory strategies, as individuals or smaller groups that inhabit more remote or ecologically distinct terrain, where trapping is more difficult, may follow different patterns.

Additionally, other methods of data collection, such as birdwatching surveys or citizen science programs, have severe limitations, including observer error, duplicate sightings, inability to detect nocturnal migration, and the fact that it is usually not feasible to determine the geographic origin of such birds through these methods Gregory, Gibbons & Donald (2004). Thus, it is impossible to reconstruct an accurate migratory path.

Lastly, data gaps are evident in key regions of the species' distribution and migratory range, mainly across North Africa and the Middle East. These regions lack coordinated monitoring programs and do not have a consistent method or cooperation with international or European policies EU ISSAP (European Commission, 2018). This inconsistency limits the ability to get a complete image of migratory pathways and to assess population threats accurately throughout the full annual cycle. Tackling these regional gaps and biases is essential for improving our understanding and putting better conservation measures in place for this declining migratory species.

1.3. How can new technologies help to get a better picture?

Advancements in technology can help improve our understanding of turtle dove behavior and migration (Kays *et al.,* 2015; Nathan *et al.,* 2022). These technologies help enhance spatial precision and temporal resolution, and unlock the ability to track movements overnight (Kays et al., 2015).

Tiny GPS/GSM devices now have accelerometers and magnetometers, which help uncover the finest details of birds' movements, as well as their orientation (Kays *et al.,* 2015).

Moreover, automated radio telemetry networks such as Motus and ATLAS provide a cheaper alternative in the long run (Taylor *et al.,* 2017; Beardsworth *et al.,* 2022). These systems rely on networks of stationary receivers (towers) that detect tagged individuals passing within range; even though they have limitations—such as a high initial cost for building the towers, ongoing maintenance costs, birds moving to areas/countries with no towers, and providing much less data than GPS/GSM systems—the low price of each tag makes it more affordable to track a larger portion of the population than with GPS/GSM when you are on a budget (Taylor *et al.,* 2017; Beardsworth *et al.,* 2022).

Furthermore, even more cheaply and without the need for new expensive equipment, weather radar can detect nocturnal migration or large movements of birds by filtering insects and rain out of the sky (Nilsson *et al.,* 2019). This method, of course, is not species-specific, but it can help scientists detect when and where migrations take place, which can help them find more birds to track, as well as compare the data with previous years (Nilsson *et al.,* 2019).

Lastly, bioacoustic monitoring using autonomous recording units (ARUs) records vocalizations of different birds, which can then be processed through machine-learning classifiers such as BirdNET to sort the recordings by species; validity and accuracy can be checked by listening to samples and estimating error rates (Shonfield and Bayne, 2017; Kahl *et al.,* 2021)

Together, these advancements in technology can provide a more comprehensive, multi-scale perspective on the ecology of turtle doves, as well as other migratory birds (Kays *et al.,* 2015; Nathan *et al.,* 2022; Dokter *et al.,* 2019).

1.4. The focus and aim of this study

Despite the recent advancements in tracking technologies, fine-scale information on the behavior, stopover sites, and migration of the turtle dove are still limited, especially in the eastern flyway. This study focuses on turtle doves migrating through Cyprus using GPS/GSM trackers on six birds. Spatial and temporal migration patterns, stopover durations, and habitat use were analyzed. The objective was to identify stopover areas as well as the duration, timing, and their land-cover composition, and establish the true migratory routes and their variability. By addressing these gaps, this research provides new insights into turtle dove migration ecology and supports evidence-based conservation for this declining species.

2. Literature review

2.1 About turtle doves in general

The turtle doveis a long-distance, trans-Saharan migratory species. It breeds across most of Europe and winters mainly in the Sahel region of sub-Saharan Africa (Marx, Körner-Nievergelt & Quillfeldt, 2016; Eraud *et al.,* 2013). It inhabits a mixed landscape consisting of open farmland, hedgerows, and woodland, it feeds mainly on seeds from wild and cultivated plants (Browne & Aebischer, 2003). Nowadays Turtle dove populations have been declining due to many challenging factors and pressures including agricultural intensification, loss of habitat/urbanization, over-hunted on migratory routes (Browne & Aebischer, 2003; BirdLife International, 2021). In addition, changes in rainfall patterns in their wintering grounds have reduced seed availability which increase mortality during migration as the birds find it more difficult to be fully conditioned. (Eraud *et al.,* 2009). These factors combined resulted on the species being now listed as vulnerable in the IUCN red list (BirdLife International, 2021).

2.2 About the Species migration

Studies using geolocators and satellite telemetry showed that the turtle dove uses three main flyways. The western flyway from Iberia and Morocco, the Central flyway through Italy and Tunisia and the eastern flyway through the Balkans and the Mediterranean (Marx, Körner-Nievergelt & Quillfeldt, 2016). Tracking data showed a pattern where birds use a different route in autumn than inn spring (Eraud *et al.,* 2013; Lormée *et al.,* 2016). Most migration occurs nocturnally and multiple stopover sites are used by the turtle doves before crossing major ecological barriers such as the Mediterranean and the Sahara (Lormée *et al.,* 2016; Barboutis *et al.,* 2023). These stopovers are essential for refueling and the duration the birds spend varies depending on weather conditions, resources available and the conditioning of individual birds (Eraud *et al.,* 2013).

Until recently, most information we had on migration patterns came from ringing recoveries, this provides very limited spatially accurate results and have very low return rates (Schumm *et al.,* 2021). Modern GPS/GSM tracking and automated telemetry networks have vastly improved temporal and spatial precision allowing for researches to study fine scale movements, migration with much higher accuracy and stopover locations and behavior.

2.3 About the species' status in Cyprus

Overall, most migration studies from Cyprus (e.g., Roth, 2008) showcase the island's importance as a flyway for many different species of birds, while turtle-dove–specific management is set out in policy and national reports (European Commission, 2018; Game and Fauna Service, 2024). Cyprus also serves as a stepping-stone stopover site for turtle doves migrating between Europe and Africa additionally it holds a small local breeding population, mainly in agricultural mosaics and open woodlands (Game and Fauna Service, 2024).

following the European Turtle Dove International Action Plan conservation has intensified (European Commission, 2018). While most member states have implemented a temporary ban for hunting turtle dove, Cyprus has embraced a different method aimed to help the conservation effort but also protect the traditional hunting of the turtle dove in the island. This approach is a short and highly regulated hunting season. Hunting is restricted to a few coastal areas for 15 days in early September, with bag limits of 6 birds a day and 12 a season per hunter and caps at 3500 birds nationally in addition there is mandatory harvest reporting through the Artemis CY mobile application (Game and Fauna Service, 2024). Cyprus has also established a GSM-monitoring program to collect data on migratory behavior and population dynamics.

2.4 Other studies on the species and similar migratory birds

In western Europe, studies have assessed migration patterns through ringing, geolocators and GPS, unveiling established routes across Iberia and Morocco and showcasing the significance of the western Sahel for wintering (Marx *et al.,* 2016; Eraud *et al.,* 2013). While studies in Italy and Tunisia concentrated on the central flyway which exhibited shorter migration distances and earlier arrival times compared to the eastern routes (Lormée *et al.,* 2016). In the Balkans and Greece recent telemetry work by Barboutis *et al. (2023)* established new information in stopover timing and behavior of turtle doves before crossing the Mediterranean and the Sahara. Studies using automated telemetry with networks like Motus and ATLAS have successfully tracked similar migratory bird species and provided detailed data on flight timing and stopover durations (Taylor *et al.,* 2017; Beardsworth *et al.,* 2022). These systems show the potential for cost effective monitoring for turtle doves as well as other migrants. Additionally, weather radar and bioacoustic monitoring have been used to detect nocturnal migration and quantify passage intensity for passerines and nightjars (Dokter *et al.,* 2019; Nilsson *et al.,* 2019; Shonfield & Bayne, 2017; Kahl *et al.,* 2021). common cuckoo

(Cuculus canorus), European nightjar (Caprimulgus europaeus), (Hewson *et al.,* 2016; Evens *et al.,* 2017).

Overall, similar themes have come to light across different studies distinct flyways, individual flexibility, the significant role of stopovers before during and after ecological barriers, methodological biases, and knowledge gaps. Addressing these gaps will be pivotal in understanding turtle dove migration/behavior and implement the best conservation strategies possible.

3. Material and Methods

3.1 Study Site

The study was conducted in two coastal regions in Cyprus Paphos in the southwest and Larnaca in the southeast. These two regions were selected because they cover different parts of south coastal Cyprus and geopolitical reasons make it difficult to cover the northern coast. Paphos is a region highly consisting of fallow land, scattered shrubs and trees but also mosaics of agricultural fields which is an ideal habitat for turtle dove, while Larnaca has open plains, very small hills, olive groves, and a more agricultural intensity than Paphos due to its favorable environment fieldwork was carried very close to the coast for both cities. Furthermore, these regions were chosen due to historical knowledge of high turtle dove activity within them as well as easy accessibility for repeated field visits and high likelihood of successful trapping.

3.2 Field Work Description (Capturing, Tagging, and Tracking)

Turtle doves were captured using mist nets with a 16 × 16 mm nylon mesh (Figure 1), matching the configuration used by Barboutis *et al.* (2023). Nets were set up in areas that turtle doves were spotted with vegetation cover to make them less visible but also a flat area to place the nets. The efforts took place at dawn when the bird activity was the highest to maximize the capture probability. The nets were not left unattended for more than an hour at a time to minimize the stress for individual turtle doves as well as bycatch.

Figure 1. Captured turtle dove being taken out of the mesh nets in kouklia (Paphos) in Cyprus

After capturing each turtle dove was weighted using a digital scale, sexed based on size, aged based on plumage and given an identifier. Morphometric measurements such as wing, tail and tarsus length were not collected to minimize handling time and stress as turtle doves also have very sensitive plumage.

Figure 2. Captured turtle dove gets fitted into a bag to measure its weight

individuals were fitted with a lightweight GPS/GSM transmitter attach with a Teflon loop harness the total weight of which never exceeded 3% of the bird's body mass to avoid effects on the bird's behavior.

Figure 3. Captured turtle dove is being fitted with a GSM transmitter

The unites were programmed to record positional fixes once every hour, with hopes as to establish a detail migratory pathway, stopover locations, and timing. Data was transmitted through the GSM network when signal coverage was available.

After tagging the birds were release immediately at the capture site and monitored until they resumed normal activity.

In the end eight birds were successfully tagged and monitored across the two regions Paphos and Larnaca.

3.3 Data analysis

All GPS/GSM tracking data were imported into QGIS (Version 3.36.1) for processing and spatial analysis. Two different types of data were available for each bird, one from satellited based locations (high accuracy) and the other from base station locations (low accuracy).

3.3.1. Data Cleaning and preparation

To filter out bad data with unrealistic information this expression was used in the attribute table: "Altitude" > 0 AND "Satellite used" > 0 AND "VDOP" < 3

This ensured that all the data collected were above sea level (turtle doves do not migrate under water), that at least one satellite was used and that the data followed a reliable and high accuracy altitude (VDOP). All point data were reprojected to ETRS89 / LAEA Europe (EPSG:3035) to allow metric distance calculations. Moreover, GPS fixes recorded prior to each bird's release were excluded based on their timestamps to ensure that only post-release movements were analyzed. In addition, folders were created within QGIS layers panel to organize data by individual bird and to differentiate low accuracy base station data a field was created using the field calculator named satellite used (to make merging easier later) of which base station data were assigned the value -99999. Afterwards both datasets were merged using the merge vector layers tool to form a single layer per bird.

3.3.2. Cluster identification and stopover delineation

To establish stopover sites, the DBSCAN (Density-Based Spatial Clustering of Applications with Noise) tool was used for each bird's dataset. The parameters used Epsilon: 1000 meters, minimum points 3. These parameters ensured that for the points to be considered a cluster there had to be at least 20 points within 25 meters. The conservative approach of 25 meters was done to avoid false stopover detections.

Afterwards the aggregate tool was used to group points by cluster_id and a field named position_source was created with the expression:

```
CASE
  WHEN "sat_used_numeric" = -99999 THEN 'base'
  ELSE 'gnss'
END
```

Moreover, a point_count field was added to record the number of GPS fixes within each cluster

Centroids were created from each cluster using the Centroid tool Producing one centroid per cluster. To visualize and compare the relative importance of stopover sites, labels were applied to centroids in QGIS showing the total number of fixes per cluster (point_count field).

Figure 4. Spatial clustering of GPS tracking fixes for all tagged Streptopelia turtur individuals. Each circle represents a DBSCAN-derived cluster, with the number indicating the total GPS fixes contained within that cluster.

Thereafter using Minimum Bounding geometry to create minimum convex polygons (MCPs) this was done to help with visualization and make it easier to compare different stopovers of different birds as well as establishing land cover use for the birds later.

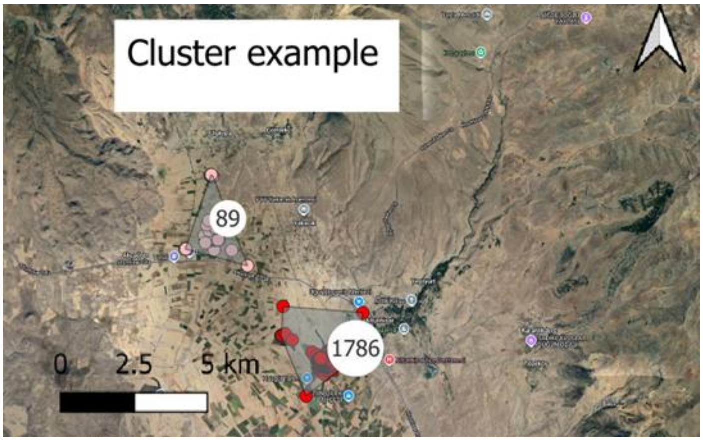

Figure 5. Example of clustered GPS tracking points produced using the DBSCAN algorithm. Each shaded polygon represents a detected stopover cluster for Streptopelia turtur, and the numbers indicate the total GPS fixes within each cluster. This visualization illustrates how stopover sites were delineated for subsequent spatial and habitat analyses.

3.3.3. Land-cover overlay and habitat composition

Each cluster was intersected with the CORINE land cover 2018 data set using the intersection tool to quantify habitat types at stopover sites. After the statistics by categories tool was used to calculate the proportion of clustered points falling within each CORINE class. Land-cover categories were assigned using a CASE expression that converted the CORINE numerical codes (e.g., 111, 211, 243) into descriptive class names

Figure 6. CORINE Land Cover (CLC) classification codes and corresponding habitat categories used for overlay analysis of turtle dove stopover sites.

Subsequently percentages were computed and later compared using the formula:

"count" / sum("count") * 100

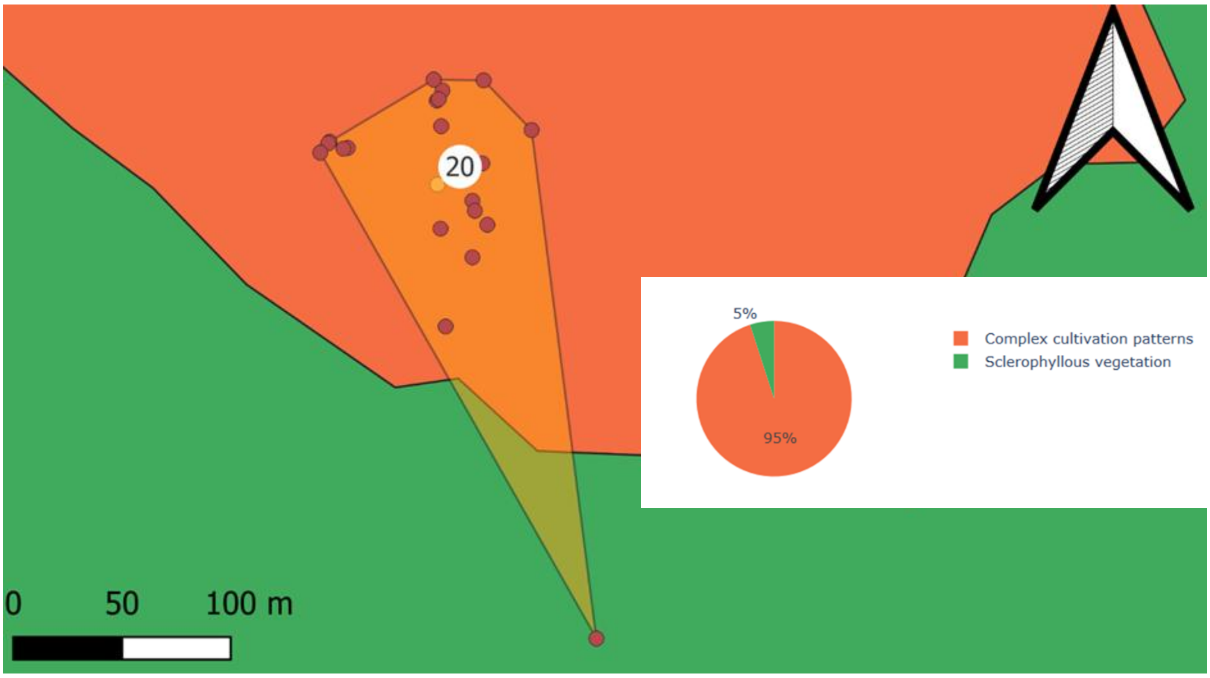

Figure 7. Example of a turtle dove stopover cluster (20 GPS fixes) overlaid on CORINE Land Cover (CLC) data. The shaded polygon represents the minimum convex hull encompassing all GPS fixes within the cluster, used to calculate land cover composition at stopover

For each stopover site, the proportion of GPS fixes within each CORINE land-cover class was calculated. To obtain overall habitat-use estimates for the individual, these proportions were weighted by the duration of each stopover (in days). Weighted averages were calculated using the formula:

Weighted proportion= (stopover duration) x (proportion of land type) / (total stopover duration)

3.3.4. Migration/stopover Visualization

Each GPS fix had a time stamp which was used to extract temporal and behavioral information. The time gap between the first and last fix within the clusters was used to estimate stopover duration, this made the distinction between short and long stopover stops possible. Additionally, a visual of the bird's migration was made possible this way and made it easier to describe birds' movements. Each frame represents 1.5 days so that the temporal clips would not take too long and for ease of analysis thus there could be a 1.5-day margin of error in the times bird spent in an area estimation. Furthermore a simplified migration route was shown using the first cluster one in the middle and the last one.

4. Results

4.1. Overview of tracking

A total of six turtle doves were successfully equipped with GPS/GSM transmitters during the 2023 spring field season. Seven individuals were captured in the Paphos region (Kouklia and Mandria) and one in the Larnaca region (Mari). Tracking duration varied considerably among individuals due to differences in transmitter performance, GSM signal coverage, and potential early tag failure. The following section provides individual summaries for each bird, including basic biometric information, tagging dates, and total tracking duration. Overall, the tracking periods for the 6 birds ranged from fifteen to hundred and thirty-seven days. despite data gaps the information provided by the transmitters was enough to establish local movement patterns and migratory activity. These data formed a strong argument for stopover identification but also examining spatial behavior

4.2. Results (per bird)

Bird ID	Capture date	Tracking duration(days)	Final location	No. of stopovers	Migration description
62205(Paphos)	01/05/2023	41	Kyrenia, Cyprus	8	Local movements in Cyprus with short excursions to southern Turkey before final fixes near Kyrenia.
62197(Paphos)	04/05/2023	89	Central/eastern Ukraine	2	Migrated north from Cyprus to central Turkey and southern Ukraine, with major stopover in central Anatolia
62242(Paphos)	10/05/2023	24	Antalya, Turkey	3	Moved across Cyprus with coastal and inland activity before departing northward to

					southern Turkey and final fixes near Antalya.
62192(Larnaca)	01/05/2023	33	Çankırı Province, Turkey	5	Departed southern Cyprus, crossed directly to Turkey, and moved north through Niğde to Çankırı Province before signal loss.
63109(Paphos)	03/05/2023	137	Southern Ukraine	4	Migrated north from Paphos to southern Turkey and continued to southern Ukraine by late June.
62270(Paphos)	03/05/2023	15	Zonguldak, Turkey	3	Migrated north from Paphos to central and northern Turkey, with a short stopover near Nevşehir–Yozgat before signal loss near Zonguldak.

Figure 8.Summary of GPS-tracked Streptopelia turtur individuals, showing migration duration, stopover activity, and final recorded locations.

Bird 62205

Bird 62205 displayed a complex and short-range migration pattern over 41 days (1 May–10 June 2023), characterized by multiple back-and-forth movements between Cyprus and southern Turkey, possibly influenced by unfavorable weather or sea-crossing conditions.

Figure 9. General migration overview of turtle dove 62205.

The first location was near Mandria Beach, where the bird remained for approximately 21 days. This was the release and initial residency site, where it showed local movements before migration.

The second stopover occurred near the Evretou Dam in Paphos, where it stayed for about five days before continuing north.

After departing from Evretou, the bird reached Kyrenia, near Saint George Monastery, and remained there for roughly six days. This period followed the bird's first return to Cyprus after an attempted sea crossing.

The next recorded stopover was in southern Turkey (Antalya region), immediately after crossing the Mediterranean, where it remained for a brief three-day period, likely resting and recovering before continuing eastward.

The final stopover took place in eastern Antalya, where the bird stayed for about six days before returning to Cyprus. The last GPS transmissions were recorded shortly after this return, suggesting either a brief stopover or transmitter failure.

Overall, Bird 62205 exhibited a short-distance and repetitive migration pattern, characterized by multiple crossings between Cyprus and southern Turkey. These movements likely reflect barrier-avoidance behavior and rapid responses to changing weather or sea-crossing conditions.

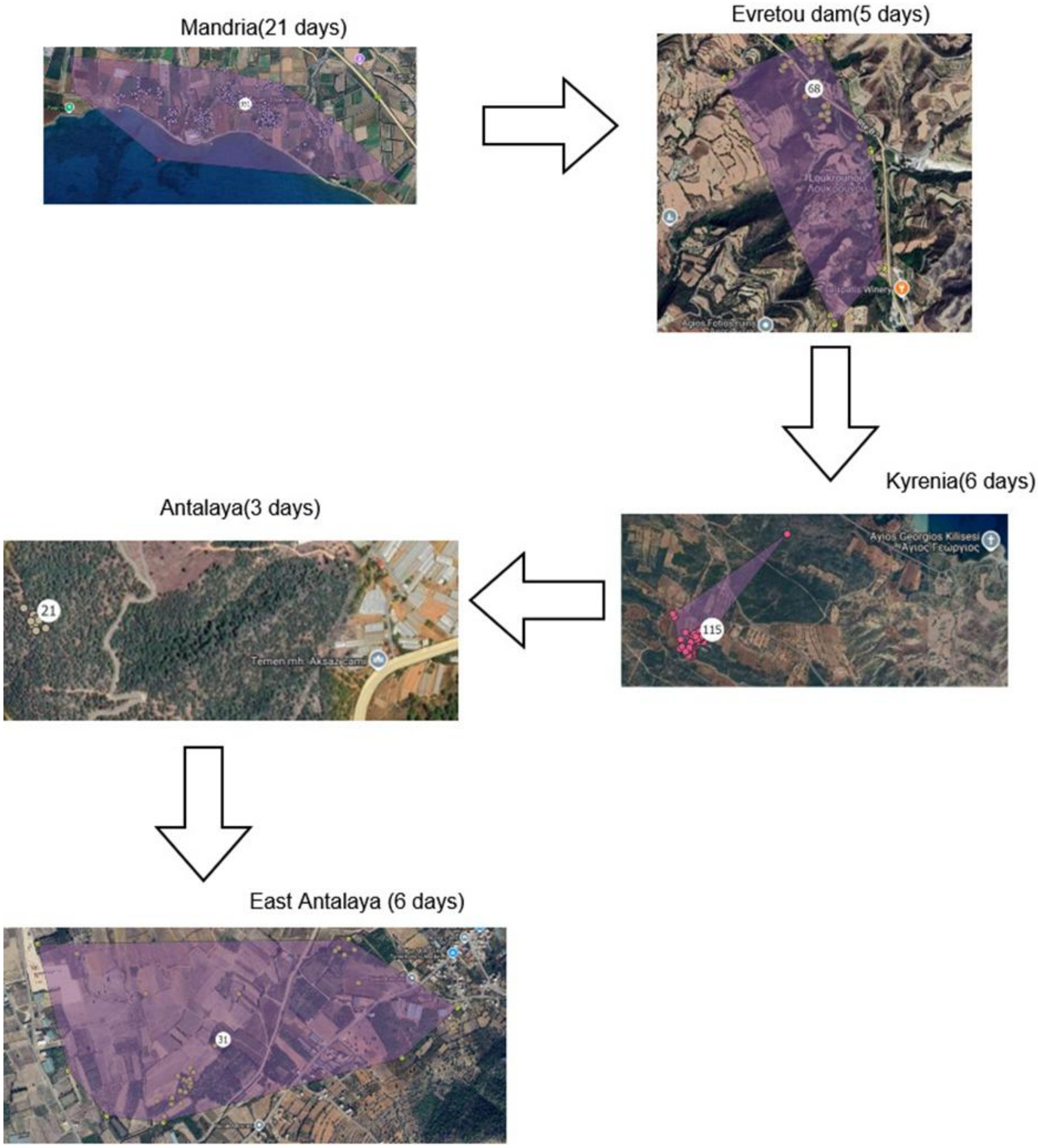

Figure 10.Stopover sequence of turtle dove 62205 during spring migration.

Overall, after calculating the weighted average of time spent for bird 62205, it devoted nearly two-thirds of its stopover time 68% to cultivated landscapes, particularly complex cultivation patterns, and fruit plantations, confirming an apparent reliance on agro-mosaic habitats for refueling during migration. The remaining time was distributed among more natural habitats coniferous and sclerophyllous vegetation likely used for shelter and resting rather than foraging.

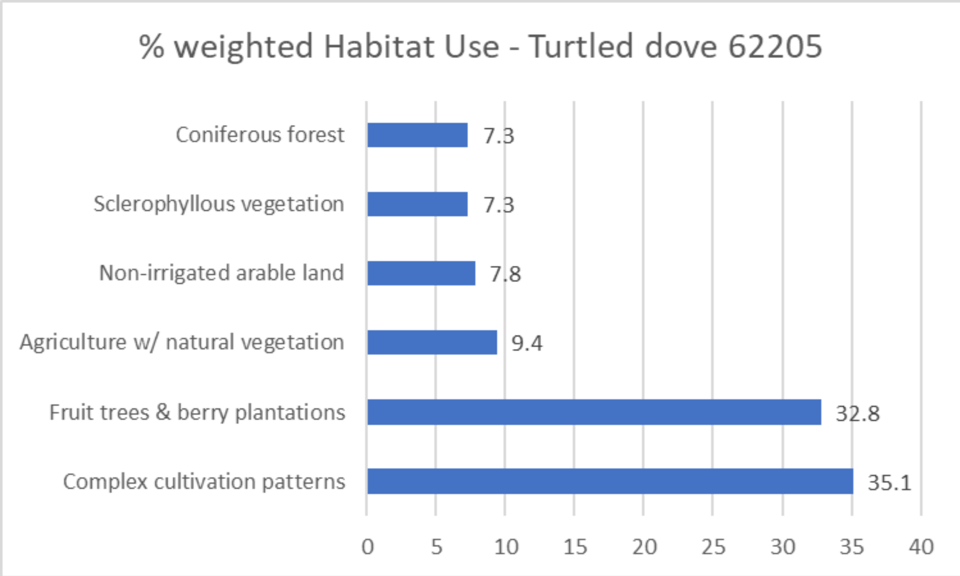

Figure 11. Weighted habitat use of turtle dove 62205 across all identified stopovers.

Bird 62197

Bird 62197 between May 4-August 1(89 days) migrated northward from Paphos (Cyprus) through central Anatolia (Turkey) to central Ukraine.

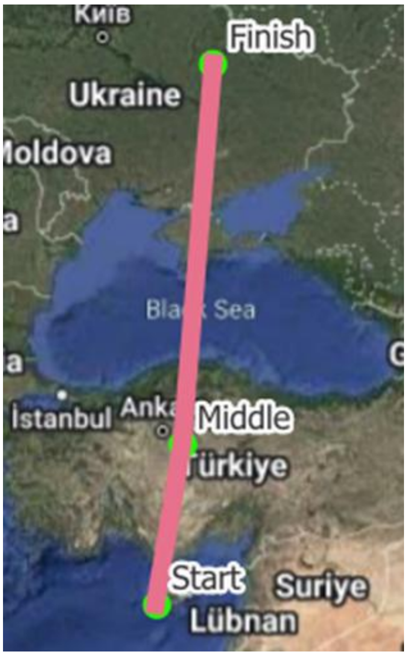

Figure 12. General migration overview of turtle dove 62197.

This bird began its journey in May 4; in Mandria (Paphos)it remained there for an approximate period of 3 days. It then departed the island from the Morphou (Güzelyurt) area and crossed the Mediterranean without making any apparent stopovers. By May 8, it arrived in southern Turkey and continued northwards, settling in a region south of Ankara where it remained for roughly three weeks (around May 8 to June 1). Within this region, the bird established several successive short stopovers including Suyugüzel, Anka Yumurtası, Aşağıhacıbeyk, Karahmetli Dam, Danacıobası, Çerikkale, and Konur–Müsellim spanning from early May to late June

These sites (shown in Figure 13) likely represent local movements within a prolonged stopover phase in Central Anatolia, possibly reflecting foraging or moulting behavior rather than continued long-distance migration.

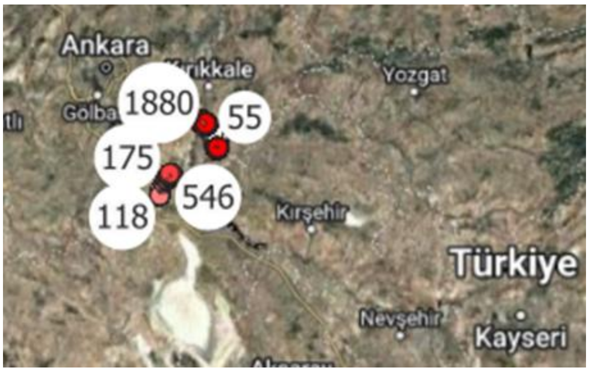

Figure 13. bird 62197 concentration of clusters near central Anatolia

. The next available data point was recorded on June 19, located north of the Black Sea in southern Ukraine, derived from a base station signal, suggesting that the bird had continued migrating northward during the interval with no GPS fixes. Between June 21 and June 22, additional base station signals were detected across central and eastern Ukraine, particularly in the Dnipro–Donetsk–Poltava region. However, since these were approximate locations rather than GPS-based fixes, stopover sites within Ukraine were not analyzed for land cover use due to the limited spatial precision of the data.

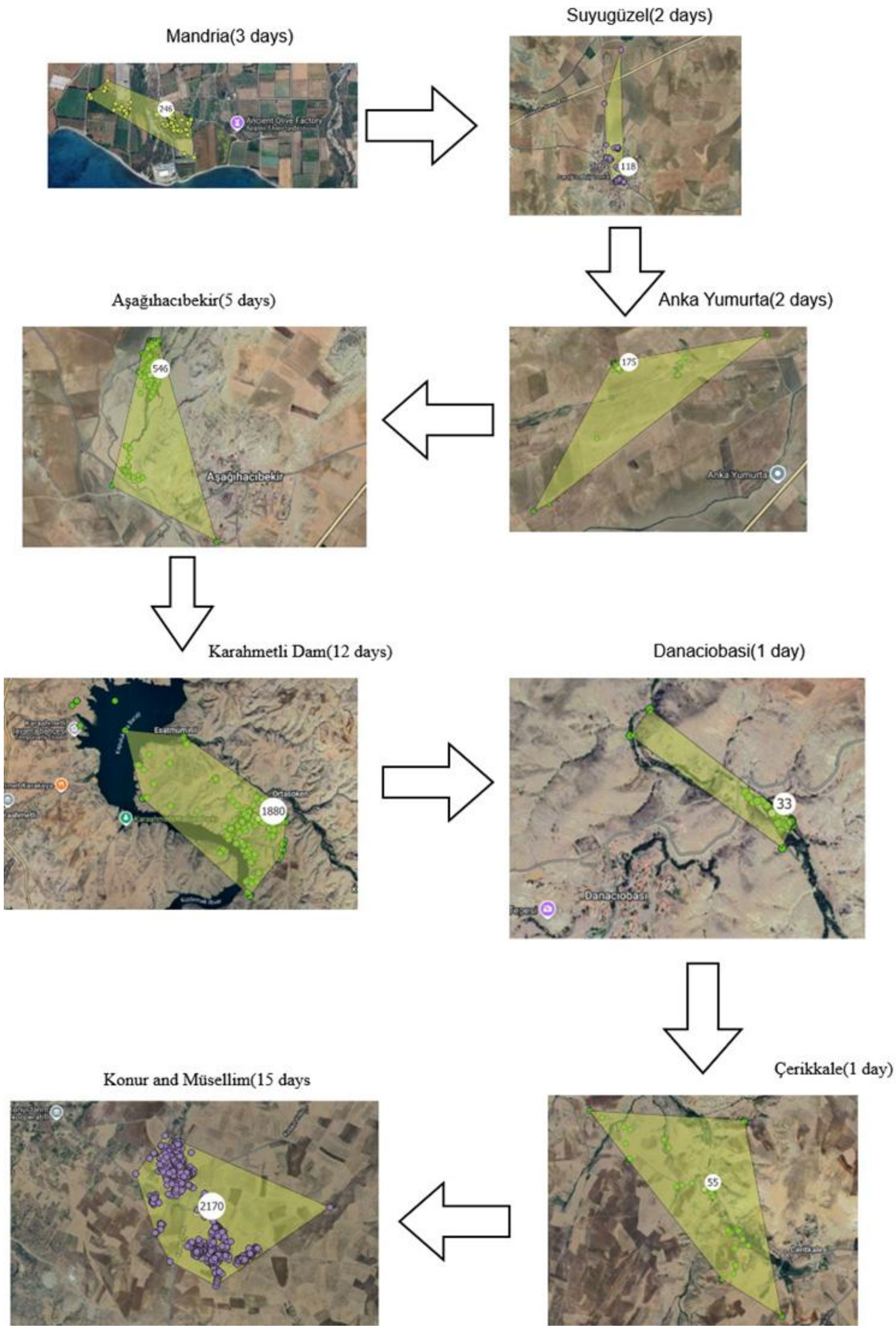

Figure 14. Stopover sequence of turtle dove 62197 during spring migration.

Overall, after calculating the weighted average of time spent, Bird 62197 devoted most of its stopover time (around 71%) to cultivated landscapes, primarily non-irrigated arable land, complex cultivation patterns, and permanently irrigated fields, indicating a strong preference for open agricultural environments that likely provided favorable foraging conditions. The bird remained in one location for approximately two weeks, showing limited movements within a concentrated area — a pattern that may indicate a pre-breeding stopover or temporary settlement, although subsequent movements north toward Ukraine suggest that breeding likely occurred farther north. The remaining time was spent in sparsely vegetated and semi-natural habitats, likely used for resting or shelter between foraging periods

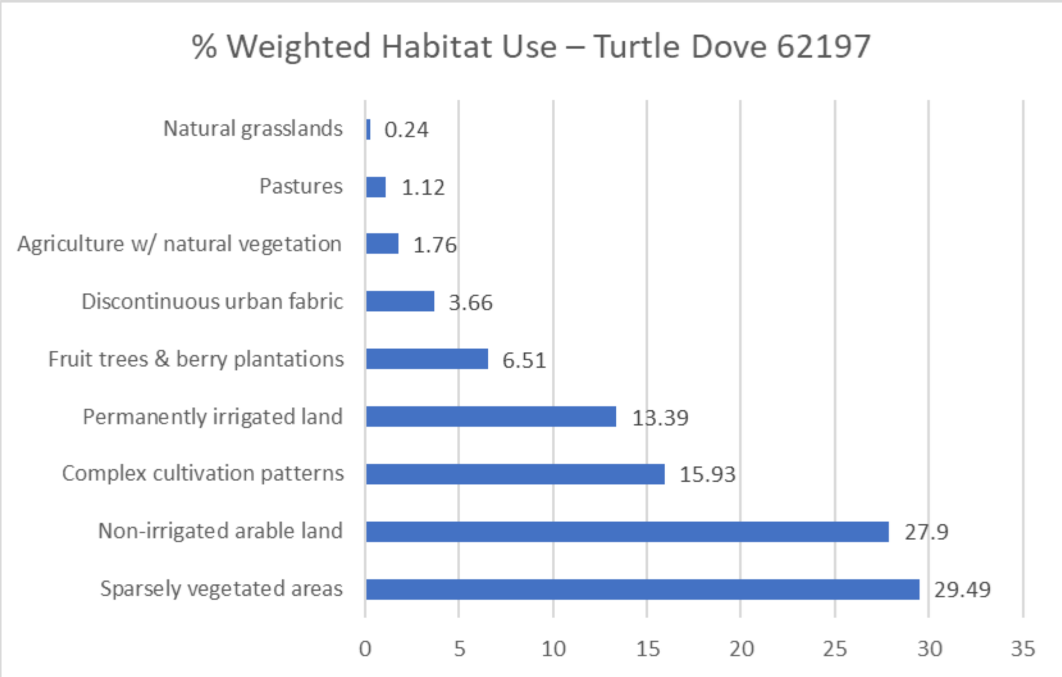

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Figure 15. Weighted habitat use of turtle dove 62197 across all identified stopovers.

Bird 62242

Bird 62242, an adult male weighing 168 g, displayed a complex and looping migration pattern over 24 days (10 May–3 June 2023), involving repeated movements across Cyprus and a final northward crossing to southern Turkey, where the signal was lost near Antalya.

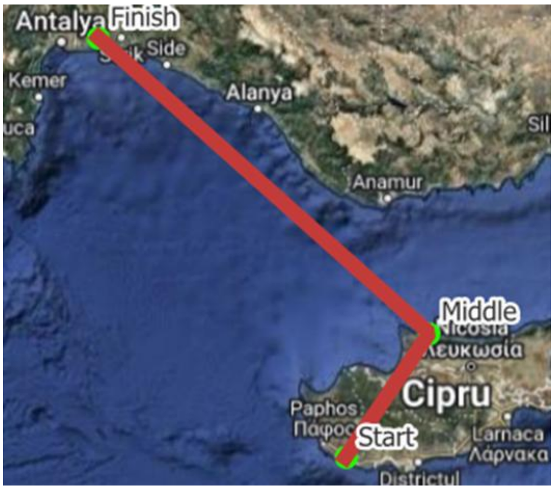

Figure 16.General migration overview of turtle dove 62242.

The first cluster corresponded to the capture and release site in Mandria, where the bird remained for approximately 21 days (May 4–25). This period likely represents local activity within its established home range prior to the onset of migration rather than a true migratory stopover.

The bird's second stopover occurred in the Güzelyurt / Deneia region (Cyprus), where it remained for about seven days (May 25–June 1) after leaving Mandria. Its core-use area was located within the UN buffer zone, and daily movements frequently crossed the de facto boundary between the Republic-controlled and Turkish-controlled parts of Cyprus.

The third stopover took place in the Karşıyaka / Lapta region, where the bird stayed for approximately four days (May 31–June 4). The coastal location may have facilitated pre-departure staging before the bird's eventual crossing toward mainland Turkey.

Subsequent movements were recorded east of Antalya, Turkey, where the bird remained from early July until late August, when the final signal was received. However, only base-station detections were available for this period, so no further spatial or habitat analysis was possible.

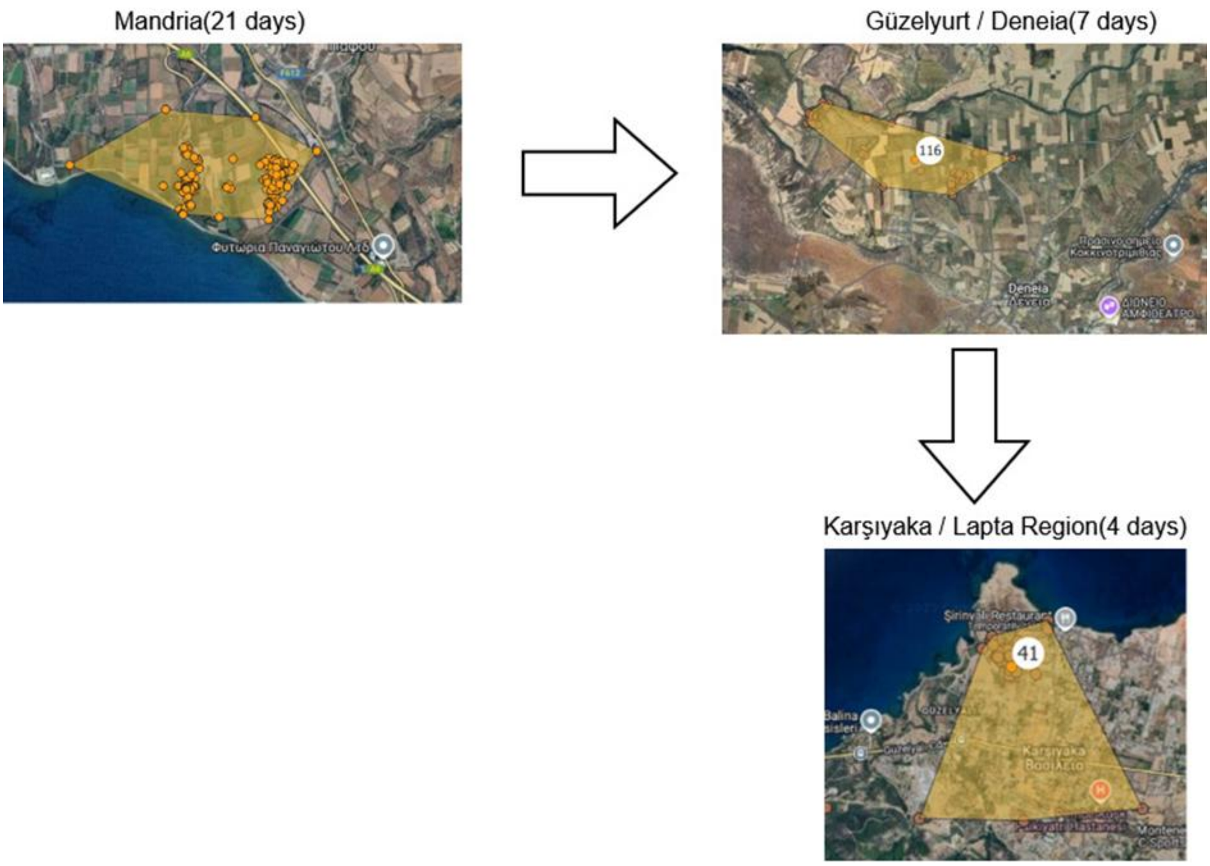

Figure 17. Stopover sequence of turtle dove 62242 during spring migration.

Overall, after calculating the weighted average of time spent for bird 62242, it devoted the vast majority of its stopover time (≈77%) to complex cultivation patterns, with an additional 21% spent on non-irrigated arable land. This indicates a strong association with agricultural mosaics and cultivated landscapes similar to those used by other individuals, suggesting that such areas provide key foraging opportunities during migration. Only a negligible fraction (<1%) of its time was associated with natural grasslands, discontinuous urban areas, and agriculture with natural vegetation, likely reflecting peripheral use or short resting events rather than core habitat use.

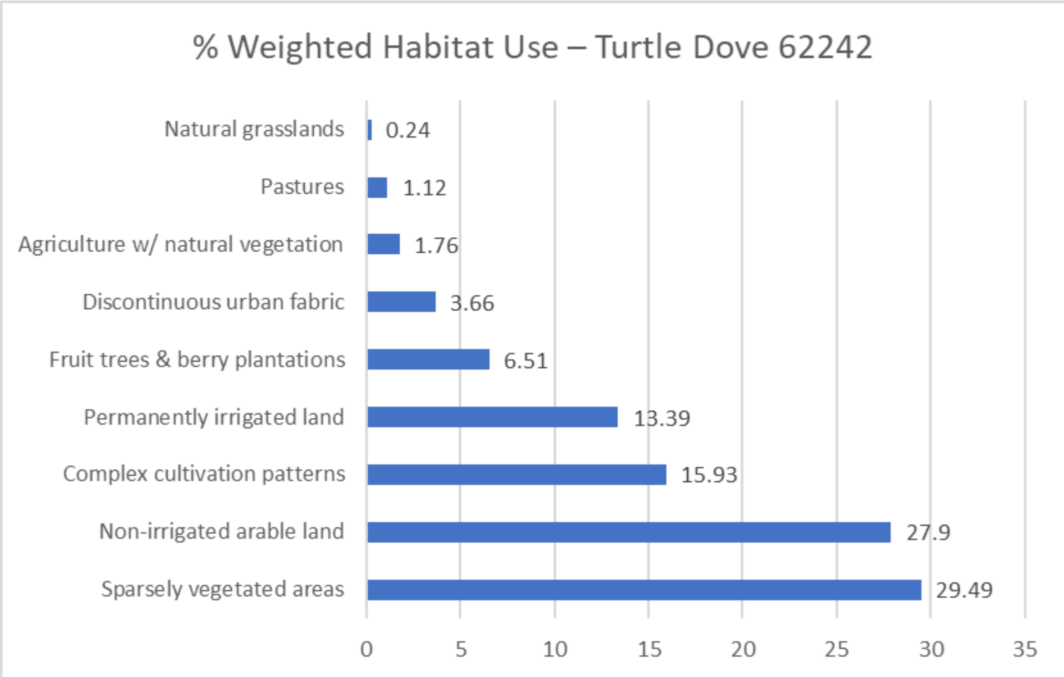

Figure 18. Weighted habitat use of turtle dove 62242 across all identified stopovers.

Bird 62192

Bird 62192 was tracked for 33 days between 1 May and 2 June 2023, moving from southern Cyprus to central Anatolia, with distinct stopovers near Mari–Zygi, Niğde, Dinek Dağı National Park, and the Koyunbaba Dam region in Çankırı Province.

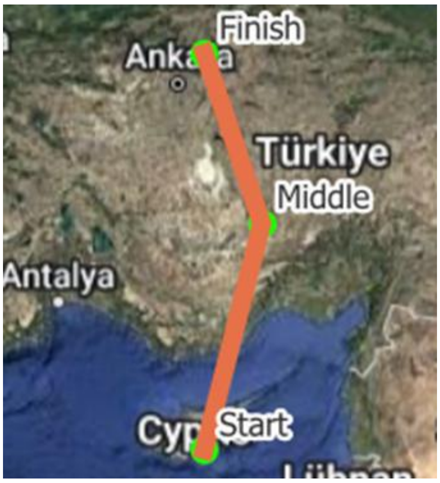

Figure 19. General migration overview of turtle dove 62192.

The first stopover occurred in the Mari–Zygi agricultural plain, which also served as the capture and release site. The bird remained there for approximately 9 days (7–16 May) along the southeastern coast of Cyprus, showing localized movements typical of pre-migratory activity.

After leaving the Mari–Zygi plains, the bird moved north across the island to the Görneç area, where it stayed for around 2 days (17–19 May). This brief inland stop likely served as a short refueling period before the bird crossed the Mediterranean.

Upon departure from Cyprus, the bird made landfall near Akçaören, east of Silifke on the southern Turkish coast, where it paused for another 2 days (17–19 May) before continuing inland.

The next stopover occurred slightly further north, in the Niğde region, where the bird remained for about 9 days (19–28 May). This extended stop likely allowed for rest and replenishment before continuing deeper into Anatolia.

Finally, the bird settled near Şemşeninköy, just east of the Koyunbaba Dam, for approximately 7 days (28 May–3 June), marking the last recorded location before the signal was lost.

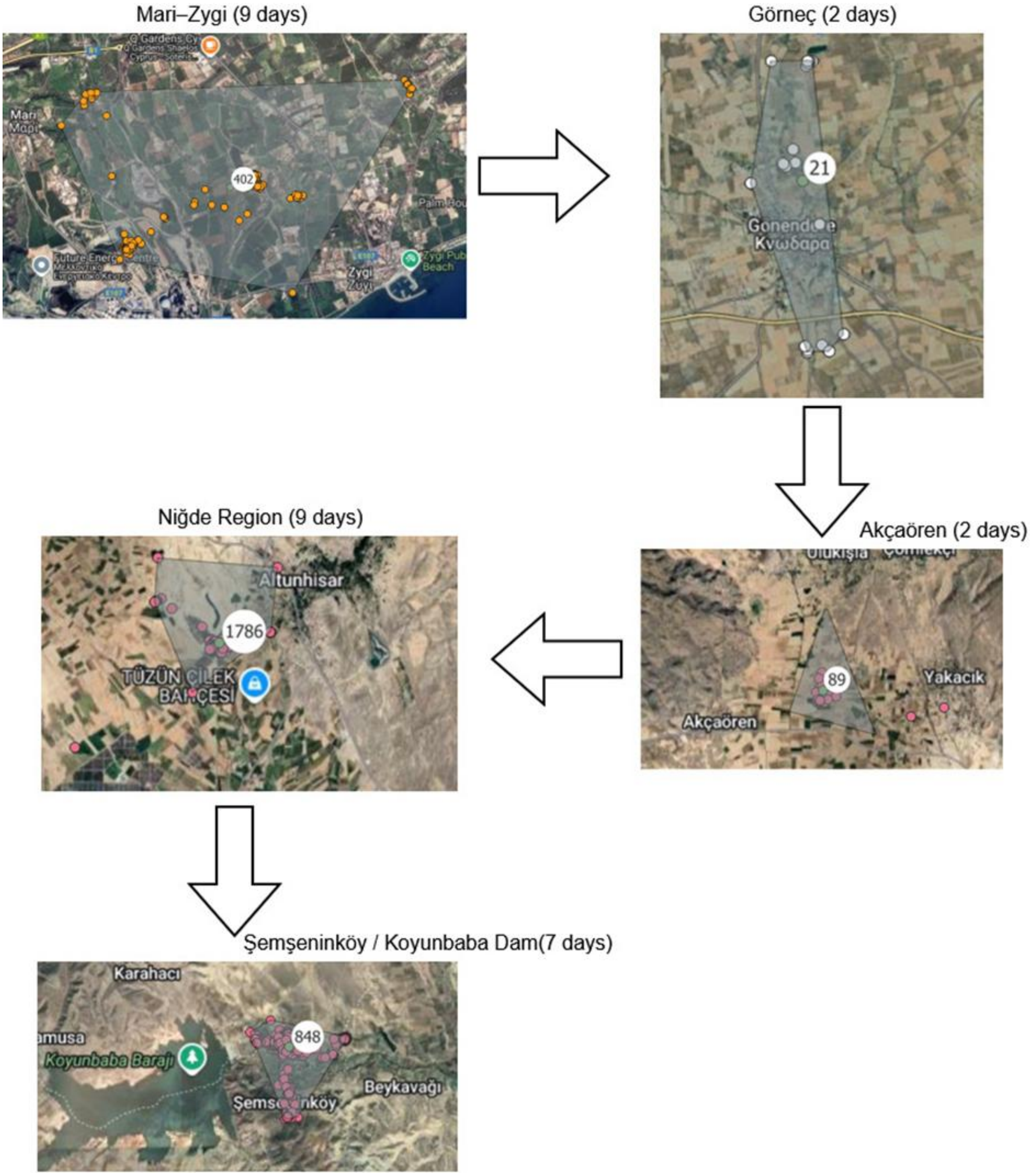

Figure 20.Stopover sequence of turtle dove 62192 during spring migration.

The overall weighted average habitat composition along the migration route of bird 62192 reveals a strong preference for agricultural landscapes, particularly non-irrigated arable land (37.86%), which represents over one-third of the total habitat use. This dominance indicates a strong association with open farmland typical of the Anatolian interior and central Cyprus.

The second most utilized habitat type was fruit trees and berry plantations (20.57%), followed by permanently irrigated land (19.25%), together accounting for nearly 40% of the total. These habitats likely provided both foraging opportunities and access to water, which are crucial during refueling stops.

Additionally, land principally occupied by agriculture with signs of natural vegetation (11.25%) contributed notably, suggesting the bird occasionally used semi-natural mosaics that combine cropland with patches of native cover. Minor land cover types included industrial or commercial units (4.25%), discontinuous urban fabric (4.14%), complex cultivation patterns (2.36%), and vineyards (0.32%), each reflecting localized use near settlements or mixed agricultural areas.

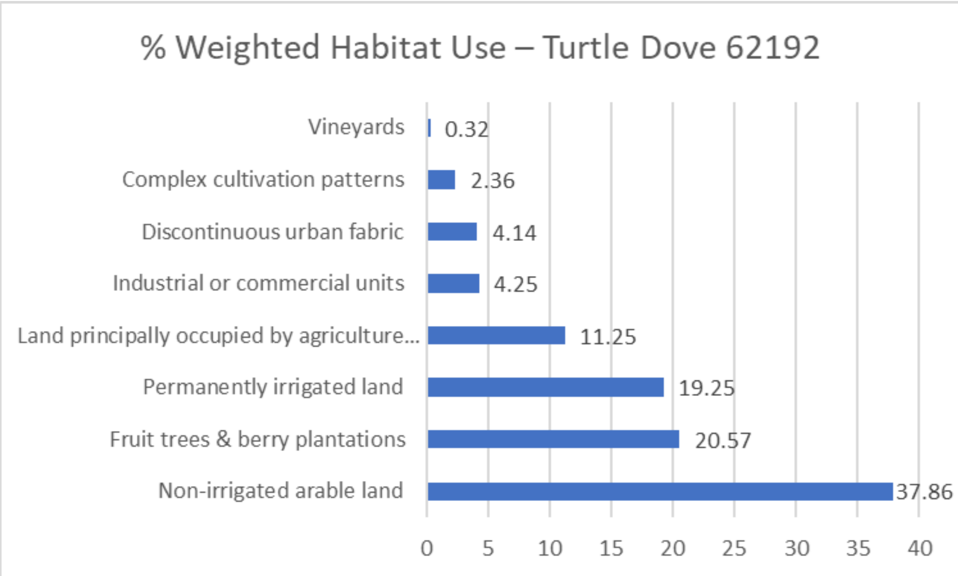

Figure 21.Weighted habitat use of turtle dove 62192 across all stopover sites.

Bird 63109

This adult male undertook a long-distance migration from southwestern Cyprus (Timi–Anarita) to southern Ukraine, with a major stopover in central Turkey, covering an overall tracking period of 137 days (May–September).

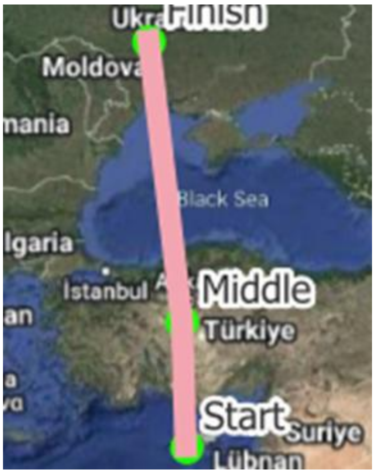

Figure 22. General migration overview of turtle dove 63109.

The first stopover for bird 63109 occurred in the Kouklia–Mandria area (Paphos district), which was also the capture and release site. The bird remained there briefly for approximately one day, showing limited local movements before departure.

The second stopover took place in the Anarita–Timi area (also within the Paphos district), where the bird stayed between 4 May and 22 May, for a total of about 18 days. This period likely represented a pre-migratory staging phase, during which the bird utilized the surrounding agricultural landscape before initiating its northward journey.

After leaving Cyprus, the bird made landfall in southern Turkey, where it briefly stopped near Demirözü for approximately one day. This short stopover likely served as a resting point immediately following the Mediterranean crossing.

The final identified stopover occurred near Yaprakbayırı, a mountainous area in central Anatolia, where the bird remained for one day before continuing northward toward Ukraine.

Following its last high-resolution GNSS positions in central Turkey, the dove's subsequent detections were received via base stations in central Ukraine, in the vicinity of Uman and Pervomaisk. Due to the lower spatial accuracy of these data, no detailed land-cover analysis was conducted for this period.

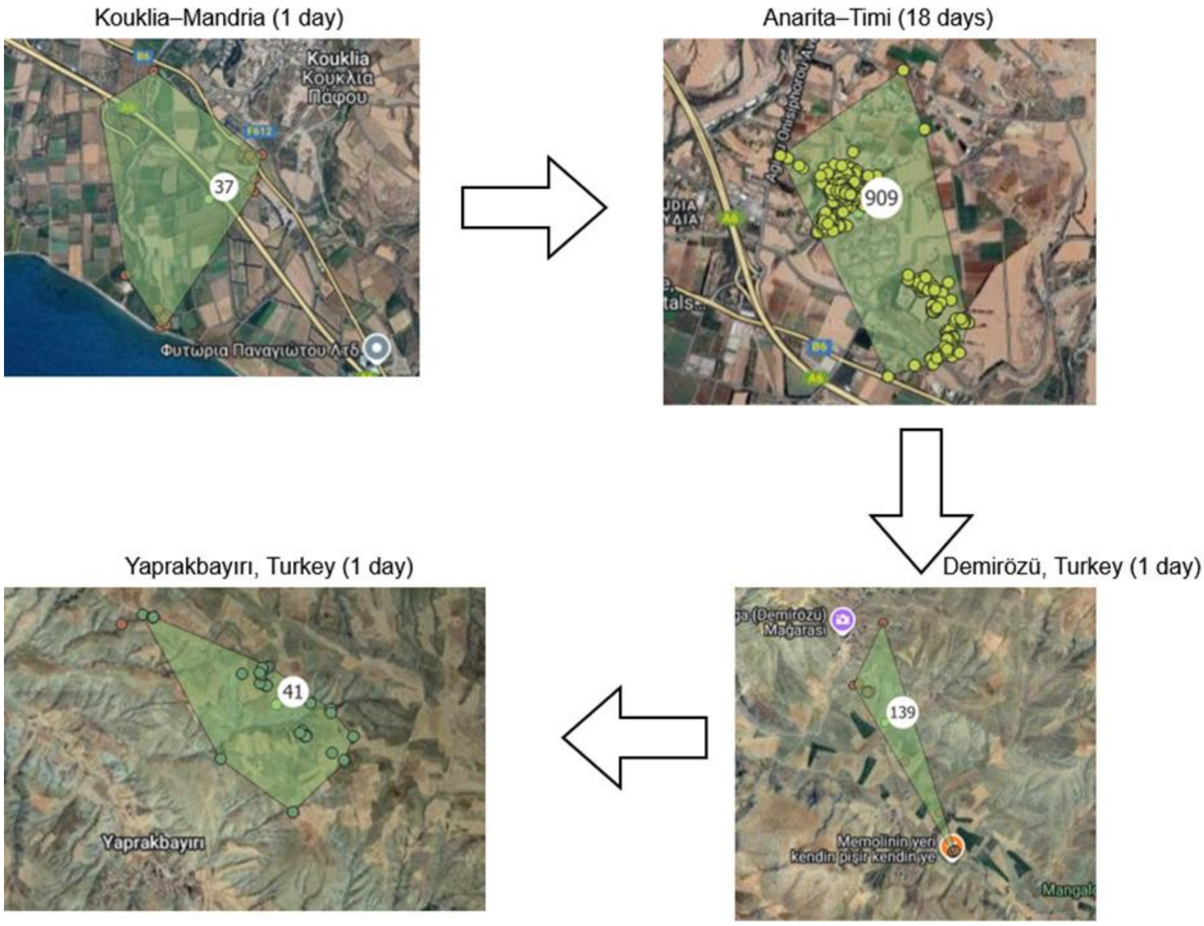

Figure 23.Stopover sequence of turtle dove 63109 during spring migration.

The weighted average of land cover types across all GNSS stopovers for turtle dove 63109 shows a strong dominance of non-irrigated arable land (50.27%), followed by sparsely vegetated areas (20.75%), and complex cultivation patterns (18.83%). Smaller proportions were associated with fruit trees and berry plantations (5.52%), permanently irrigated land (2.17%), and land principally occupied by agriculture with signs of natural vegetation (2.17%).

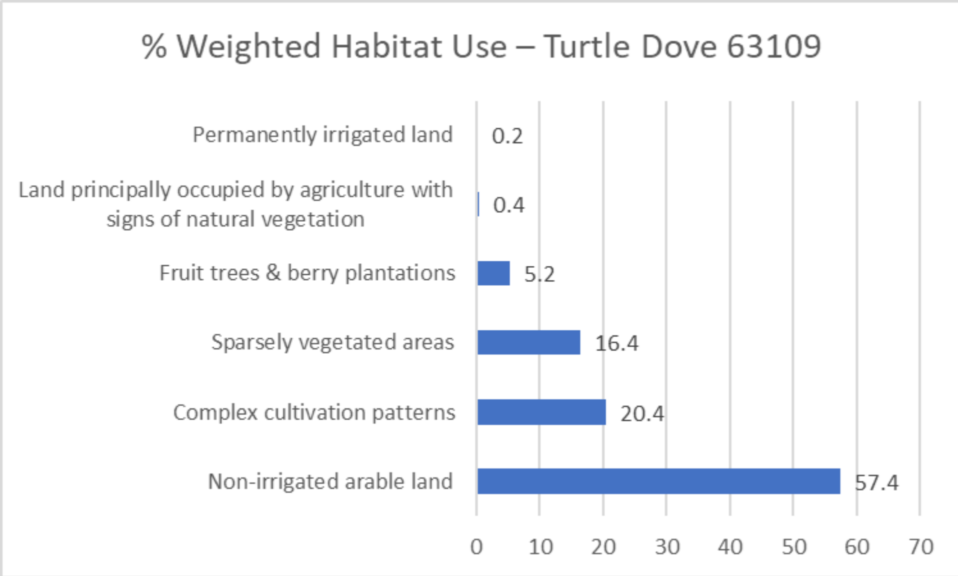

Figure 24.Weighted habitat use of turtle dove 63109 across all stopover sites.

Bird 62270

This adult female turtle dove migrated northward from Kouklia (Cyprus) through central Anatolia to the northern Turkish Black Sea region near Zonguldak, where the final signal was recorded in late May.

Figure 25.Weighted habitat use of turtle dove 62270 across all stopover sites.

The first stopover of turtle dove 62270 occurred in Kouklia, Cyprus, close to its release site, where it remained for approximately eight days (2–10 May 2023). The bird's movements during this period were highly localized within the agricultural landscape, reflecting post-release settling and pre-migratory preparation.

After departing Cyprus, the dove crossed the eastern Mediterranean and arrived near Silifke, southern Turkey, where it stayed for about three days (8–11 May 2023). This short stopover likely served as a recovery phase following the sea crossing before continuing northward.

The bird's final stopover was recorded near Üçobalar, in central Anatolia, where it remained for roughly six days (10–16 May 2023). This site likely functioned as a key inland refueling location before the dove resumed migration toward the northern Black Sea region.

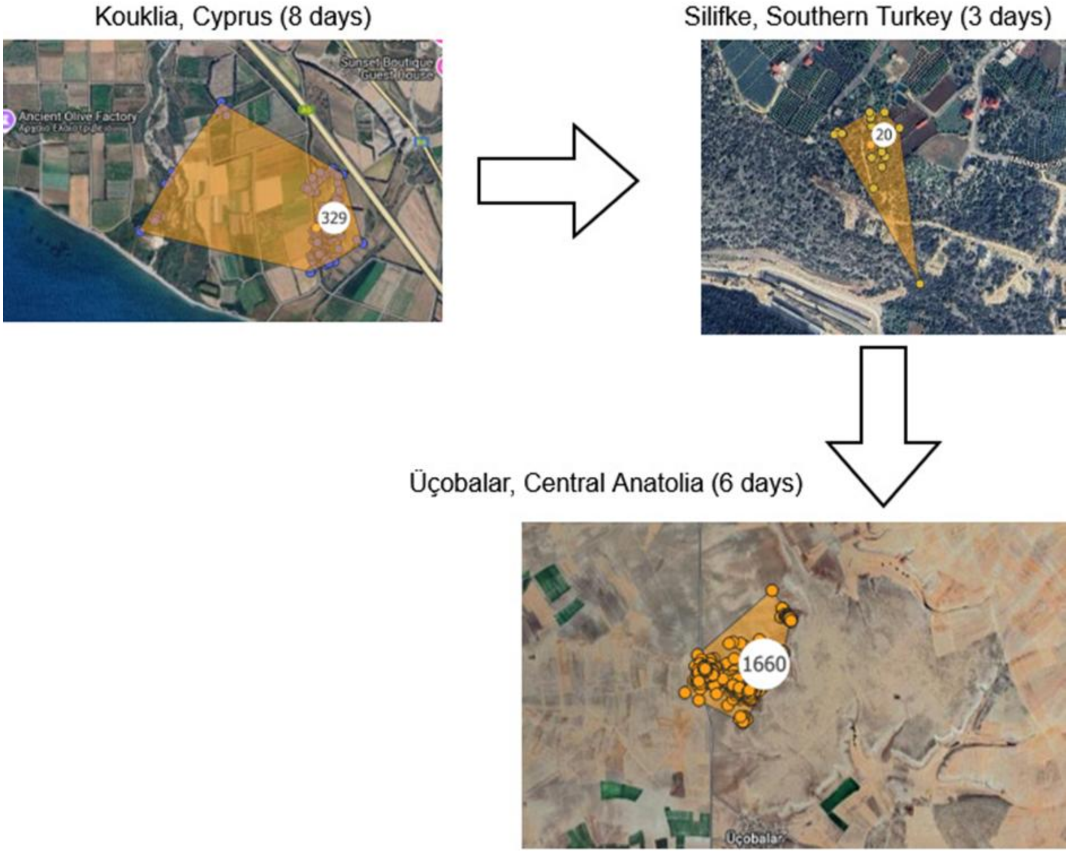

Figure 26.Stopover sequence of turtle dove 62192 during spring migration.

The weighted land cover analysis for turtle dove 62270 shows that the bird spent the majority of its stopover time within complex cultivation patterns (61.18%), followed by non-irrigated arable land (37.65%), and a small proportion within sclerophyllous vegetation (1.18%). This indicates a clear preference for agricultural landscapes, particularly mixed and mosaic farmlands that provide abundant foraging opportunities in the form of weed seeds and grain residues. The minimal use of natural scrub habitats further supports the species' strong association with human-modified agricultural environments during migration.

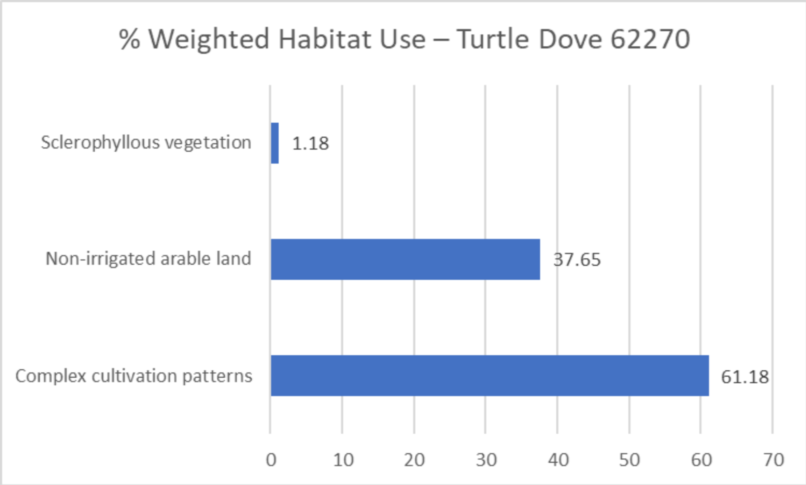

Figure 27.Weighted habitat use of turtle dove 62270 across all stopover sites

4.3. All Birds

Across all individuals, the majority of stopover time was spent in complex cultivation patterns (mean = 35.3 ± 28.5%), followed by non-irrigated arable land (35.8 ± 12.3%). Other habitats such as sparsely vegetated areas and permanent crops accounted for smaller proportions.

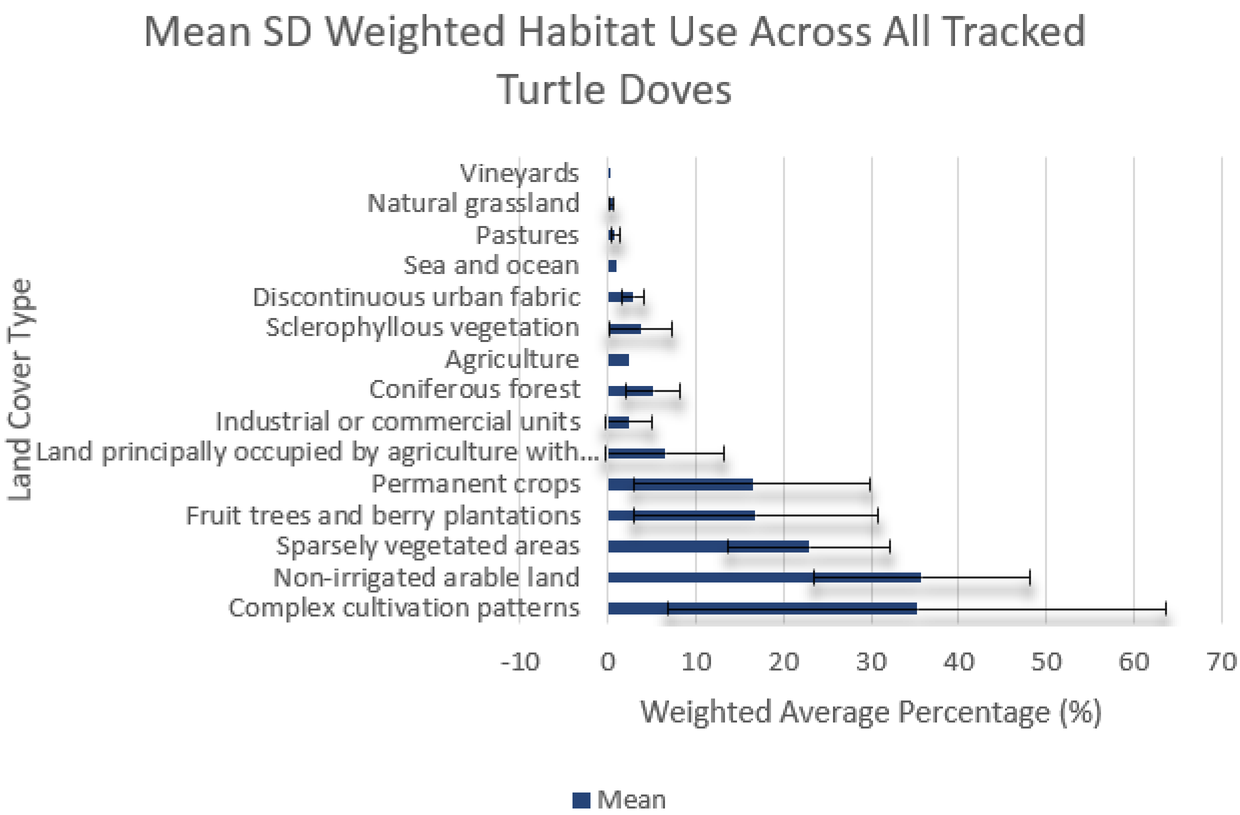

Figure 28.Mean (±SD) weighted habitat use across all tracked turtle doves

5. Discussion

5.1. Migratory Patterns and Routes

All tracked turtle doves crossed the Mediterranean through the southern coast of turkey between May 5 and June 16, showcasing a shared migratory route.

Figure 29.Mediterranean crossing routes of all tracked turtle doves.(each colour marks a different bird)

Although individual timing and location of crossing varied, four out of the 6 birds converged in central Anatolia, hinting that this region serves as a key stopover or refueling zone during the turtle doves spring migration in the eastern flyway. This convergence, together with published evidence that turtle doves rely on prolonged spring stopovers in the eastern Mediterranean before continuing inland, suggests that central Anatolia may function as an important refueling region (Barboutis *et al.,* 2023; Eraud *et al.,* 2013).

two birds reached Ukraine, while two others followed a similar direction before their signals were lost implying that they could have continued onwards to Ukraine as well.

Figure 30.Spring migration routes of tracked turtle doves across Anatolia and into Eastern Europe.

Overall, the movements indicate a north east aligned with the eastern Mediterranean flyway connecting Africa with breeding grounds in eastern Europe. (Marx *et al.,* 2016; Lormée et *al.,* 2016). The strong spatial convergence in central Anatolia may be due to a mix of ecological and geographical influences like the ample agricultural mosaics that provide food and resting opportunities. (Eraud *et al.,* 2013).

After the sea crossing, turtle doves typically engage in several-day to multi-week stopovers for refueling before continuing inland, a pattern documented in GPS-tracked individuals across the eastern Mediterranean (Barboutis *et al.,* 2023).

Fixes received from Ukraine were exclusively from base station data rather than GNSS satellite signals, this was likely due to satellite interference associated with the ongoing war. As a consequence, accuracy of the fixes was lower. Additionally, no further data was recorded in the bird's southward return migration, as none of the transmitters stayed functional until the post-breeding period.

5.2. Stopover Site Selection and Spatial Behavior

All five turtle doves captured/released in mandria (Paphos) initially remained within the area and their movements overlapped extensively

Figure 31.Overlapping movement ranges of five tracked individuals at the Paphos–Mandria release site. High spatial overlap reflects post-release activity rather than true migratory stopover behaviour.

However, this overlap could be due to the release location rather than a stopover powerhouse location. In addition, multiple stopover events were showcased in the birds' migratory routes with durations ranging from a couple of days to several weeks. The majority of whom occurred in central Anatolia an area that appears to act as a key refueling zone

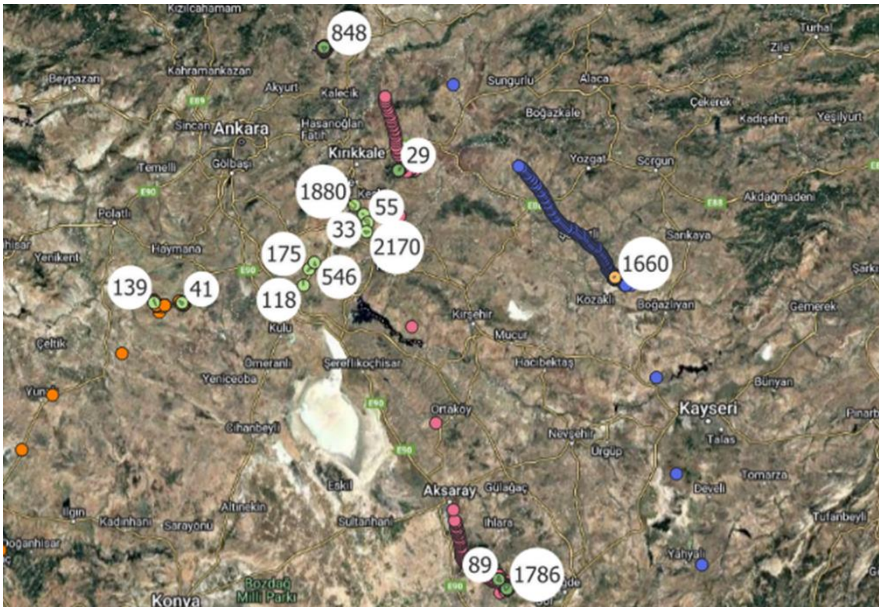

Figure 32. all stopovers from all birds that occured in central Anatolia

stopovers usually exhibited limited local movements before a long-distance flight(migration) a pattern suggesting an energy-based approach by the birds. Moreover, the relatively small stopovers in southern turkey right after the birds crossed the Mediterranean Sea in comparison to the much larger ones in central Anatolia, suggests that the birds have small resting phases after crossing ecological barriers before continuing their migration northwards. This interpretation aligns with previous telemetry studies showing that turtle doves often pause in productive agricultural landscapes following major ecological barriers (Barboutis et al., 2023; Eraud et al., 2013).

Figure 33. south turkey stopovers

5.3. Habitat Use and Land Cover Preference

Across all tracked turtle doves, as shown in figure(28) there was a stong inclination for agricultural landscapes more particularly areas characterised by complex cultivation patterns and non irrigated arable land. These habitats occurred in high concentrations in the majority of stopovers across all birds indicating a heavy dependance on agricultural mosaics that combine open fields scattered vegetation and tree cover for shelter. This pattern is consistent with previous work showing that turtle doves forage predominantly in open, low-intensity farmland mosaics and rely on seed resources in cultivated areas (Browne & Aebischer, 2003).

Other land cover types such as sparsely vegetated areas, permanent crops, and fruit tree or berry plantations, were also used but to a smaller extent, indicating that the birds may take advantage of semi-arid cultivated habitats depending on local conditions. The variability among individuals in habitat use for some land cover types was evident as high standard deviations were showcased this can suggest a degree of flexibility among individuals but it might have also been influenced by differences in timing, weather, or landscape configuration.

The lack of forested and heavily urbanized habitats among stopover sites strongly suggest that turtle doves actively avoid dense cover and built environments but instead prefer open and semi-open habitats that permit easier foraging and less human disturbance as supported by (Browne & Aebischer, 2003).

These finding are consistent with finding from previous studies which highlighted the species dependence on cultivated and semi natural habitats during migration. Eraud *et al.* (2013) identified agricultural mosaics as key stopover environments supporting refueling before major crossings. Lormée *et al.* (2016) also noted that stopover sites were largely located in low-intensity farmland, linking such habitats to higher survival rates during migration. Collectively, these parallels reinforce the conclusion that agricultural landscapes with structural diversity remain critical to the species' migratory success and conservation.

5.4. Limitations and Future Work

This study has several limitations that need to be addressed for starters there was linear data continuity as the transmitters did not send signals every hour as they were programmed to do and the sometimes-large gaps in GPS fixes translated in large gaps of understanding while gaps in satellite fixes from Ukraine can be a result of the ongoing war. in addition, the suboptimal performance of the GPS transmitters was further damaging to the study as none of the birds kept transmitting data on the birds return trip south back to their wintering areas.
In the future we should Pair GPS/GSM tracking with automated radio-telemetry networks (e.g., Motus/ATLAS) to recover movements during GSM blackouts and reduce per-bird costs, while acknowledging trade-offs in spatial precision (Taylor et al., 2017; Beardsworth et al., 2022).Besides, there were only two capture and release sites one of whom consisted 5 of the 6 birds in the entire study this might have brought biased results as birds that reached Cyprus from other parts of the coast could be from a different place in Africa and have different behavior and migration strategies this paired with the fact that the sample size was very small and limiting, in order to get a more precise understanding on what is really happening we will need a much bigger sample. moreover, the land cover overlay from Corine was outdated 5 years at the time that the data was being collected and its resolution of minimum 25 hectares is far too small to get a clearer image of smaller land cover types within the land in the future a more up-to date with higher resolution product should be used for overlaying land type. lastly in the future cooperation with foreign governments should take place to get a better image of both the birds' movements but also the fate of the birds.

Overall, the study provides great insight for spring migration and ecology of turtle doves in Cyprus and the eastern flyway. A combination of GPS tracking and habitat analyses underlined the importance of central Anatolia as a key region and confirm the species preference for agricultural mosaics and its tendency to avoid urban and heavily forested areas. this study can serve as a baseline for future conservation studies on the turtle dove.

6. Abstract

The purpose of this study is to understand the migration ecology and strategies of the turtle dove to be able to develop the most effective conservation strategies possible for this declining species. Six turtle doves were tracked with GPS/GNSS transmitters in Cyprus during spring of 2023. The study included temporal migration with visuals following each bird's path, stopover behaviour interpreting the reasons for birds spending significant amounts of time in one location and habitat use analysis my overlaying the CORINE 2018 land cover data. the results showed that four of the six birds reached central Anatolia while one returned back to Cyprus from the southern coast of turkey before the signal was lost and the other bird reached only up to southern turkey before its signal was lost, out of the four birds that reached central Anatolia two of them eventually found their way to Ukraine while the other two stopped transmitting GPS fixes likely before also reaching Ukraine as their paths until that point were very similar. The land cover analysis showcased a reliance on agricultural mosaics and the avoidance of urbanized and heavily forested areas. Unfortunately, there were some data gaps as the transmitters failed to collect a signal every hour as they were programmed to and the performance of each transmitter varied greatly. Moreover, there was no cooperation with the authorities of north Cyprus and Turkey were most of the transmitters transmitted their final signal therefore the fate of all the birds remains unknown. In spite of these problems the findings are the first of their kind for turtle doves in Cyprus and provided us with enough essential information that help make the knowledge gaps for what we know about turtle dove smaller.

7. Acknowledgements

I would like to express my sincere appreciation to the Game and Fauna Service of Cyprus for granting me the opportunity to participate in the capturing and tagging of turtle doves, and for providing permission to access and utilize the GPS tracking data used in this study. Their assistance and readiness to address any questions that arose during the research were invaluable.

I would also like to extend my deepest gratitude to my supervisor, Dr. Schally Gergely Tibor, for his continuous guidance, constructive feedback, and professional support throughout the development of this thesis. His expertise and supervision were essential to the successful completion of this work.

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9. List of tables and figures

Figures

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Neptun ID:	IVG6QL
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III.1. Study and Examination Regulations
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