# Introducing tape luring, a low-cost tool to enhance bio-pest control services by birds in desert agriculture.

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# Summary

Pesticides in agriculture pose a significant threat to biodiversity. Integrated Pest Management (IPM) aims to enhance habitat quality for beneficial organisms and reducing the needs of pesticides. However, little research has focused on incorporating migratory insect eating birds species into IPM strategies. This study investigates if birds and bats contribute significantly to biological pest control, if habitat structures and manipulations can enhance their abundance, species richness and hence control impact and which of these manipulations can be included in farming protocols as tools for farmers.

We investigated whether audio lures can attract migratory insectivorous birds to field crops and date plantations, what factors influence abundance of birds in the crops, whether the birds' diet include crop-related insect pests, and which bird species are most effective for pest control? This data was collected and analysed by a Master student from Vienna Austria with the help of local field assistants and researchers.

Over three years in southern Israel's Arava Valley, we conducted several surveys for the study using point counts to compare the abundance of both migratory and sedentary birds at locations with and without audio luring. Additionally we recorded several variables to assess their influences on bird abundance.

The results showed that audio lures successfully increased the local abundance of the most numerous migratory birds in the crops, though no clear effects were found on sedentary birds. The effect of the variables varied strongly between the species groups and the crops and need to be examined in each case separately. Due to the limited number of analysed faecal samples, we could not obtain reliable data on migratory bird diets, though some evidence of insect pests was found in the faeces. The study identified Blackcaps (*Sylvia atricapilla*) and Lesser-Whitethroats (*Curruca curruca*) as promising pest control agents in the date plantations, while Red-throated Pipits (*Anthus cervinus*), Yellow Wagtails (*Motacilla flava*), and Barn Swallows (*Hirundo rustica*) were effective in the field crops. Although migratory birds cannot fully manage pest populations alone, they have the potential to complement IPM approaches, especially in field crops, though the assessment about their effectiveness is limited by unknowns in migration behaviour and their annual variations.

In the following this report consists of an adapted version of the Master thesis (data has not been published yet, we are planning on doing so in 2025).

Master Thesis:

**Using audio lures as a tool for Integrated Pest Management (IPM) in desert agriculture: How farmers can call help from migratory birds to control insect pests.**

Submitted by Nicolas Jakob Moritz Neumann, BSc in the framework of the Master program Wildlife Ecology and Wildlife Management in partial fulfilment of the requirements for the academic degree Master of Science Vienna, October 2024.

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## 1. Introduction

In November 2022 the world population surpassed eight billion humans (United Nations Department of Economic and Social Affairs, Population Division , 2022). The continuous growth in the world's population leads to ongoing changes in land use and is the major driver for global environmental degradation (Ramankutty et al., 2018). Producing enough food for the growing population is a challenge, leading to the use of intensive agriculture (Ramankutty et al., 2018). Since almost one-third of the total land area is covered by agricultural fields (FAO, 2023), intensive agriculture is one of the main threats to the global biodiversity and ecosystem functions (Chagnon et al., 2015; Dawoud et al., 2017; Raven & Wagner, 2021). Pesticides in intensive agriculture threaten biodiversity and ecosystems, not only on a local but also on a global scale (Geiger et al., 2010; Hallmann et al., 2014; Kennedy et al., 2013). The natural pest control is greatly reduced in such artificial landscapes (Bianchi et al., 2006). Thus a major challenge for farmers who are growing the crops to feed the world population is the high prevalence of pests, a result of this ecosystem changes that accompany the large-scale monoculture cultivation (Oerke, 2006). Insect pests cause significant crop losses globally by directly damaging crops and spreading plant diseases (Douglas, 2018). The global loss in the most important crops due to insect pests is estimated by Dhaliwal et al. (2015) to average 13.6% but varies by crop and can reach up to 20.7% in rice. This crop loss is expected to increase further due to the global warming, which accelerates the metabolism and population growth rates of insect pests (Deutsch et al., 2018). To prevent farmers from suffering even greater massive losses, various protective measures are employed. The most common measure is the use of pesticides, including herbicides, fungicides, and insecticides of all kinds.

Many experts believe that the use of chemical insecticides is a major contributor to the worldwide decline in insect populations that contribute to the biodiversity crisis as well as to the loss of ecosystem functions (Dar et al., 2021; Vanbergen et al., 2013 ;Wagner, 2020). To mitigate species extinction, it is necessary to change some fundamental agricultural practices without jeopardising global food security or economic feasibility. One potential solution might be to enhance ecosystem functions that support the natural enemies (antagonists) of these pests. Among the potential natural enemies, birds stand out as a promising option due to their diverse range of insect prey, mobility, and the substantial amount of invertebrate food they consume on a daily basis (Kirk et al., 1996; Nyffeler et al., 2018). Many other studies have already investigated breeding bird populations as part of an integrated pest control management (IPM) in different crops (Garcia et al., 2020; Garfinkel et al., 2022; Jedlicka et al., 2017; Orłowski et al., 2014). These IPMs try to use multiple tactics to optimise the control of pests in an ecological and economically sound manner (Ehler, 2006). However, certain regions of the world are crucial corridors for bird migration, where the seasonal high abundance of migratory birds offer an even greater potential for guided, yet natural, pest control. Very little research has been conducted on migratory birds as pest control so far, but this approach might have the potential to reduce reliance on insecticides. Moreover, reducing insecticide use would offer additional benefits by creating better conditions for other beneficial antagonistic insects, which can also act as natural pest control agents (Geiger et al., 2010; Hidrayani et al. 2005). One of these areas known for the high abundance of migratory birds is the Arava Valley in southern Israel, where our study is conducted (Zduniak et al., 2013).

In this study, we investigated migratory birds as additional biological pest control approach in combination with the sedentary bird species in various agricultural areas, aiming to reduce the need for insecticides. These approaches of biological pest control can then be integrated into IPM protocols. The surveyed crops included dates, melons, and onions, which are three of the main crops in this region. We investigated the technique of using audio lures in order to attract migratory birds to the crops and collected faecal samples from some birds to examine whether they were feeding on crop pest species with DNA analyses. This study encompasses data collected over three years of research and aims to answer the following questions: (I.) Can audio lures be used as a tool to attract migratory insectivorous birds to field crops and date plantations?, (II.) What other factors influence the abundance of birds in date plantations?, (III.) Does the diet of birds include insect pests related to the crops?, and last (IV.) What are the most promising pest control bird species? We hypothesise that audio lures can be used as a tool to attract migratory birds to the crops where they function as a natural pest controller without negatively impact the local bird communities.

## 2. Methods and study area

### 2.1. Research area and included surveys

All survey areas are in southern Israel (HaDarom), near Eilat (Figure 1). They are all in the Arava Valley with a maximum elevation of 110 m above sea level. This area is known as a main bottleneck for many migratory birds moving from their wintering grounds in Africa to their breeding grounds in Europe and Asia (Buechley et al., 2018; Zduniak et al., 2013). The climate is hot arid, with an average annual precipitation of 32 mm (Goldreich & Karni 2001). Due strong irrigation efforts, the area is widely used for agriculture purposes. The crops are mainly seasonal, such as vegetables and flowers, but also include palm plantations and vineyards (Oren et al., 2004). To investigate whether birds could be attracted to agricultural areas, data were collected in spring 2023 at two date plantations belonging to Kibbutz Elifaz and Kibbutz Samar which are two settlements in the region. Dates are farmed in date plantations with approximately 10-15m high palm trees evenly spaced in rows, with a distance of 10 m between each tree. The dataset was supplemented with three unpublished datasets from previous years of data collection and different agricultural sites. One additional dataset was collected in autumn 2021 in melon fields of Kibbutz Ketura and Kibbutz Grofit. Melon fields in Israel are cultivated in fertile, well-drained soils with ample sunlight and irrigation. The harvesting period of this crop in Israel is generally in autumn. We collected another dataset in autumn 2022 in the onion fields of the kibbutzim Eilot, Grofit, and Yotvata. Onion fields in Israel are agricultural habitats typically cultivated in well-irrigated soils under sunny conditions. The harvest time of this crop in Israel can be year-round, but in the surveyed areas, it is in late autumn. We collected the third dataset in spring 2022 at the same date plantations as the survey 2023. The dataset from the 2023 date plantation was exclusively recorded for this study, while the others were utilised to explore similar research questions using audio lures and faecal collection and thus can also be employed in our study, albeit with slight methodological variations.

### 2.2. Bird countings with audio playbacks

#### 2.2.1. General research design

Our study includes datasets from several surveys. The following part will elucidate the gen-

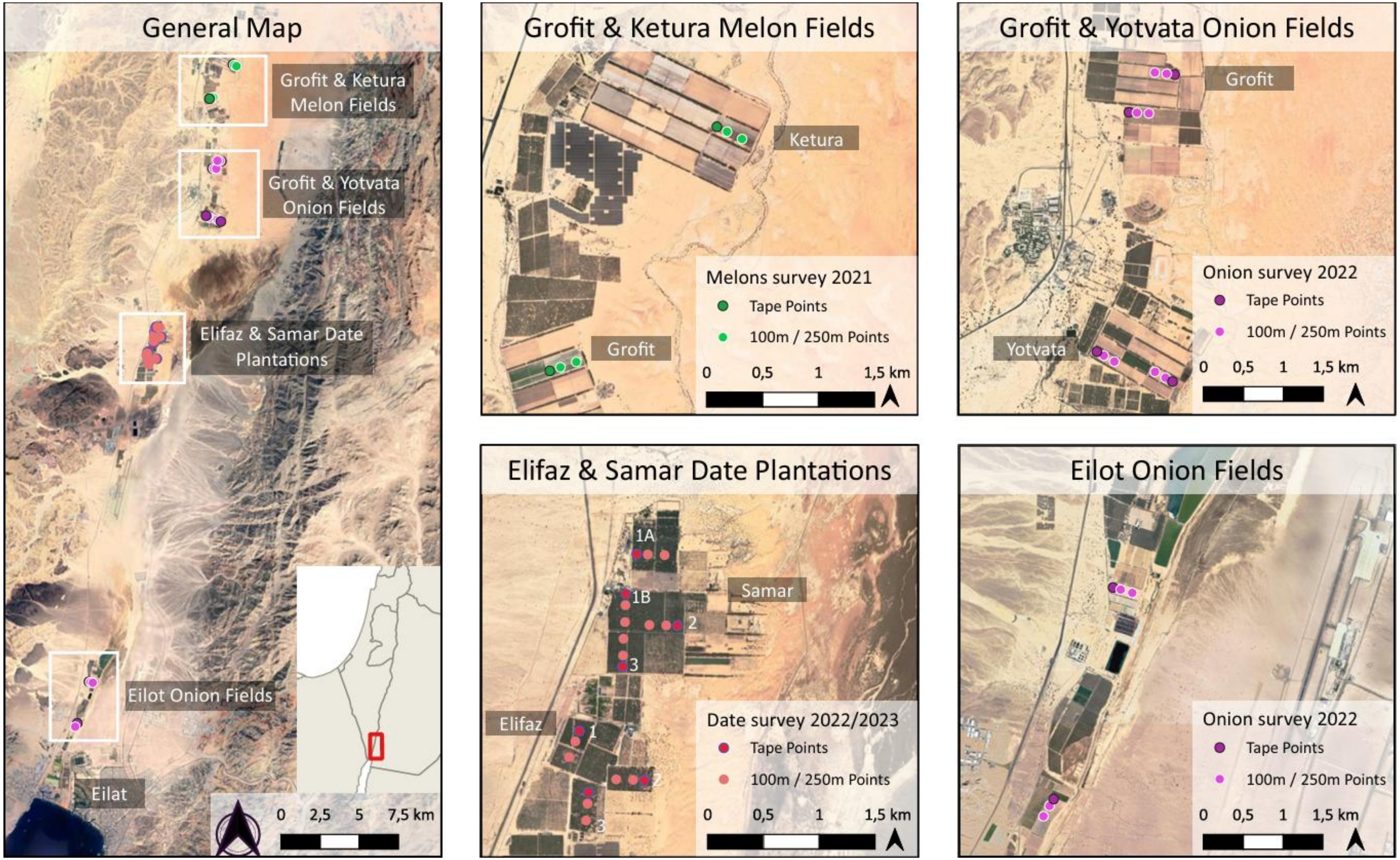


*Figure 1: Map of all crops surveyed in this study. On the left, a general map provides an overview of the distribution of the different crops. Map data ©2015 Google.*

eral similarities of the research design, while the subsequent subchapters will address the differences.

We used audio playbacks of bird songs as audio lures attract target bird species to our research areas. This was consistent throughout the data collection for all years in all crops. This method has already proven efficient in many other surveys (Schaub et al. 1999, Smith & Achuff 2020). In our study we tested if this method also enhances the abundance of insectivorous migratory birds in the agricultural areas at the point count locations of our study. The focus in the project was on the migratory birds. However, for the purpose of our study, it is informative to investigate the potential effect on the sedentary bird population as well. We used the point count method to collect data about bird abundance and species richness with and without audio lures. The point-stop count, during which the researcher collected data of on bird abundance at each point, lasted for 5 minutes each, following common methodological standards (Südbeck et al. 2005). To investigate the influence of the audio lures on the abundance of the migratory birds across our entire study region, three point counts were implemented at each survey location. One was located at the playback ("tape point”), the second at a distance of 100 m from the playback and the last one was 250 m away. The minimum distance between the different locations with playbacks was at least 500 m. For orientation in the date plantation we wrapped purple tape around one date palm next to the point count beforehand. At the point count location the abundance and species richness of all birds in the point count radius of 40 m were counted with the help of binoculars and by listening. Birds that were merely observed while flying overhead or heard calling from afar with no apparent connection to the audio lure were not counted. The point counts always began around sunrise. The starting point was always at the tape point, but the first location inside the surveys was switched every survey day. For data entry, we used the ArcGIS Survey 123 application. The recorded data differed between the surveys and will be elucidated in the following chapters. The bird song species used for the audio lures differed between the weeks and were adapted to the migratory peaks of the most common migratory bird species known to rest in the respective examined field. The species were all selected based on the ringing data collected by the local expert Noam Weiss who leads the nearby "Birding and Research Center Eilat". Countings were only conducted when the wind speed was less than 25 km/h and when it was not raining, allowing for accurate observsations without weather-related interference..

### 2.2.2. Audio playbacks

We used different playbacks with various setup details for each survey. The song species combination for the audio lures of the two date plantation surveys (2022 & 2023) varied over the season and consisted of ten different species (Table 1). In 2022, we used three "Miracase MBTS800" speakers , and in 2023, we used three larger speakers (one "RichTech RT-12V" and two "DOME DM-3015") for playing the bird songs. The speaker size was enhanced in 2023 as we assumed that the efficiency can be increased by bigger speakers. To enhance the sound range of the speakers in the date plantations, we set up the small ones hanging on trees, and the larger ones standing on chairs. The audio lures started in 2022, at the latest 30 minutes before sunrise, and in 2023, at the latest 60 minutes before sunrise, and continued until the last count of the survey day was finished. For the onion fields, we used only one song species (Table 1) and the speaker model "Miracase MBTS800". The speaker was placed on the ground

| **DATE** | |
|---|---|
| **Week** | **Song Species** |
| 1-2 | Common Chiffchaff (*Phylloscopus collybita*), Lesser Whitethroat (*Curruca curruca*), Bluethroat (*Luscinia svecica*) |
| 3 | Common Chiffchaff (*Phylloscopus collybita*), Lesser Whitethroat (*Curruca curruca*), Eastern Bonelli's Warbler (*Phylloscopus orientalis*) |
| 4 | Common Chiffchaff (*Phylloscopus collybita*), Lesser Whitethroat (*Curruca curruca*), Eastern Bonelli's Warbler (*Phylloscopus orientalis*), Tree Pipit (*Anthus trivialis*) |
| 5-7 | Lesser Whitethroat (*Curruca curruca*), Eastern Bonelli's Warbler (*Phylloscopus orientalis*), Tree Pipit (*Anthus trivialis*), Blackcap (*Sylvia atricapilla*) |
| 8 | Lesser Whitethroat (*Curruca curruca*), Tree Pipit (*Anthus trivialis*), Blackcap (*Sylvia atricapilla*), Willow Warbler (*Phylloscopus trochilus*) |
| 9-10 | Blackcap (*Sylvia atricapilla*), Garden Warbler (*Sylvia borin*), Eastern Olivaceous Warbler (*Iduna pallida*) |
| **Onion** | |
| **Week** | **Song Species** |
| 1-4 | Red-throated Pipit (*Anthus cervinus*) |
| **MELON** | |
| **Week** | **Song Species** |
| 1-3 | Yellow Wagtail (*Motacilla flava*), Barn Swallow (*Hirundo rustica*) |
| 4 | Yellow Wagtail (*Motacilla flava*), Red-throated Pipit (*Anthus cervinus*) |

*Table 1: List of the song species that were used for the audio lures in the date plantations, onion fields, and melonfields*

and activated a few minutes before sunrise. The setup and the activation time for the speaker in the melon fields was similar to the onions but included two different combinations of four different bird species instead of one (Table 1). All speakers in every survey were set to full volume.

### 2.2.3. Date plantation surveys

We conducted the surveys in the date plantations in spring. The date plantations belong to the two kibbutzim Elifaz and Samar. We chose the two different date plantations purposely as they mainly differ in management and cultivation methods and we assumed that this effects the efficiency of the bird luring. Kibbutz Samar prioritises ecological values such as reduced pesticide use, no herbicide use, which results in a higher amount of shrubs and reeds between the date palms and around their trunks. The undergrowth vegetation is only pruned a few times a year but is never completely removed. The Kibbutz Elifaz manages the plantation conventionally with normal pesticide use and almost no other plants between the date palms. Herbicides, as well as physical means, are used to clear the ground. We chose six locations in these date plantations and surveyed them over two years (2022 & 2023), whereby one location (1B) had to be replaced in 2023 as at the original location (1A) the date trees were cut down at the end of 2022 (Figure 1). The three northern locations are in the plantation of Kibbutz Samar, and the southern three are in the plantation of Kibbutz Elifaz. The fieldwork was done by different people in each of the two years, with no changes in researchers occurring within the same year.

The research designs of the two surveys in the date plantations are very similar, and thus, the methods are described together. We spread the point counts over the migration season before each crop was harvested. In both years of the date plantation surveys, we used ten weeks of the main spring migration season (between the 01.03. - 15.05.) for the data collection. The surveys consisted of survey days with active playback and of survey days without active playback. On every day of the surveys with active playbacks, we implemented two rounds of counting, with a break of at least one hour between the two counting rounds. We did this in order to monitor the different daily activity periods of the birds, as well as to obtain a more reliable counting result and to count birds that were attracted later by the audio lures. On one day with active playbacks, we could process a maximum of three locations with three counting points each. Up to two days before the actual point counts with the audio lures, we conducted a control count. This short period between the bird counts and the control counts aims to minimise changes in the current migratory bird population being monitored. At the control count we surveyed only the tape points, and thus we could do them all on one day. In 2022, the control count included only one round, and in 2023, we conducted two rounds. While each point count, we noted the vegetation stratum (canopy, attached, trunk, and ground) in which the bird was located. In 2022, we compiled only the total number of birds for each vegetation stratum, whereas in 2023 we recorded also the maximum abundance of bird individuals per species per point. To obtain the total counts for the bird abundance per species per point in 2022, we combined the stratum count with the highest abundance of each species with the approximated mean of the other counts in the different strata. It was necessary to walk a little bit around the trees to spot the birds in the canopy and bushes around the trunk. The surveys were conducted in 2022 by two individuals with lesser ornithological experience, while a more experienced researcher conducted the studies in 2023 alone.

In addition to the maximum number of birds of each species that we detected, we compiled a collection of several abiotic factors. This included the round of counting, the number of minutes that passed since sunrise, the wind speed, the amount of available water, the amount of undergrowth vegetation around the trees, and if there was additional shelter for the birds. To take account for the bird activity peak in the morning, accompanied by better detectability of those, we recorded the minutes after sunrise when the five minutes counting starts for each count as well as the number of the round of counting. We estimated the wind speed in the field and categorised it into three groups (non, light and medium). We defined wind, as soon as it became sensible on the skin, as “light”. Any wind speed higher than approximately 15 km/h (as soon as the branches of the palms started to move), we defined as “medium”. If there was no noticeable wind, we classified the wind speed as “non”. The amount of available water was categorised into three different classes. If there were puddles or wet soil areas from recent rainfalls, we considered the water availability as “intensive”. If the water came solely from the date plantation irrigation system or if the irrigation system was active during the count, we considered the water availability as “temporary”. If there was no available water, we classified the water availability as “non”. We monitored and categorised the undergrowth vegetation into three classes as well. We considered it as “intensive” when it was dense enough to provide a proper cover for birds and was higher than approximately 1.5 m. We considered it as “sparse” if there were only a few bushes or a scarce reed belt around the trunks, providing limited hiding places for birds. If no hide existed at all the undergrowth we assessed the vegetation class as “non”. We defined the existence of shelter (“yes” or “no”) by the existence of a hedge, windbreaks, or a row of bushes within (< 100 m) to the counting point.

### 2.2.4. Onion field survey

In 2022, six locations in six onion fields belonging to three different kibbutzim were surveyed. The two northern locations belong to the Kibbutz Grofit, the two southern locations belong to the Kibbutz Yotvata, and the two locations in the far south near Eilat belong to the Kibbutz Eilot (Figure 1). All kibbutzim farmed their fields using similar methods. We spread the counting over 13 days in four weeks in the main migration period in autumn (11.10.-10.11.2022), whereby we surveyed every location five times. The gaps between the counting time depended on the weather conditions. We made every second counting day without active playback. Each counting day consists of two counting rounds and an additional third round without playback if the playbacks were activated in the other two rounds before. We implemented this third round to test the if the lured birds stay after the playbacks are turned off.

In addition to the maximum number of birds of each species that could be detected, we compiled a collection of several abiotic factors. This includes the number of the round of counting, the number of minutes that passed since sunrise, the amount of available water, the intensity of the wind, and whether there was shelter for the birds. To account for the peak bird activity in the morning, accompanied by better detectability, we recorded the minutes after sunrise when the five-minutes counting starts as well as the number of the counting round. We classified the amount of available water and the wind speed as in the date plantation in chapter 2.2.3. We represented the existence of shelter as a binary variable (yes or no) and defined it by the presence of structures like bushes or trees close enough to the counting point and dense enough to provide a hide from predators for the lured birds.

### 2.2.5. Melon field surveys

In the melon fields, we surveyed two different locations in two different kibbutzim in the autumn 2021, right before the melons were harvested. The northern location belongs to the Kibbutz Ketura and the southern location belongs to the Kibbutz Grofit (Figure 1). Both kibbutzim farm their fields with similar methods. We executed the counting for this dataset over four days spread across the time period of the 15$^{th}$ of September to the 16$^{th}$ of October. Between the first and second counting days was a gap of two weeks due to time constraints, but afterwards, the gap between the counts was always approximately one week long. On each counting day, we surveyed both locations three times. The first two times were with active playback, and the last round was without active playback. We implemented this third round to test the if the lured birds stay after the playbacks are deactivated.

In addition to the maximum number of birds of each species that could be detected, we compiled a collection of several abiotic factors in this project as well. This includes the number of the round of the counting, the number of minutes that have passed since sunrise, the amount of available water, and whether there was shelter for the bird. To take into account the peak bird activity in the morning accompanied, by a better detectability, the minutes after sunrise that have passed when the five-minutes counting starts are recorded. We classified the amount of available water as in the date plantation in chapter 2.2.3. We defined the existence of shelter like in the onion field chapter 2.2.4.

## 2.3. Faeces collection

To analyse whether the diet of birds contained insect pests related to the crops, we collected faeces of the birds during the melon field survey in 2021 and during the two date plantation surveys in 2022 and 2023. We conducted mist netting to trap the birds and collect their faeces (Karr, 1981). Mist netting involves setting up fine, nearly invisible nets in bird habitats, where bird inadvertently fly into the nets and become entangled. Researchers then carefully extract the birds, collect data, and release them unharmed. We implemented the trapping once every survey week in all surveys. For the trapping of birds for the date surveys, we used mainly the date plantation of Samar. Only on one occasion in the 2023 survey, we additionally used the date plantation of Elifaz, as we assumed that this plantation has better chances of obtaining samples of bird species that were underrepresented in the sample collection so far. We positioned three 18 m long mist nets, with a height of 1.5 m in the melon fields and 3 m in the date plantations, in a U-shape around an active playback during the point counts. We set up all nets before sunrise. To ensure that the birds fed in the date plantations long enough to detect the local insects in the faeces, we remained the nets closed until about two hours after sunrise. In the melon fields, we started the trapping with the point counts at sunrise. We closed the nets upon finishing the last round of point counts of the day. One person always stayed close to the open nets and checked them at least every 15 minutes. If we caught a bird in the net, we extracted it from the net and placed it then directly into a small sterile cloth bag and left it inside for a maximum of 30 minutes. As soon as the birds deposited faeces into the bags, they were all ringed by a licensed and trained ringer who was in charge of the trapping. The ringer collected relevant ringing data before the birds were released immediately afterward. We collected the faeces dropping with the help of sterile tweezers out of the cloth bag and placed it into a labelled Eppendorf vial containing approximately 1 ml of 100% ethanol. Every tool that we used for the faeces collection was sterilised with 70% ethanol between each use. We placed the samples promptly into a -20 °C freezer after each ringing session. We cleaned the small cloth bags and washed them in a washer at 90 °C after each use.

## 2.4. Metabarcoding

We conducted all subsequent preparation and analysis at the "Dead Sea & Arava Science Center" in Masada. First we cleaned the collected faecal samples of the ethanol in which they were stored. This step is necessary to avoid interferences in the subsequent procedures. To clean the samples of ethanol, we centrifuged them first for three minutes at 5000 xg and 4 °C, and the ethanol floating on the top was then removed by pipetting. After this step, we added 0.5 millilitre of PBS (phosphate buffer saline), and centrifuged the sample one more time before removing the top liquid layer again. We repeated this step once more before another 0.5 millilitre of PBS were added and the samples were weighted in order “normalise” them.

For the DNA extraction, we used the DNeasy® PowerSoil® Pro Kit, and the procedure followed the manufacturer's protocol. As it involved a liquid solution, we used 100 µl for extraction instead of 250 mg of soil. After completing the DNA extraction, we proceeded with the PCR following the Illumina library preparation protocol. This involved two cycles of PCRs with one "cleaning" step after each PCR cycle. For the cleaning we used magnetic beads (AMPure XP® beads -Beckman Coulter) to clean the samples, isolating the resolved DNA. For 45 µl of PCR product 36 µl of beads were used. Each PCR reaction contained 2 µl of the template DNA, 9 µl of molecular biology-grade water, 12,5 µl KAPA HIFI HotStart Readymix, and 1.5 µl of equal v/v mixed primers. Primer selection followed the recommendations of Alberdi et al. (2017). The primers used for the first PCR were F1_ZBJArtF1c and R1_ZBJArtR2c as well as the overhang primers of the same. For the second PCR the primers F1_515F, and R1_806 were used. The machine settings of the SimpliAmp Thermal Cycler for the two PCR reactions (PCR1 & PCR2) followed the laboratory’s recommendation (Table 2).

After the two PCRs using the Illumina iSeq 100, we used the Quant-iT™ PicoGreen® dsDNA Kit to quantify the double-stranded DNA. We followed manufacturers protocol for this procedure.

| **PCR1** | | | | |
|---|---|---|---|---|
| **Stage** | **Step** | **Temperature** | **Time** | **Cycles** |
| 1 | Initial denatura-tion | 98 °C | 120 sec | 1 |
| 2 | Denaturation | 98 °C | 10 sec | 35 |
| | Annealing | 61 °C | 15 sec | |
| | Extension | 72 °C | 35 sec | |
| 3 | Final extension | 72 °C | 300 sec | 1 |
| | Holding | 4 °C | - | |
| **PCR2** | | | | |
| **Stage** | **Step** | **Temperature** | **Time** | **Cycles** |
| 1 | Inital denatura-tion | 95 °C | 180 sec | 1 |
| 2 | Denaturation | 98 °C | 20 sec | 8 |
| | Annealing | 55 °C | 15 sec | |
| | Extension | 72 °C | 15 sec | |
| 3 | Final extension | 72 °C | 60 sec | 1 |
| | Holding | 4 °C | - | |

*Table 2: Settings for the SimpliAmp Thermal Cycler for the two PCRs.*

To analyse and conduct quality control metrics on the forward and reverse sequence files obtained from the fluorescence microplate reader, we utilised the program RStudio (Version 2023.3.1.446). To enhance the quality of the data, the DNA sequence data underwent filtering and trimming. We retained only bases with a minimum Phred Quality Score of 3. Additionally, we trimmed 20 bases from the end of each sequence string to eliminate the low-quality region in the beginning of a sequence. We accepted sequences with a minimum length of 100 after trimming. Any sequences falling below this threshold was removed from the dataset. We performed error correction only on errors found in a maximum of 20 sequences. Following the removal of duplicate sequence reads from the forward and reverse sequence files, we employed the DADA2 algorithm to process and denoise the sequence data. Finally, we identified chimeric sequences and removed using the consensus-based method.

We examined the results of the DNA extraction in an excel table for the most important pest species (insects and arachnids) affecting dates in Israel. These species were selected based on

*Table 3: List of relevant pest species (insects and arachnids) in the date plantations of Israel, along with their taxonomy. This list was used for DNA comparison following the extraction of DNA from the faecal samples. Pests assessed by the farmers as particularly important are marked in bold letters.*

| ORDER | FAMILY | GENUS | SPECIES | ENGLISH NAME |
|---|---|---|---|---|
| Acrididae | Orthoptera | Schistocerca | gregaria | Desert Locust |
| Coleoptera | Curculionidae | Rhynchophorus | ferrugineus | Red Palm Weevil |
| **Coleoptera** | **Nitidulidae** | **Carpophilus** | **hemipterus** | **Dried-fruit Beetle** |
| **Coleoptera** | **Nitidulidae** | **Carpophilus** | **mutilatus** | **Confused Sap Beetle** |
| **Coleoptera** | **Nitidulidae** | **Urophorus** | **humeralis** | **Pineapple Beetle** |
| Coleoptera | Scarabaeoidae | Oryctes | agamemnon | Rhinocerus Beetle |
| Coleoptera | Scolytidae | Coccotrypes | dactyliperda | Date Stone Beetle |
| Coleoptera | Silvanidae | Oryzaephilus | mercator | Merchant Grain Beetle |
| Hemiptera | Diaspididae | Parlatoria | blanchardi | Parlatoria Date Scale |
| Hemiptera | Pseudococcidae | Dysmicoccus | brevipes | Pineapple Mealybug |
| Hemiptera | Tropiduchidae | Ommatissus | lybicus | Dubas Date Bug |
| **Lepidoptera** | **Batrachedridae** | **Batrachedra** | **amydraula** | **Lesser Date Moth** |
| Lepidoptera | Pyralidae | Aphomia | sabella | Greater Date Moth |
| Lepidoptera | Pyralidae | Cadra | figulilella | Raisin Moth |
| Lepidoptera | Pyralidae | Ectomyelois | ceratoniae | Carob Moth |
| **Trombidiformes** | **Tetranychidae** | **Eutetranychus** | **palmatus** | **Date Palm Mite** |
| **Trombidiformes** | **Tetranychidae** | **Oligonychus** | **afrasiaticus** | **Old World Date Mite** |

input from local farmers and reference to a published paper listing the key pest species in date plantations in Israel (Blumberg, 2008). We compared the DNA data with pest DNA data from the BOLD Sys-tems (Barcode of Life Data Systems). For the lesser date moth (*Batrachedra amydraula*), we collected larvae in the nearby Kibbutz Ne'ot Semadar to obtain additional DNA data for this pest species. The final list of species examined includes a total of 17 species considered potentially relevant, with six of these species identified as important pests by the farmers (Table 3).

For the melon fields we considered only insect pest species that were named by the farmers as relevant. The list (Table 4) contains two species and one genus (Aphis) that comprise a broad spectrum of species which are considered by the farmers and local expertsas pest species in the melon fields.

| ORDER | FAMILY | GENUS | SPECIES | ENGLISH NAME |
|---|---|---|---|---|
| Diptera | Tephritidae | Dacus | ciliatus | Curcubit fly |
| Hemiptera | Aleyrodidae | Bemisia | tabaci | Silverleaf whitefly |
| Hemiptera | Aphididae | Aphis | spec | "Aphis" |

*Table 4: List of relevant pest species in the melon fields of Israel, along with their taxonomy! This list was used for DNA comparison following the extraction of DNA from the faecal samples.*

## 2.5. Statistical analysis

We entered and edited all data sets in Microsoft® Excel®, and analysed them in RStudio (Version 2023.3.1.446). To investigate the research questions, we analysed the onion data, the melon data, the two date plantation data separately, and a combined dataset including both years from the date plantation. We pooled bird counts into two groups "migratory birds" and "sedentary birds". Due to a disproportionally high number of low counts, we did not expect normal distribution for most of the datasets, but each dataset was assessed using QQ-Plots (Quantile-Quantile-Plot). To gain an initial clear overview of the data we conducted a few mean comparisons. With a Wilcoxon test for paired samples, we examined the mean bird number of sedentary and migratory birds at the tape points with active and inactive playbacks for statistically significant differences. We could not use the melon fields data for this part of analysis, as we did not conducted control counts with inactive tapes. Additionally, with the Friedman test, we examined the number of sedentary and migratory birds at the different distances (tape, 100 m, and 250 m) for any statistically significant differences.

We conducted the same statistical analyses to determine which bird species are the most promising pest control agents. Counts for every species that was lured by a playback were compared at the tape points with active and inactive playbacks, and additionally, we conducted a comparison of differences of the counts on the different distances (tape, 100 m, and 250 m). Statistical significance we checked again with the Wilcoxon test for paired samples and the Friedman test.

To check the effect of the variables on the number of lured bird individuals, we applied LMMs (Linear Mixed Models) and GLMMs (Generalised Linear Mixed Model) depending on the distribution of the dependent variable. To accomplish this, we applied the model functions from the R package lme4. The dependent variable is the number of bird individuals and is split into the number of migratory and the number of sedentary birds. We analysed the date surveys individually and once together with "year" as an additional predictor. This was conducted to discuss the differences of the two date surveys, such as the changed location (1A and 1B), different migration intensity, researchers, type of speaker, time management, and general weather condition. To determine the distribution of the data, we used the 'descdist' function from the 'fitdistrplus' package in R. To ensure the robustness of the result we performed the analysis with 2500 bootstrap samples. For the datasets of the migratory bird counts we expected a disproportionally high number of low counts. To be able to describe the distributions of the data using a classical distribution (normal, Poisson, and negative binomial), we removed a minimal number of outliers when necessary. In case of a normal distribution, we used QQ-Plots additionally to ensure a sufficient fit of the distribution. We used the location of the survey tape points as well as the week of the counting as random effects in the model. In addition to checking multicolinearity using the model function itself, we used the Variance Inflation Factor (VIF) to test for multicollinearity among the predictors. A VIF value of under five was considered as tolerable. We checked the assumption of normal distribution of the residuals and the normal distribution of the random effects by QQ-Plots, though only strong violations of these assumption were considered relevant, as current studies have revealed that mixed models are quite robust against a violation of this assumptions (Schielzeth et al. 2020). If we detected multicollinearity, the “higher level” predictor or the predictor that gave the model a better AIC (Akaike Information Criterion) was kept, and the other predictor was re-moved. We selected the best model for describing the coherence using AIC selection. After-wards we describe the results of the models in the result section.

# 3. Results

## 3.1. General overview

In the date plantation surveys in 2022 and 2023, we performed a total of 900 point counts (Table 5). Of these, 480 point counts were made in 2023 and 420 in 2022, as only one control count at each tape point was conducted in the first year, compared to two counts in the following year. The data from the date plantations included 13,702 counted individuals, with 7,403 individuals observed in the 2022 survey and 6,299 individuals in the 2023 survey. Across both surveys, we observed a total of 65 species, with 55 species detected in in 2022 and 39 in 2023. For the onion fields survey in 2022, we conducted a total of 224 point counts recording 2,806 bird individuals of 59 species. Lastly, the melon field survey in 2021 included 69 point counts, with 1,024 individuals of 22 species observed.

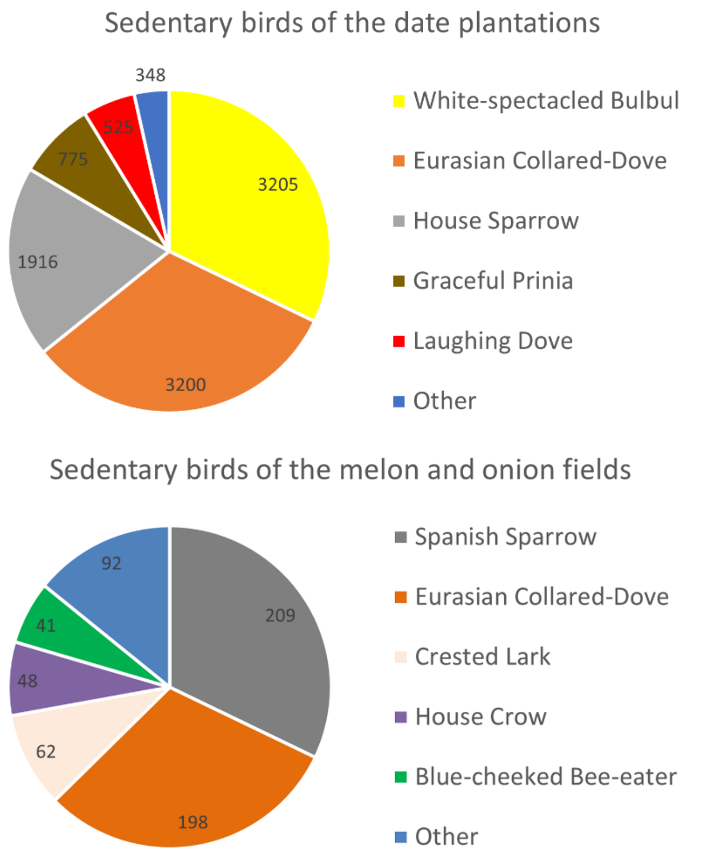


*Figure 2: Species composition of sedentary birds in both date surveys combined (above) and in the onion and melon surveys combined (below). The latter are combined as they provide similar bird habitats.*

| Survey | Point count number | Species diversity | Number of individuals | Number of migratories | Number of sedentaries |
|---|---|---|---|---|---|
| Date 2022 | 420 | 55 | 7,403 | 3,009 (41%) | 4,394 (59%) |
| Date 2023 | 480 | 39 | 6,299 | 724 (11%) | 5,575 (89%) |
| Date combined | 900 | 65 | 13,702 | 3,733 (27%) | 9,969 (73%) |
| Onion 2022 | 225 | 59 | 2,809 | 2,253 (80%) | 556 (20%) |
| Melon 2021 | 69 | 22 | 1,024 | 925 (90%) | 99 (10%) |

Table 5: Overview of the number of point counts, the diversity of observed species and the abundance of total counted individuals, number of total counted migratories, and number of total counted sedentaries for each survey and for the both date surveys combined.

The proportion of sedentary birds compared to migratory birds was higher in the date plantations than in the melon and onion crops (Table 5). In both date plantation survey years, sedentary birds comprised over 70 % of the total bird abundance. The migratory species composition consistent mainly of the species that we lured with the playbacks. The sedentary populations were dominated by a few species (Figure 2), such as the White-spectacled Bulbul (*Pycnonotus xanthopygos*), Eurasian Collared-Dove (*Streptopelia decato*), House Sparrow (*Passer domesticus*), Graceful Prinia (*Prinia gracilis*), and Laughing Dove (*Spilopelia senegalensis*). In contrast to the date plantations, in the combined field crops, sedentary bird species accounted for slightly less than 20% of the total abundance and were dominated by a few species, such as the Spanish Sparrow (*Passer hispaniolensis*), Eurasian Collared-Dove (*Streptopelia decato*), Crested Lark (*Galerida cristata*), House Crow (*Corvus splendens*), and the Blue-cheeked Bee-eater (*Merops persicus*).

## 3.2. Audio playback as a mean to attract birds

The results for the total abundance of migratory and sedentary birds at the point counts with active and inactive tapes are reflected in Table 6 (Wilcoxon test). The datasets of the abundance of lured birds in the onion fields showed no significant differences between the points with active tape, neither for migratory bird species nor for sedentary birds. The abundance of sedentary birds in the date plantations in 2022, was significantly higher ($p < 0.001$) with inactive playback. The migratory bird species were less abundant, but this difference was not significant. On the contrary, in 2023 the we observed that for both migratory and sedentary birds, active playbacks caused a higher abundance of birds. This was significant only for migratory bird species ($p < 0.01$).

| | **Total counts of migratory bird** | **Total counts of sedentary bird** |
|---|---|---|
| Date 2022: | active (10.07) < inactive (13.40) | active (12.12) **<** inactive (24.83)*** |
| Date 2023: | active (2.39) **>** inactive (1.62)** | active (12.97) > inactive (12.82) |
| Date both: | active (4.95) < inactive (5.54) | active (12.68) **<** inactive (16.82)*** |
| Onion 2022: | active (12.03) > inactive (7.20) | active (2.93) > inactive (2.33) |

*Table 6: Comparison of the abundance of lured bird individuals of all migratory bird species respectively sedentary bird species at the tape points with active and inactive playback. The mean is given in brackets and non significant differences are greyed out. The counts are not normally distributed, but the mean, due a high number of zero counts, provides a better impression of the data than the median. Levels of significance are provided for each comparison with asterisks marked as follows: p < 0.05*, p < 0.01**,p < 0.001***. Non-significant comparisons have no asterisks.*

Both datasets of the date plantations combined did not give us any statistically significant difference in the abundance of migratory birds. For the sedentary birds, the combination of both years showed a significantly ($p < 0.001$) lower abundance of birds at points with active tapes than at points with inactive tapes.

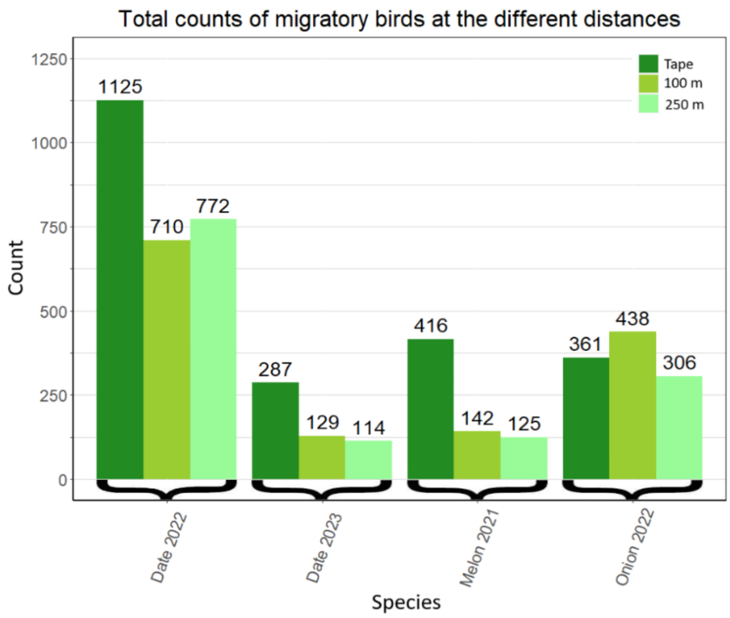


*Figure 3: Comparison of the total counts of migratory bird species at the counting points at the different distances (tape, 100 m and 250 m) for each survey with active audio luring.*

The comparison of the differences between the point count distances to the playback yielded many significant results that validate playbacks as a mean to attract the birds (Table 7 and Figure 3).

| | **BIRD COUNTS** | | |
|---|---|---|---|
| | **Migratory** | | |
| | tape vs. 100 | tape vs. 250 | 100 vs. 250 |
| Date 2022: | 9.38 > 5.92*** | 9.38 > 6.43*** | 5.92 < 6.43 |
| Date 2023: | 2.39 > 1.07*** | 2.39 > 1.21*** | 1.07 < 1.21 |
| Date both: | 5.88 > 3.50*** | 5.88 > 3.69*** | 3.50 < 3.69 |
| Onion 2022: | 12.03 < 14.60 | 12.03 > 10.20 | 14.60 > 10.20 |
| Melon 2021: | 26.00 > 8.88*** | 26.00 > 7.81*** | 8.88 > 7.81 |
| | **Sedentary** | | |
| | tape vs. 100 | tape vs. 250 | 100 vs. 250 |
| Date 2022: | 10.91 > 9.10** | 10.91 > 10.40 | 9.10 < 10.40 |
| Date 2023: | 12.97 > 9.75*** | 12.97 > 10.93* | 9.75 < 10.93 |
| Date both: | 11.94 > 9.43*** | 11.94 > 10.66 | 9.43 < 10.66** |
| Onion 2022: | 2.93 > 2.27 | 2.93 < 5.63 | 2.27 < 5.63 |
| Melon 2021: | 1.50 < 1.88 | 1.50 > 1.38 | 1.88 > 1.38 |

*Table 7: Comparison of the abundance of lured bird individuals of all migratory bird species respectively sedentary bird species at the three different distances from the tape points (tape, 100 m, and 250 m). The mean abundance of birds at each distance is in brackets. The counts are not normally distributed, but the mean, due a high number of zero counts, provides a better impression of the data than the median. Levels of significance are provided for each comparison with asterisks marked as follows: p < 0.05*, p < 0.01**, p < 0.001***. Non-significant comparisons have no asterisks and are greyed out.*

In the melon fields, the abundance of migratory birds was significantly ($p < 0.001$) higher at points with active playback than at points located further away. We observed the same significant ($p < 0.001$) results at the date plantation. For the survey points in the onion fields we did not obtain any significant results. We could not detect a significant difference in the abundance of migratory birds at the comparisons between the 100 m and the 250 m points in any crop.

The result of the counts of sedentary bird individuals fitted partly to the previous of the migratories. At all date plantation points, the abundance of birds at the points with active tapes was significantly ($p < 0.01$) higher than at the points in 100 m distance. Only in the date plantation survey of 2023, we could detect a significant difference ($p < 0.05$) between the point with active tape and the 250 m point. Both date surveys combined showed a significantly ($p < 0.01$) higher abundance of bird individuals at the 250 m point than at the 100 m point. In the melon and onion surveys, we could not detect any significant difference.

## 3.3. Audio playback effects on specific species

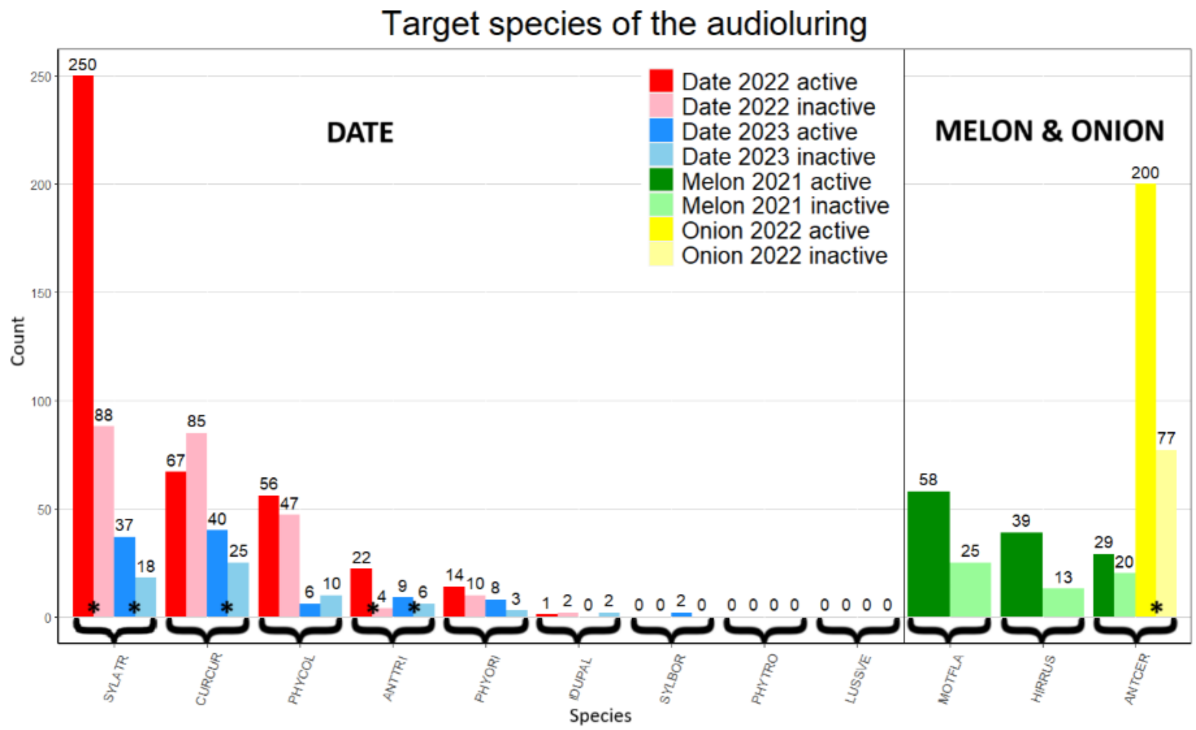


*Figure 4: Species-specific total count of the species observations at the tape points with active and inactive tape. The left part shows sums of the date plantations and the right part shows sums of the melon and onion fields. For better comparability, only counts from the first counting round were summarised for the dates. In the melon the third round was used as control count. SYLATR = Blackcap, CURCUR = Lesser Whitethroat, PHYCOL = Common Chiffchaff, ANTTRI = Tree Pipit, PHYORI = Eastern Bonelli's Warbler, IDUPAL = Eastern Olivaceous Warbler, SYLBOR = Garden Warbler, PHYTRO = Willow Warbler, LUSSVE = Bluethroat, MOTFLA = Yellow Wagtail, HIRRUS = Barn Swallow, ANTCER = Red-throated Pipit.*

The species-specific comparison of the bird abundance at the points with active and inactive tapes yielded a few significant results for the bird abundance (Table 8 and Figure 4). In the

| **Species** | **DATE 2022** | | | |
|---|---|---|---|---|
| | tape vs. control | tape vs. 100 | tape vs. 250 | 100 vs. 250 |
| *Phyl. Collybita* | 2.33 > 1.96 | 1.90 < 2.00 | 1.90 < 2.19 | 2.00 < 2.19 |
| *Curruca Curruca* | 1.40 < 1.77 | 1.58 > 0.66** | 1.58 > 1.07 | 0.66 < 1.07 |
| *Luscinia svecica* | 0.00 = 0.00 | 0.00 < 0.08 | 0.0 = 0.00 | 0.08 > 0.00 |
| *Phyl. Orientalis* | 0.47 > 0.33 | 0.55 < 0.60 | 0.55 < 0.87 | 0.60 < 0.87 |
| *Anthus trivialis* | 0.73 > 0.13* | 0.48 > 0.05 | 0.48 > 0.03 | 0.05 > 0.03 |
| *Sylvia atricapilla* | 6.94 > 2.44** | 6.72 > 3.92** | 6.72 > 3.32*** | 3.92 > 3.32 |
| *Phyl. trochilus* | 0.00 = 0.00 | 0.08 > 0.00 | 0.08 = 0.08 | 0.00 < 0.08 |
| *Sylvia borin* | 0.00 = 0.00 | 0.12 > 0.04 | 0.12 > 0.04 | 0.04 = 0.04 |
| *Iduna pallida* | 0.08 < 0.17 | 0.25 < 0.29 | 0.25 = 0.25 | 0.29 > 0.25 |
| **Species** | **DATE 2023** | | | |
| | tape vs. control | tape vs. 100 | tape vs. 250 | 100 vs. 250 |
| *Phyl. collybita* | 0.23 < 0.40 | 0.23 > 0.08 | 0.23 > 0.08 | 0.08 = 0.08 |
| *Curruca curruca* | 1.10 > 0.51* | 1.10 > 0.36 | 1.10 > 0.18* | 0.36 > 0.18 |
| *Luscinia svecica* | 0.00 = 0.00 | 0.04 > 0.00 | 0.04 > 0.00 | 0.00 = 0.00 |
| *Phyl. orientalis* | 0.37 > 0.15 | 0.37 > 0.15 | 0.37 > 0.30 | 0.15 < 0.30 |
| *Anthus trivialis* | 0.35 > 0.12* | 0.35 > 0.25 | 0.35 > 0.15 | 0.25 > 0.15 |
| *Sylvia atricapilla* | 0.96 > 0.49* | 0.96 > 0.33 | 0.96 > 0.33 | 0.33 > 0.28 |
| *Phyl. trochilus* | 0.00 < 0.33 | 0.00 = 0.00 | 0.00 = 0.00 | 0.00 = 0.00 |
| *Sylvia borin* | 0.08 > 0.00 | 0.08 > 0.00 | 0.08 > 0.00 | 0.00 = 0.00 |
| *Iduna pallida* | 0.04 < 0.17 | 0.04 > 0.00 | 0.04 > 0.00 | 0.00 = 0.00 |
| **Species** | **ONION 2022** | | | |
| | tape vs. control | tape vs. 100 | tape vs. 250 | 100 vs. 250 |
| *Anthus cervinus* | 9.50 > 3.78* | 9.50 < 10.00 | 9.50 > 7.17 | 9.50 > 7.17 |
| **Species** | **MELON 2021** | | | |
| | tape vs. control | tape vs. 100 | tape vs. 250 | 100 vs. 250 |
| *Motacilla flava* | - | 11.31 > 1.94*** | 11.31 > 1.75** | 1.94 > 1.75 |
| *Hirundo rustica* | - | 8.50 > 3.92 | 8.50 > 1.83** | 3.92 > 1.83 |
| *Anthus cervinus* | - | 15.50 > 6.25 | 15.50 > 9.50 | 6.25 < 9.50 |

*Table 8: Comparison of the species-specific efficiency of the tapes for each crop. The data from the date surveys is presented here only for each survey individually, due to species specific fluctuations in migration intensity. The left/right figures represent the mean abundance of bird individuals of the left/right column heading of each species at different counts. The comparison operators describe which mean is higher and the text is greyed out if the difference was not significant.* The counts are not normally distributed, but the mean, due a high number of zero counts, provides a better impression of the data than the median. *Levels of significance are provided for each comparison with asterisks marked as follows: p < 0.05*, p < 0.01**, p < 0.001***. Non-significant comparisons have no asterisks. The abbreviation "Phyl." stands for Phylloscopus.*

melon fields, we detected significant differences in the abundance for the yellow wagtail (*Motacilla flava*) and the barn swallow (*Hirundo rustica*). Three out of four comparisons showed a significantly higher abundance of individuals at the tape points compared to the 100 m and 250 m distances. In the onion fields, only the tape vs. control comparison showed a significantly higher abundance of red-throated pipit (*Anthus cervinus*) at the tape points. In the date plantation surveys of 2022 and 2023, only three species had significant results in at least one survey: Lesser whitethroat (*Curruca curruca*), tree pipit (*Anthus trivialis*), and blackcap (*Sylvia atricapilla*). For no species in any field type we detected a significant difference between the 100 m and 250 m point. Most counts had numerous zero values, which enabled a high number of significant results. In summary, it can be said that the species-specific counts show some significant differences, which support our assumption that certain species are attracted by the playbacks.

## 3.4. Factors influencing the abundance of birds at the counting points

To investigate the influences of the different factors on the count of migratory and sedentary birds, we applied mixed models (Table 9). For most of the data, we used GLMMs with negative binomial distributed response variable. Only for the sedentary birds in the 2023 date plantation survey and in both surveys combined the response variable showed a normal distribution, making a LMM the better choice. The bird abundance showed no linear response to the time that has passed since sunrise and also exhibited multicolinearity with the "round"

| Model | Fixed effects in the Model | AIC | BIC | Dev | $R^2$c |
|---|---|---|---|---|---|
| Date 2022 (M): | TAP+RND+WAT+WIN+KIB+SHT | 2377.3 | 2417.7 | 466.9 | 0.64 |
| Date 2022 (S): | TAP+RND+WAT+WIN+KIB+SHT | 2499.5 | 2548.0 | 431.0 | 0.59 |
| Date 2023 (M): | TAP+RND+WAT+WIN+KIB+SHT | 1496.5 | 1542.4 | 494.6 | 0.48 |
| Date 2023 (S): | TAP+RND+WAT+WIN+KIB+SHT | 2786.9 | 2841.1 | 2760.9 | 0.54 |
| Date both (M): | TAP+RND+WAT+WIN+KIB+SHT+Year | 4012.1 | 4074.4 | 971.6 | 0.56 |
| Date both (S): | TAP+RND+WAT+WIN+KIB+SHT+Year | 4840.6 | 4907.1 | 4812.6 | 0.36 |
| Onion 2022 (M): | TAP+RND+WAT+WIN+SHT | 1416.8 | 1461.3 | 245.0 | 0.46 |
| Onion 2022 (S): | TAP+RND+WAT+WIN+SHT | 861.2 | 902.1 | 211.8 | 0.29 |
| Melon 2021 (M): | TAP+RND+WAT+SHT | 484.8 | 507.1 | 79.0 | 0.49 |
| Melon 2021(S): | TAP+RND+WAT+SHT | - | - | - | - |

*Table 9: Overview of all models with the fixed effects retained after AIC (Akaike's Information Criterion) model selection shown in black, and the fixed effects that increased AIC, hence not included in the model, shown in grey. Additionally, the AIC, BIC (Bayesian Information Criterion), deviance, and R²c for each model are displayed. Abbreviations used: TAP for tape status and distance combined, RND for round, WAT for water availability, WIN: for wind intensity, SHT for shelter, KIB for kibbutz.*

| EFFECT | STUDY SITES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **DATE** | | | | | | **ONION** | | **MELON** | |
| | **migratory** | | | **sedentary** | | | **migratory** | **sedentary** | **migratory** | **sedentary** |
| | Date 2022 | Date 2023 | Date All | Date 2022 | Date 2023 | Date All | Onion 2022 | Onion 2022 | Melon 2021 | Melon 2021 |
| Year - 2023 | | | -1.460*** | | | | | | | |
| TAP - 100 m | -0.638*** | -0.626*** | -0.543*** | -0.183*** | -1.856** | -1.728*** | | | -1.119*** | |
| TAP - 250 m | -0.498*** | -0.743*** | -0.503*** | | | | | | -1.166*** | |
| TAP ctrl. - 0 m | | -0.388** | | +0.679*** | | +0.855* | -0.444* | | | |
| TAP ctrl. - 100 m | | | | | | | -0.445* | | | |
| TAP ctrl. - 250 m | | | | | | | -0.733*** | | | |
| RND - 2 | | | | -0.159*** | | -0.838** | +0.284* | | +0.474* | |
| RND - 3 | | | | | | | | -1.275*** | | |
| WAT - temporary | | -0.327** | | | -1.245** | -0.720* | | | | |
| WAT - intensive | | | | | | -3.219** | | | | |
| WIN - light | +0.285* | | +0.201* | -0.136* | | -0.881** | | -0.554* | | |
| WIN - medium | | | | -0.346** | -4.031** | -2.406** | +1.152** | | | |
| SHT - existent | | +0.714*** | +0.260* | +0.493* | +8.344*** | +4.729*** | | | -0.917** | |
| KIB - Samar | | | +0.245* | +0.460* | | | | | | |
| VEG - intensive | | | | | -0.321*** | -0.102* | | | | |

*Table 10: Results from the mixed models for each study and both date datasets combined. Only significant results are displayed. Predictor effect are shown as follows: Negative "**-**" or positive "**+**".TAP: influence of the distance (100 m and 250m) with simultaneously active playback compared to 0 m distance with active playback, TAP ctrl.: points without active playback and the different distances compared to the tape-point with active tape, RND: influence of the counting round of the day (2-3) compared to the first round, WAT: Water availability compared to no water availability, WIN: Wind intensity compared to no wind, SHT: Existent compared to no shelter and Time change since Sunrise, KIB: Kibbutz Samar with ecological exploitation methods, VEG: Vegetation density "intensive" compared to no vegetation density "sparse" in the date plantations of Kibbutz Samar. Dark grey shaded areas indicate values that couldn't be checked in the models because they weren't collected. Light grey shaded areas show indicate that only a sub-dataset could be used for this predictor. Significance levels are marked as follows: p < 0.05*, p < 0.01**, p < 0.001***.*

predictor. Therefore, the predictor “time” couldn’t be used in the model. All significant results are displayed in Table 10. Significance levels are marked as follows: $p < 0.05$*, $p < 0.01$**, $p < 0.001$***. The year 2023 of the date surveys showed a significant lower abundance of migratory birds (-1.460***), while no significant difference of the sedentary bird could be detected. The use of playback as a mean to attract migratory birds to specific locations was also validated in the models. In all date surveys, the abundance of migratory birds was significantly lower at 100 m distance (2022: -0.638***, 2023: - 0.626***, ALL: -0.543***) and at 250 m distance (2022: -0.498***, 2023: -0.743***, ALL: -0.503***) points compared to the point with active playback. In the melon survey the same was observed (100 m: -1.119***, 250m: -1.166***). Only the onion survey did not show a significant influence. Additionally, the control counts with no active playback gave us significant results in the onion crops (-0.444*) and in the date survey of 2023 (-0.388**). The control counts in the other surveys and crops did not yield any significant results.

For the influence of the playback on sedentary birds, we obtained significant results in the date surveys only, and these results were partly contradictory. At a distance of 100 m from the playback in the date plantations, the abundance of sedentary birds was significantly lower (2022: -0.183***, 2023: -1.856**, ALL: -1.728***) than at the points with playback, though no significant change in the abundance was detected at a distance of 250 m. In 2022 (+0.679***) and in the combined model (+0.855*), however, the control counts without active playback showed a significantly higher abundance of sedentary birds at the tape locations than with active playback. For the other crops, we could not detect a significant influence of the tapes on the sedentary bird abundance.

We tested the influence of time on the counting by using the round as factor and had varying effects on the bird counts. While we have not detected any differences in the abundance of migratory birds in the date plantations, the onion crops (+0.284*) and melon crops (+0.474*) showed a significantly higher abundance of migratory birds in the second round. In the date plantations, sedentary birds showed a significant response to the time of the day in the 2022 survey (-0.159***) and in both surveys combined (-0.838**) as they were less abundant in the second round compared to the first. The abundance of sedentary birds in the onion fields showed a similar result in the third round (-1.275***), being significantly lower than in the first round.

The availability of water showed a significant impact on the abundance of migratory and sedentary birds in a few models. The abundance of migratory birds was negatively impacted by “temporary” water availability only in the date survey of 2023 (-0.327**). The abundance of sedentary birds was more strongly influenced by the water availability. “Temporary” water availability significantly reduced the abundance of these birds in the survey of 2023 (-1.245**) and in the combined dataset (-0.720*). With an effect of -3.219 on the abundance of sedentary birds in both date datasets combined, the negative influence of “intensive” water availability was particularly high. The onion and the melon fields did not yield any significant result.

Wind speed had contrary effects on the abundance of migratory and sedentary birds. In the date plantation in 2022 (+0.285*) and in both surveys combined (+0.201*), a positive impact on the abundance of migratory birds was observed when the wind speed was considered as “light”. In the onion fields, this positive impact (+1.152**) on migratory bird abundance was significant only for “medium” wind speed. Conversely, “light” wind showed a significantly negative influence on the abundance of sedentary birds at the counting points in the onion survey (-0.554*) and all date surveys except the date survey of 2023 (2022: -0.136, ALL: -0.881**). At “medium” wind speed, all date plantations exhibited a mainly pronounced and significant reduction in the abundance of sedentary birds compared to countings with no wind (2022: -0.346**, 2023: -4.031**, ALL: -2.406**). In the melon fields the windspeed was not recorded.

Except for the model of migratory birds in 2022, the presence of shelter had a significantly positive impact on the abundance of migratory (2023: +0.714***, ALL: +0.260*) and sedentary birds (2022: +0.493*, 2023: +8.344***, ALL: 4.729***) in all date models. The effect on the sedentary birds in the date plantations was particularly strong. While no significant influence on bird abundance in the onion fields was observed, the presence of shelter in the melon fields had a significantly negative impact on the abundance of migratory birds (-0.917*).

The Kibbutz Samar plantation as a factor and the undergrowth vegetation density in the date plantations are predictors that show a high correlation in the models, as the existence of undergrowth vegetation is one of the main differences between the two plantations which we surveyed. Therefore, the main models only include Kibbutz Samar as a predictor to avoid multicolinearity between these predictors. We created sub-models to investigate the differences between “sparse” and “intensive” undergrowth density, using data points only from the Kibbutz Samar. In Kibbutz Elifaz, where the undergrowth vegetation was mostly absent, we could not draw conclusions regarding its influence on the bird abundance. In Kibbutz Samar, only "sparse" and "intensive" undergrowth vegetation levels were present, allowing us the investigation of these two levels only. Kibbutz Samar showed a significantly higher abundance of migratory birds only in the combined analysis (+0.245*) of both date surveys, and a significantly higher abundance of sedentary birds (+0.460*) only in the date survey of 2022. "Intensive" undergrowth vegetation density had a significantly negative impact on the abundance of sedentary birds in 2023 (-0.321***) and both surveys combined (-0.102*).

## 3.5 Results of the faecal collection and the metabarcoding

The faecal analysis did not succeed for every sample group, even though the laboratory protocol for each DNA analysis was the same. In the date survey of 2022, we collected 106 samples from 17 species, of which we could analyse only 28 samples from ten different species. In the date survey of 2023, 36 samples of seven species were collected, but from non of them we could extract enough DNA for the analysis. We detected only four of the 17 pest species in the faeces from the date plantations (Table 11), and of the six pest species that were assessed by the farmers as particularly important, we detected only two (*Carpophilus mutilanus* and *Urophorus humeralis*). We detected in seven out of 28 samples, *Caprophilus mutilanus* and *Ectomyelois ceratoniae*, highlighting their greater importance in the birds' diet. It is noteworthy that the lesser date moth (*Batrachedra amydraula*), which is according to the farmers the most concerning pest in the date plantation, was not detected. In the melon survey of autumn 2021, we collected 22 samples from seven species. We were able to analyse all the samples of this survey. In the melon fields, we detected only two species of the genus "*Aphis*". Because of a relatively low number of samples per species, we determined no clear preference by the bird species, though we can assert that some pests are consumed by the investigated birds.2021, we collected 22 samples from seven species. We were able to analyse we collected 22 samples from seven species. We were able to analyse from seven species. We were able to analyse all the samples of this survey. In the melon fields, we detected only two species of the genus "*Aphis*". Because of a relatively low number of samples per species, we determined no clear preference by the bird species, though we can assert that some pests are consumed by the investigated birds.

| Bird species | Carpohilus multilanus | Urophorus humeralis | Cadra figulilella | Ectomyelois ceratoniae | Aphis craccivo | Aphis gossypii |
|---|---|---|---|---|---|---|
| **DATE** | | | | | | |
| **ANTTRI** | 0/2 | 0/2 | 0/2 | 0/2 | | |
| **CERPOD** | **1/1** | 0/1 | 0/1 | 0/1 | | |
| **CURCUR** | **1/5** | 0/5 | **1/5** | **2/5** | | |
| **LUSLUS** | **1/1** | 0/1 | 0/1 | 0/1 | | |
| **PHYCOL** | 0/5 | 0/5 | 0/5 | **2/5** | | |
| **PHYORI** | 0/2 | 0/2 | **1/2** | 0/2 | | |
| **PRIGRA** | **1/2** | 0/2 | 0/2 | **1/2** | | |
| **PYCXAN** | **1/5** | 0/5 | 0/5 | 0/5 | | |
| **SYLATR** | **2/5** | **1/5** | 0/5 | **2/5** | | |
| **MELON** | | | | | | |
| **ACRSCI** | | | | | 0/1 | 0/1 |
| **ANTTRI** | | | | | **1/4** | **1/4** |
| **HIRRUS** | | | | | **1/3** | 0/3 |
| **LANCOL** | | | | | **1/1** | 0/1 |
| **MOTFLA** | | | | | **1/11** | 0/11 |
| **PHYTRO** | | | | | 0/1 | 0/1 |
| **RIPRIP** | | | | | 0/1 | 0/1 |

*Table 11: Detected pest species from all analysed faecal samples per analysed species. Pests of the date crops are highlighted in red, and those of the melon crops in green. The left number indicated the number of birds in whose faeces the respective pest was detected. The right number represent the number of individuals of each species that was analysed. If pests were detected in a sample of a species, the number was highlighted in bold black. Species abbreviations were as follows: ACRSCI: Acrocephalus scirpaceus, ANTTRI: Anthus trivialis, CERPOD: Cercotrichas pordobe, HIRRUS: Hirrunda rustica, LANCOL: Lanius collurio, LUSLUS: Luscinia svecica, MOTFLA: Motacilla flava, PHYCOL: Phylloscopus collybita, PHYORI: Phylloscopus orientalis, PHYTRO: Phylloscopus trochilus, PRIGRA: Prinia gracilis, PYCXAN: Pycnonotus xanthopygos, RIPRIP: Riparia riparia, SYLATR: Sylvia atricapilla, CURCUR: Curruca curruca.*

## 4. Discussion

### 4.1. Audio lures as mean to attract birds

The investigation of migratory bird abundance at the tape points indicate a significantly higher migratory bird abundance at points with active playback in several surveys. Specifically, we observed a higher abundance in the 2023 date plantation survey and in the onion field model. In the melon survey, we lacked separate control counts on different days and had only a small number of point counts during an third additional round, which limited our ability to conduct a thorough investigation of this crop. The high average migratory bird abundance at the control spots in 2022 date plantation survey contradicts our expectations and also influences the combined results when data from both surveys are included. We believe that one possible reason for this result might be the method of bird counting we used in the 2022 date plantation survey. Unlike 2023, where we compiled a total abundance per point, we recorded only the maximum abundance of birds per stratum in 2022. We attempted to estimate total bird counts for each points in the 2022 survey data, but these estimated might be skewed if birds are more mobile without speakers. Moller (1992) suggest that the playback signals to birds the absence of predators, potentially leading to reduced hiding behaviour and support this assumption. This behaviour was also observed by Johnson & Maness (2018) in their research on the response of wintering birds to playbacks, describing highly reduced movement and foraging behaviour of birds during active playbacks.

Our comparison of the migratory bird abundance at different distances also supports the idea of an observer biased control tape count. Both the mean comparison and the mixed model consistently show a highly significant attracting effect on migratory birds in every date survey. Bird abundance was consistently higher at the points with active playback compared to more distant points. Differences between the speaker sizes used in the two survey years can only be observed at the 250 m distance, where active playbacks with bigger speaker in 2023 had a significant effect on migratory bird abundance. The melon fields also demonstrate the effectiveness of playbacks with similar results. In the onion field survey, we did not detect any statistical effect of the distance to the playback on the bird abundance. While we cannot offer a clear explanation for these divergent results, several factors may have contributed to them. Firstly, in the onion field survey we used only one playback song species, the Red-throated

Pipit (*Anthus cervinus*), whereas we used between two and four song species simultaneously in all other surveys for luring with playbacks. The overall effect on the abundance of migratory species other than the Red-throated Pipit might not been pronounced enough to yield significant differences. Secondly, there may have been a “pushing effect“ on birds during the point counts. Generally, birds in open landscapes with less cover have a higher escape distance than birds in landscapes with more cover like scrubs or forests (Fernández-Juricic et al., 2001; Morelli et al., 2022). Starting point counts always at the tape point situated close to the border of the onion fields (Figure 1) could have pushed bird species ahead of the observer to the next point, resulting in higher bird abundance at subsequent counting points. This effect is more significant in field crops than in plantations, where we assume that birds are more likely to hide in palm trees rather than relocate. In summary, our study supports the attracting effect of the playbacks on migratory birds, although we could not observe significant result in all surveys. Many other studies also support higher migratory bird abundances at points with playbacks on species specific levels (Lehnardt & Sapir, 2024; McNeil et al.,2014; Smith, 2020) and on an interspecific levels (De la Hera et al., 2017; Mukhin et al., 2008).

We also observed several significant effects on the sedentary birds in the date plantations. Sedentary birds were more abundant at points with active playbacks than at distances of 100 m, suggesting that birds from a distance were attracted to the playbacks despite no use of sedentary bird songs. At a greater distance of 250 m from the playback the statistical comparisons of means in the 2023 survey showed a significantly lower abundance of sedentary birds compared to points with active playback. This indicates an elevating effect of the playbacks on the abundance of birds at the tape points. However, contrary to these results, comparisons of point counts with active playback to control counts indicated the opposite effect. For the 2022 date survey and the combined survey, control counts had significantly higher abundance of sedentary birds than points with active playback. This result is likely due to the absence of a second round of control counts in the 2022 survey where remarkably lower abundances were detected than in the first rounds. Although we accounted some of these effects by the round predictor, the model may not have sufficiently distinguished this effect from the control count predictor. Other studies have shown a negative effect of constant noise pollution, such as anthropogenic road noise, on the long-term bird abundance (Rashidi et al., 2019; Senzaki et al., 2020). The comparability of these studies with the influence of temporary use of migratory bird playbacks on the different bird communities is limited though we also assume a temporary effect of noise pollution on local bird communities. Only a very few studies have investigated the effect of bird playbacks on other bird species. De la Hera et al. (2016) observed an increase in the abundance of many other bird species caught while luring Bluethroats (*Luscinia svecica*) with playbacks of their song in southwestern France. However, it was not clear if the additional caught birds belonged to the migratory or the sedentary bird populations. DeJong et al. (2015) identified in their study focusing on breeding bird communities in North America that there is a reducing effect on the abundance of bird species that are not played by the playbacks. It is important to note that DeJong et al. conducted daily playbacks for several hours in the morning over two-month period during the main territory establishment phase. This likely caused a greater disturbance to sedentary breeding birds compared to the weekly playbacks we used in our surveys. Nonetheless, we cannot exclude a negative impact of migratory bird playbacks on sedentary bird communities, especially if we would increase the number of days with active luring. Since these discussed results are conflicting, we were unable to obtain clear conclusions on how the playbacks influence the abundance of sedentary birds.

## 4.2. Factors influencing the abundance of birds at the counting points

We thoroughly discussed the effects of the playback on the birds in the previous chapter but the statistical models have highlighted also other factors that influenced the detected abundance of birds in the different crops. The impact of these factors differed sometimes between migratory and sedentary birds, which we will discuss in the following.

### 4.2.1. Time

The time, represented by the round, had no significant influence on the abundance of migratory birds in the date plantation. This result contrasts with the finding from the onion and melon fields, where we detected significantly higher abundances of migratory birds in the second round, hence later in the day and after the tape lures were active for a while. It can be assumed that over migratory birds land as soon as they come within range of the playback lures. A major difference in the migration strategy between the migratory birds resting in the onion and melon fields and those resting in date plantation is the time of day during which the major migration movement occurs. Blackcaps (*Sylvia atricapilla*), Lesser Whitethroats (*Curruca curruca*), and Common Chiffchaffs (*Phylloscopus collybita*) were the most abundant migratory bird species in the date plantation, and they are all predominantly nocturnal migrants (Bauer et al., 2005). In contrast, Red-throated Pipits (*Anthus cervinus*), Barn Swallows (*Hirundo rustica*), and Yellow Wagtails (Motacilla flava) were the most abundant species in the onion and melon fields and are predominantly diurnal migrants (Bauer et al., 2005). While migratory birds in the melon and onion fields could be drawn in during their migration, those in the date plantations could only be attracted if they were already resting within the range of the playbacks. To our knowledge, no other studies have yet compared the effectiveness of playbacks on nocturnal versus diurnal migrants. Smith & Achuff (2020) experimented with different starting times for the playback (4.5 or 1.5 hours before sunrise) but obtained only in autumn a significantly higher abundance of nocturnal migrants for the longer playback. This effect also varied between the surveyed species and was significant for only a few. However, a few studies have explored landfall decisions, which we believe may influence the efficiency of our audio lures over time. For many nocturnal migrants, it is likely that landfall decisions are influenced not only by acoustical cues but also by visual cues (Chernetsov, 2006). Furthermore, Mukhin et al. (2005) propose that predominantly nocturnal migrants with fragmented breeding habitats, like the Reed-Warblers (*Acrocephalus spec*.), rely on acoustic triggers for landfall, what would indicate a higher efficiency of playbacks on such species. The factors influencing landfall decisions for diurnal migrants, aside from visual cues, have not been well researched yet.

For sedentary bird species, our results for the rounds were the opposite, as sedentary birds in the date plantations seemed to be less abundant in the second round. In the onion fields, only the third round showed a significantly lower abundance of sedentary birds. In this context, it is important to differentiate between lower detectability and lower abundance of sedentary bird species when interpreting the results. The most common sedentary passerine species in the date plantations were the White-spectacled Bulbul (*Pycnonotus xanthopygos*) and the Graceful Prinia (*Prinia gracilis*). These birds, like many other passerines, have a peak in song activity at dawn to maximise signal performance (Brown & Handford, 2003). This leads to better detectability in the early morning, as supported by several studies (Foote et al., 2017; Robins, 1981). Therefore, the reduced abundance of sedentary birds in the second round in the date plantations and the third round in the melon fields may not necessarily result from longer playback activity duration. Furthermore, in 2022, we were slower in processing the point counts, leading to an average start of the second round of point counts 1.5 h earlier in 2023 compared to 2022. This suggests that the later time of the day reduces bird abundance, as the round effect was only significant for the 2022 date survey with the later start of the second round and the combination of both, but not for the 2023 survey. To our knowledge, no research has been conducted on the temporary reactions of birds to noise from playbacks of bird songs. DeJong et al. (2015) observed only a long-term negative effect of intensive daily playback use on the sedentary bird community but did not mention fluctuations throughout the day.

### 4.2.2. Water

The bird abundance was significantly influenced by the water availability only in the date plantations. In the 2023 survey, "temporary" water availability reduced the abundance of both migratory and sedentary birds. Again it is important to distinguish between effects that lower bird detectability and those that reduce the abundance of birds. Even though the irrigation system is not very loud, it still hampers the acoustic localisation of birds compared to silence without an active irrigation system. Pacifici et al. (2008) showed in their research that even a light background noise of 10 dB (comparable to the sound of light water splashing) significantly reduces the detection probability and the maximum detection distance. Since this effect occurred only in the date plantations of 2023, it stands to reason that another factor in the 2022 date survey compensated for this effect. One factor might be the number of researchers during the point counts, which was two in 2022 and only one in 2023. Two people will obviously locate more birds visually in the same amount of time than just one, making the counting more robust against a reduced possibility of vocal detection. This compensating effect has already been confirmed by several studies (Forcey et al., 2006; Moore et al., 2004; Nichols et al., 2000). Another possible reason might be that the 2023 date survey was conducted by a more experienced ornithologist than in 2022. More experienced ornithologist rely more on acoustical detection of the bird species than less experienced observers (Bergen et al., 2023). For both date surveys combined, the sedentary bird abundance showed a significant reaction on temporary and intensive water availability. With an effect of -3.219, this effect was remarkable high. The water availability in 2023 was generally higher due several heavy rainfalls in March and April, compared to 2022, which had only a small amount of precipitation during this period. Sedentary birds are less attracted to the date plantations when the surrounding desert habitats provide enough water and food due the green vegetation. Khoury & Al-Shamlih (2006 ) discovered in their research that especially sedentary opportunistic bird species like the

Eurasian Collared-Dove (*Streptopelia decaocto*), Graceful Prinia (*Prinia gracilis*), and the Laughing Dove (*Spilopelia senegalensis*) are more abundant in desert habitats next to agricultural areas as they use the agricultures for drinking. It stands to reason that they use the farms less if water is available in the desert habitats as well. This might led to a reduced abundance of birds at our point counts during this rain periods with “intensive” water availability. A direct enhancing effect of the temporary water availability on birds could not be detected. However, other studies have highlighted the general advantage of regular irrigation in urban desert habitats like an increased insect abundance in irrigated landscapes within desert habitats (Cook & Faeth, 2006; Gotlieb et al., 2011; Shochat et al., 2008). This increased food source leads to a higher abundance of both sedentary bird species (Khoury & Al-Shamlih, 2006) and migratory bird species, as latter have been shown to be more abundant in habitats with increased insect availability (Martin & Karr, 1986).

### 4.2.3. Wind

Light wind in the date plantations of 2022 and the combined surveys had a significant positive effect on the abundance of migratory birds. The influence on the migratory bird abundance might be stronger than shown in the models as higher wind speeds reduce the acoustic detectability of birds due to the noise caused by the wind. It also decrease visual detectability, as spotting moving birds against moving background vegetation is more difficult. We noted in none of the surveys the wind direction, though many researchers highlight the importance of the wind direction combined with the wind speed for stopover decisions an migration intensity (Erni et al., 2002; Weber & Hedenström, 2000). Strong headwinds force migratory birds to interrupt their migration until the wind subsides. In the onion fields, this effect was significant only for “medium” wind. Higher wind speeds close to the surface often indicate stronger winds aloft, as wind speed generally increases with altitude, although local topography can significantly deflect direction (Liechti, 2006). High wind speeds against the migration direction force birds to interrupt their migration and wait out windy periods in the fields. On the other hand, “light” wind did not cause a significant change, as it can be assumed that light wind in open areas is comparable to no wind in plantations. The effect of the wind speed on the abundance of sedentary birds was negative in almost every survey. The impacts were remarkably strong with “medium” wind speed. As we do not expect any changes in the abundance of sedentary birds, these results indicate directly the reduced detectability of birds due to vegetation noise caused by the wind, as well as a possibly reduced song and forage activity in such conditions. These results related to wind were also observed in other studies (Rigby & Johnson, 2019; Yip et al., 2017).

### 4.2.4. Shelter

In the date plantations shelter, positively affected the abundance of migratory birds in the 2023 survey and in both surveys combined. It had even stronger positive effects on the abundance of sedentary birds in all surveys. Date palms seem to provide less suitable habitats, offering minimal hiding places compared to native vegetation like tamarisks thickets (*Tamarix aphylla*) and acacia trees (*Acacia tortilis*), where birds were generally more abundant (personal observation). This native scrub and tree vegetation, located nearby the counting points, seem to enhanced the hiding possibility for birds, as these habitats generally offer high-quality resting and breeding sites for many species (Khoury et al., 2006; Ward & Rohner, 1997). These birds are likely attracted by the speakers from the scrubs into the date plantations, thereby increasing the abundance of both migratory and sedentary birds at the point counts in the plantation. Other studies have also highlighted the importance of structures like windrows and scrubs for bird abundance and species diversity in plantations (Cury, 1991; Jones et al., 2005; Lindenmayer & Hobbs, 2004). In the melon fields, the effect of shelter on migratory birds was negative. A possible explanation for this divergent result is the ecology and habitat preference of the migratory species in the different crops. In the date plantations, birds with a preference of scrubby and wooded areas, such as the Blackcaps (*Sylvia atricapilla*), Lesser Whitethroats (*Curruca curruca*), and Common Chiffchaffs (*Phylloscopus collybita*) are dominant. In the fields of the onion and melon crops, species like Red-throated Pipits (*Anthus cervinus*) and Yellow Wagtails (Motacilla flava) are dominant. Other studies have described that open habitat birds exhibits avoidance behaviour towards woody vegetation (Robinson & Sutherland, 1999; Thompson et al., 2014). It is commonly hypothesised that this behaviour originates from the avoidance of predators associated with such structures, as raptors use them as lookout perches. Lower habitat quality for “open-land bird species”, maybe due higher competition with generalist bird species at the scrubs compared to more open habitat structures, might also lead to a reduced bird abundance at counting points close to woody areas. Therefore, fewer bird species with an open habitat preference could be attracted near the scrubs, as shelter structures might negatively influence the bird abundance of some “open-land bird species”.

Furthermore, it seems likely that birds from the scrubs could be less easily attracted from the shelter out to the open field crop habitats than into the date plantations, which still offer a considerable amount of shelter.

### 4.2.5. The impact of the date plantation and farming methods used

For the two investigated date plantation, we compared the more organic farmed date plantation owned by Kibbutz Samar with the conventional plantation farmed Kibbutz Elifaz. The organic agriculture is characterised not only by reduced pesticide use and the absence of herbicides, but also by a striking difference between these two date plantations: in Kibbutz Samar, undergrowth vegetation, mainly composed of grass species like reed (*Phragmites australis*), grows around the trunks, whereas the ground in the Elifaz plantation is nearly bare. We could not assess the differences between the kibbutzim and the density of undergrowth vegetation could by the models, as these two predictor correlate highly and are therefore discussed together below. In the models, only the predictor "Kibbutz - Samar" was chosen and indicated a slightly higher bird abundance of migratory birds in both surveys combined and a higher abundance of sedentary birds in the date survey of 2022. The limited number of significant results and their minimal impact were contrary to our expectations. We expected that organic farming practises, with greater shelter and insect abundance, would significantly increase bird abundance, as observed in other plantations with breeding bird communities (Calvo & Blake 1998; Camprodon & Brotons, 2006; Nájera & Simonetti, 2010) and migratory bird communities (Kirk & Lindsay, 2017; Oliveira et al., 2021). One reason for this minimal impact might again be the simultaneously reduced visual detectability of birds in the plantations. In Elifaz's date plantations, where the ground beneath the date palm trunks is nearly bare, every bird is in this stratum immediately visible. More time could have been spend searching for migratory birds in the palm canopies. However, the reeds at Kibbutz Samar made it significantly more challenging to detect all the birds present in the reeds around the trunk, potentially leading us to overlook many migratory birds. Evidence supporting this theory includes the number of a hardly detectable migratory birds species like the Eurasian Reed-warbler (*Acrocephalus scirpaceus*), which we ringed during faeces collection in the date surveys (n=5) compared to the number observed during point counts (n=5). These identical numbers indicate a significant hidden Figure in the abundance of this migratory species and other similarly difficult-to-observe species like the Great Reed-Warbler (*Acrocephalus arundinaceus*) and the Sedge Warbler (*Acrocephalus *schoenobaenus*). Even in species lured by the playbacks, such as the Eastern Olivaceous Warbler (Iduna pallida) and the Garden Warbler (Sylvia borin), which tend to stay deep in cover, we cannot exclude a substantial hidden population. A similar issue may arise with the vegetation predictor, which compared intensive vegetation density with sparse vegetation density exclusively in the date plantations of Kibbutz Samar. For the survey of 2023 and for the combined surveys, we observed a significantly lower abundance of sedentary birds at points with "intensive" vegetation. However, we did not detect a significant difference in the 2022 survey, which could be explained by the higher number of researchers while the survey counts.

### 4.2.6. Additional factors

In addition to the factors discussed in the previous chapters, there are a few other variables that we did not examine in this study but also might have influenced the bird abundance in the crops. Boesinger et al. (2017) review several studies and discuss factors that contribute positively to pest control by birds in agricultural landscapes. They also emphasise the importance of habitat availability for bird species that provide pest control in the agricultural landscape but highlight additionally the need for landscape connectivity and heterogeneity as key elements for avian-mediated pest control. Yahya et al. (2016) noted increased diversity and abundance of nocturnal birds in palm oil plantations with diverse orchard age structures. Due to the diversification of habitat structure, more species are attracted to the plantations, resulting in a generally higher bird abundance. The date plantations in this study had a homogenous age structure, so this effect could not be assessed. While this finding may not be applicable to all crops, diversification of habitat structure can also be achieved through combined cultivation of different crops ("mixed crops") in the same area. Jones et al. (2005) observed higher bird abundance and species diversity among migratory and sedentary birds in mixed green crops in Florida (USA), whereas Kathuwal et al. (2022) noted increased species diversity but not a corresponding increase in bird abundance in different mixed crops in Nepal. Therefore, enhancement effects may vary between different crops and regions.

## 4.3. The composition of the diet of birds in relation to pests control in crops

Due to the very low number of samples that we could analyse, we could not obtain clear results. Even though we collected 142 samples in the date plantations, we were only able to analyse 28 which does not allow us a proper interpretation. Additionally, these 28 samples in the date plantation cover ten different birds species, but none of them have a sufficiently large sample size. The same is true for the 22 species that we collected and analysed in the melon fields. Since PCR can distort the template-sequence frequency relationship, a quantitative interpretation of metabarcoding analysis is here restricted to simple presence/absence evidence (Alberdi et al., 2019; Piñol et al., 2018). The lesser date moth (*Batrachedra amydraula*), which farmers assessed as the most important pest species, could not be detected. This might indicate a lesser relevance of this species in the bird diet, although the data situation does not permit a definite interpretation of these results. In spring 2023, several local date moths were trapped by a nearby kibbutz and analysed by us to ensure that possible local genetic variations are covered. However, all successful DNA extractions happened earlier, in the spring 2022, hence new genetic markers could not be detected in the premier analysis. This output does not provide any evidence to prove the assumption that the birds predominantly feed on the pest species, but it also cannot refute the same. Despite the small number of samples, in seven of 28 faecal samples, the important pest species Confused Sap Beetle (*Caprophilus mutilanus*) was detected, indicating that this a species the birds are feeding on more. The same applies to the lesser important pest species Carob Moth (*Ectomyelois ceratoniae*), which was also found in seven of 28 faecal samples. To our knowledge, no other study has so far examined the diet of migratory birds in date plantations. In the melon fields only the Yellow Wagtail (*Motacilla flava*) had a higher sample size, with eleven samples. Only insect pests from the genus Aphis were detected. These pests were found only sporadically in the examined bird faeces. Consequently, this output is similar to that from the date plantations and does not provide any evidence to prove the assumption that the birds predominantly feed on the pest species, but it also cannot refute the same. To our knowledge, no other study has researched the diet of migratory birds in melon fields either.

Other studies have conducted general research on the diets of migratory birds, providing a foundation that is helping to explain the low number of recorded pest species in the faeces and for further surveys on this topic. Though many migratory passerines are insectivorous (Somveille et al., 2015) and need substantial nutrition to refuel after crossing the dessert, it is supposed that many switch their diet to a more fruit-based composition during migration (Baierlein, 1998; Bairlein & Gwinner, 1994; Gómez et al., 2018). Jenni-Eiermann et al. (2011) detected fruit and nectar in the faeces of nearly every migratory bird species in Mauritania.

Ony a few species, like the Barn Swallow (*Hirundo rustica*), are assumed to feed extensively on insects while migration (Baierlein & Gwinner, 1994) but only a very small number of these species was captured and analysed. The extent to which the diet of migratory birds in crops like date plantations, melon fields, and onion fields consists of invertebrates, and more importantly, insect pest species, remains unclear. To our knowledge, no research on the pest species content of migratory birds' diet during migration has been published. However, some breeding bird communities, from which some migrate through our survey region, have been shown to feed primarily on invertebrate species regarded as pests in other crops. Barn Swallows, along with other swallow species that migrate numerous through our survey region, are already assumed to have a pest-controlling effect at their breeding grounds in southwestern Poland (Orłowski et al., 2014). Jedlicka et al. (2017) found that in vineyards in California (USA), birds' diets included over half herbivorous insects, while natural arthropod enemies constituted only a minor part. Crisol-Martinez et al. (2016) also proved in her study on the diet of birds in macadamia crops in eastern Australia the presence of one of the major pest species in this crop in almost one quarter of every analysed bird faeces. Another study by Garfinkel et al. (2022) investigated that in soybeans fields in Illinois (USA), sedentary birds were feeding predominantly on herbivorous insect species, whereby some of the main pest species were detected. Though the insect content may be reduced during migration for these species, we can assume that these species will still feed partly on the pest species during their migration.

The analysis of the bird faeces presented several problems. In 2022, the method using the "DNeasy® PowerSoil® Pro Kit" worked quite well for a subset of samples from the 2022 date survey and for the samples of the melon survey. Therefore, the same method was applied in the following year at the same institute, despite a small change in the staff. However, for the remaining 2022 date samples and all samples 2023 date samples, not a single successful DNA could be conducted. To identify the problems causing this failure in DNA isolation, fresh primers were ordered and used. The amount of faeces per sample was increased by pooling the faeces of two birds of the same species caught on the same day. Additionally, other extraction kits, such as the "DNeasy® PowerSoil® HTP 96 kit" and "QIAamp Fact DNA Stool Mini Kit", were used, but neither method provided sufficiently isolated DNA. Although this does not explain the different results between the two laboratory analyses, Alberdi et al. (2019) suggest a reduced effectiveness of such kits on bird faeces due their chemical characteristics. Bird faeces are excreted along with uric acid, which is a highly acidic and concentrated substance (Podulka et al., 2004). The involved laboratory is researching further methods to improve the isolation of DNA in bird faeces for future projects.

## 4.4. The most promising pest control bird species in the crops

To asses which bird species are the most promising for pest control in an IPM, we need to consider several aspects resulting from our findings. These include the occurrence of the species in different agricultural areas in sufficient abundance, their controllability in terms of how well the species can be lured to the crops, and their foraging stratum in comparison to the relevant pests.

### 4.4.1. Occurrence of the species

Many migratory birds use agricultural areas and orchards in desert landscapes for refuelling and are significantly more abundant in these areas than in natural habitats (Norfolk et al., 2015). As shown in Figure 4, some species, like the Eastern Olivaceous Warbler (*Iduna pallida*), Garden Warbler (*Sylvia borin*), Willow Warbler (*Phylloscopus trochilus*), and Bluethroat (*Luscinia svecica*) still occur only in low abundance, making it inadvisable to focus on these species for pest control. Although fluctuations in the abundance of migratory species between and within years are common due to factors like weather and wind conditions (Shamoun-Baranes et al., 2017), it is unlikely that these species will reach an abundance that makes them a promising option for pest control. Other species, like the Common Chiffchaff (*Phylloscopus collybita*), show strong fluctuations between the years, being quite abundant in the 2022 date survey and only sparse in the 2023 survey. As the onion and the melon surveys were conducted only in one year each, we cannot assess the fluctuation in these crops. Additionally, with only two years of data from the date plantations, a proper evaluation of these fluctuations is difficult. In both years of the date plantation surveys, a good abundance of Blackcaps (Sylvia atricapilla) and Lesser Whitethroats (Curruca curruca) was observed. The Lesser Whitethroat was present almost throughout the entire spring migration period due migration differences among seven subspecies that use the region as migration corridor (Zduniak & Yosef, 2012). Furthermore, this species complex inhabits a wide spectrum of habitats (Shirihai et al., 2001), making it an important species group for our study in the spring. The autumn abundance of this bird in the region is averagely 25 times smaller (Zduniak & Yosef, 2012), reducing its importance for pest control services to the spring migration period. The Blackcap has a wide range of migration patterns (Berthold, 1988), but the population that occurs in the study region is wholly migratory, arriving in early April and staying until the end of the migration period (Yosef & Wineman, 2010). Additionally, the Blackcap is the most abundant passing migratory bird species in the area, but it has also a significantly reduced abundance during autumn migration compared to spring migration (Zduniak et al., 2013). This makes these two species the most promising for pest control in the date plantations due to their abundance. In the melon and onion crop surveys, all lured species were abundant in good numbers, making them all promising potential pest control species. The most observed species in the melon survey was the Yellow Wagtail (*Motacilla flava*), which occurs with many different subspecies during the migration season (Alström & Mild, 2010). The Red-throated Pipit (*Anthus cervinius*) was the most abundant species in the onion survey and occurs generally in good numbers as the whole western population mainly migrates over the bottleneck of Israel into the winter grounds in Africa and back (Zduniak & Yosef, 2011). Additionally, Reed-Warblers (*Acrocephalus spec.*) were probably more abundant than assumed, as they were caught regularly during faeces collection in the date plantations, and the Eurasian Reed-Warbler (*Acrocephalus scirpaceus*) is one of the most abundant migratory species in the region as well (Zduniak et al., 2013). Though they were not lured by playbacks of their own songs, they might be a promising additional pest control species in the crops. Finally, it is important to highlight the difference between spring and autumn migration intensity. Several authors and local bird experts mention a substantial lower abundance of migrant birds over most taxa in autumn compared to spring in the southern Arava region (Zduniak & Yosef, 2011; Zduniak et al., 2013). This effect might be related to the geographical bottleneck, which is more pronounced for migratory birds in spring following the Red Sea coastline from the south (Yom-Tov, 1984). It might also be related to the fact that in autumn, the birds have not yet crossed the desert and therefore are less likely to stop for refuelling (Yom-Tov, 1984).

### 4.4.2. Controllability of the species

The controllability of how well the species could be lured with its playbacks varied. Species like the Lesser Whitethroat (*Curruca curruca*), Tree Pipit (*Anthus trivialis*), and Blackcap (*Sylvia atricapilla*) showed a significantly higher abundance at the tape points compared to the control points or points with a greater distance from the active playbacks in at least one survey of the date plantations. For all other migratory species, no significant difference was detected in the date plantations. This result was due to the fact that most of the other species were not abundant enough to obtain statistically significant result. Only for the Common Chiffchaff (*Phylloscopus collybita*) and the Easten Bonelli's Warbler (*Phylloscopus orientalis*) did the lack of significant result go against our expectations, as they occurred in sufficient abundance for this. In the melon fields, the Yellow Wagtail (*Motacilla flava*) and the Barn Swallow (*Hirundo rustica*) were significantly more abundant at the tape points than at greater distances. For the Red-throated Pipit (*Anthus cervinus*) and the Barn Swallow at the 100 m distance, we could not obtain a statistically significant result, which is most likely related to the low number of point counts. In the onion fields, the Red-throated Pipit was significantly more abundant at the tape points compared to the control points, indicating that the playback was effective for luring this species. Lehnardt & Sapir (2024) observed similar positive effects from playbacks on migratory Blackcap abundancy in southern Israel. Szymkowiak et al. (2017) also observed significantly higher abundance of Blackcaps and Common Chiffchaffs in their breeding grounds after playback use. Furthermore, Szymkowiak et al. (2017) provide a possible explanation for the unexpected result with the two *Phylloscopus* species. Their study also examined the influence of non-conspecific playbacks on the habitat choice of another Phylloscopus species, the Wood Warbler (*Phylloscopus sibilatrix*), and observed an avoidance reaction to playbacks of birds like the Blackcap while closely related species like the Common Chiffchaff had an elevating effect on bird abundance. Although habitat choice decisions might differ between breeding sites and stopover sites, the avoidance behaviour, justified by interspecific competition for food resources with larger bird species, might also explain the unexpected result for the Common Chiffchaff in these surveys. Barn Swallows are regularly caught with the help of playbacks in numerous projects (Winkler, 2006), proving the efficiency of playbacks as a means to lure Barn Swallows. For the other species mentioned above, no species-specific evidence for the efficiency of playbacks outside the breeding range was described in other studies. Mukhin et al. (2008) described the efficiency of playbacks on migratory birds in general, and partly in contrast to the findings of other surveys. They compared the efficiency of playbacks on different bird taxa and suggest the hypothesis that playbacks attract habitat specialists like Reed-Warblers (*Acrocephalus spec.*) strongly, while the efficiency on generalist is minor and not detectable in their study. Overall, the aspect of controllability appears valid for most migratory bird species with sufficient data.

### 4.4.3. Foraging stratum of the species in comparison to the pests

Several insect pests were identified by the local farmers as particularly important in the date plantations. Therefore, the potential pest control bird species needs to forage in the stratum where these pest species occurs. The most important pest species in the date plantations of southern Israel in spring is the Lesser Date Moth (*Batrachedra amydraula*). The larvae of this species attack newly formed inflorescences of date palms that evolve into fruits, with each larvae potentially damaging three to four fruit in its lifetime (Blumberg, 2008). It overwinters in well-hidden white cocoons in the fibres at the bases of the palm fronds (Blumberg, 2008). Since this species occurs almost exclusively in the canopy, it is crucial that the bird species also forage in this stratum. The three most important pest species of the Nitidulidae family (*Carpophilus hemipterus*, *Carpophilus mutilatus*, and *Urophorus humeralis*) damage the ripe date fruit in mid-summer and early autumn and are therefore less controllable during the spring migration period. In spring, the beetles of this family are usually still pupating in the soil (Blumberg, 2008) and thus not easily accessible to bird species. The two date pest species of the *Tetranychidae* family (*Eutetranchyus palmatus* and *Oligonychus afrasiaticus*) occur throughout the year. *Eutetranchyus palmatus* feeds mainly on ripe fruits, while *Oligonychus afrasiaticus* feeds mainly on green date fruits (Blumberg, 2008). Consequently, the main damage occurs in the canopy at the fruits. In summary, it is essential that pest control bird species in the spring have their primary foraging activity in the date canopies, where they can feed on all significant pest species of the date plantations. This reduces the importance of species that forage mainly close to the ground or in the reeds near the trunk, such as all of the Reed-Warbler species but also the Bluethroat (Bauer et al., 2005). Blackcaps, Lesser Whitethroats, Tree Pipits and species of the genus *Phylloscopus* meet these requirements well and thus could be potential pest control species in terms of foraging stratum. All of these bird species, except the Tree Pipit, had at least at least one faecal sample with a detection of a pest species from this stratum (tabelle 11). In the melon and onion fields, only one stratum exists. Furthermore, onions and melons are cultivated as annual plants with only a few months between sowing and harvesting. Thus, the peak of all insect pest species of these crops occurs during this short growing period in autumn. The pest control species of these two crops only need to be able to catch small flying insects on the crop or close to the ground, which fits all three surveyed species. However, only pest species of the genus *Aphis* were detected in the faeces.

## 4.5. Conclusion

The conclusion drawn from the findings in the previous chapters is that the playbacks in all crops and the shelter for the date plantations are the only clear factors that directly support higher migratory bird abundances and which can be directly influenced by farmers. This leads to several practical implementations. The playbacks had a clear attracting effect on the migratory birds and can therefore be used to raise bird abundance on a local scale. In the date plantations, it is likely that the migratory birds were just attracted to the playbacks from within the same plantation. In the onion and melon fields, the result indicate the possibility that migratory birds interrupted their migration movement because of the playbacks. In the date plantations, the main migratory event occurred before the activation of the tapes. These effects differ between the different species, and for some species, this effect is not statistically significant. Not every bird species is equally appropriate as a pest control species because the foraging behaviour and the habitat preference must fit the seasonality and ecology of the insect pest species, which reduce the yield of the agricultural crop the most. Furthermore, the bird species need to occur in sufficient numbers during each spring migration period to provide a predictable insect control. With some bird species, this is problematic as they occurred in these survey years, and probably in general, in such low abundances that an insect pest controlling effect cannot be ensured. Another way to enhance the abundance of breeding birds might be achieved by providing more natural resting habitats and shelter for the bird species such as planting more tamarisk hedges and acacia bushes next to the plantation from which these birds can forage in the date plantations. Although the vegetation around the trunk is expected to provide this additional shelter as well, no clear evidence that supports this assumption was achieved in our study.

We must also consider effects from these measures on sedentary bird populations. The sedentary passerine bird species most commonly found in the date plantations are the White-spectacled Bulbul (*Pycnonotus xanthopygos*), the Eurasian Collared-Dove (*Streptopelia decaocto*), and the House Sparrow (*Passer domesticus*). In the field crops, the most common sedentary species were the Spanish Sparrow (*Passer hispaniolensis*), the Eurasian Collared-Dove and the Crested Lark (*Galerida cristata*). However, the overall abundance of sedentary birds was quite low compared to those in the date plantations. In the date plantations the White-spectacled Bulbul and the Graceful Prinia (*Prinia gracilis*), which were also quite abundant in this crop, had pest insects from the canopy stratum detected in some of the faecal samples, indicating a possible pest control service as well. The Eurasian Collared-Dove, which was very abundant in all crop types, is not of further interest as they feed mainly on vegetable matter. While some sedentary bird species may provide a more stable insect pest control service due to their consistent presence and abundance, other authors consider some of these birds as pest species themselves (Benras et al., 2023; El-Shafie, 2018; El-Shafie & Abdel-Banat, 2018; Manzoor et al., 2013). Specifically, Bulbuls (*Pycnonotus spec.*) and House Sparrow (*Passer domesticus*) are mentioned as important avian pest species in the date plantations (Benras et al., 2023; El-Shafie, 2018; El-Shafie & Abdel-Banat, 2018), and House Sparrows are noted for field crops like melon fields (Manzoor et al., 2013). Additionally, for the melon crop, two invasive species, the Common Myna (Acridotheres tristis) and House Crow (*Corvus splendens*), are listed. Although these species currently have little impact in the region, local researchers indicate that their abundance is increasing, which may make them important avian pest species in the future. As most of the avian pest species are predominantly frugivorous outside the breeding season, their damage might be restricted to the fruiting period of the crop. Also, as many authors primarily consider these bird species as pest species, potential pest control effects, especially during the breeding period, may have been underestimated so far (Garcia et al., 2020; Pejchar et al., 2018). Therefore, the effects of measures on sedentary birds must be evaluated with caution and assessed individually for each case.

Many studies have described potential opportunities for integrating birds into integrated pest management (IPM) in their breeding grounds (Garcia et al., 2020; Lindell et al., 2018; Perdhana, 2023). It is doubtful whether migratory birds alone can provide sufficient protection against all insect pest species, but they have great potential to complement existing IPM approaches. Other authors share our opinion that enhancing pest control services with migratory birds could represent another step towards ecological and nature-compatible farming practices that simultaneously enhance the crop yields measurable (Díaz-Siefer et al., 2022; Jones et al., 2005). Migratory birds seem to have a higher potential in field crops, as their abundance relatively to the sedentary birds was much higher than in the date plantations. However, the use of migratory birds as pest control species in agriculture landscapes is challenging due to many unknown aspects of bird migration behaviour and variations between migration years. Further research, conducted in close collaboration with local farmers, is needed to adequately assess this potential and to provide case-specific practical implementations (Geertsema et al., 2016). These implementations must consider effects on local fauna as well as impacts on migratory bird populations.

### 4.6. Future research perspectives

With the results of our study we provide already some practical implementations. Future research should focus on more case-specific insight into different crops in the same area, as well as additional surveys in melon and onion fields. To better assess the impact of migratory birds on insect pests, it would be helpful to additional measure crop damage on test plots and compare it with damage on plots where no bird playback were used. Measuring insect pest densities with insect traps at the same could also help to assess the effectiveness of bird pest control. While the effects of playbacks on the main migratory bird species in date plantations are better understood, our study also highlights the need for further research in other crops to achieve more significant results and deeper understanding. Our study provides data from only one year of research for each field crop. To assess yearly fluctuations in migration intensity and pest species abundance, more survey years are necessary. Similarly, for migratory birds in date plantations, more future studies build on these recent findings could yield results with higher levels of significance. Even with two surveys years in date plantations, we obtained only a limited overview of possible migration fluctuations in crops, though we could already observe significant differences between the years. While migration intensity was likely the biggest difference between the two survey years, other factors such as the speaker size, set up time, number of researchers in the field, and ornithological experience of the observers varied and could not clearly be separated from the influence of the migration intensity. Some of these factors may have even reduced the observed difference between the years. Further studies are needed to assess changes in these different methods. For the future studies, it is crucial that researcher obtain detailed information about research methods used in previous years in the same crops. Unclear definitions of parameters and survey methods may influence overall study result and their validity, and should be avoided at all costs. Additional future studies should mor precisely measure variables already examined in this study, such as documenting both wind speed and wind direction during field recordings. For some points in open fields, we assumed a “pushing effect” as we started all the point counts at the tape point. Implementing a rotating start point between the tape point and the counting point at 250 m distance could eliminate such effects. A challenge in our study was the retrospective calculation for the 2022 date survey due to initially unavailable data of the total abundance per species at each point count. While the aim was to gather information on bird species’ foraging stratum, it may be feasible to assess this adequately without separate counts, as most species have clear preferences for their foraging stratum. Additionally, this approach allows the researcher more time for locating and identifying birds during point counts as this approach is more time extensive. Another consideration for future studies is the difficulty in detecting bird species in date plantation with dense vegetation. While a 5-minute duration seemed sufficient in date plantations with dense vegetation, it seemed insufficient at points with intensive vegetation. Authors such as Bonthoux & Balent (2012), Leu et al. (2017), and Südbeck et al. (2005) suggest that a 5-minute point count is adequate for recording breeding birds abundance, but due to reduced acoustical detectability of birds during migration and visual difficulties in dense undergrowth vegetation, extending point counts duration is recommended. This research indicate that the most abundant migratory bird species in date plantations are nocturnal migrants, while those in open fields are diurnal migrants. Consequently, initiating playback earlier in date plantation could be beneficial. Smith & Achuff (2020) noted significant changes resulting from an earlier start of the playbacks. Conversely, conducting bird species counts in fields later in the day with early morning playbacks activated could yield stronger results by potentially attracting more migrant birds to the crops during the active migration time. The effectiveness of audio lures on diurnal versus nocturnal migrants remains insufficiently studied, and further research is required in this area and how audio lures affect the local bird community and other migrating bird species. Research on migratory bird diets in different crops yielded no significant results, though it serves as the basis for further steps such as species-specific luring attempts. Several issues arose in researching faeces from captured birds, and a suitable method still needs to be determined before proceeding with further research. Achieving a sufficient sample size for promising species, though challenging and time-consuming for most species, could be facilitated more easily by capturing Barn Swallows in large numbers at evening roosting sites, offering the potential to obtain many faecal samples at once. Another promising research area could be focusing on shrubs and hedges near date plantation, as they significantly increased bird abundance in our study in the plantation itself. In open habitats, mixed crops (Jones et al., 2005; Kathuwal et al., 2022) or flower strips (Tschumi et al., 2015; Tschumi et al., 2016) might similarly enhance populations of migratory target bird species as well as sedentary birds. In summary, our study has provided some first important insights in this topic, upon which further research can build.

## 5. Summary

Global biodiversity loss and increasing food demand together are likely to force farmers to combine intensive agriculture with ecological farming methods if further ecological impacts are to be mitigated. This study aimed to provide a stepping stone for additional research related to pest control by migratory birds. A core part of this study was to investigate the use auf audio lures to attract birds into agricultural areas. We conducted point counts to check for the effect of audio lures on the bird abundances in combination with faeces analysis to address the study topic. We analysed data of four surveys in three different crops using several models to gain a broad overview of the potential of this method.

The results indicate that for the most commonly observed migratory species, audio lures can increase abundance. The effectiveness of this lures differs between the crops and lured species. These complex coherences are likely connected to different migration strategies of the birds and the habitats that are provided for them by the crops. The effect of audio lures on the sedentary birds could not be assessed unequivocally on account of contradictory findings.

In addition to the playbacks, other factors also influence the abundance of both migratory and sedentary birds. Factors like specific wind conditions and the availability of shelter positively affected migratory bird abundance in the date plantations. These factors vary in their effects across the different crops as shelter had for instance a negative effect on the migratory bird abundance in the melon crop but wind was supportive for higher migratory bird abundances as well. Shelter availability also had a positive impact on the abundance of sedentary birds. Time of the day had a positive effect on migratory bird abundance in the field crops indicating the landfall of migratory bird populations in these crops during the day while in the migratory bird populations of the date plantations the main landfall event happens during the night. Temporary water availability, wind, time, and undergrowth vegetation density also strongly influence bird detectability, thus their impacts on bird abundance complicating sometimes generalisations and interpretability. Notably, “intensive” water availability was found to negatively affect sedentary bird abundances as these birds do not need to come out of the desert habitats into the agricultural crops for drinking. The year had a strong impact on the migratory bird densities in the region, indicating a certain variability in bird abundances that could affect the reliability of specific pest control services.

We were only able to examine a small number of faecal samples, which did not allow us to obtain reliable data on the diet of migratory birds. Although several studies suggest that certain migratory birds switch their diet to a more fruit-based composition, we found evidence of insect pests in some bird faeces.

Selecting the most effective pest control agent in the surveyed crops for future luring efforts depends on various factors. For the date plantations, the general migration abundance and the foraging stratum strongly support focusing on Blackcaps and Lesser-Whitethroats. Further research is needed for instance on *Phylloscopus* species to investigate the effects of interspecific audio lures, and also a genus-specific approach for the other *Phylloscopus* species should be considered. Although Reed-Warblers do not tend to use the canopy as foraging stratum in date plantations, they might be a promising species group for future studies on pest control services in lower strata and other crops. The most promising control agent species in the two field crops are the three species that were already lured. Including results from other studies swallows seem particularly auspicious for the field crops due to their predominantly insectivorous diet during migration. However, for all migratory species in the region, the spring migration season seems to have greater importance, as the migratory bird abundance during this time far exceeds the abundance in autumn. This suggests a limited effectiveness of pest control effect of migratory birds in the autumn migration period.

Migratory birds have the potential to complement IPM approaches in agriculture, particularly in field crops, but their effectiveness is limited by unknowns in migration behaviour and yearly variations. While an increase in migratory bird abundances in desert crops likely provides some insect pest regulation effects, it is also important to consider the impact on the local bird population in order to avoid simultaneously exacerbating agricultural damage caused by sedentary birds. Further research and collaboration with farmers are necessary to assess their role in pest control while considering differences between crops and bird species.

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