Enhancing the economic value of bio-pest control by migratory birds in desert agriculture

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1. Background

Vegetable and fruit production in the Southern Arava region face significant challenges due to yield losses induced by insect pests. In particular, date plantations suffer from insect pests, causing severe damages to the crops and reducing significantly the yield (El-Shafie *et al.* 2017). While the conventional use of pesticides is limited as the application for date plantations is often not practical, biological pest-control can help significantly decreasing insect pest induced yield losses. Several studies provide evidence that birds can depress abundance of insect pests and hence, significantly increase the yield (Blount *et al.* 2021; Díaz-Siefer *et al.* 2022; Tscharntke *et al.* 2005; Whelan *et al.* 2008). Seasonal high abundance of migratory songbirds can provide important biological pest-control services to the agricultural site (Blount *et al.* 2021; Kross *et al.* 2016) that they may use for stopover, when songbirds land to refuel, rest and recover (Schmaljohann *et al.* 2022).

The Southern Arava region is located along the eastern migration flyways between Eurasia and Africa used as intercontinental junction by a variety of migratory birds and in high abundance (Shirihai 1996). Particularly during spring migration, a large number of migratory songbirds funnel via the Red Sea coast over the Arava Valley in Southern Israel (Schekler *et al.* 2022; Shirihai 1996). Moreover, this stopover site is of particular relevance due to the close proximity to a wide ecological barrier *en route*, the Saharo-Arabian desert belt. Consequently, migratory songbirds concentrate here in spring to refuel after crossing a wide ecological barrier (Schekler *et al.* 2022; Shirihai 1996). Besides the high importance as migratory route and stopover site for many migratory songbirds, the Southern Arava region is also characterized by its importance for date production and hence, large date plantations are located along the valley. This unique setting makes the study area ideal to address knowledge gaps in our understanding of pest-control services provided by migratory songbirds.

Biological pest-control services result from the birds' foraging behaviour. Therefore, pest-control services is mostly provided by predominantly or occasionally insectivorous birds (Wenny *et al.* 2011), and mostly by common species that occur in larger numbers (Gaston 2022). Previous research projects conducted in the

Southern Arava found several species of insectivorous, migratory songbirds present within agricultural sites, including date plantations (unpublished data). Importantly, the habitat quality for birds presumably differs between farming practices and crops (Blount *et al.* 2021; Dänhardt *et al.* 2010). Consequently, we expect that the pest-control service will vary accordingly. After landfall, migratory songbirds perform fine-tuning movements to select suitable sites with habitats that provide required functions from the stopover (Chernetsov 2012), e.g. high food abundance to refuel (Bairlein 2002), or shelter to rest and recover from the preceding flight (Aborn *et al.* 2004; Maggini *et al.* 2020). Depending on various intrinsic and extrinsic conditions, songbirds require different functions from the stopover, such as refuelling, rest or recovery (Schmaljohann *et al.* 2022). These required stopover functions likely affect the behaviour of songbirds and consequently, the pest-control service provided by different individuals. Measuring ecosystem services, i.e. quantifying the pest-control services provided by individual insectivorous, migratory songbirds (Whelan *et al.* 2008; Zhang *et al.* 2007), is crucial to understand the importance of migratory birds for the agriculture in general, and to formulate efforts to enhance the provided pest-control service for date plantation in the Southern Arava region in particular.

2. Research Questions

To enhance the economic value of biological pest-control, provided by migratory songbirds, we study songbirds' habitat preferences and foraging activity during their stopover in date plantations of the Southern Arava region, more specifically we ask:

(1) Which habitat types, i.e. agricultural date plantation or semi-natural shrublands, are selected by insectivorous, migratory songbirds after landfall?

(2) Do insectivorous, migratory songbirds use agricultural stopover sites in date plantations to refuel, by active foraging, or to rest?

3. Research Objectives

To reach the overall objective, enhancing the economic value of biological pest-control by migratory songbirds in desert agriculture, we aim to address a major knowledge gap and provide measurements of pest-control services of migratory songbirds in date plantations. Consequently, we study the songbirds' behaviour during stopover in date plantations, particularly behaviour related to their biological pest-control services, such as habitat selection and foraging activity. This knowledge is crucial to measure biological pest-control service and integrate it in management programmes as sustainable tool to control insect damage in date plantations.

Using Motus radio-telemetry, a bio-tracking system that enables us to follow movements of small songbirds equipped with light-weight radio-telemetry transmitter (Taylor *et al.* 2017), we can answer the research questions above and help gaining the necessary knowledge to measure pest-control services. Notably, quantifying pest-control services is essential in order to understand and enhance biological pest-control services (Zhang *et al.* 2007). By answering which habitat types are selected by insectivorous, migratory songbirds after landfall, we gain deeper understanding on migrants' habitat preferences and can quantify the time they spent in date plantations, potentially providing pest-control services. Additionally, we specifically study the activity of insectivorous, migratory songbirds during stopover. This can provide insights on the behaviour during stopover, i.e. active foraging to refuel or passive resting, and hence, quantify the provided pest-control service.

4. Methods

Study site and Motus radio-telemetry receiver station

The Arava Valley is an important agricultural area in Southern Israel, characterized as important region for date production. Consequently, large date plantations are a predominant land cover type in our study site. During spring, a large number of migratory songbirds funnel along the Red Sea coastline of Sinai towards the study site (Schekler *et al.* 2022; Shirihai 1996), many of them land at the first green areas, including agricultural fields and date plantations as well as semi-natural and urban areas around Eilat. The International Birding and Research Center, Eilat (IBRCE) conducts standardized bird ringing efforts from mid-February to end of May. In our cooperation with the IBRCE, we took advantage of the standardized bird ringing efforts to attach Motus radio-telemetry transmitter (0.26 g; Nano Tags, NTQB2, Lotek, Ontario, Canada) to some individuals. We placed the automated Motus receiver station at the northern border of the IBRCE bird sanctuary, our ringing site (Fig. 2). This location was selected due to the variety of habitat types in the surrounding. To the South of the receiver station, the IBRCE bird sanctuary is a semi-natural shrubland, including restored saltmarshes and drier Acacia shrublands, while to the North of the station agricultural date plantations dominate (Fig. 1). The closest date plantation, Eilot, is under conventional farming practices with herbicide and pesticide use.

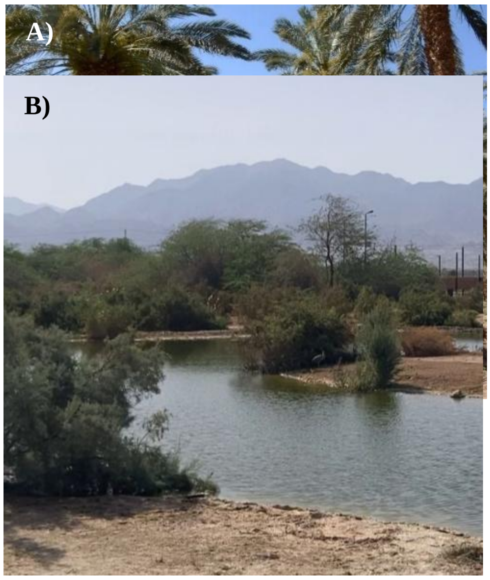

Fig. 1: Pictures of **A)** a conventional date plantation in the Southern Arava region and **B)** the semi-natural habitat at the IBRCE bird sanctuary.

Fig. 2: The Motus receiver station is placed between semi-natural habitats, the IBRCE bird sanctuary, and agricultural date plantations. Here, we show the simplified antenna range, the actual antenna range is of a more oval shape and coverage depends on additional factors, such as the terrain. The Motus receiver station is shown as an black antenna icon in both figure. **A)** The modified aerial image shows the simplified antenna coverage of the Southern antenna (in blue) and Northern antenna (in red). These two antennas covered both main habitat types the semi-natural habitat, by the Southern antenna, and agricultural date plantations, by the Northern antenna. **B)** In the map a satellite image shows all habitat types within a larger scale. The simplified coverage of the antennas from the Motus receiver station is shown here in grey shaded areas.

We constructed and activated the Motus receiver station on 2nd April 2024, located as shown in Fig. 2 at the northern border of the IBRCE bird sanctuary (Fig. 3). The station uses the Cellular Tracking (CTT) Sensor Station as receiver for the radio-telemetry signals, uploading data directly to the CTT and Motus servers. In the beginning, the station run with four directional 6-element Yagi antennas, respectively with a bearing of approximately 0, 90, 180 and 270 degree (Fig 2B). Additionally, we used one omnidirectional antenna. Due to technical problems with the CTT Sensor Station, from the 13th April 2024, the station was running with a reduced number of antennas, using only the two most important antennas directed towards the North and South, i.e. 0 and 180 degree (Fig. 2A), which are essential to answer our research question.

Fig. 3: Picture of the Motus radio-telemetry receiver station.

Study species

We selected eight study species of a subset of 12 pre-selected potential study species, including different abundantly occurring, insectivorous, migratory songbirds. Individually coded radio transmitters were glued to clipped feathers on the back of the birds (surgical glue, Perma-Type), see Fig. 4. The potential adverse effects on the natural behaviour are slight if the attachment does not exceed 3-5 % of the birds' body mass (Casper 2009). We deployed 49 radio-telemetry transmitters in total, on eight study species with different migration strategies (long-, medium- and short-distance), 12 Thrush Nightingales (*Luscinia luscinia*), 13 Garden Warbler (*Sylvia borin*), three Barred Warbler (*Curruca nisoria*), four Common Nightingales (*Luscinia megarhynchos*), four Eastern Orphean Warbler (*Curruca crassirostris*), 11 Masked Shrikes (*Lanius nubicus*), one Rüppell's Warbler (*Curruca ruppeli*), and one Eastern Bonelli's Warbler (*Phylloscopus orientalis*). Of these 49 transmitters only one never got detected (Table 1).

Fig. 4: Process of deploying radio trans-mitters to a Garden Warbler (*Sylvia borin*).

Table 1: Number radio-transmitters that were deployed, detected and detected until the departure of the tracked individual, shown for each study species separately.

Study Species	Migration distance group	Total number of deployed transmitters (detected)
Thrush Nightingale (*Luscinia luscinia*)	long	12 (11)
Garden Warbler (*Sylvia borin*)	long	13 (13)
Barred Warbler (*Curruca nisoria*)	medium	3 (3)
Common Nightingale (*Luscinia megarhynchos*)	short	4 (4)
Eastern Orphean Warbler (*Curruca crassirostris*)	short	4 (4)
Masked Shrike (*Lanius nubicus*)	short	11 (11)
Rüppell's Warbler (*Curruca ruppeli*)	short	1 (1)
Eastern Bonelli's Warbler (*Phylloscopus orientalis*)	short	1 (1)

Fig. 5: Pictures of individuals deployed with radio-transmitter from the eight study species. **A)** Thrush Nightingales (*Luscinia luscinia*), **B)** Garden Warbler (*Sylvia borin*), **C)** Barred Warbler (*Curruca nisoria*), **D)** Common Nightingales (*Luscinia megarhynchos*), **E)** Eastern Orphean Warbler (*Curruca crassirostris*), **F)** Masked Shrikes (*Lanius nubicus*), **G)** Rüppell's Warbler (*Curruca ruppeli*), and **H)** Eastern Bonelli's Warbler (*Phylloscopus orientalis*).

Data analysis

Motus radio-telemetry data downloaded directly from the Motus server comes as raw data of the signal strength measured for each radio-transmitter in each antenna. We used R-Studio (R version 4.3.1) to analyse the signal strength to infer movements of the tracked individuals. Here, we identified whether and in which direction birds performed relocation movements to other sites after release and before departure for migration. Using an algorithm developed by Schmaljohann et al. we identified the individual departure timing from the radio-tracking data in a standardized method. Due to the limited amount of directional Yagi antennas, an estimation of the direction of landscape-scale relocation movements or departure was not possible. From the departure timing we calculated the stopover duration that the tracked bird remained at the stopover site after trapping. Since nocturnally migratory songbirds usually depart in the evening (Packmor *et al.* 2020), we were able to differentiate landscape-scale relocation movements from presumably "real" departure for nocturnal migration, by defining plausible departure time between 16:00:00 and 22:00:00 UTC time. We used independent t-test to compare the stopover duration between long- and short-distance migrants, and a linear regression model to test whether departure time within- and between-nights depends on the fat score. From the diurnal landscape-scale relocation movements we calculated the percentage of last signals, indicating the direction, in the northern antenna, towards a large agricultural patch.

To understand the habitat-use and activity during the stopover we run several algorithms to separate the data into several time periods of consecutive detection. Firstly, we separated periods with signals further apart than 60 seconds. Here, we analysed which antenna detected the strongest signal, indicating the closest distance and hence, direction of the bird. If the dominant antenna changed within the periods defined previously, we split these periods again. From the total time detected by the receiver station, we quantified the proportion of time spent in agricultural date plantations, i.e. strongest signal detected in the Northern antenna, versus time spent in semi-natural habitats, i.e. strongest signal detected in the Southern antenna. We compared this proportion between species and performed a linear regression model for the proportion in the Northern antenna and the birds' fat score. From these periods, that were 60 seconds apart and different in the dominant antenna, we further classified if individuals were stationary or active, using the variation in signal strength. Here we used a threshold of 0.85 in the variation (i.e. the standard deviation) of the z-transformed signal strength, defined by manually defining 30 random periods into stationary or active. Furthermore, we used the cpt.var() function in R-studio to detect changes in the variance of the signal strength within these predefined periods. If the variation of the signal strength significantly changed, we split the periods again, classifying stationary and active periods using the threshold as before (see Fig. 6).

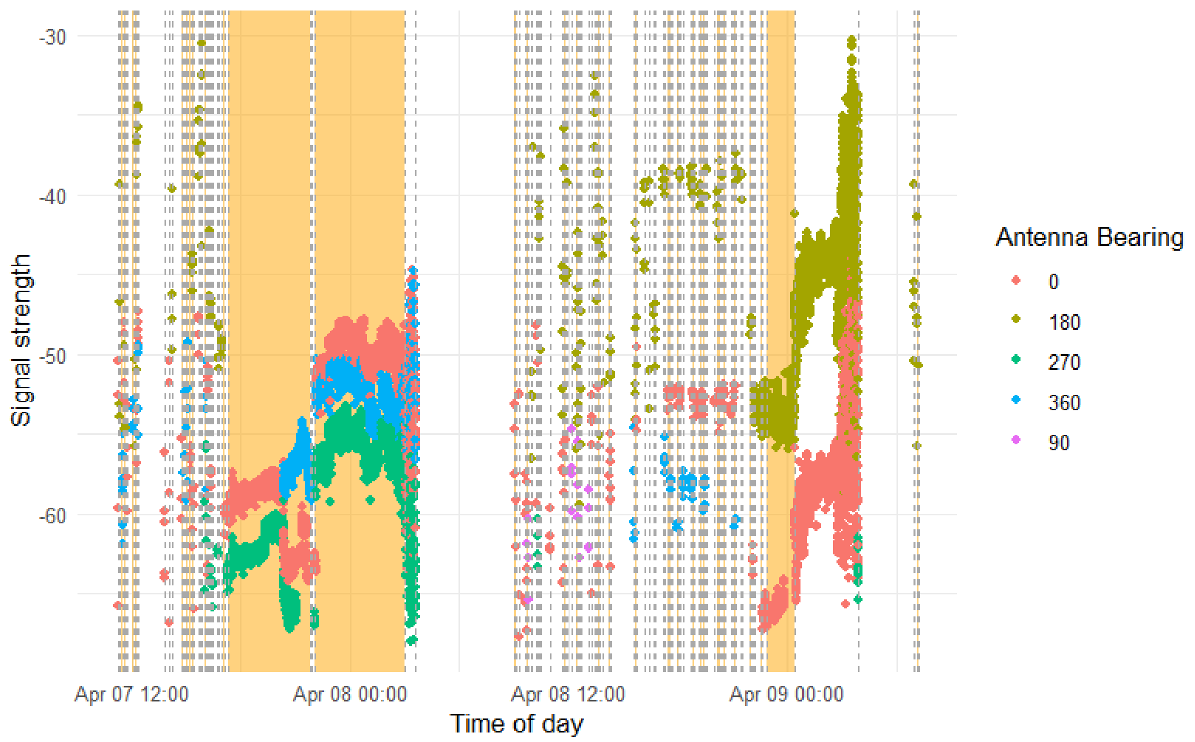

Fig. 6: Classification of and active periods, shown in the raw data for the signal strength in one Eastern Orphean Warbler (*Curruca crassirostris*, transmitter number: 13) from noon of the 7th April to noon of the 9th April. Each period, that is over 60 seconds apart and differs in behaviour, is separated by a dashed vertical line. Stationary periods are indicated by the orange fill.

5. Implemented Work

Time	Implemented Work
2023	• Literature research • Selection of sites for data collection and construction of the Motus radio-telemetry receiver station • Ordering equipment needed for the Motus radio-telemetry receiver station and transmitter • Planning fieldwork and data collection • Writing research proposals for additional funding
2024 (March)	• Installation of the Motus radio-telemetry receiver station at the IBRCE
2024 (April & May)	• Trapping study species as part of the standardized ringing effort at the IBRCE and attaching radio-telemetry transmitters • Maintaining the Motus radio-telemetry receiver station, solving technical challenges
2024 (May)	• Deinstalling the Motus radio-telemetry receiver station to store equipment save until the next season of data collection
2024 (June to December)	• Data exploration and preliminary analysis • Exchange with the research lab of H. Schmaljohann at the Carl von Ossietzky University Oldenburg (Germany) to learn Motus radio-telemetry data analysis • Writing of reports

6. Preliminary Results and Discussion

From the 48 individuals we detected, 24 stayed within the proximity of the receiver station until departure. For these individuals we observed a strong variation in stopover duration, i.e. the period between trapping until departure, of 0.44 to 16.6 days. Most birds remained relatively shortly at the stopover site with a median of 0.69 days (mean = 2.92, SD = 4.31). Long-distance migrants had a significantly shorter stopover duration compared to short-distance migrants (t = -2.16, df = 10.17, p-value = 0.05, Fig. 7). Moreover, results from the linear regression model suggest that individuals with a lower fat score remained longer at the stopover site than birds with high fat score (intercept = 130.77, slope = -30.98, adjusted R^2 = 0.17, p-value = 0.03). This indicates that stopover duration and likely the behaviour during stopover are context-dependent and differ between migration strategies and the birds' intrinsic condition. Consequently, we can predict that also pest-control services during stopover will be context-dependent and likely vary between individuals.

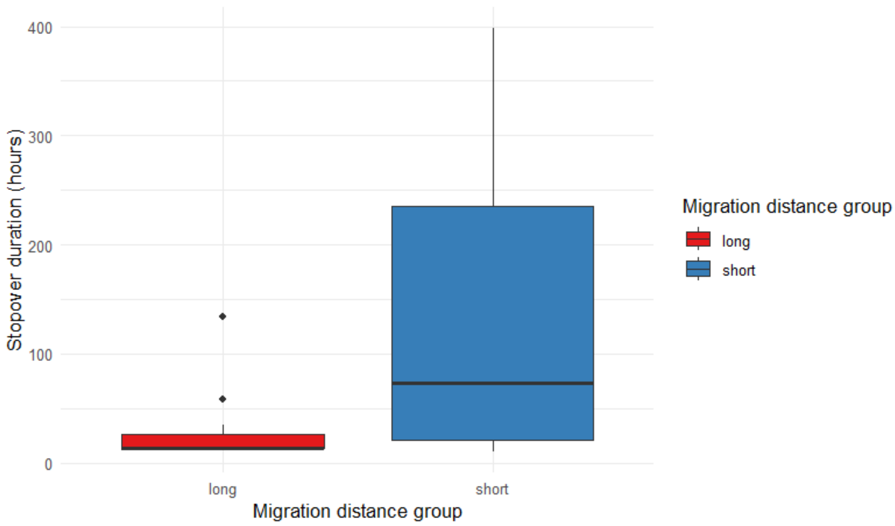

Fig. 7: Departure time in relationship to fat score.

Individuals that did not departure during the evening or early night, as it would be typical for nocturnal songbirds (Packmor *et al.* 2020), likely performed landscape-scale relocation movements to leave the study site. Noteworthy, due to the limited number of antennas, the coverage of the area was hampered and birds that seem to leave the study site might actually remained in close proximity but outside the antenna coverage. Nevertheless, we investigated in which direction birds that left the study site during the day moved. 12.5 % of all tracked birds left the study site towards the northern antenna, indicating that they performed landscape-scale relocation movements towards the large agricultural patches to the North of the study site. The others moved to semi-natural or urban areas around Eilat and Aqaba. This might indicate that movements towards the agricultural patch may be under-represented in all relocation movements, yet, the limited number of antennas hampered an exact analysis of the flight direction. To understand the use of agricultural areas, such as the date plantation north of the IBRCE, we need to analyse more closely the behaviour and movements during the stopover period.

During the entire time spent at the stopover site, agricultural areas (covered by the North directed antenna) were under-represented in most birds (Fig. 8). Noteworthy, birds were captured at the IBRCE, which likely resulted to the bias towards the South directed antenna, in particular for birds that departure shortly after capture. We found differences between the species and in particular Masked Shrikes, but also Common Nightingales and Eastern Orphean Warblers, used also the agricultural areas. Interestingly, these three species are short-distance migrants that were shown to spent longer times at the stopover site. This underlines that particularly individuals with short stopover moved less around before departure, resulting in an under-represented use of the agricultural areas. Moreover, the results indicate that certain species, such as the Masked Shrike, may select agricultural habitats at stopover site more often compared to other species. Noteworthy, the small sample size hampers further statistical tests and species comparisions.

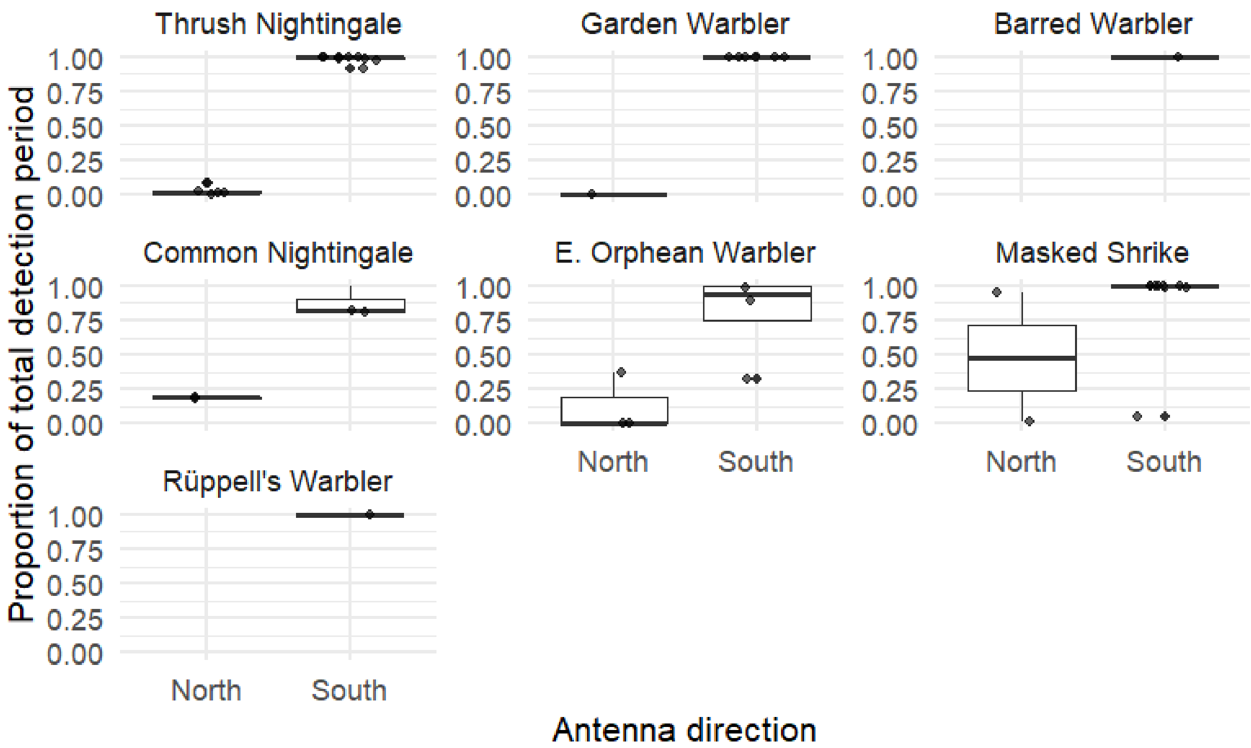

Fig. 8: Boxplots with jitter points, showing the proportion of time spent in the North and South directed antenna for each study species.

There was no significant relationship between the birds' fat score and proportion of time detected in the North directed antenna, i.e. in the agricultural area (intercept = 0.16, slope = -0.01, adjusted R^2 = 0.09, p-value = 0.82). This can also be seen in the boxplots for each fat score (Fig. 9), however, the sample size is low and hampers in-depth statistical tests.

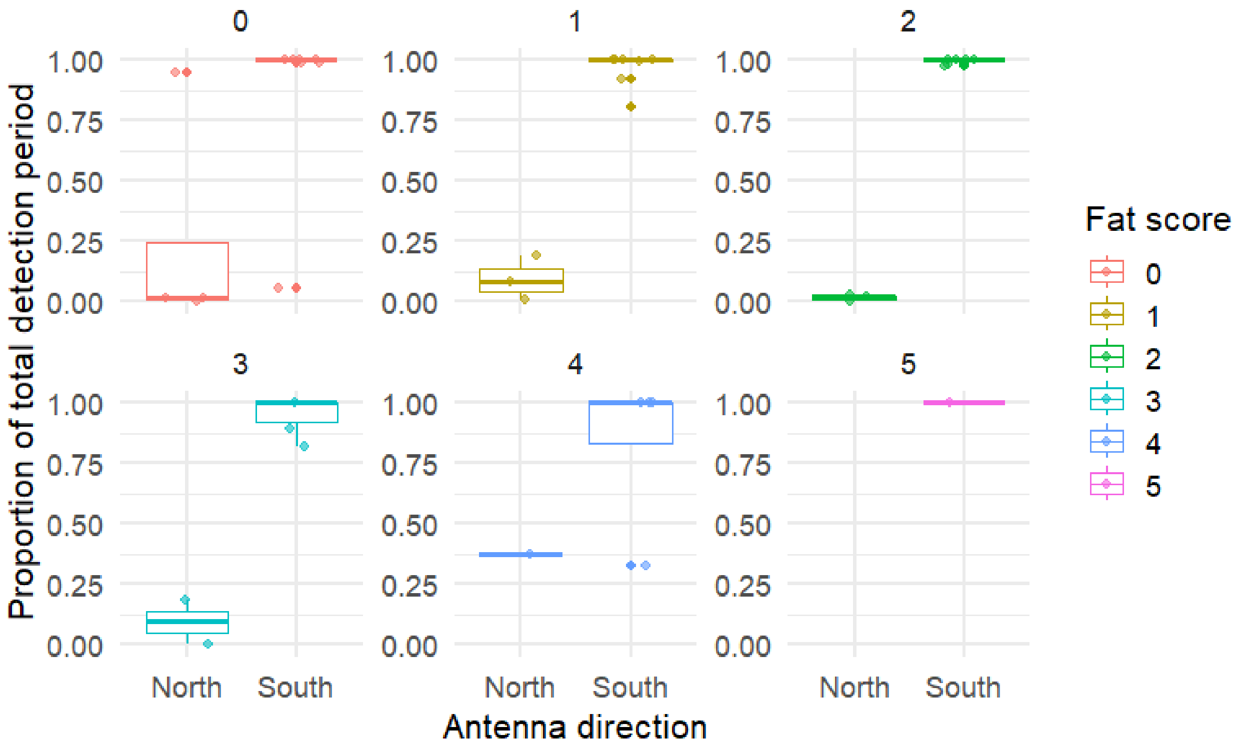

Fig. 9: Boxplots with jitter points, showing the proportion of time spent in the North and South directed antenna for individuals with different fat score.

Preliminary results and data exploration of the classification in stationary and active behaviour gives first insights in the behaviour of songbirds at the stopover site. Most individuals and species were predominantly stationary, indicating that most time was spent to rest and recover. However, we need refine the algorithm to classify the birds' behaviour. Particularly for Masked Shrikes, which forage using a sit-and-wait strategy (Yosef 2008), different thresholds for the standard deviation should be used. Refining the threshold for each species-group will help to improve the classification to not overlook active periods for birds with different foraging strategies, such as Shrikes. Moreover, in the further development of the classification we should differentiate general activity, likely foraging behaviour, from directed flights. Latter are indicated by parabolic, increasing or decreasing signal strengths (Taylor *et al*. 2017). An example for such a directed flight in a period classified as active can be seen in Fig. 6 on the 9th April from about 00:00 when the signal strength in the 0- and 180-degree antenna gradually increases until the pattern changes to non-directed movements. Filtering out these directed flights, could help to improve the quantification of periods during which birds are likely active foraging. Nevertheless, our preliminary results show that the signal strength has a potential to be used to quantify pest-control services in different habitat types. Yet, the algorithm to classify the behaviour needs to be further improved and more data needs to be collected. For this further data collection, it will be important to improve the coverage of the antennas to detect more signals and follow birds' behaviour over longer periods.

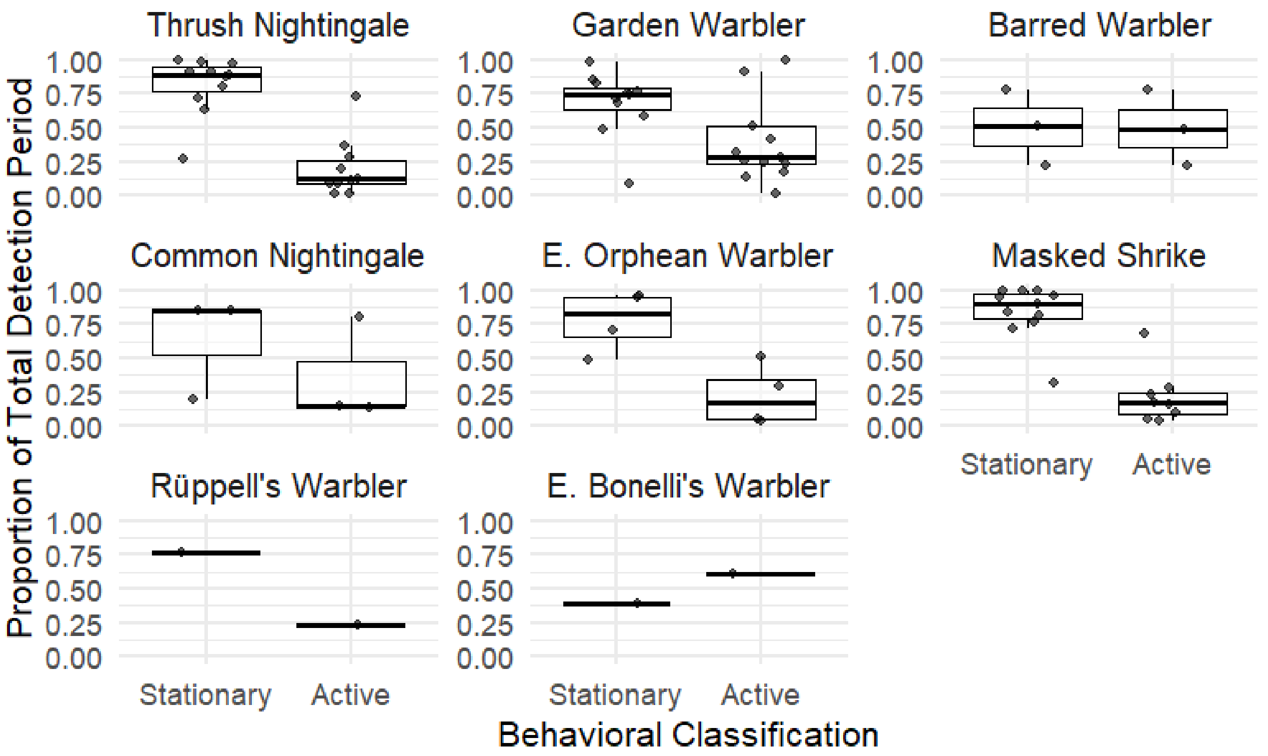

Fig. 10: Boxplots with jitter points, showing the proportion of time classified stationary or active for each study species.

7. Future directions

For the future analysis, we will collect further data from another spring migration season in 2025. Here, we will also address the technical challenges that hampered the antenna coverage last spring. With additional data we can also perform in-depth statistical analysis of the collected dataset to better quantify the time spent in agricultural habitats and classify (foraging) activity. For the latter, we will refine the algorithm to classify birds' behaviour. With a larger dataset and refined behavioural classification, we are confident to address the major challenge of quantifying pest-control services in different habitats, such as the date plantation and semi-natural area.

8. Outreach

Outreach and awareness activity with farmers and decision makers were implemented in the field throughout the implementation process whenever encountering farmers. Future more targeted outreach is planned after the second field season when we have a bigger data set and more results. This includes presentations and posters as well as meetings.

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