



Movement patterns of the endemic flightless bush-cricket, *Isophya beybienkoi*

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Abstract

Knowledge on the mobility of threatened species is a clue to understanding population dynamics and is needed to develop appropriate conservation strategies. Here, we investigate movement patterns of the Bei-Bienko's Plump Bush-cricket (*Isophya beybienkoi*), an example of a flightless and critically endangered species endemic to the Slovak Karst (southern Slovakia, Central Europe). The capture-mark-recapture method was used to estimate the mobility of the species using fluorescent dye as a marking medium. We found that the mean (\pm SD) daily distance travelled by this species was only 3.2 ± 2.6 m, with significant differences between males (4.1 ± 3.0 m) and females (2.7 ± 2.1 m). Our results indicate that *I. beybienkoi* is a short-distance disperser. Males disappeared faster than females from the study plots (at maximum, two females were recaptured even after 41 days). The observed movement patterns suggest that the most urgent conservation measure for this species is to improve the habitat quality of sites, which suffer from overgrowth, and to maintain the quality of other suitable sites that might increase the size of the existing subpopulations.

Implications for insect conservation Our results show that *I. beybienkoi* is a short-distance disperser and wanders only within its optimal habitat. Hence, to incorporate movement behaviour into conservation, one of the measures that should mitigate this threat is to preserve or improve the quality of habitats that suffer from overgrowth, in order to increase the size of existing subpopulations. The observed movement patterns suggest that the species is probably incapable of responding to changes in the availability of suitable habitats by dispersing, indicating a limited exchange of individuals between isolated populations. Thus, to enhance structurally diverse mosaic of high-quality habitats, restoration of migration corridors former used as movement corridors for grazing animals may support the dispersal of the threatened bush-cricket.

Keywords Dispersal · Mark-recapture · Orthoptera · SmartWater® solution

Introduction

Information about animal movement and dispersal have become crucial subjects in conservation biology (Bönsel and Sonneck 2011; Weyer et al. 2012; Kral-O'Brien and Harmon 2021). Knowledge on the mobility of threatened species is a key to understanding population dynamics and is often needed to develop appropriate conservation strategies

(McCartney et al. 2006; Rada et al. 2015). The movement patterns of insects are a well-studied concern, especially in orthopteran species (Bönsel and Sonneck 2011; Weyer et al. 2012), because many of them are flightless; thus, they are easy to catch and mark, representing excellent subjects for detailed dispersal studies (Kindvall 1999; Diekötter et al. 2005; Heller 2020). This is especially true in the case of isolated or non-flying species, which are often strongly restricted to their specific habitat (Holuša et al. 2013; Nuhličková et al. 2021a, b) and thus unable to cross larger distances, for example through unsuitable habitat. As a result, isolated and small populations that live for a long time in unchanged conditions could evolve a low dispersal ability (Bönsel and Sonneck 2011; Bonte et al. 2012; Cote et al. 2017; Fletcher et al. 2018).

Among bush-crickets (Tettigoniidae), the majority of species show a female-biased sexual sized dimorphism often

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linked to higher survival rate or longer life spans in the larger sex (Hochkirch et al. 2007; Hochkirch and Gröning 2008). On the other hand, males typically benefit more from rapid development and protandry, as they have to invest more in reproduction (e.g. energetically expensive production of nuptial gifts or calling songs) (Whitman 2008; Lehmann 2012; Sielezniew et al. 2020). Therefore, more conspicuous behaviours, such as greater mobility or dispersal, are often more characteristic for males when searching for females (Ingrisch and Köhler 1998; Wedell and Ritchie 2004; Voigt et al. 2005; Lehmann 2012).

Bei-Bienko's Plump Bush-cricket (*Isophya beybienkoi* Mařan 1958) is an example of a flightless and critically endangered species which is endemic to the Slovak Karst (southern Slovakia, Central Europe) (Chobanov et al. 2016). Only limited information exists for this species, except for several studies on its morphology, distribution or bioacoustics (Mařan 1958; Orci et al. 2001; Heller et al. 2004; Kriřtín et al. 2009, 2020). No information is known about its movement behaviour. Thus, to fill this information gap, a capture-mark-recapture experiment (CMR) was conducted to estimate its mobility (daily distance, movement trajectory, dispersal) and survival. For this purpose, fluorescent dye was used as the marking medium, as it is non-toxic, easy to use and highly visible (Faiman et al. 2021) and therefore suitable for animals with nocturnal activity. Based on previous studies on flightless Orthoptera species (Holuřa et al. 2013; Breuer et al. 2017; Heller 2020; Kenyeres and Varga 2023), we expected the movement capability of *I. beybienkoi* to be low. Similar to other species of the genus *Isophya*, we also assumed that it would be strongly restricted to its specific habitat, providing individuals with a required food source or shelters in vegetation (Bauer and Kenyeres 2006; Nuhlíčková et al. 2021b). Next, we also expected that males may disappear faster than females in the experiment due to more rapid development (protandry) and higher investments in reproduction (Lehmann 2012; Sielezniew et al. 2020). Finally, our study provides basic information that will be implemented in the conservation strategy of this highly endangered species.

Material and methods

Study species

The genus *Isophya* comprises about 90 species distributed around the Palearctic (Chobanov 2009). Bei-Bienko's Plump Bush-cricket occurs in only very small (up to 30 adults/ha) and isolated subpopulations with an area of occurrence of only 24 km² (Chobanov et al. 2016; Kriřtín et al. 2020). It is a relatively large (up to 26 mm) species with well-developed acoustic communication (Orci et al. 2001), reproducing from June to September (Chobanov et al. 2016, own unpublished

observations). Like other species of this genus, it is characterised by mostly crepuscular to nocturnal activity and a high frequency of male calling song (Berg et al. 1996; Vadkertı and Szövényi 2005). Its occurrence is linked to karstic grasslands up to 800 m a.s.l. (Chobanov et al. 2016).

Study site

The study was conducted in the Slovak Karst National Park (NP). The karst phenomena is associated with rich xerophilous steppe vegetation on sunny slopes, rocky fields and the edges of plateaux (Dúbravková-Michálková et al. 2008). To obtain data on the species' current distribution, all historical and suitable sites were intensively surveyed prior to this experiment by walking slowly through the relevant habitats and sweep-netting the vegetation (Wagner 2015; Nuhlíčková et al. 2021b). In doing this, a total of 484 km of transects were conducted in suitable habitats in 2021 (254 km) and 2022 (230 km). Based on this survey, two sites (ES) were selected according to the population density and suitability for such a field experiment: (1) Rakařa meadows (ES1; Fig. 1a): Silická planina plateau, NE of the Silica village, 565 m a.s.l.; slope: 5° and (2) the karstic grasslands of Malý vrch Hill (ES2; Fig. 1b): Silická planina plateau, NE of the Gombasek village, 550 m a.s.l.; slope: 11°. Both sites (ES1 and ES2) were characterised by fringe vegetation (*Bromion erecti*, *Geranion sanguinei*) rich in broad-leaved flowering plants in transitional zones between forests edges, xerophilous grasslands or solitary old oaks (*Quercus* sp.), hornbeams (*Carpinus betulus*) and meadows (Dúbravková-Michálková et al. 2008; own unpublished data) (Fig. 1). The vegetation of the ES1 was very irregularly grazed by cattle. The territory of ES2 is currently without any management. Both study plots are isolated from other suitable habitats by forests and other habitats unsuitable for this species (see Fig. 3).

Marking procedure

For fluorescence marking of bush-cricket, a non-toxic, water-based SmartWater® solution was used (Faiman et al. 2021), rendering the marked animal visible under UV light (365 nm) (Fig. 2a and b). Each individual (79 males and 113 females) was labelled with a unique code on the pronotum using a permanent non-toxic paint marker. The animal was subsequently painted with light-green fluorescence colour using a thin brush on the abdomen (every side around) and both femurs to maximise the detectability in the field, avoiding any sensitive parts, such as the head, mandibles, eyes or tympanal organ on the front legs (see Fig. 2b). After the marking was done, the coloured individuals were carefully returned to the place of their collection. Sex, GPS location (Garmin GPSMAP 65 EUROPE with Multi-GNSS receiver,

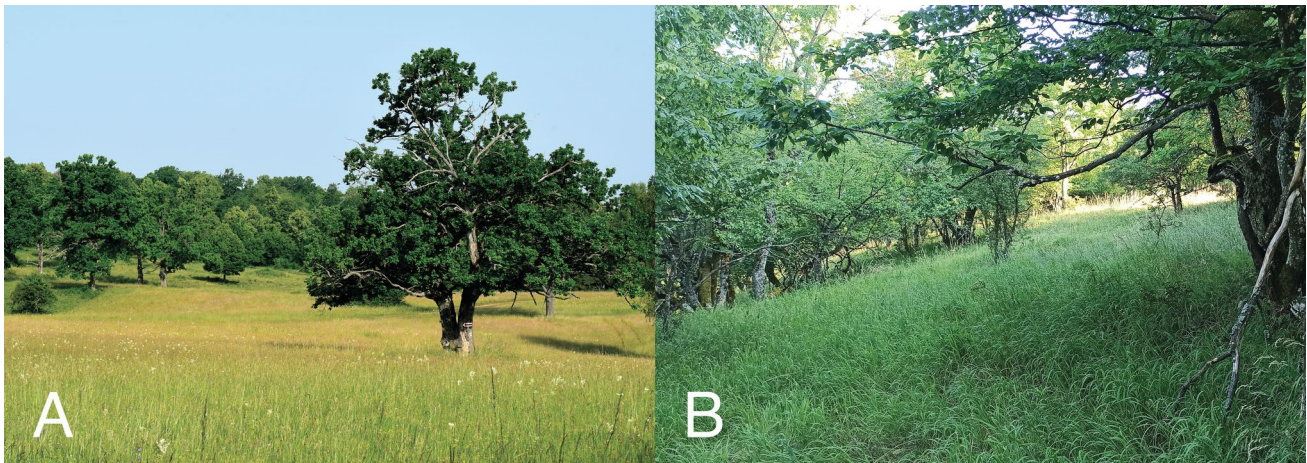


Fig. 1 Study sites: **a** Rakafa meadows (ES1) and **b** Karstic grasslands of Malý vrch Hill (ES2)

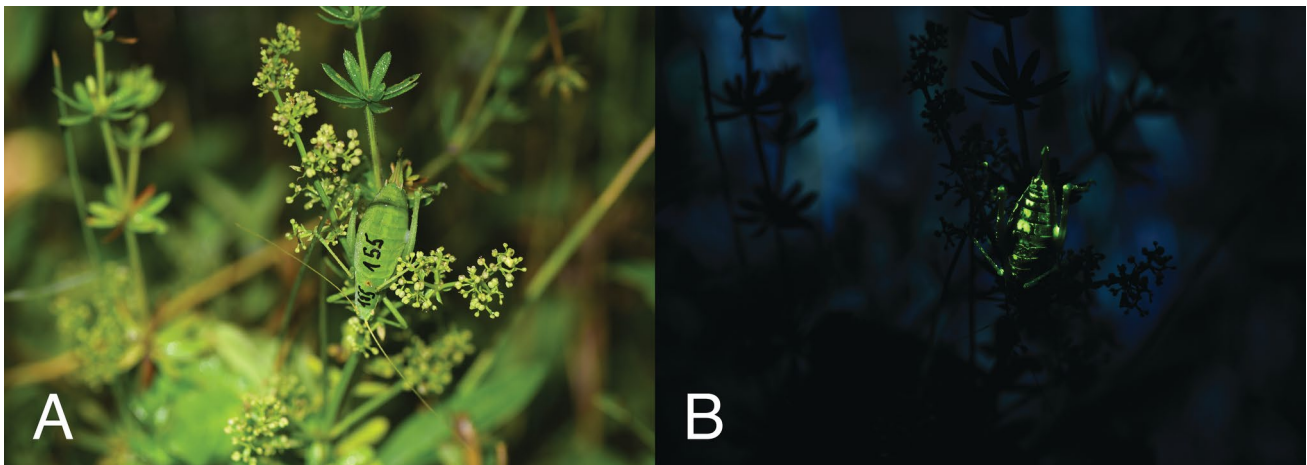


Fig. 2 Fluorescence marking in the field: visibility of the same individual **a** during the day and **b** during the night. The animal was not arranged

with location accuracy about ± 2 m) and time of capture and recapture were recorded before release.

Tracking of bush-cricket movements

The capture session started on 21 June 2022 at ES1 and 26 June 2022 at ES2 (see Online Resource 1), by slow walking and sweep-netting, following line transects arranged by GPS devices. In total, territories covering an area of 20,000 m² (Fig. 3a) and 22,500 m² (Fig. 3b) were investigated at ES1 and ES2, respectively, without any re-passing of already inspected vegetation or missing of unchecked habitats.

Recapture controls were performed during night hours (12 h after dusk, usually from 9:30 p.m. to 01:00 a.m.) (Online Resource 1 and Online Resource 2) using a UV flash-torch (UVB-V3-365, USA) and supported by a bat-detector to enhance the search for calling males. In this

way, vegetation was carefully examined in the same way as during the marking procedure, following the line transect arranged by GPS devices. For each labelled individual resighted by UV, the new GPS location, date and time were recorded. During the night controls, newly captured individuals that had not been previously labelled were marked and released. The CMR experiment ran for 18 days, until 4 August 2022 (10 controls at ES1, 8 controls at ES2, Online Resource 1). Each control was carried out during calm weather (no wind, clear sky, without rain) to maximise the detection of animals. Labelled individuals that were not recaptured at all during the experiment were assumed to have been consumed by predators or emigrated from the site. For a detailed overview of all captured, marked and recaptured individuals found in this study, see Online Resource 2.

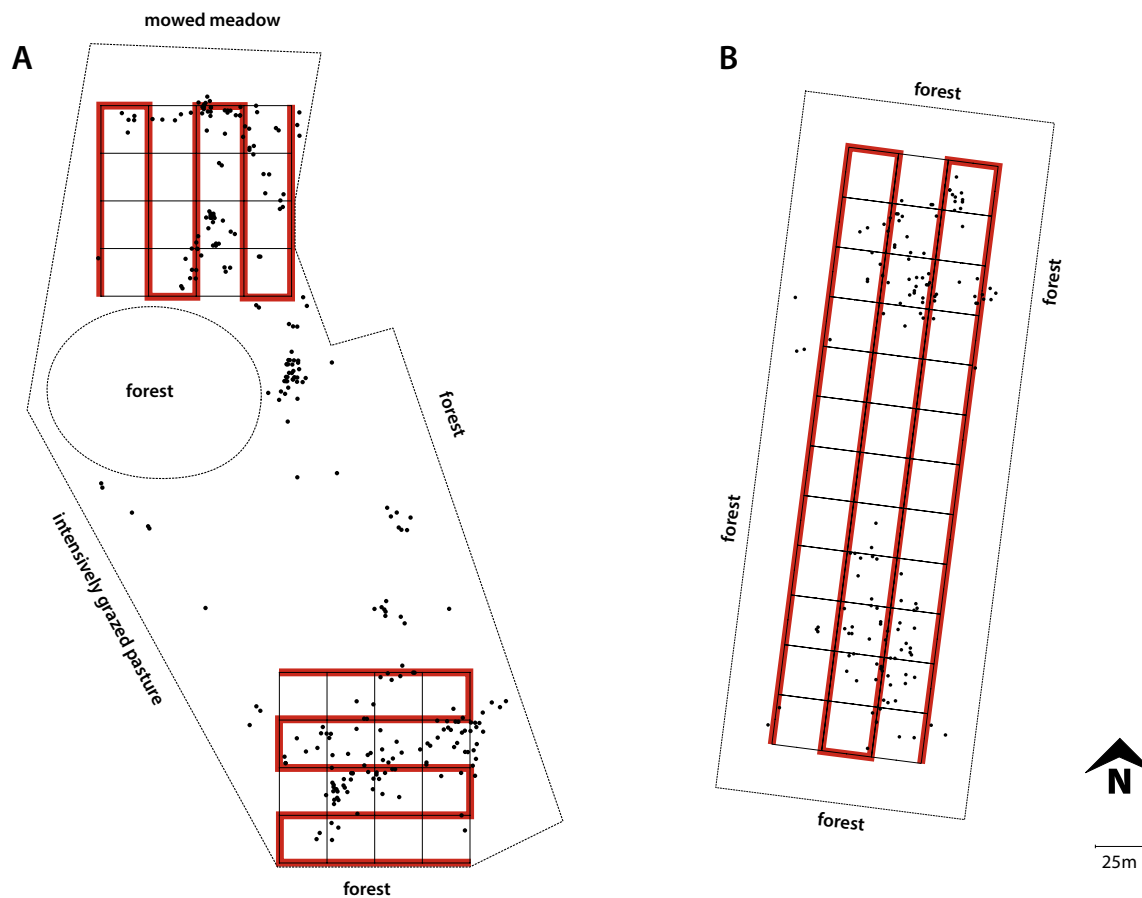


Fig. 3 Outline of the two experimental sites with all capture and recapture points of *Isophya beybienkoi*. Explanations: **A** experimental site 1 (ES1), **B** experimental site 2 (ES2). Red line – line transect. Dashed line – polygon boundaries of two experimental sites

Data analysis

To evaluate the movement pattern of the species, the following linear movement parameters of individuals were calculated: i) *the daily distance* (average net displacement distance; m/day) representing the straight-line distance covered by an individual within 24 h; ii) *the direction of turning angles* ($^{\circ}$) representing the change of movement direction between consecutive relocations of an individual; iii) *movement trajectory* (m) – linear distance between consecutive relocations of marked and recaptured individuals; iv) *dispersal distance* (m) – linear distance between a site where an individual was marked for the first time and recaptured for the last time (i.e. distance of the first and the last location). Movement trajectories were calculated from GPS data using the function `as.ltraj` in the package “`adehabitatLT`” (Calenge et al. 2023) of the R 4.3.0 statistical environment (R Core Team 2023). Association between sex and capture/recapture events were evaluated using the Chi-squared test (Pearson’s Chi-squared test with Yates’ continuity correction) in the base R package “`stats`” (R Core Team 2023). To compare the temporal pattern of recaptures between the sexes, the

difference between survival curves from a Kaplan–Meier formula using the functions `survfit` and `surdiff` from the R package “`survival`” (Therneau and Grambsch 2000; Therneau 2022) was used. We set the day when an individual was marked as day zero.

Generalised linear models (GLMs) with Gamma distribution and identity link were fitted to assess the association between movement trajectory and dispersal as response variables, and time and sex of the crickets as explanatory variables. The number of fixes was included in the models as an offset term. The function `glm` from the base R package “`stats`” and subsequently the function `Anova` (type 3) from the R package “`car`” (Fox and Weisberg 2019) were used to compute an analysis-of-variance table for the objects of the models. For the GLMs, Nagelkerke’s R^2 was computed using the R package “`sjstats`” (Lüdecke 2022). The function `model_check` from the R package “`performance`” (Lüdecke et al. 2021) was used to check the models’ assumptions. To analyse directionality or randomness of the crickets’ movements (i.e. direction of the turning angles), the Rayleigh test of uniformity was used separately for both sexes. To test for differences between sexes in the direction of movement,

Watson’s two sample test of homogeneity was used. Both tests are implemented in the R package “circular” (Ago-stinelli and Lund 2022). Finally, the R packages “ggplot2” (Wickham 2016) and “ggfortify” (Horikoshi and Tang 2016; Tang et al. 2016) were used for plotting.

Results

Altogether, 192 bush-crickets were marked at both study sites (41.1% males and 58.9% females). A total of 44 males and 71 females were recaptured 69 and 150 times, respectively. The overall recapture rate (i.e. the proportion of individuals recaptured at least once) was 59.9%, with fewer males (38.3%) than females (61.7%) recaptured. We found that a lower proportion of unique males were recaptured

than marked and released, but the differences between the sexes were not statistically significant ($\chi^2=0.14$, $P=0.710$). However, the proportion of male recaptures was significantly lower than that of females ($\chi^2=3.72$, $P=0.054$), i.e. more unique female individuals were recaptured repeatedly than males. This is due to the faster disappearance of males during recaptures: females were recaptured almost twice as long as males ($\chi^2_{18}=146.0$, $P<0.001$; Fig. 4).

The mean daily distance of the bush-crickets was 3.2 m. The mean daily distance of males was higher than that of females ($\chi^2=8.93$, $P=0.003$, $R^2=0.10$). Males moved an average of 4.1 m per day, while females 2.7 m per day (Table 1). The direction of turning angles between successive movements was random in both males (Rayleigh test, test statistic=0.2082, $P=0.287$) and females (test statistic=0.1372, $P=0.226$) and no difference was found between the sexes (Watson’s two-sample test, test statistic=0.06, $P>0.10$). The movement trajectory (m) of recaptured individuals was positively associated with observation time (tracking time) ($\chi^2=66.64$, $P<0.001$, $R^2=0.58$; Fig. 5a). We found that the bush-crickets moved an average dispersal distance of 16.2 m (Table 1). The dispersal distance (Fig. 5b) was also positively related to time ($\chi^2=26.67$, $P<0.001$), but the strength of this association was weaker ($R^2=0.26$) than for the movement trajectory (Fig. 5a and b). Sex did not affect the variability of the response variable, either alone or in interaction with time ($\chi^2 \leq 1.83$, $P \geq 0.18$). The longest observed individuals were two females that were recaptured for more than a month (41 days in total), i.e. throughout the entire experiment (Fig. 4). The maximum trajectory travelled by a bush-cricket was 182.7 m (Table 1).

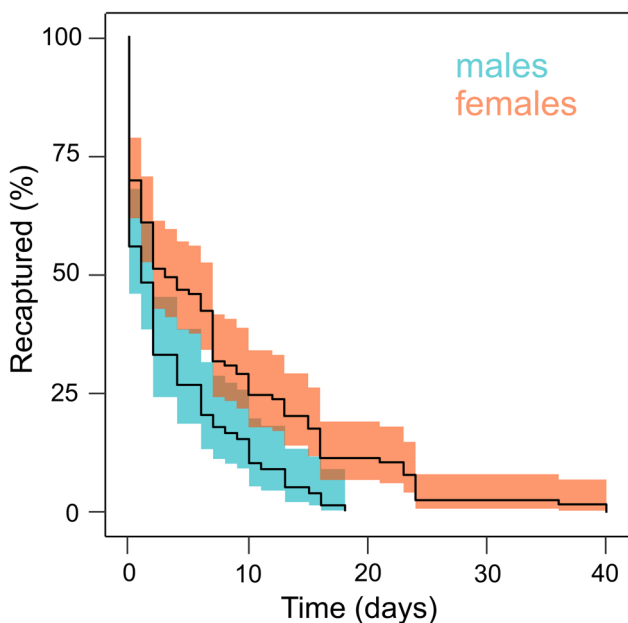


Fig. 4 Temporal pattern of proportion of recaptured males and females of *Isophya beybienkoi* visualised using the Kaplan–Meier estimator. Day zero is the day when an individual was marked

Discussion

Tracking of bush-cricket movements

In this study, we found a very low movement ability of *I. beybienkoi*, with a mean daily dispersal distance of 3.2 m and a maximum of 13.8 m per day. The main types of

Table 1 Descriptive statistics of movement characteristics of *I. beybienkoi* (n = 115)

Statistic	Tracking time (days)	Average daily distance M (m/day)	Average daily distance F (m/day)	Movement trajectory (m)	Dispersal distance (m)
Mean	9.5	4.1	2.7	25.2	16.2
SD	8.2	3.0	2.1	25.6	14.2
Median	6.6	3.2	2.2	18.4	11.7
Q1	2.5	1.9	1.3	8.3	6.3
Q3	13.3	5.6	3.8	35.3	22.7
Min	1.2	0.5	0.2	0.7	1.0
max	41.4	13.8	10.8	182.7	70.0

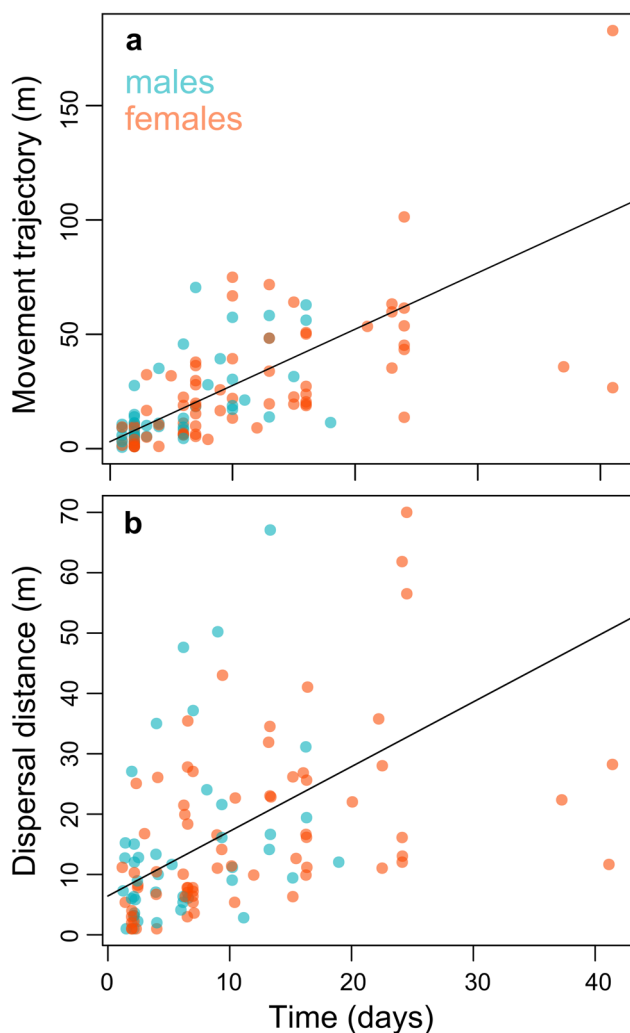


Fig. 5 Association between tracking time and **a** movement trajectory, and **b** dispersal distance of recaptured males and females of *Isophya beybienkoi*

movements found in this species were climbing or clambering. Even when disturbed, the bush-cricket preferred falling or slow hiding into the lower vegetation layers rather than jumping. In most of the measured characteristics, movement patterns were similar to other flightless bush-crickets. For example, the predatory katydid *Saga pedo* moved extraordinary low distances between 0.5 and 2 m in 24 h, but one individual was able to travel up to 330 m in one night (Holuša et al. 2013). In the related *Isophya kraussii*, Köhler et al. (2019) found that the daily movement (average of 58 days) in males was 6.5 (1.5–9) m and in females only 3.5 (2.0–2.5) m. On the other hand, the large and flightless Mormon cricket (*Anabrus simplex*) has shown a great variability in daily distances. The animal was found to have travelled from 0.66 m up to 331 m per day (Lorch et al. 2005). Movements in the Cook Strait Giant Weta (*Deinacrida rugosa*), resident on Mitiu-Somes Island, has shown that the average

distance between consecutive daytime refuges ranged from 7 to 41 m (Watts et al. 2012). Extremely low daily movements were also detected in two species of endemic grasshoppers from South Africa (*Betiscooides meridionalis* and *B. parva*). Approximately 60% of females of both species travelled less than 0.5 m per day, while males of both species crossed cumulative distances up to 15 m during 9 and 10 days (Matenaar et al. 2014). In fact, low movement ability and dispersal are reason why the majority of flightless Orthoptera are known to be at higher extinction risk than well-flying species (Van Dyck and Baguette 2005; Matenaar et al. 2014; Cote et al. 2017). We showed that both sexes of *I. beybienkoi* featured very low dispersal (on average 16.2 m), with only random directions between successive moves, suggesting routine movements (Van Dyck and Baguette 2005). In this regard, many flightless species limit their movement only to their specific habitat and are therefore unable to cover longer distances, e.g. through unsuitable vegetation (Weyer et al. 2012; Nuhlíčková et al. 2017, 2021b). As a result, even isolation represents a serious threat, especially in species with reduced mobility. For instance, distribution of the related *Isophya costata* is restricted to small and isolated subpopulations linked to historical refugia (Nuhlíčková et al. 2017, 2021b). The flightless *Chorthippus montanus* is strongly restricted to its optimal habitat and is probably not able to cross larger distances through unsuitable vegetation (Weyer et al. 2012). Finally, the occurrence of *I. beybienkoi* is restricted to only small and isolated subpopulations in semi-natural calcareous grasslands, which are threatened by inadequate management leading to succession of its habitat (Chobanov et al. 2016). Thus, the bush-crickets seem to restrict their movements to the routine type – being mostly reflected within its habitat and hence, being sedentary (Van Dyck and Baguette 2005). As a result, species that live in habitats where the conditions remain largely unchanged over the long-term could evolve low dispersal patterns (Van Dyck and Baguette 2005; Bönsel and Sonneck 2011; Bonte et al. 2012; Cote et al. 2017; Fletcher et al. 2018; Bartlow and Agosta 2021).

Recapture rates, survival and sex-specific differences in mobility

At both experimental sites, the recapture rates of bush-crickets decreased over time. This pattern is characteristic, especially for CMR methods, and can generally be attributed to higher mortality of individuals (Morton 1982; Narisu et al. 1999; Hein et al. 2003; Diekötter et al. 2005, 2007). Given the fact that both study plots were isolated from other suitable habitats by forests and other habitats unsuitable for this species, we assume that individuals of *I. beybienkoi* could not emigrate out of the range of the CMR-area. However, lower recaptures rates of males compared to females may indicate

the disappearance of males during the recapture sessions, indicating sex-biased survival caused by specific differences in the behaviour of both sexes, as males mature earlier than females (protandry) and have to invest more in reproduction (Whitman 2008; Lehmann 2012; Sielezniew et al. 2020). For instance, males of *Poecilimon thessalicus* which were more preferred by conspecific females faced a higher predation risk by the parasitoid fly *Therobia leonidei* (Lehmann et al. 2001). Spermatophylax of *I. kraussii* can supply a female's energy demands for one or two days. As females can mate every two or three days, they may obtain most of their food by mating (Voigt et al. 2005). Females of *Gryllus integer* from two populations differing in predation pressure did not differ in hiding times compared to males. Males from a high-predation habitat were hidden for a longer time than males from a low-predation habitat (Hedrick and Kortet 2006). Thus, it appears that males have to move towards females, because they spend more time searching for a mate (Wedell and Ritchie 2004; Voigt et al. 2005; Hochkirch et al. 2007; Lehmann 2012). In contrast, females are the sex that benefits from a larger body, possible longer life spans or higher survival rates (Hochkirch et al. 2007; Hochkirch and Gröning 2008; Lehmann 2012). *I. beybienkoi* females were recaptured at almost twice as long-time intervals than males, and males travelled significantly longer daily distances than females. The longest observed individuals were two females that were recaptured after 41 days, which was longer than known in other (flightless) bush-cricket species (e.g. Heller and von Helversen 1990; Köhler et al. 2019).

The effectiveness of CMR experiments is generally reflected in the recapture rate, which depends on the target species, habitat structure, research intensity and on the way in which individuals are marked (Ingrisch and Köhler 1998). We have shown that the fluorescent dye has very good retention, indicating a suitable product for marking threatened species. However, we were unable to clearly assess whether the lower recapture rates of males were a result of predation or other life history strategies, as indicated by the results above. Therefore, it is possible that the earlier development of *I. beybienkoi* males (Whitman 2008; Lehmann 2012; Sielezniew et al. 2020) is responsible for the lower recapture rates in later stages of the vegetation season. Hence, further research will be needed to explore in more detail the sex-specific differences between males and females. Furthermore, it is also possible that this species is more mobile than we thought. For example, different mobility of individuals can be affected by stressful conditions (e.g. high population density) or disturbances. While some species show higher dispersal (e.g. *Metrioptera roeselii* – due to macropterous individuals), other species are only capable of limited mobility (e.g. *M. brachyptera*) (Poniatowski and Fartmann 2011a, b). However, the dispersal ability of *I. beybienkoi* was very low, which indicates only a limited exchange of individuals

between isolated populations. Based on our results, the bush-cricket is probably unable to respond to changes in the availability of suitable habitats by dispersing and hence may be especially dependent on habitat management activities that promote the long-term stability of existing habitat patches (see Poniatowski and Fartmann 2011b). On the other hand, we found that the majority of recaptured individuals were sitting in a very similar location, usually at the top of a host plant. Thus, our bush-cricket may search for food or mate but returns to a similar place, e.g. a host plant. Such homing behaviour is characteristic for a few nocturnal bush-cricket and katydids (Tettigoniidae), which return, e.g., to their daytime roosts after nightly excursions (Hale and Bailey 2004; Heller 2020). However, the methodological limitations of this study do not yet allow safe conclusions.

Finally, it should be noted that the results obtained in this study are based on the location of individuals using a GPS device with an accuracy of ~2 m, which may bias to some extent the results of the subtle movements detected in this endemic bush-cricket. In a fine scale movement tracking study, statistically significant measurement errors of the GPS approach were observed for distances and bearings (Růžičková and Elek 2021). Distances measured by GPS (with an accuracy of ~3 m) were approx. 20–30% greater than direct distance-bearing measures. The shorter the distance covered, the greater the relative error, and the average bearing error of GPS was evenly distributed over all directions. These errors were larger under a dense forest canopy (Růžičková and Elek 2021). The implications of these findings are case specific and depend on the objective of the study. In the case of overestimation of movement distances by GPS, our conclusion about the low dispersal capability of *I. beybienkoi* and related conclusions for conservation management activities that promote the long-term stability of existing habitat patches (see below) remain valid.

In conclusion, our results show that *I. beybienkoi* is a short-distance disperser and wanders only within its optimal habitat. Hence, to incorporate movement behaviour into conservation, one of the measures that should mitigate this threat is to preserve or improve the quality of habitats that suffer from overgrowth, in order to increase the size of existing subpopulations. The observed movement patterns suggest that the species is probably incapable of responding to changes in the availability of suitable habitats by dispersing, indicating a limited exchange of individuals between isolated populations. Thus, to enhance structurally diverse mosaic of high-quality habitats, restoration of migration corridors formerly used as movement corridors for grazing animals may support the dispersal of the threatened bush-cricket.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10841-023-00529-0>.

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Author contributions All authors contributed to the study conception and design. Material preparation and data collection were performed by [Soňa Nuhličková], [Ján Svetlík], [Anton Krištín] and [Benjamín Jarčuška]. Data analysis was performed by [Benjamín Jarčuška] and [Peter Kaňuch]. The first draft of the manuscript was written by [Soňa Nuhličková] and [Anton Krištín]. All authors commented on previous versions of the manuscript. All authors have read and approved the final manuscript. Conceptualisation: [Soňa Nuhličková]; Methodology: [Soňa Nuhličková], [Ján Svetlík], [Anton Krištín], [Peter Kaňuch] and [Benjamín Jarčuška]. Formal analysis and data investigation [Benjamín Jarčuška] and [Peter Kaňuch]; Writing – original draft preparation: [Soňa Nuhličková] and [Anton Krištín]; Writing – review and editing: [Soňa Nuhličková], [Ján Svetlík], [Anton Krištín], [Peter Kaňuch] and [Benjamín Jarčuška]; Funding acquisition: [Soňa Nuhličková].

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Availability of data and material (data transparency) Not applicable.

Code availability (software application or custom code) Not applicable.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval (include appropriate approvals or waivers) All authors declare that they did not collect threatened arthropods from the study areas. All marked animals were carefully returned to the place of their collection.

Consent to participate (include appropriate statements) Not applicable.

Consent for publication (include appropriate statements) Not applicable.

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