Microhabitats of planted sea wall strips used by pollinators and Orthoptera

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Abstract

As part of an Urban Buzz scheme, strips of teasel (*Dipsacus fullonum*) and greater knapweed (*Centaurea scabiosa*) have been established along a sea wall flood defense in the UK to provide a corridor of flower-rich habitat for pollinators such as bees and butterflies. The cutting of tall grassland and planting of dicotyledons also created a suitable short sward environment (c. 30 cm height) for Orthoptera nymphs in the establishment year (2018). However, by 2019, the grassland in the pollinator strips was taller (c. 75 cm) and suboptimal for grasshoppers; in contrast to Roesel's bush-cricket (*Roeseliana roeselii*), which inhabited the taller vegetation in greater abundance. The progression to established grassland with flowering *D. fullonum* saw the pollinator strips attract significantly higher numbers of bees and butterflies than the floristically poor control strips. This small-scale study illustrates that pollinator strips can have multi-functional benefits for ecosystems beyond pollination, with Orthoptera of tall grassland (*R. roeselii*) likely to persist alongside planted wildflowers.

Keywords

bumblebee, bush-cricket, butterfly, conservation, dicotyledon, grasshopper, flood defense

Introduction

The loss of 97% of wildflower-rich meadows in the UK has necessitated conservation interventions to restore essential ecosystem services such as pollination (Blowers et al. 2017, Cresswell et al. 2018, Gardiner and Fargeaud 2018a). Sea wall flood defenses often have the last remnants of unimproved meadow in lowland areas (Gardiner et al. 2015), which can be important habitats for bumblebees (Gardiner and Fargeaud 2018b) and Orthoptera (Gardiner and Charlton 2012, Fargeaud and Gardiner 2018) largely due to the varied sward structure and microhabitats. In response to the decline in urban pollinator populations in the UK, Buglife, the Invertebrate Conservation Trust, led an Urban Buzz project with Ipswich as one of the focus towns in eastern England (Buglife 2018). As part of the scheme, strips of wildflowers have been established along an urban fringe sea wall flood defense in Ipswich to provide a corridor of flower-rich habitat for pollinators. It is the aim of this short communication to ascertain the incidental benefits of the pollinator strip microhabitats for Orthoptera.

Methods

As part of the Urban Buzz project, the Environment Agency (EA) was given wildflower plugs (small-sized seedlings grown in trays) to plant in spring 2018. The Wherstead sea wall that runs under the Orwell Bridge towards Fox's Marina (Ordnance Survey grid reference start: TM169410, end: TM166414) was selected due to the good opportunities for enhancement. Rank grassland on the folding (flat area between borrowdyke and landward slope) was chosen as being suitable for planting after consultation with engineers at the EA. The grassland was mainly composed of coarse grasses such as cock's-foot (*Dactylis glomerata*), occasional reed (*Phragmites australis*), and hemlock (*Conium maculatum*). The diversity of the flora was low and plants providing pollen and nectar for bees were virtually absent over much of the flood defense apart from scattered creeping thistle (*Cirsium arvense*) and teasel (*Dipsacus fullonum*) plants. Locally scarce plants found on the flood bank included three orchids: pyramidal orchid (*Anacamptis pyramidalis*), common-spotted orchid (*Dactylorhiza fuchsia*), and bee orchid (*Ophrys apifera*). Two Nationally Scarce species were recorded: dittander (*Lepidium latifolium*) and annual beard-grass (*Polypogon monspeliensis*), the former in some abundance, the latter on one small patch of disturbed ground.

The vegetation of seven strips (strip length x width in m, 1: 15×1, 2: 10×1, 3: 17×1, 4: 15×1, 5: 5×1, 6: 10×1, 7: 6×1) within the 1 km long sea wall folding was cut by hand (with shears to avoid mechanical mortality of orthopteran nymphs) to a height of 20 cm in early April 2018 to create favorable planting conditions for the plugs. Strips were separated by at least 10 m from each other by a buffer of uncut grassland. On 18 and 19 April, 300 greater knapweed (*Centaurea scabiosa*) and 200 teasel were planted into a strip of 1 m wide grassland in each strip (plugs of both species intermingled during planting; planted at a density c. 6.4 plants per m^2), 2–3 m away from the landward slope to avoid machinery

tracking over them during subsequent management of the flood defense. These two plant species were chosen because they have been recorded in the Ipswich area and could be considered locally native and suitable for clay soil. They are also excellent species for foraging pollinators (Rollin et al. 2016, Nichols et al. 2019). Stakes were used to mark out each section for ease of location in the field. On the 14 May 2018, vegetation was again cut to a height of 20 cm in the planted strips to aid establishment. In April 2019, the sward was cut to a height of 20 cm for pollinator plants and Orthoptera.

Orthoptera sampling.—In each pollinator strip and an adjacent unplanted/uncut control strip, a 1-m-wide transect (the same length as each pollinator strip and control) was established closely following the methodology of Gardiner et al. (2005) and Gardiner and Hill (2006). The pollinator and control strips were parallel to each other and at least 3 m apart due to space limitations on the folding. The vegetation of the pollinator and control strips were both selected for this study due to their homogeneity in vegetation composition/structure and overall similarity in environmental characteristics. Each transect was walked at a slow strolling pace (2 km/hr) in early June and July of 2018 and 2019 (four surveys in total). During the June surveys, only nymphs flushed from a 1 m wide band (using a 1-m-long pole swept back and forth in a 180° arc) in front of the observer were recorded. The June surveys were undertaken when the vegetation was sufficiently short (<50 cm) to minimize the possibility of overlooking nymphs in the tall grass (Gardiner et al. 2005). Adults were not recorded in the June surveys due to their low abundance at this stage of the season. With practice, it was relatively easy to ascertain the species of each orthopteran without capture. During the July surveys, only adults were recorded as nymphs were in low abundance by this time in the summer (most had matured). The weather conditions on all survey days were favorable for insect activity, being largely sunny and warm (>17°C).

Pollinator sampling.—In the pollinator strips and sea wall grassland (control), transects were established (a total of seven transects each for the pollinator and control strips, the same length as the strips). The methodology for surveying bees (Hymenoptera) and butterflies (Lepidoptera) followed that of Carvell et al. (2007). Surveys were undertaken between 10:00 and 17:00 h, when weather conditions conformed to the following criteria for the UK Butterfly Monitoring Scheme: 1) transects are not walked when the temperature is below 13°C; 2) between 13–17°C, a transect may be walked providing there is at least 60% sun; 3) above 17°C, a transect may be walked in any conditions, providing it is not raining; 4) when wind speeds are above 5 on the Beaufort scale, transects should not be walked (Pollard and Yates 1993). Seven surveys of the transects were undertaken in 2019 from early June to mid-July. Bee and butterfly species were only recorded if they visited flowering plants (either natural or planted).

Sward height and rabbit droppings.—Ten sward heights were recorded at random positions using a meter rule in each pollinator and control strip in early July 2018 and 2019 (70 heights for pollinator and control strips in each year). In addition, during the sward height surveys, the number of wild rabbit (*Oryctolagus cuniculus*) (Lagomorpha: Leporidae) droppings (dung balls) were counted for each transect (in 1 m band for entire length of strips) in each year to ascertain the level of grazing pressure on each strip (Wood 1988, Gibb and Fitzgerald 1998, Millett and Edmondson 2013).

Statistical analysis.—To correct for non-normality, the data were square-root transformed (Heath 1995). The mean density of *C. scabiosa* and *D. fullonum* plants were compared between the pollinator and control strips in both years using a two-way ANOVA in the online VassarStats package (Lowry 2020). A paired samples t-test was used to compare the mean number of pollinators/100 m and the mean pollinator species richness/strip in 2019 between pollinator and control strips.

Only grasshopper (all Acrididae species combined) and Roesel's bush-cricket (*Roeseliana roeselii* Hagenbach) nymphs were in high enough abundance from the Orthoptera to allow meaningful analysis. The mean nymphs and adults of both, overall species richness, rabbit droppings, and sward height were compared between the pollinator and control strips in both years using a two-way ANOVA (Heath 1995). To further investigate the influence of variables (sward height, height variance (standard deviation of sward height), rabbit grazing pressure) on nymph (grasshopper and *R. roeselii*) and adult abundance, a Prinicipal Components Analysis (PCA) was undertaken for the combined 2018 and 2019 data using ClustVis software (Metsalu and Vilo 2015).

Results

Pollinator plants.—Of the 300 *C. scabiosa* planted, only 24 were left (8%) in the strips by September 2018. The plant species experienced significant damage by grazing rabbits, with defoliation and digging up of newly planted plugs. This significant decline continued into 2019 (t-test: 5.09, P = 0.002), with only 7 plants (2%) surviving into July (Table 1). Contrastingly, *D. fullonum* fared better with 56 (28%) surviving into July 2019 and no significant decline noted (t-test: 1.9, P = 0.1). Only one *D. fullonum* flowered in 2018, whereas 44 *D. fullonum* flowered in July 2019, providing numerous flowers for pollinators to ultilize.

Pollinators.—Fourteen species of pollinator were recorded on the planted strips, composed of common species of bee: buff/white-tailed bumblebee (*Bombus terrestris/lucorum*), common carder bee (*Bombus pascuorum*), and red-tailed bumblebee (*Bombus lapidarius*); 63, 17, and 16 workers, respectively. Other pollinators included butterfly species such as peacock (*Aglais io*) and Essex skipper (*Thymelicus lineola*); 8 and 7 butterflies, respectively. The UK 'priority' species, small heath (*Coenonympha pamphilus*), was seen on the pollinator strips, although it did not visit the flower-

Table 1. Recorded variables for the pollinator strips and control.

	Pollinator 2018	Pollinator 2019	Control 2018	Control 2019	P v C sig.
Orthoptera					
Grasshopper nymphs/m^2	1.4 ± 0.3	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	**
R. roeselii nymphs/m^2	0.1 ± 0.0	0.9 ± 0.3	0.1 ± 0.1	0.3 ± 0.2	NS
Grasshopper adults/m^2	0.4 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	NS
R. roeselii adults/m^2	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	NS
No. species/strip	2.3 ± 0.4	0.7 ± 0.4	1.9 ± 0.7	0.0 ± 0.0	NS
Habitat characteristics					
Rabbit droppings/m^2	6.1 ± 2.0	1.1 ± 0.5	0.9 ± 0.5	0.1 ± 0.1	**
Sward height (cm)	29.0 ± 3.7	74.4 ± 7.7	94.4 ± 8.2	113.0 ± 7.2	**
Pollinators/plants					
No. pollinators/100 m	–	17.1 ± 8.2	–	0.4 ± 0.3	*
No. pollinator species/strip	–	4.3 ± 1.5	–	0.4 ± 0.3	*
Dipsacus fullonum density/m^2	1.0 ± 0.7	0.7 ± 0.2	–	–	–
Centaurea scabiosa density/m^2	0.6 ± 0.2	0.2 ± 0.1	–	–	–

* P < 0.05, ** P < 0.01

ing *D. fullonum*. Only three pollinator species were recorded on the control strips. Species richness was significantly higher on the pollinator strips (t-test: 3.01, P = 0.02) as was the mean number of pollinators (t-test: 2.74, P = 0.03) (Table 1).

Orthoptera.—Grasshopper (143 individuals, 55% of total number) and *R. roeselii* (110 individuals, 42%) nymphs were abundant, with *Conocephalus fuscus* Fabricius (4 individuals) and slender groundhopper (*Tetrix subulata* L., 2 individuals) extremely scarce. The latter species was only seen on a damp, mossy patch between tall *Phragmites australis* on a pollinator strip in 2019.

For grasshopper nymphs, there was a significantly higher density on the pollinator strips compared to the control strips (F = 12.32, P = 0.002), where the swards were shorter (F = 63.20, P < 0.001) and rabbit droppings more evident (F = 16.47, P = 0.001). This overall trend in numbers was reflected in a significantly higher grasshopper nymph density on the pollinator strips in 2018 (F = 6.52, P = 0.017) where sward height was lower around the establishing plants (F = 8.07, P = 0.009) (Table 1). The density of *R. roeselii* nymphs did not differ between pollinator and control strips in either year.

Overall, there were significantly lower numbers of grasshopper nymphs in 2019 (F = 43.57, P < 0.001), which contrasted with *R. roeselii* nymphs that were higher (F = 5.27, P = 0.031). Sward height increased on all strips (F = 26.95, P = 0.001) with a concomitant decline in rabbit droppings (F = 14.93, P = 0.001). Grasshopper nymphs decreased significantly on the pollinator strips in 2019 as sward height increased around the planted flowers (F = 8.07, P = 0.009), despite early cutting.

Adults of six Orthoptera species were recorded on both the pollinator strips and controls. Numbers were generally low (only 76 adults recorded), the most abundant being the meadow grasshopper (*Pseudochorthippus parallelus* Zetterstedt), lesser marsh grasshopper (*Chorthippus albomarginatus* De Geer), and *R. roeselii* (a total of 25, 22, and 20 adults, respectively, for both strips combined). Rare species (<10 adults) in the survey included field grasshopper (*Chorthippus brunneus* Thunberg), long-winged conehead (*Conocephalus fuscus* Fabricius), and dark bush-cricket (*Pholidoptera griseoaptera* De Geer). However, species richness did not differ significantly between pollinator or control strips, but did decline in 2019 (F = 13.84, P = 0.001).

Overall, there were significantly lower numbers of grasshopper adults in 2019 (F = 23.36, P < 0.001) and there was a higher density on the pollinator strips compared to the control strips (F = 4.61, P = 0.042). The density of *R. roeselii* adults did not differ between pollinator and control strips in either year or vary between years.

The PCA for nymphs revealed that PC1 and PC2 accounted for 60.9% and 25.3% of the variance in the dataset, respectively (Fig. 1). Component loadings for PC1 revealed the importance of sward height (coefficient -0.61), while *R. roeselii* nymph density (coefficient 0.99) was a major factor in PC2. For adults, PC1 and PC2 accounted for 57.9% and 25.5% of the variance in the dataset, respectively (Fig. 2). Similar to nymphs, component loadings for PC1 revealed the importance of sward height (coefficient -0.58), while *R. roeselii* adult density (coefficient 0.76) was a major factor in PC2.

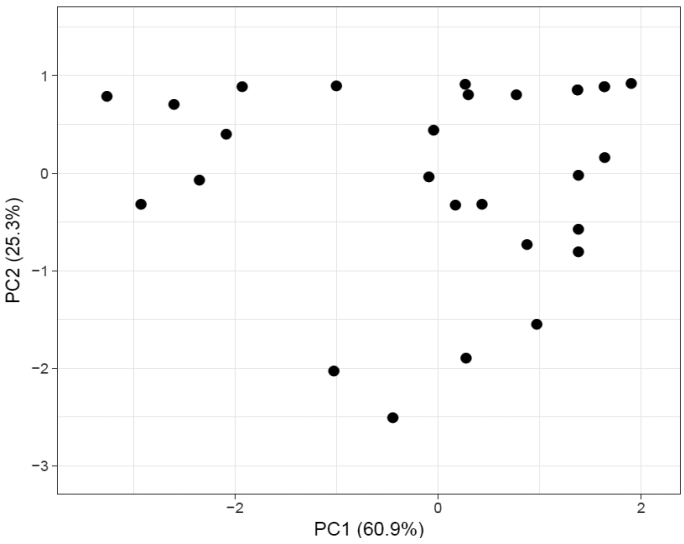

Fig. 1. Principal components for the nymph (grasshopper and *R. roeselii*), sward height/variability, and rabbit grazing data. PC1 represents sward height, PC2 represents *R. roeselii* nymph density.

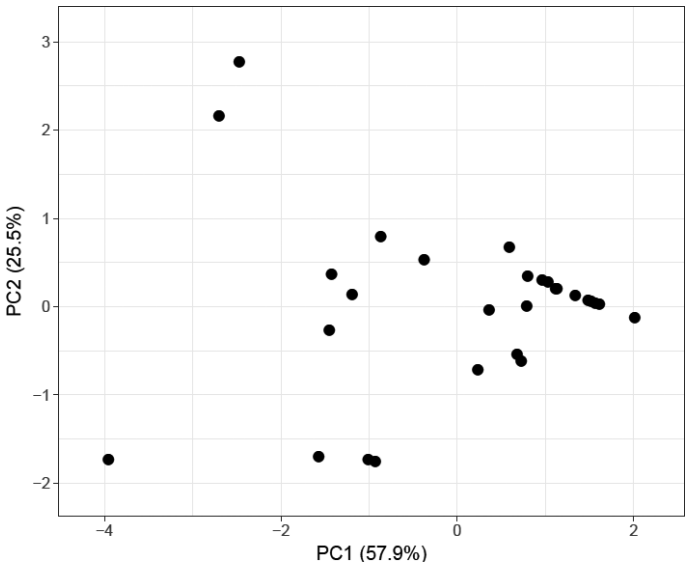

Fig. 2. Principal components for the adult (grasshopper and *R. roeselii*), sward height/variability, and rabbit grazing data. PC1 represents sward height, PC2 represents *R. roeselii* adult density.

Discussion

Vegetation structure is a key factor for grassland fauna (Duffey et al. 1974, Morris 2000), particularly for Orthoptera. Clarke (1948) and Gardiner and Hassall (2009) noted that vegetation height/density is the most important habitat factor for grasshoppers, particularly in respect to the influence on microclimate. Vegetation which is dense and tall is not readily warmed by the sun or cooled by free circulation of air, in contrast to sparser vegetation which provides better conditions for diurnal activity (Clarke 1948, Gardiner and Hassall 2009). Dense vegetation with high percentage cover, however, provides abundant food sources (Bernays and Chapman 1970a, b). Therefore, Orthoptera may be abundant in habitats which possess both dense vegetation and areas of sparser vegetation, and such local differentiation of sward structure may be important (Richards and Waloff 1954, Gardiner et al. 2002).

In the current study, the shorter vegetation of the pollinator strips due to vegetation cutting in spring 2018 (Fig. 3) led to their favorability for grasshopper nymphs perhaps because of warmer microclimatic temperatures more conducive to development

Fig. 3. Pollinator strip with a short sward ideal for Orthoptera nymphs being planted with plugs by the second author in April 2018. Photo credit: T. Gardiner.

(Gardiner and Hassall 2009). Grazing animals also play a part in reducing vegetation height and cover (Gardiner 2018). On the Ipswich sea wall, rabbit grazing was more intensive on the pollinator strips than in the control strips in 2018 (Table 1), with a significant impact on sward height. Sward height was confirmed as a significant influence in this study, particularly in respect of *R. roeselii* nymph and adult density (Figs 1, 2).

Clarke (1948) suggested that excessive grazing by rabbits promoted sparser vegetation comprised of less vigorous grass species such as sheep's fescue (*Festuca ovina*), which was consequently more favorable to grasshoppers. A study at Flatford Mill (Bhadresa 1987) concluded that the diet of wild rabbits consisted mainly of grasses. In another study on a heavily rabbit-grazed grassland, *C. brunneus* was more abundant within an exclosure than on the surrounding grazed grassland (Grayson and Hassall 1985). The authors of that study suggested that the taller vegetation in the exclosure provided better cover from vertebrate predators and higher quality food resources for grasshopper nymphs than the shorter grazed vegetation. Intensive grazing by wild rabbit populations in Epping Forest in the UK, led to the extirpation of the locally scarce common green grasshopper (*Omocestus viridulus* L.), a species with a preference for tall grassland (Gardiner 2010). The grazing created a very homogenously short grassland sward resembling a 'lawn' (Crofts 1999), which may not have provided the necessary shelter or 'cool' microclimate for *O. viridulus*.

In the current study, the cutting of tall grassland and planting of wildflowers for pollinators appears to have created a suitable short sward environment (c. 30 cm height) in 2018 for nymphs but not adults, which may have migrated into the taller vegetation of the control strips (Gardiner and Hill 2004, Gardiner 2009). The cutting of the pollinator strips allowed wild rabbits to graze the closed grassland, further reducing grass growth (Isermann et al. 2010) and creating patches of exposed soil due to their burrowing activities, which may be favorable for basking nymphs (Gardiner et al. 2002). Grasshoppers have been found in higher densities (2.9 adults/m^2) on rabbit-grazed sea walls in Essex when compared with mown flood defenses (0.7 adults/m^2) due to the shorter swards created by lagomorphs (Fargeaud and Gardiner 2018).

Vegetation structure may also influence egg development (van Wingerden et al. 1991a). Tall vegetation could lead to lower maximum temperatures in the soil surface and consequently delay hatching of eggs laid in the soil (Waloff 1950, Choudhuri 1958), resulting in a loss of some mesophilous grasshopper species (van Wingerden et al. 1991b). Such tall grasslands may be described as 'cold', whilst those with shorter, sparse vegetation are 'warm' (van Wingerden et al. 1991b). The 'warm' grasslands of the pollinator strips post-planting may have contributed to the early hatching of nymphs compared to the controls.

In 2019, the pollinator strips had progressed to a taller sward (c. 75 cm) with less rabbit grazing; consequently, the colder microclimate was unfavorable for grasshopper nymphs and adults that prefer grassland of 10–20 cm in height (Gardiner et al. 2002). The tall sward species, *R. roeselii*, appeared to benefit from this transition to longer grassland on the pollinator strips and controls (Fig. 4). It appears that despite the decline in species richness in 2019, the pollinator strips can support up to seven species of Orthoptera including more localized insects such as the groundhopper *Tetrix subulata* (Ling 2000).

The pollinator strips were also effective at attracting over ten species of insect to the *D. fullonum* flowers (Fig. 5). The abundance of pollinators in 2019 illustrates the success of the strips with common grassland bee (such as *B. pascuorum* and *B. vestalis*) and but-

Fig. 4. Roesel's bush-cricket (*Roeseliana roeselii*) nymph on a planted teasel (*Dipsacus fullonum*) leaf in 2019. Photo credit: T. Gardiner.

Fig. 5. A teasel (*Dipsacus fullonum*) flowerhead visited by the tree bumblebee (*Bombus hypnorum*) in 2019. Photo credit: T. Gardiner.

terfly (*Pyronia tithonus* and *T. lineola*) species utilizing the flowers. The abundance of grass species should also be favorable for egg-laying and larval feeding of the grassland butterflies (e.g., meadow brown, *Maniola jurtina*) in successive years.

The multifunctional nature of the pollinator strips, which supported foraging bees, nectaring butterflies, and populations of Orthoptera, particularly in their nymphal stages, indicates that if carefully managed, these habitats can be beneficial to several orders of insect. The early season cutting (1–2 cuts) of the pollinator strips with hand tools, to avoid any mortality that may occur during mechanized cutting (Gardiner 2009), should continue in future years to ensure that a suitable warm microclimate is maintained for basking nymphs. Cutting by hand is possible on small sea wall strips (c. 78 m^2 of pollinator strips in this study), as it is in churchyards where scythes are used to cut flower-rich grassland (Gardiner 2011). The absence of mechanized cutting may be a significant factor in the persistence of Orthoptera on the pollinator strips.

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