Above-ground arthropod biomass response to short- and long-term soil wetting in Dutch dairy farmland

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Background. Especially over the last 50 years, the world's biodiversity has suffered great losses in the wake of agricultural intensification. In The Netherlands, intensive agriculture has resulted in meadows almost devoid of arthropods and birds. Meadow birds appear to be especially vulnerable during the chick-rearing period. So far, studies have focused mainly on the causes of population declines, but solutions to effectively stop these trends on the short term are lacking. In this study we experimentally manipulated soil moisture through occasional irrigation, to mitigate against early season drainage and create favourable conditions for the emergence of above-ground arthropods during the meadow bird chick rearing phase.

Methods. The land use and intensity of the study site and surroundings were categorized according to the national land use database and quantified using remote sensing imagery. From 1 May to 18 June 2017, we compared a control situation, with no added water, to two wetting treatments, namely an "irrigated" treatment using a sprinkler system and "near-water" with a consistently high water table. We measured soil temperature, soil moisture and resistance as well as the biomass of arthropods at three-day intervals. Flying arthropods were sampled by sticky traps and crawling arthropods by pitfall traps. Individual arthropods were identified to Order and their length recorded, to assess their relevance to meadow bird chicks diet. diet.

Results. The land use analysis revealed a very low intensity management in the fields of the surrounding (20 km radius) area which was characterized by (very) high intensity land use. The results of the experiments showed that irrigation contributed to cooler soils during midday already in the early part of the season and the differences with the control increased later on. In the irrigated and near-water treatments, compared with the control treatment, soil moisture increased and soil resistance decreased from mid-season onward. Cumulative arthropod biomass was higher in the near-water treatment, and remained unchanged in the irrigation treatment, compared to the control. We conclude that the effects on above-ground arthropod abundance of small scale interventions such as occasional irrigation, which did favourably affect local soil properties, are currently limited or overridden by negative landscape-scale processes on arthropod production and abundance.

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Abstract

Background. Especially over the last 50 years, the world's biodiversity has suffered great losses in the wake of agricultural intensification. In The Netherlands, intensive agriculture has resulted in meadows almost devoid of arthropods and birds. Meadow birds appear to be especially vulnerable during the chick-rearing period. So far, studies have focused mainly on the causes of population declines, but solutions to effectively stop these trends on the short term are lacking. In this study we experimentally manipulated soil moisture through occasional irrigation, to mitigate against early season drainage and create favourable conditions for the emergence of above-ground arthropods during the meadow bird chick rearing phase.

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Results. The land use analysis revealed a very low intensity management in the fields of the selected dairy farm, unlike most of the surrounding (20 km radius) area which was characterized by (very) high intensity land use. The results of the experiments showed that irrigation contributed to cooler soils during midday already in the early part of the season and the differences with the control increased later on. In the irrigated and near-water treatments, compared with the control treatment, soil moisture increased and soil resistance decreased from mid-season onward. Cumulative arthropod biomass was higher in the near-water treatment, and remained unchanged in the irrigation treatment, compared to the control. We conclude that the effects on above-ground arthropod abundance of small scale interventions such as occasional irrigation, which did favourably affect local soil properties, are currently limited or overridden by negative landscape-scale processes on arthropod production and abundance.

Key words:

arthropod biomass, field experiment, water table, irrigation, agricultural intensification, soil properties

Introduction

Biodiversity continues to decline, despite the international efforts to stop this negative trend (Mace et al., 2018). Although the trajectory of arthropods decline is probably longer (Benton et al., 2002; Potts et al., 2010), flying insects in German natural reserves suffered a loss of 75% of biomass from 1989 to 2017 (Hallmann et al., 2017). The post-war intensification of agriculture has often been considered one of the major causes behind arthropod decreases, because of the heavy use of agrochemicals and the reduction of vegetation heterogeneity (Biesmeijer, 2006; Goulson et al. 2015; Nilsson, Franzén, & Jönsson, 2008; Ollerton & Crockett, 2015; Vickery et al., 2001). Soil drainage, overuse of machinery, short crop rotation, and elevated grazing pressure are typical of intensive agricultural regimes and lead to dry and hard topsoil (Hamza & Anderson, 2005). Below an optimal range of moisture, the mortality of many arthropods increases (Cho, Rhee, & Lee, 2000; Tsiafouli et al., 2005), while elevated soil resistance, given by compact soil, hampers the emergence of insects (Roach & Campbell, 1983), as well as the ability of birds to probe in the ground (Gilroy et al., 2008; McCracken & Tallowin, 2004). Wet and soft soil, on the other hand, is expected to have positive effects on arthropods and birds.

Declines in arthropods and the loss of habitat has also affected insectivorous meadow bird species, that represent good indicators of rural habitat quality (Newton, 2004, 2017). In the last 40 years, in The Netherlands, the Black-tailed Godwit (*Limosa limosa limosa*) population has declined by 70%, with an alarming rate of 6.3% per year (BirdLife International, 2004; Kentie et al., 2016; van Dijk et al., 2010). Similar patterns can be found for Eurasian Oystercatcher (*Haematopus ostralegus*), Northern Lapwing (*Vanellus vanellus*), Eurasian Curlew (*Numenius arquata*) and Common Redshank (*Tringa totanus*) (PECBMS, 2017; van Dijk et al., 2010). Scarce food affects meadow birds particularly during the breeding season, since the diet of chicks is entirely composed of arthropods (Kentie et al., 2016; Loonstra, Verhoeven, & Piersma, 2018; Schekkerman & Beintema, 2007). On the long term, reducing the management intensity of the agricultural fields, with low additions of organic fertilizer and moderate levels of grazing, can encourage sward heterogeneity and benefit invertebrate prey, thus improving food availability (Vickery et al., 2001). However, the rapid rate of bird decline calls for immediate and innovative solutions on the short term, which are currently lacking or insufficient (but see Fuentes-Montemayor, Goulson, & Park, 2011).

We hypothesized that increased soil moisture at the onset of the meadow bird breeding season would directly promote suitable conditions for the emergence of flying and crawling invertebrates during the chick rearing period of meadow birds. Previous studies show that highly intensive cultivated fields offer very limited food supply and have less chance to host successful broods (Howison et al., 2018; Loonstra et al., 2018; Schekkerman & Beintema, 2007). Currently, areas where farming takes place in ecologically benign forms are too few and fragmented to offer sufficient refuge. Therefore, to maximise the possibility of encountering a healthy arthropod community the experiment was carried out on a conventional agricultural dairy farm with low intensity management, specifically promoting habitat for breeding meadow birds (Onrust & Piersma, 2017).

On this farm, soil characteristics (temperature, moisture and soil resistance) were experimentally manipulated by means of a sprinkler irrigation system and compared to a neighbouring field with a continuously higher water table and a control situation (without added water). Vegetation composition and height were measured at three intervals throughout the season, to account for potential habitat differences. In May-June 2017, at three-day intervals, at all three treatment sites the biomass, size class and identity of crawling and flying arthropods were measured by means of pitfall traps and sticky traps.

We predicted an improvement of the soil conditions in the irrigated treatment given by the occasional irrigation and consequently an increase in the arthropod biomass. We used the near-water treatment as a comparison to show how long-term stable conditions of high water table influence arthropod biomass.

Materials and Methods

Contextualization of the landscape

In order to determine the ecological quality of the surrounding landscape, we analysed the spatial footprint of different land use intensities at increasing buffer distances from the study farm (2, 5, 10 and 20 km with the proposed study site as the central point). Land use identity, at four buffer zone distances was categorized with the Dutch national land use database (Ministerie van Economische Zaken en Klimaat, 2018). Land use intensity, referring to the amount of disturbance, was quantified using the variation surface roughness measured by the Sentinel-1 C-SAR (active radar) satellite and verified with detailed ground surveys (see Howison et al. 2018 for a detailed description).

Study site

The experimental study took place at the dairy farm of Murk Nijdam in Wommels, province of Friesland, The Netherlands (N53°5’35”, E 5°33’51”) (Fig. S1). Land use on this farm has been classified as permanent agricultural grassland since at least 2009 (Ministerie van Economische Zaken en Klimaat, 2018) and managed for the protection of breeding meadow birds within the Dutch Agri-Environmental Schemes. The management of the grasslands includes one fertilization per year with farmyard manure: a mixture of straw, cattle dung and urine collected and composted for up to a year (Onrust & Piersma, 2017). Mowing takes place after 15 June and is followed by a period of grazing that continues until October or November. Water is drained by an underground system of pipes, while foot-drains are absent. All the grasslands of the farm have clay soils.

Wetting experiment

Two herb-rich meadows of respectively 2.8 ha and 5.4 ha were chosen for the wetting experiment. On the first grassland an irrigation pipe with six sprinklers was installed. The pipe crossed the land diagonally, from the northwest to the southeast corner (Fig. S1). The sprinklers were placed within 50 m from each other and had a reach of 12 m. The pipe was connected to a pump that drained water from adjacent canal. The system was manually activated when the farmer expected a warm day and it was on for a minimum of 5 min to a maximum of 70 min (Fig. S2). The irrigated meadow was divided into four blocks, two irrigated and two non-irrigated (control). Each block contained two replicates for the measurements of soil temperature and arthropod abundance, placed 15 m from each other. The second grassland, located 100 m south-west from the first one, had a higher water table because it included a water pond of ~90 m x 50 m. A set of two replicates was placed in this grassland at equivalent distances (~35 m) from the pond and the field margin.

Vegetation and soil parameters

One 50 m transect was laid out perpendicular to the irrigation pipe to account for both the irrigation treatment effect closest to the pipe (distance 0 – 12 m), and the control treatment beyond the reach of the irrigation pipe (distance 20 – 50 m). In the field near water a 50 m transect was laid out 25 m from the edges of the field to avoid any edge effects and orientated in the same direction as the field with control and irrigation treatment. Vegetation height (± 1 cm) was measured at 1 m intervals along the transects by lowering a 1 m vertical measuring rod into the vegetation to the soil surface and drawing the 10 closest leaves their full vertical height. Plant species touching the rod at each 1 m interval were identified (Streeter et al., 2009).

Soil temperature was measured by Thermochron® iButton® devices (DS1921G) located at each replicate, sealed into small plastic bags and attached to the ground. The loggers were programmed to record the temperature every hour starting from the 0.00 on 1 May 2017 until the end of the experiment at 0.00 on 19 June 2017.

Soil moisture was measured at 1 m intervals along the transects using a ML3 Theta probe (ML3-UM-1.0, EijkelkampAgrisearch Equipment), with settings: device = ML2 and soil type = organic. To account for the full range of well-drained to water-logged soils, field capacity was set to $0.999m^{-3}$.

Soil penetration was measured at 1 m intervals along the transects using a hand-penetrometer for top-layers, (Type IB, EijkelkampAgrisearch Equipment). The internal springs used were 100N, Ø 1.6 mm for soft moist soils and 150N, Ø 1.75 mm for dry hard soil. The force used to push a 0.25 cm^2 cone to a depth of 11 cm into the soil (the depth important both for emerging arthropods and probing meadow birds (Lourenço et al., 2010) was calculated as: Resistance (N/cm^2) = (total force (cm) x spring force (N/cm)) / cone diameter (cm^2), thereafter converted with a constant factor to $kg.cm^{-2}$. Soil moisture, soil penetration pressure, vegetation composition and height were surveyed at three moments during the season, i.e. early (1 May), midterm (17 May) and late (8 June 2017) (Fig. S2).

Arthropods

Arthropods were sampled over intervals of three days between 1 May and 18 June. Sticky traps were used to collect flying arthropods. The traps consisted of yellow plastic boards of 10 by 60 cm coated in a thin layer of non-drying glue (Bug Scan®, Biobest Group NV). In each replicate, the sticky boards were positioned facing a north-south orientation. All the arthropods on the traps were identified to Order and the lengths in millimetres (± 1 mm) was recorded. Pitfall traps were used to collect crawling arthropods. They consisted of transparent plastic containers (300 ml) buried into the ground with the rim on the surface. The containers were half filled with a mixture of ethylene glycol and water (1:4) and were refilled approximately once a week to prevent complete evaporation or excessive dilution in case of rain. Arthropod biomasses were calculated using the length-weight equations from Roger et al., 1977 (Rogers, Buschbom, & Watson, 1977).

Data analysis

Variation in soil temperatures during the day were analysed using a Generalized Additive Model (GAM) with a normal distribution from the R package mgcv (Wood, 2011). The dataset was divided in two periods: early season (1 May- 16 May, 2017) and late season (17 May– 8 June 2017) and analysed separately for days with and without irrigation events. Because rain falls across all treatments and therefore cannot be attributed to an experimental manipulation, days with precipitation events were excluded from the analysis,. Temperature was used as a response variable, while the treatments and date were used as predictors. Differences in soil moisture, soil resistance and vegetation height among the treatments were investigated using one-way ANOVA, post hoc group contrasts were analysed using Tukey's HSD from the R package Agricolae (de Mendiburu, 2017) with 95% confidence interval.

The yields of sticky traps and pitfall traps were analysed separately. Treatment effects on the variation in arthropod biomass during the season were analysed for each Order separately, considering only Orders that represented at least 1% of the cumulative biomass. Generalized

Additive Models (GAM) with γ distribution were used to analyse arthropods biomass (the accumulation of arthropods over three-day intervals), with date and treatment as predictor variables (Zuur et al., 2009). To account for the difference in sample size between treatments, cumulative biomass was calculated for the duration of the experiment; differences between treatments were compared using effect size ratios (Hedges, Gurevitch, & Curtis, 1999). To analyse the composition in size, the biomass was divided in three length classes: big (≥4 mm), small (2-3 mm) and very small arthropods (1 mm). Land use intensity, categorized into different land use types (Ministerie van Economische Zaken en Klimaat, 2018), was analysed with one-way ANOVA for each buffer distance, and post hoc Tukey HSD was used to determine significantly different groups (de Mendiburu, 2017). All analyses were performed using R 3.3.1 (R core team, 2017).

Results

Contextualization of the landscape

Land use intensity, referring to the amount of disturbance, for different categories of registered land use were significantly different from each other for the 2 km (ANOVA: $F_{(3,473)} = 23.4$, $R^2 = 0.12$, $P<0.001$), 5 km (ANOVA: $F_{(3,2368)} = 13$, $R^2 = 0.01$, $P<0.001$), 10 km (ANOVA: $F_{(4,8897)} = 269.5$, $R^2 = 0.10$, $P<0.001$), and 20 km buffer zones (ANOVA: $F_{(4,21953)} = 1301$, $R^2 = 0.19$, $P<0.001$) (Fig. 1A). With protected areas and semi-natural grassland corresponding to low land use intensity and agricultural grasslands and arable fields corresponding to high land use intensity (represented by variation in C-SAR1) (Figs. 1A and B). The land use intensity of the study site, characterized as agricultural grassland (Fig. 1A), scored lower than that of the protected areas (Fig. 1B).

The quantification of land use intensity confirmed that only 50% of the agricultural land in the immediate proximity of the study site is under low intensity management. The rest of the area is characterized by regimes that ranges from intermediate to very high intensity management. The proportion of land with low intensity management decreases with distance, until it reaches only 40% within a radius of 20 km from the farm (Figs. 2A and B).

Soil parameters

Between 13.00 h and 15.00 h, soil temperatures daily reached peaks in all treatments (Fig. 3A and B). During the days with irrigation (N=4), in the early season the highest values were reached in the control treatment (26.1 ±0.8 °C) (Fig. 3A), while in the irrigated and near-water treatments the maxima were lower (irrigated: 24.3 ±0.7 °C; near-water: 19.5 ±0.7°C). The GAM model revealed a significantly different pattern of variation between treatments, especially between the control and the near-water treatments. On dry days without irrigation events (N=18), the highest temperature was reached again in the control treatment (25.5 ±0.5°C), followed by irrigated (24.0 ±0.4 °C), and the near-water treatment (19.8 ±0.4°C). In this case, the GAM revealed different patterns of variation, either for the control and the near-water treatment, than for the control and irrigated treatment (Table 1). During the late season temperatures were higher (Fig. 3B). On days with irrigation events (N=5), the highest values were registered in the control treatment (31.3 ± 0.5°C), followed by the irrigated treatment (25.1 ± 0.4°C) and the near-water one (20.6 ± 0.3°C). The variation in temperature over time was significantly different between treatments (Table 1). Similarly, during days without irrigation (N=7) the highest peaks were in the control treatment (32.0 ±0.5 °C), followed by the irrigation (27.5 ± 0.4) and then the near water treatment (21.0 ±0.3 °C). Also in this case, the variation in temperature over time was significantly different between treatments (Table 1).

In all three treatments, soil moisture decreased during the season (Fig. 4A). During the first survey on1 May the highest moisture level was recorded in the irrigated treatment (46.5 ± 4.9%), followed by the near-water one (43.2 ± 5.6%), while the control treatment was significantly dryer (36.7±4.92%) (ANOVA: $F_{(2,90)} = 20.6$, $R^2 = 0.31$, $P<0.001$). During the second survey, the irrigated site kept the highest moisture values (48.3 ± 5.5%), followed this time by the control (35.4 ± 3.5%) and finally by the near-water treatment (33.1± 4.0%). The mean moisture value was significantly different for each treatment (ANOVA: $F_{(2,90)} = 70.8$, $R^2 = 0.61$, $P<0.001$). At the third and last survey on 8 June the irrigated treatment was still the one with the highest moisture value (33.8 ± 8.2%), but there was no significant difference with the control anymore (28.3 ± 4.4%). The near-water treatment (28.3 ± 4.4%), on the other hand, had a significantly lower level of moisture (ANOVA: $F_{(2,90)} = 70.9$, , $R^2 = 0.15$, $P<0.001$).

Soil resistance increased in the course of the season in all three treatments (Fig. 4B) (2.8 ± 0.8 kg/cm^2). During the first survey the highest resistance was recorded in the control treatment (4.5 ± 1.1 kg/cm^2) and was significantly different from the irrigated (2.9 ± 0.7 kg/cm^2) and the near-water treatments (ANOVA: $F_{(2,90)} = 30.7$, $R^2 = 0.46$, $P<0.001$). During the mid-season survey soil resistance was highest in the control treatment (6.1 ± 1.6 kg/cm^2), followed by the near-water (3.9 ± 1.1 kg/cm^2) and the irrigated treatments (2.6 ± 1.1 kg/cm^2). The means for the three treatments were significantly different from each other (ANOVA: $F_{(2,90)} = 41.7$, $R^2 = 0.48$, $P<0.001$).

In the third survey, once again the highest soil resistance was measured in the control treatment (5.8 ± 1.3 kg/cm^2), followed by the irrigated (4.5 ± 1.1 kg/cm^2) and near-water treatments (3.7 ± 1.0 kg/cm^2) (ANOVA: $F_{(2,90)} = 31.8$, $R^2 = 0.41$, $P<0.001$). Soil resistance was correlated with the level of moisture by an inverse proportion relationship (Exponential LM: $F_{(1,298)} = 110$, R2 = 0.27, $P< 0.001$).

Twenty-three different plant species were identified. The irrigated grassland presented a predominance of herbaceous species (*Taraxacum officinale*, *Trifolium pratensis*, *Rumix acetosa*, *Ranunculus acris*), while graminoid species dominated the grassland near water (*Dactylis glomerata*, *Alopercus pratensis*, *Bromus hordaceous*, *Elytrigia repens*, *Poa trivialis*). Species richness and composition were similar in the two transects, but the proportion in which the plants were present was different (Table S1). Vegetation height increased progressively in all three treatments (Fig. 4C). At the beginning of the season, vegetation was highest in the near-water treatment (17.3 ± 5.5 cm), followed by the irrigated (14.9 ± 9.4 cm) and the control treatments (11.7± 5.9 cm)(ANOVA: $F_{(2,90)} = 7.7$, $R^2 = 0.15$, $P<0.001$). In this case only the first and the last one differed significantly. During mid-season there were no significant differences among treatments and the highest vegetation was still found in the near water treatment (36.6 ± 13.9 cm), followed by the control (31.7 ± 12.6 cm) and the irrigated ones (29.0 ± 9.8 cm) (ANOVA: $F_{(2,90)} = 2.3$, $R^2 = 0.05$, $P<0.001$).

By the end of the season the situation in trend was similar to the beginning, with the site near water being the one with highest vegetation (57.8 ± 19.9 cm) followed by the irrigated (47.2 ± 19.6 cm) and the control treatments (44.4 ± 17.8 cm). As in the beginning of the season, the only significant difference was found between the near-water treatment and the control one (ANOVA: $F_{(2,90)} = 5.1$, $R^2 = 0.10$, $P<0.001$).

Arthropod biomass

The main arthropod Orders present in the sticky traps were Diptera (80.5%), Lepidoptera (12.4%), Coleoptera (2.8%), Hemiptera (2.5%) and Hymenoptera (1.7%). Aranaea, Acari and Collembola were also present, but contributed <1% to the total biomass, therefore were not used in further analysis (Table S2).

For Diptera, the pattern of variation between sticky trap biomass in the near-water treatment and the control treatment differed significantly (Table 2). Arthropod biomass was generally higher in the near-water treatment than the other two treatments. Diptera biomass peaked on 22 May with a mean biomass of 464 ± 74 mg. In the control and irrigated treatments the peak was narrower, with the maximum on the same date, but lower biomass immediately before and after (Fig. 5A).

For Hemiptera there was a significant difference in the patterns of sticky trap biomass in the near-water treatment compared to the control and irrigated ones (Table 2). The main peak in the last two was reached 12-15 June, with a mean biomass of 42 ± 9 mg in the irrigated treatment and 37 ±1 mg in the control treatment. In the near-water treatment, flying Hemiptera were consistently low or absent (Fig. 5D).

For the other Orders (Lepidoptera, Coleoptera and Hymenoptera) there were no significant differences among treatments in the patterns of variation during the season (Table 2). Lepidoptera appeared mainly in the last part of the season, small peaks were visible in the near-water treatment around the 3 June and in the control treatment around 9 June (Fig. 5B). Coleoptera reached the maximum abundance during the last part of the season, with the highest peaks in the control (60 ± 49 mg) and in near-water treatments (32 ± 24 mg) on 18 June (Fig. 5C). Hymenoptera showed a constant, low-abundance pattern during the season, with two shallow peaks in the irrigate field on the 17 (12 ± 2 mg) and 31 May (8 ± 2 mg) (Fig. 5E). The comparison of treatment effects on cumulative biomass showed no effect of the irrigation treatment and a positive effect of the near-water treatment (Table 3). On average, less than 10% of the individuals from each sampling events had a size of ≥4 mm (8.5%, SD = 4.5), while the vast majority was small, with a length of 2 or 3 mm (43.1%, SD =11.7) or very small, with a length of 1 mm (48.3%, SD = 11.8) (Fig. 6).

In the pitfall traps, the composition consisted mainly in Coleoptera (40.1%), Aranaea (33.3%), Diptera (12.6%) and Lepidoptera (7.3%). Samples presented also minor quantity (<1%) of Hymenoptera, Coleoptera larvae and Lepidoptera larvae, Hemiptera, Collembola and Acari (Table S2). All the GAM models for the different Orders of the pitfall traps showed the date affecting biomass over the season (P<0.001), but no difference in the pattern of variation among treatments (Table 4). Coleoptera showed a pattern with a progressive increase by the end of the season, with the highest peak in the control field (111 ± 5 mg) (Fig. 7A). Aranaea had a small peak in all the treatments during the first half of the season, between 19 and 22 May (control: 57 ± 1 mg, irrigated: 46 ± 9 mg, near-water: 66 ± 3 mg) (Fig. 7B). Diptera were most abundant in the pitfall traps shortly after the beginning of the season (control: 19 ± 6 mg, irrigated: 20 ± 5 mg, near-water: 22 ± 8 mg), while showed a constant and low-abundance pattern during the rest of time (Fig. 7C). Lepidoptera showed a constant pattern during the whole season, with no peaks in any particular treatment (Fig. 7D). Compared with the sticky traps, the ratio between cumulative biomass in the irrigated and near-water sites against the controls but there was still a small positive effect of the treatments (Table 3). The average of arthropods with a size ≥4 mm in each sampling events was higher than in the sticky traps (31 %, SD =12).Very small individuals with size of 1 mm represented almost half of the samples (49%, SD = 14), while arthropods with size 2-3 mm constituted the rest (20%, SD = 10) (Fig. 8).

Discussion

The experimental soil wetting was carried out in two fields classified as conventional agricultural grasslands with low land use intensity, in accordance with the intended provision for meadow bird breeding habitat (Onrust & Piersma, 2017). The quantification of land use intensity added a new and valuable dimension to the national land use categories, spatially contextualizing these low intensity managed fields within a neighbourhood of high intensity managed agricultural grasslands.

Soil temperature, moisture and resistance are key factors in the life-cycles of arthropods as they regulate diapauses, time of hatching and development of the larvae (Dimou et al., 2003; Ellis et al., 2004; Hulthen & Clarke, 2006; Johnson et al., 2010; Neven, 2000; Tauber et al., 1998). The occasional wetting was able to modify characteristics of the soil keeping the soil cool, moist and soft. Irrigation did affect ground temperature already early in the season, with greater differences in temperature peaks as the season proceeded. The addition of water also affected soil moisture, keeping it significantly higher until mid-season and soil resistance was always lower in the irrigated treatment rather than in the control. Although these conditions are expected to favour arthropods emergence (Hamza & Anderson, 2005; Hulthen & Clarke, 2006; Johnson et al., 2010), the effect on invertebrate biomass in the irrigated treatment was small. Since the irrigation only started at the beginning of the breeding season, it is possible that the beneficial effects of the irrigation on arthropods biomass only became evident after the sampling period, when the eggs and larvae that were in the soil during the experiment hatched and emerged. However, delayed effects of the irrigation treatment on arthropod biomass would not have benefitted meadow bird chicks, growing up during a short window of time (Kentie et al. 2018).

The overall conditions of lower temperatures, elevated initial moisture and soft soil led to a higher cumulative arthropod biomass in the near-water treatment suggesting that stable wet conditions may have promoted egg laying opportunities for previous arthropod cohorts. In the near water treatment, soil temperatures were consistently lower than in the other two. The stable conditions of high water table provided a buffer to temperature fluctuations and kept the soil cooler throughout the day. These may have been beneficial for the soil fauna, since heat peaks like those recorded in the control and irrigated treatments can have negative effects on arthropod larvae and adult survival (Gilbert & Raworth, 1996; Neven, 2000). Soil moisture was high early in the season but decreased rapidly later on, leaving, by the end, the driest soil amongst all the treatments. However, the level of soil resistance at the end of the season was similar to the one in the irrigated treatment.

It is unlikely that vegetation composition played a determining role in the arthropod biomass distribution, since the species composition was similar in the irrigated/control and in the near-water treatment. However, the proportion in which species were present varied and might have contributed to significantly different vegetation structures that attracted more arthropods in the near-water treatment. Differences in host species distributions might also be behind the uneven presence of the Hemiptera, that were completely absent in the near-water treatment. Almost all the individuals sampled from this Order were leafhoppers (Cicadellidae) and the distribution of these plant-sucking insects is tightly related to presence of the host plant species (Biederman, 2002).

The proximity to the artificial pond in the near-water treatment is another element that might have contributed to attract more flying arthropods for feeding or courtship (Drake, 2001). The analysis of the variation shows higher abundance and the wider peak of this Order in this treatment during the sampling period.

Importantly, the vast majority of the arthropods were either small (2-3 mm) or very small (1 mm). The pitfall traps had higher proportion of bigger individuals (≥4 mm) than the sticky traps, although the cumulative biomass in these traps was remarkably lower. According to Beintema et al. (Beintema et al., 1991), arthropods of this size would not be able to provide the necessary energy intake for birds, considering the time they should spend foraging or the total number of prey that they would require.

The landscape analysis revealed that the management intensity of the dairy farm where the study took place is even lower than in protected areas. Therefore, the study farm should yield the best chances of finding a healthy invertebrate community. However, despite the local low intensity management, the farm is still embedded in a landscape with high intensity use. In fact, the analysis revealed that half of the fields in the surroundings of the farm have intermediate or high intensity of usage, and the percentage of high intensity use increases with distance. Furthermore, the data on land use classification indicates that some of the low intensity fields that are present are monocultures and therefore with very limited diversity. Local factors, such as management practices, and regional factors, such as distance to high-diversity habitats, determine local biodiversity (Tscharntke & Brandl, 2004), therefore it is likely that the effects of the wetting were limited or overridden by negative landscape-scale processes.

While current studies meticulously document, and call attention to the alarming loss of biodiversity from the middle of the last century (Lister & Garcia, 2018; Newton, 2017; WWF, 2018), innovative short term management actions are needed to mitigate against the unchecked declining trajectory. Despite the potential landscape effect and the short time in which the experiment was conducted, the experiment showed promising results in terms of improved soil conditions, but the restoration of biodiversity-rich agricultural landscapes requires landscape-wide changes in agriculture.

Repeating the experiment during more breeding seasons would be necessary to validate the results and better understand the effect of irrigation on arthropods biomass. Future studies should also focus on the direct consequences of these type of interventions on the birds, investigating the growth rate and the foraging success of the chicks in the different treatments.

Conclusions:

We hypothesized that the occasional irrigation of a field in a dairy farm could improve soil condition for the emergence of flying and crawling arthropods during the meadow bird chick rearing period. The landscape analysis revealed that the study farm where the experiment took place had really low levels of land use and therefore was considered to have the highest chance to find a healthy invertebrate community. We found that field near water, with a stable high water table, contained more arthropod biomass than the irrigated/control fields. Despite irrigation improving key soil conditions, i.e. making the soil cooler, moister and softer, the effect on the arthropod biomass was negligible. Moreover, the arthropods that were sampled were generally too small to be considered relevant to chick diet, suggesting that the neighboring landscape of high intensity land use management limits the positive impact of locally applied interventions. We highlight the urgency of finding innovative short-term solutions to stop biodiversity loss in agricultural environments, while adequate policies are being developed as long-term strategies.

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Figure 1

Classification of land Classification of land use and land use intensity variation

(A) Agricultural land use was divided into distance buffers of 2, 5, 10 and 20 km surrounding the study site and categorized as different land use types; (B) Variation in land use intensity was classified into different land use types (colour codes in A and B are identical). The horizontal line represents the average land use intensity of our study site ± SD.

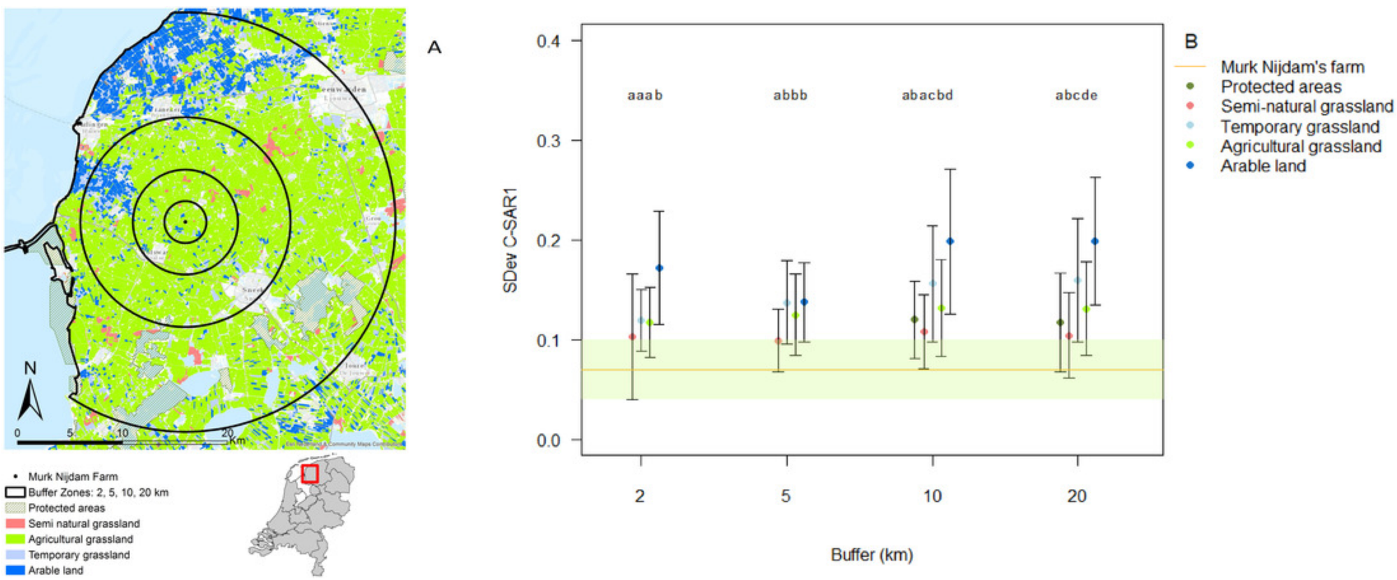

Figure 2

Agricultural land use intensity

Agricultural land use divided into distance buffers of 2, 5, 10 and 20 km surrounding the study site, quantified as (A) radar derived land use intensity summarized by the standard deviation of change in surface roughness (SDev C-SAR1); (B) Proportion of land under different land use intensities within agricultural fields surrounding the study site.

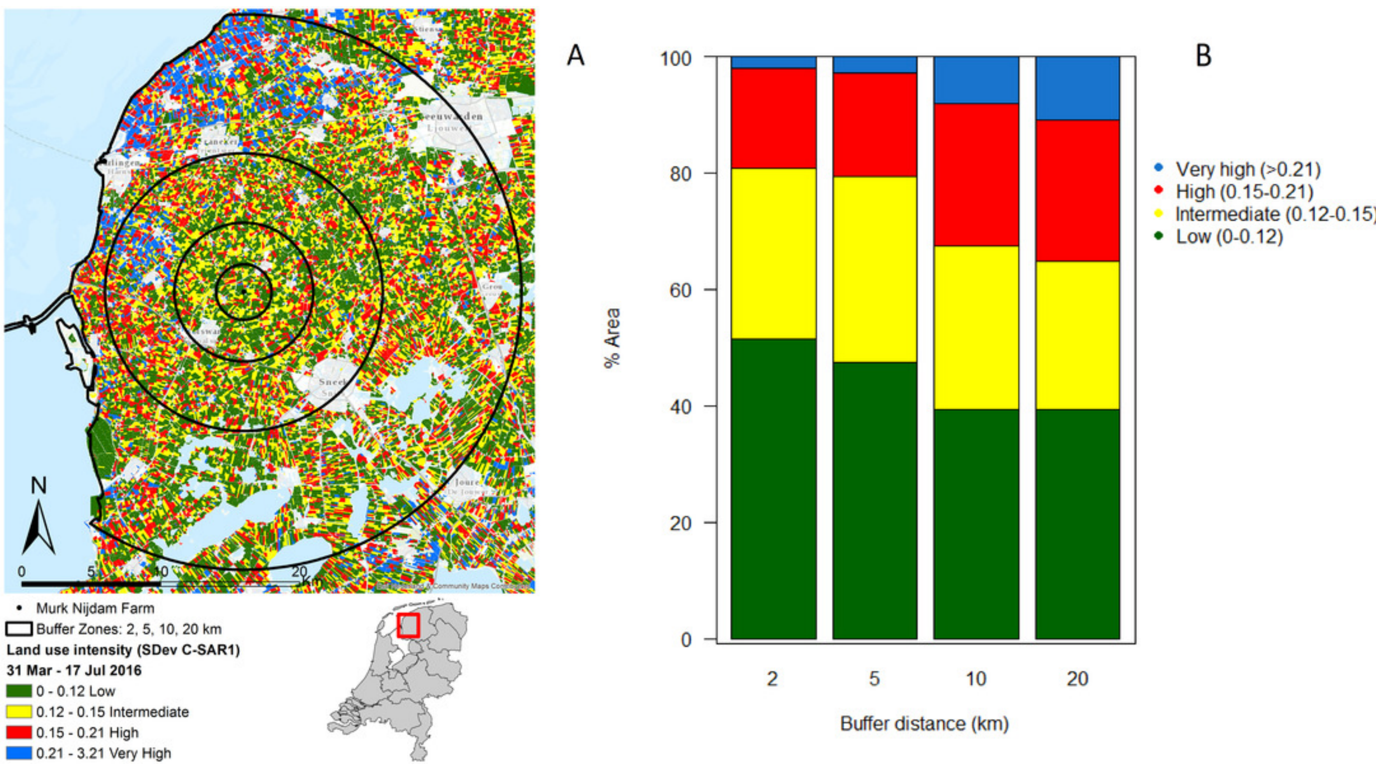

Figure 3

Soil temperature variation during the early (A) and late (B) season in days with (left) and without (right) irrigation events.

The solid red line follows the smoothed trend for the control treatment, dark blue for the near water treatment and light blue the irrigation treatment , the shaded area in the respective colour represents ± SD.

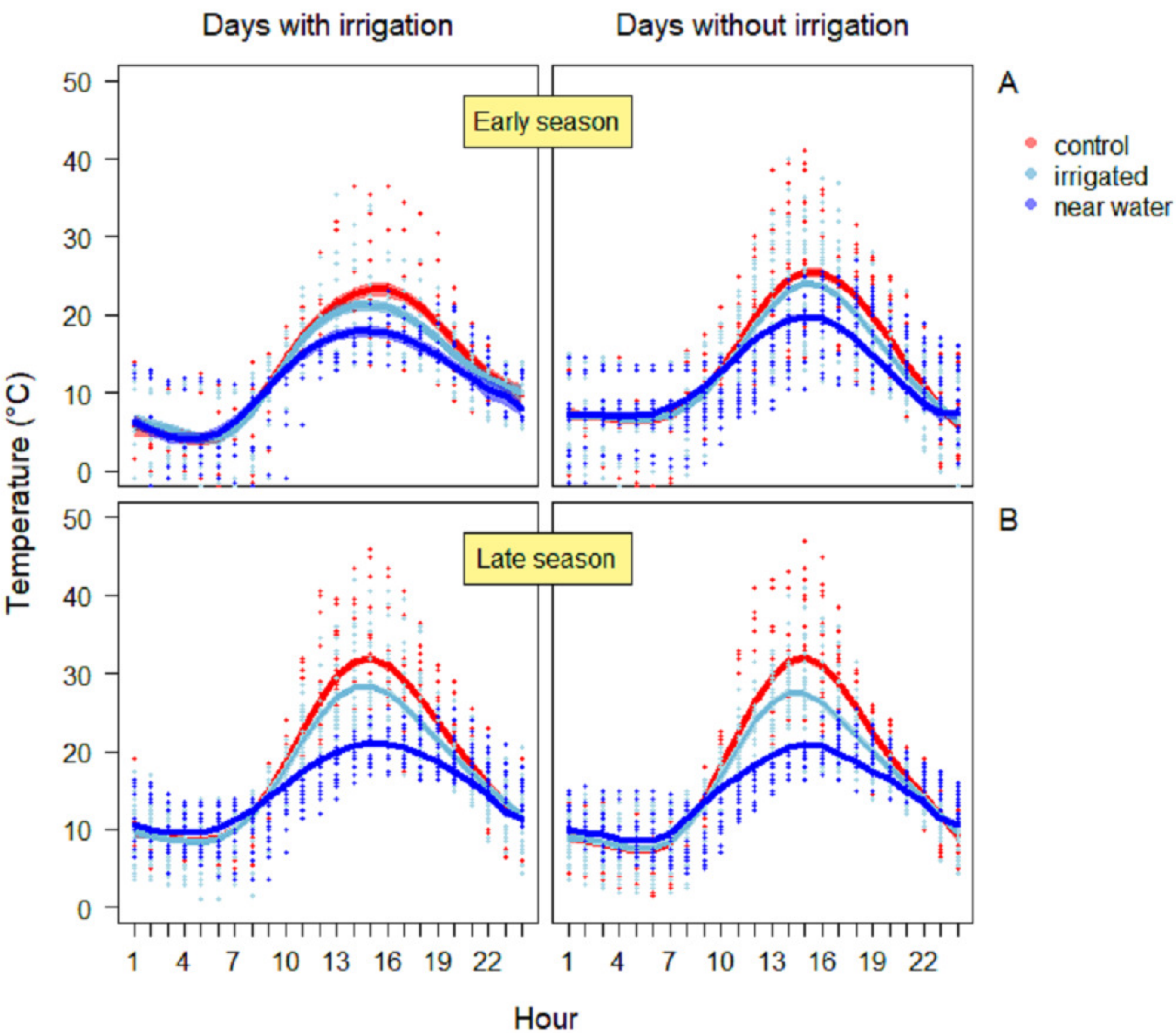

Figure 4

Soil characteristics and vegetation at the beginning (1 May), middle (16 May) and end of the season (8 June).

(A) soil moisture (%), (B) soil resistance (kg/cm^2) and (C) vegetation height (cm).

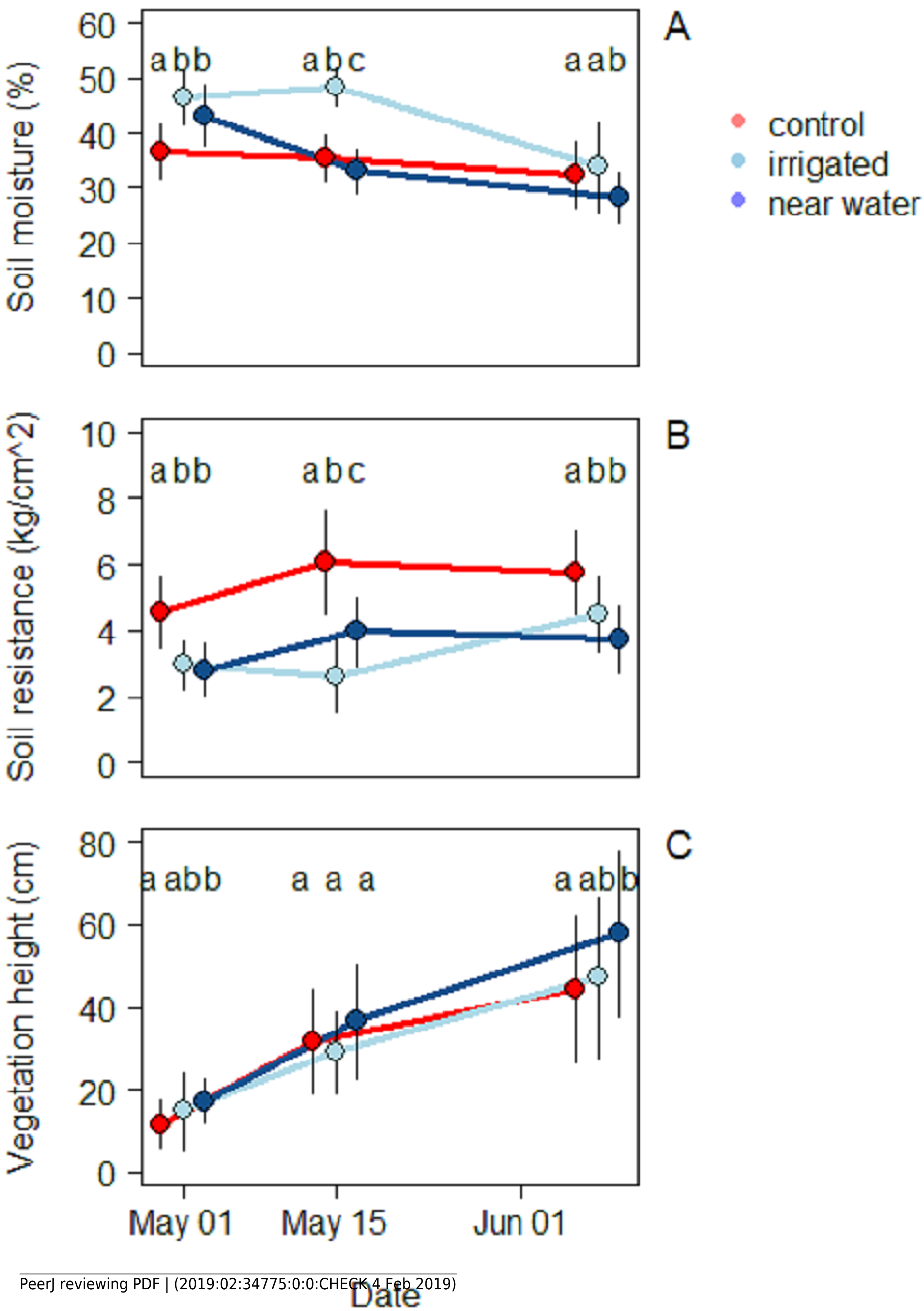
A
Soil moisture (%)
60
50
40
30
20
10
0
a b b
a b c
a a b
B
Soil resistance (kg/cm^2)
10
8
6
4
2
0
a b b
a b c
a b b
C
Vegetation height (cm)
80
60
40
20
0
a ab b
a a a
a ab b
May 01
May 15
Jun 01
Date
control
irrigated
near water

Figure 5

Biomass variation found in the sticky traps over the season.

(A) Diptera, (B) Lepidoptera, (C) Coleoptera, (D) Hemiptera and (E) Hymenoptera. The graphs are shown in order of decreasing biomass, note the different scales on the y axes. The solid red line follows the smoothed trend for the control treatment, dark blue for the near water treatment and light blue the irrigation treatment, the shaded area in the respective colour represents ± SD.

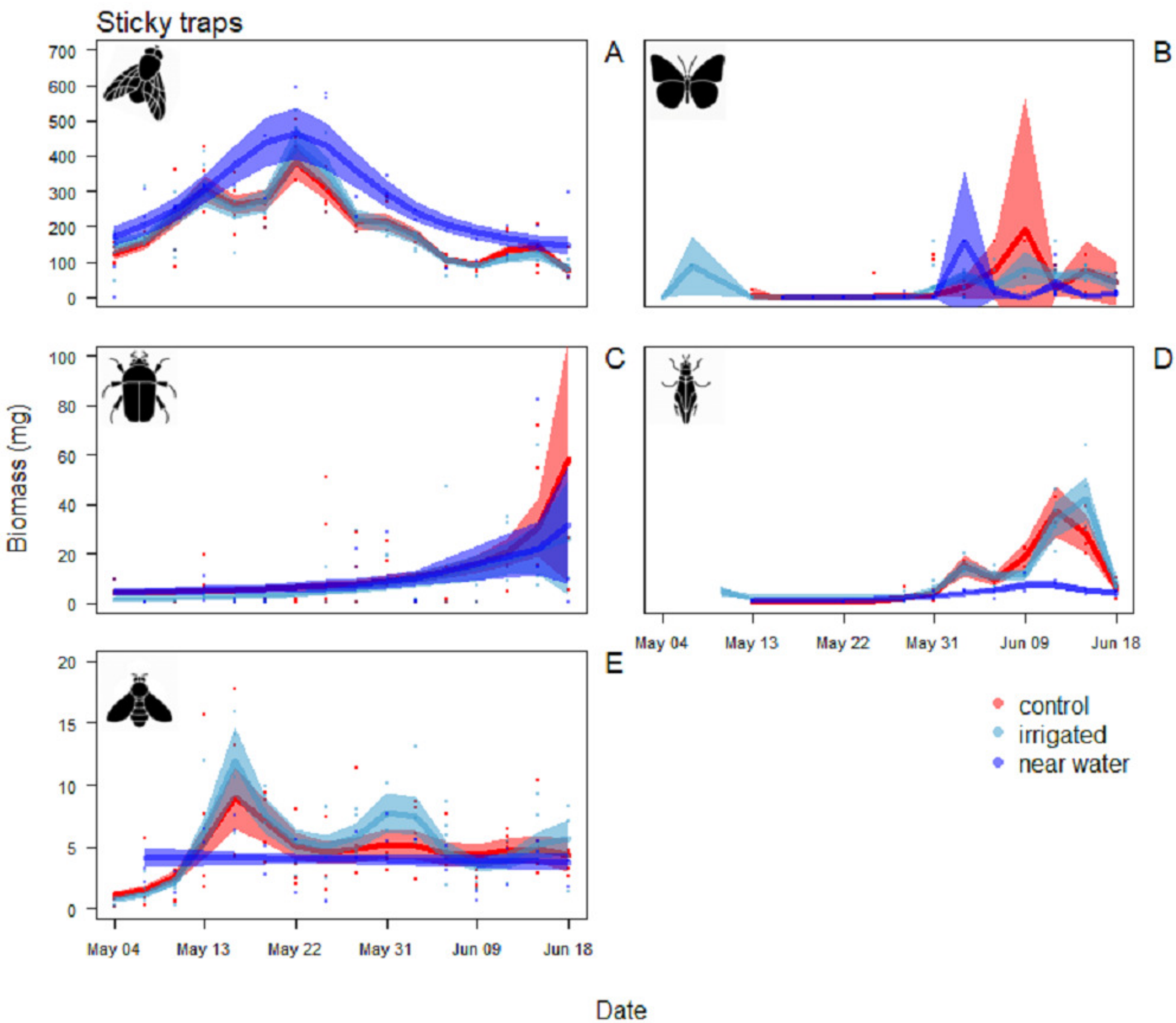

Figure 6

Size distribution of the arthropods during the season in the sticky traps.

In orange are individuals with length ≥4mm, yellow is for the 2-3 mm ones and in light blue 1mm.

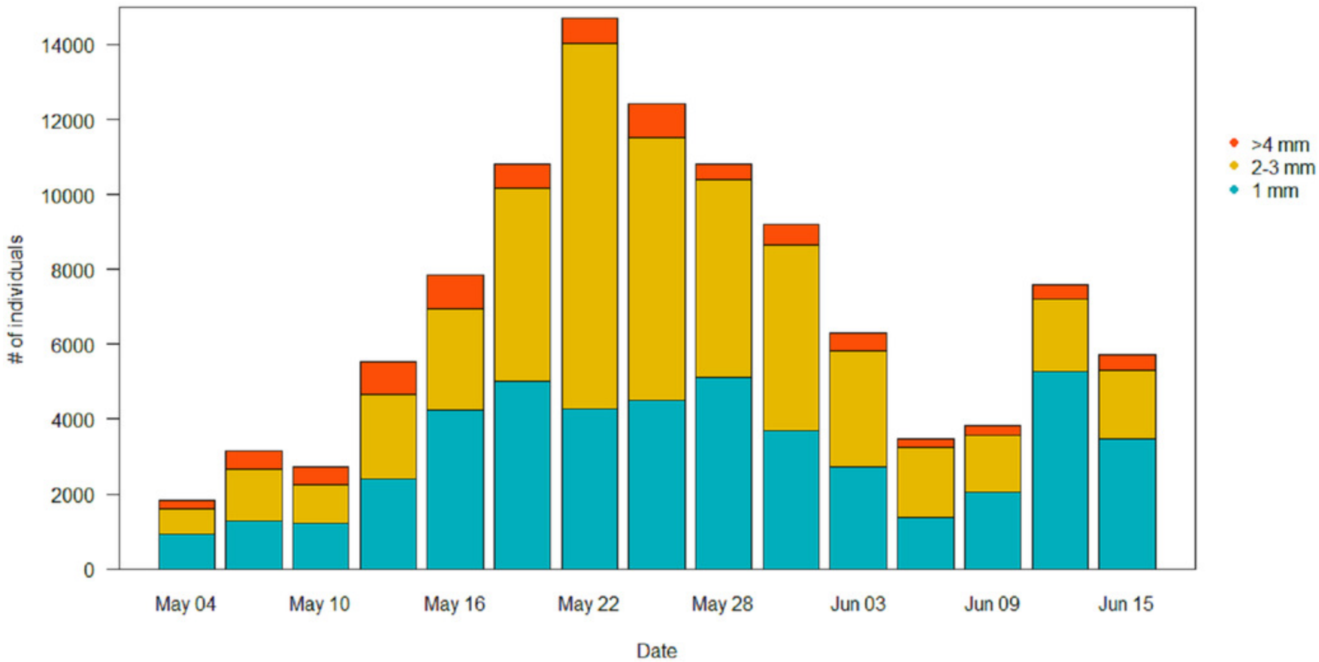

Figure 7

Biomass variation in found in the pitfall traps over the season.

(A) Coleoptera, (B) Aranaea, **(**C) Diptera and (D) Lepidoptera. The solid red line follows the smoothed trend for the control treatment, dark blue for the near water treatment and light blue the irrigation treatment, the shaded area in the respective colour represents ± SD.

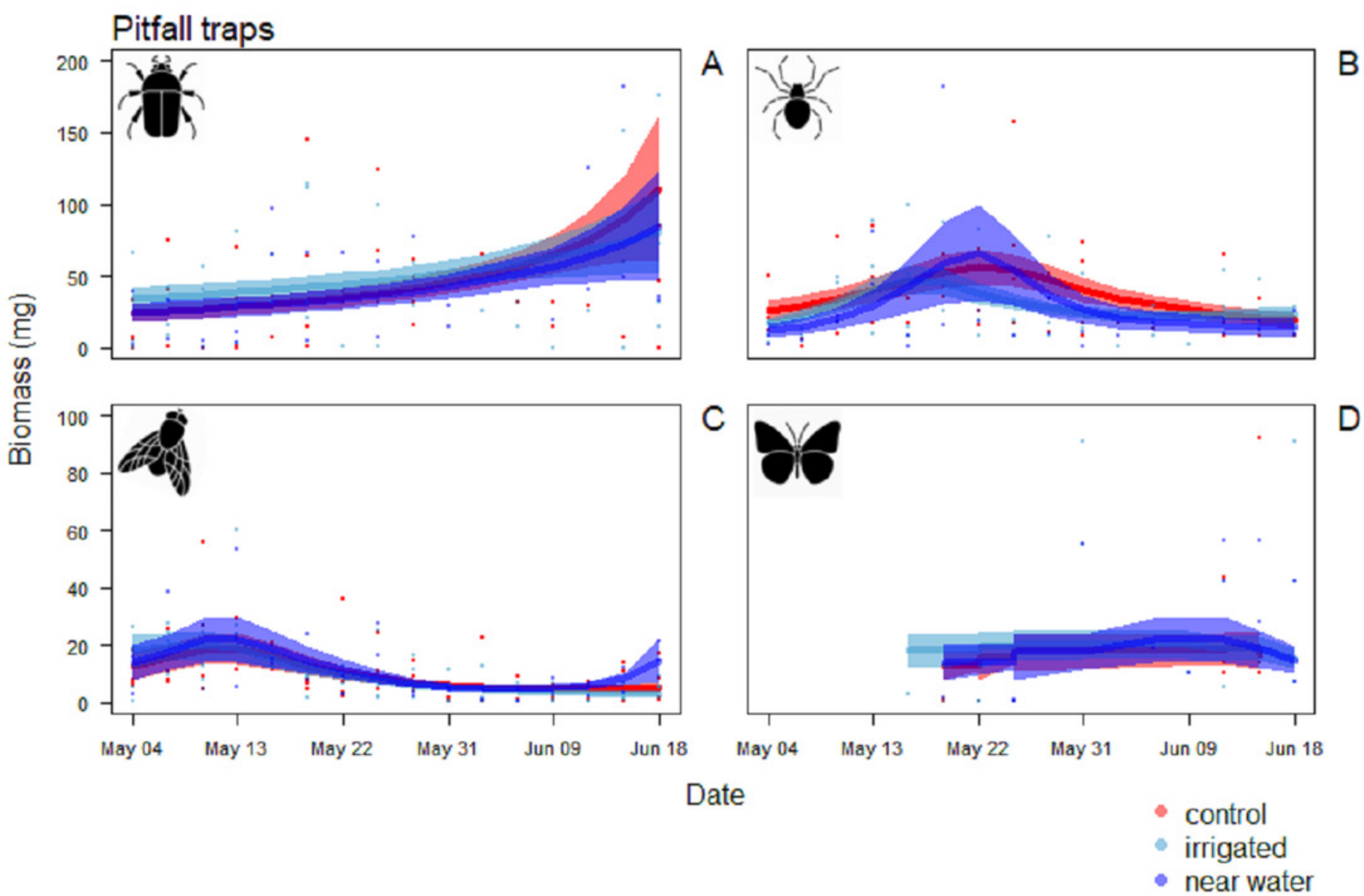

Figure 8

Size distribution of the arthropods during the season in the pitfall traps.

In orange are individuals with length ≥4mm, yellow is for the 2-3 mm ones and in light blue 1mm.

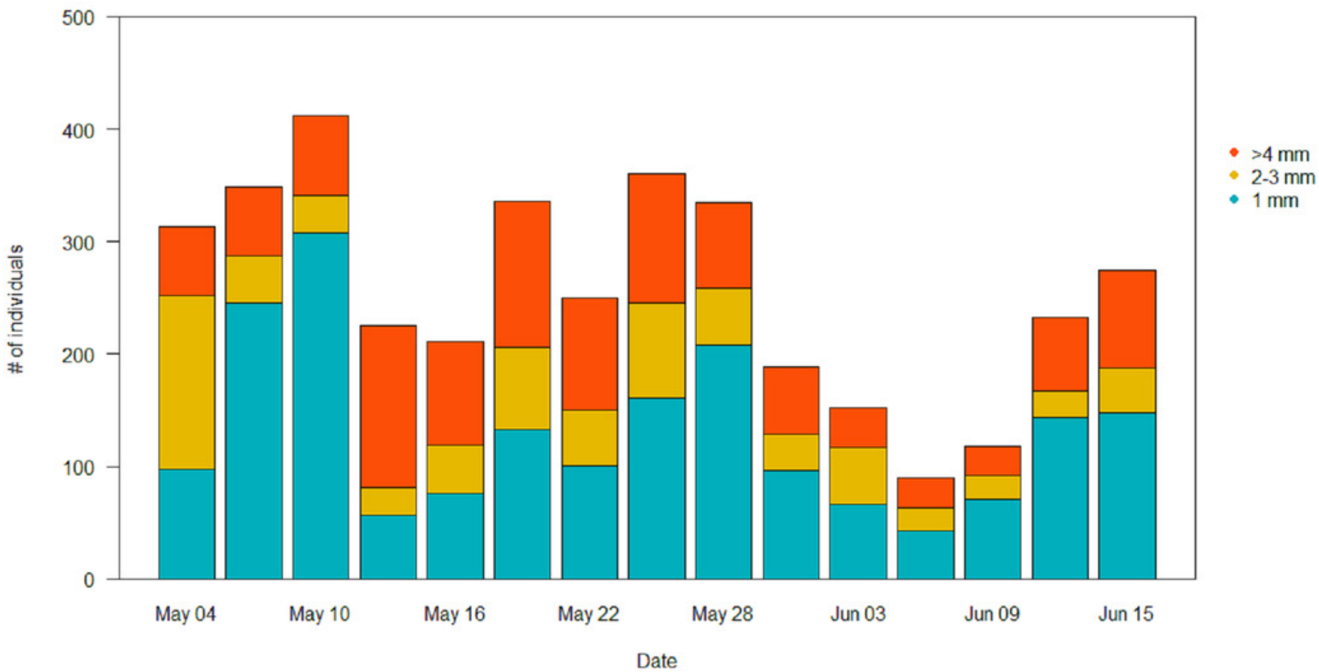

Table 1(on next page)

Generalized Additive Model fit of soil temperature to treatment using time (hours) as smoothing term.

Temperature Season	Days with irrigation	Treatment		s(hour)				
		F- value	*p*-value	F-value	Edf	*p*-value	R^2	Deviance explained
Early	Yes	$F_{2,684}$=8.54	<0.001	129.3	7.01	<0.001	0.62	62.7%
	No	$F_{2,1728}$=19.21	<0.001	366.2	7.14	<0.001	0.64	64%
Late	Yes	$F_{2,1512}$=59.45	<0.001	457.9	7.04	<0.001	0.72	72%
	No	$F_{2,1512}$=59.76	<0.001	497.7	7.64	<0.001	0.74	74.5%

Edf refers to the effective degrees of freedom for the smoothing spline.

Table 2(on next page)

Generalized Additive Models fit of arthropod biomass to treatment using date as smoothing term for sticky traps.

Sticky traps	Treatment		s(date)				Deviance
Order	F- value	*p*-value	F- value	Edf	*p*-value	R^2	explained
Diptera	$F_{2,160}$=10.57	<0.001	29.23	8.76	<0.001	0.76	56.9%
Lepidoptera	$F_{2,160}$=0.27	0.77	1.65	0.38	<0.001	0.38	56.1%
Coleoptera	$F_{2,160}$=0.28	0.75	4.4	8.79	<0.001	0.41	38.1%
Hemiptera	$F_{2,160}$=9.81	<0.001	14.92	7.66	<0.001	0.81	80.3%
Hymenoptera	$F_{2,160}$=2.65	<0.1	8.09	7.49	<0.001	0.42	41.2%

Edf refers to the effective degrees of freedom for the smoothing spline

Table 3(on next page)

Summary of the log ratio differences comparing the cumulative arthropod biomass of the control treatment (no water added) (*N*=4) to the irrigation treatment (N=4) and near water treatment (*N*=2).

	Sticky Traps		Pitfall Traps	
Replicates	Irrigated	Near Water	Irrigated	Near Water
1	0.151	0.289	0.456	0.481
2	0.124	0.106	0.223	-0.018
3	-0.032	-	-0.043	-
4	-0.059	-	-0.276	-
Average	0.046	0.197	0.090	0.232

Table 4 (on next page)

Generalized Additive Models fit of arthropod biomass to treatment using date as smoothing term for pitfall traps.

Pitfall traps	Treatment		s(date)				Deviance
Order	F- value	*p*-value	F- value	Edf	*p*-value	R^2	explained
Coleoptera	$F_{2,160}$= 0.15	0.862	14.55	1	<0.001	0.08	7.96%
Aranaea	$F_{2,160}$= 0.87	0.421	5.35	3.65	<0.001	0.13	21%
Diptera	$F_{2,160}$= 0.38	0.682	8.54	5.50	<0.001	0.35	30.5%
Lepidoptera	$F_{2,160}$= 0.20	0.818	4.88	7.70	<0.001	0.45	86.6%

Edf refers to the effective degrees of freedom for the smoothing spline.