Endangered wading birds in a revitalised alpine river: Foraging habitat selection of the Little Ringed Plover *Charadrius dubius curonicus* and its relation to invertebrate prey

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Endangered wading birds in a revitalised alpine river: Foraging habitat selection of the Little Ringed Plover *Charadrius dubius curonicus* and its relation to invertebrate prey

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Abstract

Floodplain ecosystems are one of the most threatened habitats worldwide. In the western world, a majority of rivers have been channelized and dammed, losing their natural hydrological dynamics, with dramatic consequences for all pioneer organisms depending on early stages of vegetation succession. One of these species is the endangered Little Ringed Plover *(Charadrius dubius curonicus)*. Despite restoration efforts to reinstate natural dynamics to rivers, the revitalised, but spatially-restricted riparian habitats may act as ecological traps for this species. For instance, the narrow mineral banks typically promoted by shallow riverbed widening may attract Little Ringed Plovers whose nests are flooded as soon as the water levels rise. In this study on a revitalised river stretch of the Rhône in Valais, Switzerland, we investigated the fine-grained foraging habitat selection of Little Ringed Plovers while evaluating habitat associations of their potential invertebrate prey using barber pitfall traps. Bare islands and shores consisting of vast sediment aggregations with little vegetation were the favourite foraging and home range habitat of Little Ringed Plovers. Moreover, micro-habitats with slow water flow such as non-vegetated ponds and lateral river arms provided constant foraging opportunities for wading birds, even under high discharge regime. Water cover showed a quadratic relationship with foraging birds which underlines that this species preferably forages at the interface of water and ground. Total invertebrate abundance positively correlated with boulder cover, with Little Ringed Plovers foraging preferably at an optimal boulder cover of 5%. This pattern suggests a compromise between prey availability and avoidance of predators, the boulders possibly serving as screens against the latter. Increased cover of boulder and gravel yielded the highest invertebrate abundance. Habitat management should be directed towards creating 1) increased sizes of gravel islands for flooding protection, 2) mineral islands on which small isolated boulders are arranged, and 3) ponds and artificial lateral river arms on which vegetation cover is controlled by machinery and/or grazing.

Keywords: *Charadrius dubius curonicus*, drone orthomosaic images, foraging, habitat selection, habitat management, home range, invertebrate abundance, Little Ringed Plover, orthophoto, radio telemetry, remote sensing, revitalisation, river restoration.

Introduction

Rivers are one of the most diverse and at the same time most endangered ecosystems worldwide (Ward, Tockner & Schiemer 1999; Tockner & Stanford 2002). Flood plains in particular are very rich in biodiversity as short-term increases in flow are drivers to percolate large amounts of nutrients into adjacent aquatic patches which in turn sparks primary production or mass emergence of aquatic insects (Tockner, Lorang & Stanford 2010). Freshwater systems overall are biodiversity hotspots that harbour ~10% of all known species. However, there are five major threats to global freshwater biodiversity: over-exploitation, habitat degradation, water pollution, flow modification and species invasion (Dudgeon *et al.* 2006). Rivers have been managed worldwide via channelization by dredging, straightening and constructing levees for flood protection, cultivation of arable land or hydroelectric power plants (Tockner & Stanford 2002; Dudgeon *et al.* 2006; Strayer & Dudgeon 2010). These drastic structural change of watercourses has led to a massive biodiversity decline in riverine habitats and has restrained rivers to naturally destroy and create habitats (Bunn & Arthington 2002; Dudgeon *et al.* 2006). Not only has the biodiversity declined, but also have riverine habitats been simplified by homogenisation and connectivity loss within the floodplain ecosystem, resulting in a decrease of ecosystem functioning (Dudgeon *et al.* 2006). Intensive engineering and economical efforts in urbanised and cultivated areas of the world have thus depleted the natural state of watercourses in general and led to an ecological simplification of riparian habitats (Peipoch *et al.* 2015).

In Switzerland, most riverine habitats have been channelized in the past two centuries. Reasons were mostly flood protection, cultivation of arable land and energy production (Dudgeon *et al.* 2006). In a study where the state of watercourses was analysed in respect to their geo-ecomorphology, 42% of the swiss rivers did not have a sufficient large riverine zone and 10’800 km of the analysed 30’000 km were in need of restoration (Vischer 2003; Zeh Weissmann, Könitzer & Bertiller 2009). The alpine river Rhône represents one of the many channelized rivers in Switzerland and first works to straighten the river have been done in the 19th century (Vischer 2003). In 1994, the restoration project of the Rhône in the nature reserve of Pfyn-Finges in Valais (VS) began as one of the many compensation measures for the planned A9 Highway. The habitat management consists of targeted sediment extraction carried out by local gravel exploitation companies which allows a lucrative amount of sediment extraction and at the same time boosts the riverine habitat via creation of islands, lateral arms, permanent and temporary ponds. These restoration measures have led to remarkable population increases of the Little Ringed Plover and Common Sandpiper in the years after restoration measures started in 1994 (Arlettaz *et al.* 2011). To examine the effectiveness of these habitat management measures, an ornithological monitoring in the nature park Pfyn-Finges (2013) was realised and results have demonstrated a high importance of lateral river arms as foraging sites for these endangered wading birds (Lugon 2016). In line with this finding, a study in the United States revealed that off-channel habitats on sandbar sides characterise high quality foraging sites for Piping Plovers (*Charadrius melodus*) as they offer higher arthropod abundances (Le Fer, Fraser & Kruse 2008). Subsequently, a series of studies on the same species were carried out at the Missouri river and it was demonstrated that artificial sandbars provide suitable foraging habitat replacement for the Piping Plover (Catlin *et al.* 2011; Catlin, Felio & Fraser 2012; Catlin, Felio & Fraser 2013; Catlin *et al.* 2014; Hunt *et al.* 2017). However, this effect only lasted over a short period (5 years) as it levelled out after six years where arthropod abundances decreased along artificial sandbars (Catlin, Felio & Fraser 2012). An important aspect to consider in a riverine habitat is its dynamics and variations in river flow, be it natural or artificial via hydropeaking of hydroelectric dams (Poff & Zimmerman 2010). Catlin and colleagues concluded that “increases in river flow can affect plover food availability directly by covering foraging habitat with water” (Catlin, Felio & Fraser 2013). A similar phenomenon might be found in our study area, as a hydroelectric power dam in Susten (VS) is located upstream of the restored river stretch. When snow melts in summer, it results in a high-water level period of the river Rhône and the dam overflows. As this period can stretch over weeks, there are direct consequences on foraging behaviour of the birds as they are forced to move to other foraging sites. Another major issue is the fact that these overflows happen at the same time as the pre-fledging period, when chicks have not yet developed proper flying feathers, and they may be washed away by strong and sudden currents (Catlin, Felio & Fraser 2013; Baiker 2015).

The aim of this study is to investigate foraging habitat selection and home range habitat selection of the Little Ringed Plover *Charadrius dubius curonicus* in the restored river stretch of the Rhône in the nature park Pfyn-Finges (VS). Additionally, we examine the link between foraging habitats and invertebrate prey abundance and ask whether artificial habitat features such as ponds and lateral river arms contribute to key habitat management. A further aim of this study is to investigate the effectiveness of the restoration measures taken by the A9 Highway project in Valais, and whether favoured habitat features of this wading bird can be promoted via targeted sediment extraction. First, we identified home ranges of Little Ringed Plovers (hereafter: Plovers) by systematically monitoring birds via surveys and estimated the amount of breeding pairs in the study area. Second, we examined foraging habitat selection on micro-habitat scale by assessing habitat characteristics of foraging versus pseudo-absence points by using radio-telemetry and visual observations. Habitat selection on home range scale was carried out using remote sensing data from aerial drone images via habitat classification and compositional analysis. Third, invertebrates were sampled with Barber pitfall traps to investigate invertebrate food availability in the study area. This study was a pilot within a long-term study that will be continued in 2019. Thus, methods such as radio telemetry, visual observations and invertebrate sampling were tested for their feasibility. We predict that 1) Little Ringed Plover home ranges have a higher substrate and little vegetation cover and that home ranges fall into tidal zones which are regularly flooded. Plovers may prefer islands as nesting sites due to higher predator protection. 2) Prey availability is likely to drive foraging habitat selection of this wading bird and we expect that areas with high productivity such as lateral arms will often be frequented to forage. 3) The assessment of habitat variables might provide a link between foraging habitat selection and prey availability so that preferred zones can be identified and promoted via targeted sediment extraction.

Material and Methods

Study area

The study was carried out in 2018 along the river Rhône in the nature park Pfyn-Finges stretching from Sierre (46°17’14’’N, 7°33’16’E) to Leuk (46°18’38″N, 7°38’29″E) in the Canton of Valais (VS) in south-western Switzerland. The alluvial zone and forest of Finges around the Rhône are amongst Switzerland’s landscapes of national importance listed in the Federal Inventory of Landscapes and Natural Monuments. The surrounding landscape is characterised by vineyards on the northern slope and forests with some agricultural land on the southern slope of the valley. The studied river stretch is approximatively 8 km long, includes many islands and lateral arms with some stretches wider than 200m with elevations ranging from 526 m.a.s.l. to 604m.a.s.l and a slope of 0.9% gradient. There are three sediment extraction zones in Sierre, Finges and Susten and at the same time, the extraction companies are responsible for the habitat management of the river.

Study species

The Little Ringed Plover *Charadrius dubius curonicus* is a small precocial wading bird of the family *Charadriidae* whose breeding habitat ranges from lakes, rivers, ponds to artificial habitats such as gravel pits (Leisler & Walters 1975; Parrinder 1989; Fojt *et al.* 2000; Spaar *et al.* 2012; Schmid *et al.* 2018) and even farmland (Cepakova *et al.* 2007). This European subspecies migrates to central Africa from July to September for overwintering (BirdLife International 2016). In Switzerland, Little Ringed Plovers are listed as endangered and considered a national priority species (Keller *et al.* 2010; BAFU 2011). According to the new Swiss Breeding Bird Atlas (Knaus *et al.* 2018) the breeding population of Plovers has been estimated to 90-120 pairs (2013-2016) and no significant positive or negative trend was found in the swiss population from 1990-2016 (Knaus *et al.* 2018; Schmid *et al.* 2018). Despite this seemingly stable state, Plovers are facing several threats such as high-water levels due to high snowmelt and storms in June which can lead to brood and chick loss by flooding. Another threat is the increasing disturbance due to leisure activities (Baiker 2015; Schmid *et al.* 2018).

Once a Plover pair has secured their territory at a suitable breeding site, a clutch of 4 eggs is laid into a small hollow made in the substrate present in the area. This substrate can range from gravel, cobble up to landfill substrates as long as there is little vegetation in the area (Fojt *et al.* 2000; Hein & Reiser 2000; Lugon 2016). The incubation task is shared by both males and females with incubation-shifts. Duration of incubation-shifts can vary and are strongly dependent on food availability (Maumary, Vallotton & Knaus 2007). During incubation period which lasts 22-28 days, the birds behave very quietly and rely on their cryptic plumage for camouflage (Lugon, personal comm.) and egg crypsis (Salek & Cepakova 2006). When a predator, such as foxes or corvids approaches, a distraction display can be performed where birds simulate an injury to draw attention away from the nest (Armstrong 1952; Leisler & Walters 1975) or by luring the predator away by false incubation outside the nest (Salek & Cepakova 2006). Behaviour as such can be used to assess breeding probability (Sharrock 1973). Concerning feeding ecology, this bird is known to be insectivorous and especially preys on spiders, Coleopterans, ants, dipteran and trichopteran larvae (Leisler & Walters 1975; Boros *et al.* 2006). As a wading bird, Plovers forage along shores of lakes, rivers and ponds (Leisler & Walters 1975; Lugon 2016).

Bird surveys

To assess the breeding population of 2018, six bird surveys were carried out fortnightly between end of April and beginning of July which lies within the breeding period of the Little Ringed Plover and Common Sandpiper *Actitis hypoleucos*, the other wader species investigated in this Master project (Pilati, Schranz & Arlettaz 2019). The survey consisted of walking transects with one observer per river shore. Observers moved forward alternating one after the other so that one observer could perceive whether birds were flushed by the moving team partner. Observation points were taken every 400m with an observation time of 15 to 20 minutes. Birds were observed visually with binoculars for 15 minutes at each observation point and more time was spent to increase detection probability with increased river width (>150m width). The following parameters were randomly selected for each survey: observer per river shore (northern/southern), river stretch and walking direction (upstream/downstream). Maps with orthophoto mosaic images provided by Drone Adventure were used to annotate bird observations, bird movements, atlas code and time of each observation. Afterwards, all observations noted on maps were digitalised with the software QGIS (QGIS Development Team 2018) for analysis.

Capture, ringing and radio telemetry

After settlement of territories, birds were captured and equipped with radio-tags as follows. First, suitable capture sites were identified and two rows of mist nets (32mm mesh size) were placed in the late evening. Nets were opened in the last hours of daylight and the researchers hid close to the nets and checked whether birds were caught with use of binoculars. Playback of bird calls were used with parsimony to avoid excessive disturbance. Once a bird was captured, it was extracted from the net, weighed, measured (wing length) and ringed with a metal ring on the right tarsus (ring size N, SEMPACH HELVETIA). After that, a radio-transmitter (Holohil Systems Ltd. Canada, BD-2, 1.3 g + 0.1 g harness, 40p/min, eight weeks lifespan) was placed on the individual with a nylon leg-loop harness (Rappole & Tipton 1991). The size of the harness was fitted and adjusted to the individual bird (Naef-Daenzer 2007). After handling the birds, they were released. The next morning, a first location of the tagged individuals was done with the use of radio-telemetry to check the general status of the birds. Birds were located with triangulation get their exact position (Aarts *et al.* 2008). Radio-telemetry was used to locate birds and obtain foraging points to investigate foraging habitat selection.

Habitat selection

Essentially, habitat selection of Plovers was investigated on two scales. First, on a micro-habitat scale via studying foraging habitat as described below. Second, on a home range scale with use of remote sensing data from aerial photographs taken by drones (Drone Adventure).

Foraging habitat selection on micro-habitat scale

We used the aquired information from bird surveys on Plover home ranges to identify foraging sites. In some areas, the habitat was distinctly different from others which led to more foraging sites than home ranges. To investigate foraging habitat selection of Little Ringed Plovers, "foraging points" paired with "pseudo-absence points" were obtained on micro-habitat scale. To obtain a foraging point, birds were radio tracked or observed with binoculars and a telescope until a foraging event occurred. A foraging event was defined as the picking and, as far as observable, swallowing of a prey item. Once a foraging event was observed by one of the researchers, the location was kept in the telescope and the observer of the foraging event sent the team partner to that location. While communicating with walkie-talkies, the team partner placed a marking stick on the exact location of the foraging event. Then, a radius of 1.5m was delineated around the marked location and all habitat variables and their cover estimates (Tab. 1, Tab. 2). were recorded inside the foraging point*.* The same procedure was repeated with the pseudo-absence point while taking a random distance (5-15m) and random angle (0-360°) to obtain the location, with precondition that the pseudo-absence point did not fall into full water or fully inaccessible dense vegetation. If this did happen, the randomisation was repeated to get a new pseudo-absence point. Time period for foraging observations were usually from early morning until midday at the latest.

Habitat selection on home range scale with remote sensing data

Six drone flights were performed every three weeks throughout the breeding season in order to assess the dynamics of the river and its eco-geomorphology. Each flight session lasted approximately four hours, depending on wind conditions and the need to change batteries. Drones (eBee Plus, sensefly) flew over the whole study area with an altitude of 150m above ground and took geo-tagged aerial RGB images ("S.O.D.A" camera, sensefly. RGB = red, green, blue). Programmed and supervised by the "Drone Adventure" team, the drones followed a lawn mower trajectory in order to photograph our study area. All required permits, i.e. permission to fly over nature reserves and federal law on drone flights, were managed by "Drone Adventure", a non-profit organisation located in Lausanne. The post-processed images in form of orthomosaic images by Drone Adventure had a high resolution of 3.8cm/pixel. In this thesis, home range selection of Plovers was based on habitat composition, which was classified from two orthomosaic images, representative of the low and high water level periods.

A more extensive analysis of remote sensing data over the whole study area including all six orthomosaic images has been carried out by my fellow colleague Marco Pilati.

Invertebrate sampling

To sample invertebrates throughout the breeding period of the wading birds, barber pitfall traps (Supplementary Fig. 1) were placed in suitable and accessible sites along the river. Pitfall traps are commonly used for sampling invertebrates such as Coleoptera, Formicidae and also Collembola (Greenslade 1964; Joosse-van Damme 1965; Greenslade 1973; Boetzl *et al.* 2018). Due to flooding events in the pilot sampling period, the design was adapted to a nested design in which 9 habitat types were chosen (substrate type combined with vegetation presence, see Supplementary Tab. 1) with 3 replicates for each habitat type. This leads to 27 trap locations in total which are shown on Supplementary Fig. 2 and 3. Invertebrates were sampled during 8 sessions (n = 216 samples). Sampling period at the beginning was 10-days (2 sessions), then a high water level period occurred due to snowmelt and the sampling period was adjusted to 5-days (4 sessions). A 10-day sampling period was realised at the very end as water levels had gone back to normal. Due to flooding, 10 trap locations had to be re-allocated and it was made sure that 3 replicates per habitat type were in place again. Traps were placed with at least 15m distance from each other to ensure independent sampling (Boetzl *et al.* 2018). Traps were composed of plastic cups which were filled with propylene glycol and water (2:1) and a detergent to decrease water surface tension. A funnel with 15 cm diameter was placed on top and a transparent plastic cover was placed over each trap to protect it from precipitation. Until identification, samples containing the invertebrates were transferred into 50mL plastic tubes containing 70 percent ethanol through sieving (1mm mesh size). Invertebrates were identified to order level and Coleopterans to family level as far as possible with use of identification guides (Stresemann *et al.* 2011; Chinery & Jung 2012; Harde & Severa 2014; Bellmann 2018) and binocular microscopes (M5A Wild Heerbrugg, Switzerland). For identification, we randomly allocated samples to observers and 5 sampling sessions out of 8 were identified due to time constraints.

Statistical Analysis

All statistical analyses were performed using the software R, version 3.6.1 (R Core Team 2019). After standardising and transforming the response and explanatory variables, correlations between explanatory variables were tested for using the Spearman correlation coefficient (Zuur *et al.* 2009). Analyses of orthomosaic images obtained and provided by "Drone Adventure" were done with the geographic information system QGIS, version 3.4 Madeira (QGIS Development Team 2018).

Foraging habitat selection on micro-habitat scale

First of all, data exploration was conducted according to the protocol by Zuur and colleagues (Zuur, Ieno & Elphick 2010). Then, data analysis was performed by the following steps. First, explanatory variables were tested for collinearity using the Spearman correlation coefficient. If variables had a Spearman correlation coefficient above $R_s = |0.7|$ they were excluded from further analyses (Zuur *et al.* 2009) and the more biological significant variable was retained. Second, univariate models were built to investigate potential effects of explanatory variables (Tab. 2) on occurrence probability of Plovers (foraging points) using a generalised linear model with the "glm" function from the package "lme4" (Bates *et al.* 2015). Only the explanatory variables which best explained the univariate models (p-value < 0.1) remained for the further analysis. Third, multivariate models were performed using generalised linear models. After investigating potential quadratic effects of explanatory variables, best models were finally selected with the function "dredge" from the R package "MuMIn" (Barton 2017). To visualise the results, the significant response variables were plotted with Bayesian credible intervals with the best explaining model (lowest AICc, delta AICc < 2) including the significant explanatory variables, as source for the predictions.

Habitat selection on home range scale

First, habitat classification was performed, then home range habitats were compared to the habitat of the study area. The analysis of remote sensing data from drone flights was performed with use of the "Semi-Automatic Classification Plugin" SCP (Congedo 2016) within the software QGIS (QGIS Development Team 2018). Two orthomosaic images were analysed, one from the beginning of the season (28.04.18) when water level is low, and one from later on when water level peaked, i.e. the flooding period (02.06.18). For the classification of the riverine habitat, our approach comprised the combination of delineating polygones by hand and use of the SCP. First, the study area was delineated as a polygon. Second, the water cover had to be delineated by hand using the high resolution orthomosaics as the SCP could not accurately differ between water and sediments due to high colour similarity of the pixels. Third, the resolution of the orthomosaic images had to be reduced to 1m/px due to computing and processing limitations. Fourth, a series of ROI's (Regions of Interest) was selected for the so-called "training set". That is, pixels of colours (wavelengths) were defined for these two habitat types: sediments and vegetation. The training set comprising ROI signatures embodies the base for the algorithm to classify these signatures into habitat types by considering their minimum and maximum wavelengths. Habitat classification was performed with the minimum distance algorithm (MDA), where the distance of each pixel in the image is calculated and assigned to the closest spectral signature thus corresponding habitat class (Congedo 2016). Finally, the outcome of the SCP was merged with the water polygons resulting in the habitat classification of water, sediments and vegetation. To obtain the flooded area, the symmetrical difference between two water polygons from extreme water level periods was taken, and then overlapped with Plover's home ranges in the core study area. Home ranges were composed of all observation points of Plovers from the bird surveys and foraging points. From these observation points, 100% minimum convex polygones (MCP) were calculated. To identify the major habitats selected by Plovers on a home range scale, a compositional analysis (Aebischer, Robertson & Kenward 1993) was performed with use of the function "compana" from the package "adehabitatHS" (Calenge 2006) within the software R. In this analysis, proportions of "used" habitat, that is home ranges (100% MCPs), are compared to the proportion of "available" habitat. The criteria to define "available" habitat were: the riverbed comprising sediments, early successional vegetation and gravel pits as they have shown to be suitable breeding areas for Plovers. The available habitat was delineated by hand with a polygon and then clipped to the classified river stretch area (raster of 1m/px). During analysis, taking the whole river stretch of 7km did not yield confident and significant results (Supplementary Tab. 2 and 3). Therefore, the area of "available" habitat was condensed to the core study area which was delimited by the 200m – buffered MCPs on the edges resulting in an approximately 3km long river stretch. The aim of this condensation was to reduce statistical noise and increase potential signals of habitat use and refine the definition of available habitat. Then, proportions of the previously classified habitat types, i.e. water, sediment and vegetation were tested via randomisation test (1000 repetitions) which pair-wisely compares utilisation of each habitat type with its availability.

Invertebrate abundance

Due to flooding, only a subset of the data was analysed. To account for the different amounts of days that traps were open, a capture rate was derived for each analysed invertebrate group and total abundance. That is, invertebrate abundance divided by number of open days times 10 to obtain a homogenous capture rate per 10 days.

First of all, data exploration was conducted according to the protocol by Zuur and colleagues (Zuur, Ieno & Elphick 2010). To account for overdispersion, a random observation level factor was included in the models of Staphylinidae and Heteroptera (Korner-Nievergelt *et al.* 2015). The logarithmic transformation of the other invertebrate groups as response variables led to best model fits with normally distributed data. The two explanatory variables “dead vegetation” and “big boulder” contained too many zeroes (>70%) so they were transformed into binary variables (presence/absence). Then, statistical analysis was performed following the same steps as described in the chapter on foraging habitat selection except that the “lmer” function from the “lme4” package, (Bates *et al.* 2015) was used for most response variables and “trap ID” set as random factor. Since the response variables Staphylinidae and Heteroptera could not be log-transformed, “glmer” functions from the “lme4” package were used for modelling their poisson-distributed data. Where less than three variables entered the full model during the model selection process, selection was done by hand by comparing AICc values of models (Korner-Nievergelt *et al.* 2015). To visualise the results, response variables (invertebrate group abundances) were plotted with Bayesian credible intervals based on the best explaining model, including the significant explanatory variables as source for the predictions.

Results

Capture, ringing and radio telemetry

In mid-June (16.06.18), two Little Ringed Plovers (one male, one female) were captured, measured (Tab. 5) and equipped with radio-tags.

Bird surveys and breeding success

6 bird surveys were completed, of which one was conducted in two days due to bad weather conditions. Overall, 6 ± 2 plover pairs were estimated to occur in Finges, 4 pairs were observed breeding of which was only one pair successful. One other pair was displaying territorial behaviours towards another pair which indicates that this fifth pair must also have been breeding nearby. These five pairs occupied territories in the core area of the restored river stretch from Salgesch to Rottensand (Fig. 15). In 2018, most nests were located on islands and were lost due to flooding. In one area, ponds were artificially re-created quite late in the season (mid-May) which led to the loss of one nest. These works were linked to the urgent maintenance works for electric pylons in the area. Fortunately, a replacement clutch was laid in the same area and it turned out to be the only Plover pair in the study area that had successfully reproduced.

Foraging habitat selection on micro-habitat scale

In total, 45 foraging points paired with pseudo-absence points (90 points mapped) were obtained from foraging Plovers from 7 foraging sites. 6 out of 45 foraging points were taken with use of radio-telemetry. Overall, no significant correlations between explanatory variables have been detected when analysing explanatory habitat variables of foraging points and comparing them to pseudo-absence points. Out of four competitive models (Tab. 4) the best model (delta AIC < 2) was chosen, which contained the explanatory variables boulder, live vegetation, water and the binary variable dead vegetation (Tab. 3). Water (estimate = 1.146 ± 0.311, z-value = 3.683, p-value < 0.001) and the quadratic term of boulder (-1.033 ± 0.426, z = -2.422, p = 0.015) were found to be significant for foraging (occurrence probability) of the Little Ringed Plover. The binary variable dead vegetation, presence or absence of dead vegetation, and the quadratic term of live vegetation were marginally significant (Tab. 3) within the best model. Moreover, a significant quadratic effect was found in water (-1.401 ± 0.395, $z = -3.548$, $p < 0.001$). Predictive plots of the significant explanatory variables water and boulder are shown in Fig. 1 and Fig. 2.

Habitat selection on home range scale

In total, six Plover home ranges were found when all observation points from the bird survey and foraging points were considered together. On one day, a Plover has been observed as far upstream as the gravel pit of Susten. As we did not observe Plovers in the same area again, we did not consider it as a home range. Hence, five home ranges were found in the core study area located south of the gravel pit of Finges (46°17'48 N, 7°33'47''E) and upstream to Unner Pfynwald (46°18'34'' N, 7°35'46''E). All home ranges were located within flooded habitat (Fig. 15), also apparent in Fig. 17 and Fig. 18. The proportions of flooded area per home range are listed in Tab. 8. Additionally, 46.43 % of all observation points underlying the home range of Plovers were located within the flooded area. The results of the habitat classification are shown in Fig. 16. The comparison of habitat composition of home ranges (used habitat) with the core study area (available habitat) via compositional analysis revealed significant habitat selection for sediments over vegetation indicated with triple signs by habitat ranking (Tab. 7). Although the randomisation tests did not clearly show significant differences for both the low water level ($\lambda = 0.328$, $P = 0.257$) and high water level periods ($\lambda = 0.346$, $P = 0.250$), the log-ratio differences and ranking matrix demonstrate otherwise.

Invertebrate sampling

In total, 220 samples from barber pitfall traps were collected (including flooded ones). The analysis of a subset (5 of 8 sampling sessions, see Tab. 12) and exclusion of flooded samples and missing data led to a dataset of 111 samples. 46'883 invertebrates amongst which 25 invertebrate groups were sampled and identified. Coleoptera were identified to family level as far as possible. Specifically, these were: Cicindelinae, Elateridae, Carabidae, Staphylinidae, Coccinellidae, Curculionidae and other Coleopterans not belonging to these families. Amongst these Coleopteran families, the most abundant were Elateridae and Staphylinidae which were analysed extensively. Overall, the following most abundant groups (n=7) were analysed in more depth: Coleoptera (n = 6959), Elateridae (n = 2880), Staphylinidae (n= 2490), Heteroptera (n = 679), Formicidae (n = 8348), Araneae (n = 1089) and Collembola (n = 26056). As invertebrates could not all be identified to family or species level, species richness was not analysed due to the issue of the species accumulation curve. Traps were situated in the riverine habitat with a mean distance to water of 7.106m ± 4.7162 with distances ranging from 1.2m to 26.3m. Distances from traps to water, i.e. the shoreline or nearest standing or flowing water, varied over the sampling period due to fluctuating water levels.

Total invertebrate abundance

The mean number of invertebrates (total abundance) per barber pitfall trap was 422.370 ± 538.751 ranging from 4 to 3303 items per trap (raw data). The three environmental variables gravel, boulder and large boulder affected total invertebrate abundance (capture rate/10 days) in univariate models (Tab. 9). Multivariate model analysis revealed positive effects of gravel (0.261 ± 0.094, $t = 2.769$, $p < 0.01$) and boulder (0.231 ± 0.099, $t = 2.327$, $p = 0.027$) and a negative effect of large boulder (-0.756 ± 0.257, $t = -2.945$, $p = 0.006$) on total invertebrate abundance rate. See Tab. 10 for the model selection table and Fig. 3 and Fig. 4 for predictive plots.

Coleoptera

The mean number of Coleoptera per barber pitfall trap was 62.694 ± 77.474 ranging from 2 to 504 items per trap (raw data). The environmental variables gravel, boulder and large boulder remained in the model selection process after analysing them via univariate models (Tab. 9). Coleopteran abundance (capture rate/10days) showed positive trends with boulder (0.284 ± 0.142, $t = 2.003$, $p = 0.051$) and cobble (0.153 ± 0.118, $t = 1.292$, $p = 0.202$) in the global model. But upon model selection by hand, boulder alone (Fig. 5) best explained the model by showing a positive effect on coleoptera abundance (0.350 ± 0.134, $t = 2.626$, $p = 0.012$), see Tab. 11.

Elateridae

The mean number of Elateridae per barber pitfall trap was 25.946 ± 77.474 ranging from 2 to 504 items per trap (raw data). Five environmental variables showed effects on Elateridae abundance (capture rate/10days) in univariate analysis (Tab. 9, Fig. 6). In the best performing multivariate model, boulder (0.392 ± 0.155, t = 2.526, p = 0.016) and distance to water (0.290 ± 0.133, t = 2.178, p = 0.033) showed positive effects on Elateridae abundance (Tab. 11). The linear term of live vegetation did not significantly explain Elateridae abundance (0.523 ± 0.381, t = 1.371, p = 0.174). However, the quadratic term of live vegetation (-0.874 ± 0.358, t = -2.441, p = 0.016) and the linear term of dead vegetation (-0.454 ± 0.136, t = -3.332, p = 0.001) indicate negative effects on Elateridae abundance (Tab. 11).

Staphylinidae

The mean number of Staphylinidae per barber pitfall trap was 22.432 ± 60.220 ranging from 0 to 488 items per trap (raw data). The environmental variables sand, cobble and boulder showed effects on Staphylinidae abundance (capture rate/10days) through univariate analysis (Tab. 9). Yet, after multivariate model selection only cobble and boulder remained in the best performing model (Tab. 10). Staphylinidae abundance increased with higher percentages of cobble (0.681 ± 0.215, z = 3.162, p = 0.001) whereas boulder (0.466 ± 0.242, z = 1.982, p = 0.054) only marginally affected the abundance of this invertebrate group (Tab. 11, Fig. 7)

Heteroptera

The mean number of Heteroptera per barber pitfall trap was 6.117 ± 25.321 ranging from 0 to 240 items per trap (raw data). Live vegetation, maximum vegetation height and distance to water entered the full model for heteropteran abundance (capture rate / 10 days), see Tab. 9. As live vegetation cover [%] increases, so does the abundance of Heteroptera (1.030 ± 0.235, z = 4.383, p < 0.001), see Fig. 9. Distance to water entered the best model as well (Tab. 10), but did not significantly affect the response variable (-0.399 ± 0.252, z = -1.582, p = 0.114), see Tab. 11.

Formicidae

The mean number of Formicidae per barber pitfall trap was 75.207 ± 27.0 ranging from 1 to 1443 items per trap (raw data). Dead vegetation (Fig. 10) and maximum vegetation height (Fig. 11) best explained Formicidae abundance (capture rate / 10days), see Tab. 9. In multivariate analysis, dead vegetation (-0.7622 ± 0.2768, t = -2.754, p = 0.007) indicated a negative interaction with Formicidae abundance whereas the quadratic term of dead vegetation showed a marginally significant positive trend (0.4932 ± 0.2596, t = 1.900, p = 0.060). Maximum vegetation height (0.266 ± 0.137, t = 1.944, p = 0.055) positively correlated with Formicidae abundance, although only marginally (Tab. 11). See Tab. 10 for the model selection table.

Araneae

The mean number of Araneae per barber pitfall trap was 9.811 ± 10.622 ranging from 0 to 48 items per trap (raw data). Four univariate environmental variables affected the abundance of Araneae (capture rate /10days), see Tab. 9. After model selection process, dead vegetation, sand and large boulder remained in the best model (Tab. 10). Araneae abundance increased with higher dead vegetation cover (0.237± 0.067, t = 3.544, p < 0.001), see Fig. 12. The linear term of sand (-0.716 ± 0.238, t= -3.004, p < 0.004) showed a strong negative correlation with Araneae abundance whereas the quadratic term (0.437 ± 0.235, t = 1.857, p = 0.068) reveals a marginally positive effect on Araneae abundance (Tab. 11). The graphic plot shows a U-shaped relation of sand with Araneae abundance (Fig. 13). Large boulder seems to affect Araneae abundance negatively (-0.650 ± 0.189, t = -3.445, p = 0.002).

Collembola

The mean number of Collembola per barber pitfall trap was 234.739 ± 361.670 ranging from 0 to 2246 items per trap (raw data). Univariate model analysis revealed that the explanatory variables gravel, and live vegetation affected Collembola abundance (capture rate/10days), see Fig. 14. However, upon comparison of AICc of candidate models, only gravel had a significantly positive effect on the abundance of collembola (0.521 ± 0.174, t = 2.998, p = 0.005).

Discussion

In this study, we detected 6 ± 2 home ranges of Little Ringed Plover. On a home range scale, Plovers positively selected towards sedimented habitat in comparison to vegetation and water. Water and boulder were the main factors influencing foraging habitat selection of Plovers. Water showed a quadratic relationship with an optimum between 20-80% and boulder an optimum cover of 5% in relation to foraging habitat selection. The main environmental variables affecting total invertebrate abundance were gravel (+), boulder (+) and large boulder (-). Thus, riverine habitats with small-sized sediments (gravel, cobble, boulder) harbour more invertebrates than habitats with large-sized sediments such as large boulders.

Bird survey and breeding success

6 ± 2 Plover pairs were estimated to occupy territories within the restored river stretch in 2018. According to our monitoring, five pairs have been breeding in the area (Fig. 15). The other three pairs are an estimate (personal. comm. Lugon) as the wide riverbed upstream of Salgesch (Rottensand) could potentially harbour more pairs but due to large river width, detection probability was considerably lower compared to other narrower areas of the river. In the ornithological survey carried out in 2013, eight Plover territories have been detected (Lugon 2016). In 2013, home ranges of Plovers were distributed in the same areas as in 2018, but more densely. The following questions arise: has the population density in the study area already reached its carrying capacity? Or are habitat properties such as the advanced successional stage in many areas not suitable anymore, so that potential Plover home ranges were quickly saturated? This point was discussed by Lugon, who argues that coarse sediments at Iles Falcon make the habitat unsuitable for Little Ringed Plovers for which the augmentation of gravel extraction works since 2010 may be a reason. Keeping in mind that many broods were lost to flooding, the question on ecological trap theory should be taken into consideration. This theory suggests that a habitat is seemingly suitable for a species but it can turn out to be a trap and even drive species to extinction (Battin 2004). As shown in the US (Catlin, Felio & Fraser 2013) and in Switzerland (Baiker 2015), flooding leads to brood loss and this phenomenon can be seen as an

ecological trap. A gravel island may seem to be a suitable breeding habitat in a Plover's eyes, but if that island is not elevated enough to protect the nest from flooding, that Plover is likely to lose his brood or chicks.

Foraging habitat selection and invertebrate abundance

We hypothesised that the occurrence of water, substrate and vegetation cover would influence foraging habitat selection of Little Ringed Plovers. Indeed, we found that water and boulder significantly affect foraging habitat selection of Plovers when comparing foraging points (presence points) with paired pseudo-absence points. The quadratic relationship of water implies that Plovers forage in an optimal range of approximately 20-80% water cover (Fig. 1). This finding underlines that Plovers mostly forage at the interface of water and ground. Although boulder cover affected foraging habitat selection of Plovers in a negative way (Tab. 3), the prediction plot (Fig. 2) suggests an optimal amount of 5% boulder cover, favoured by foraging Plovers. Particle size of sediments in gravel-water interfaces play a crucial role in the distribution, diversity and composition of macroinvertebrate assemblages (Buss *et al.* 2004; Beauger *et al.* 2006). Invertebrate abundance and diversity have shown to be high in habitats of coarse sediments, for instance boulders, as they indicate relatively stable habitats and sites of minimal disturbance during floods (Rice, Greenwood & Joyce 2001). Thus, boulders harbour higher invertebrate abundances and on the other hand may act as screens from predators for Plovers when foraging. In contrast, small granulometric sizes of substrates such as clay and silt, gravel and cobble play a minor role in the bird's foraging activity. As to invertebrates, gravel positively affected total invertebrate abundance. This finding is in line with extant literature, as studies have demonstrated a high taxonomic richness (on family level) in habitats consisting of gravel and cobble (Rice, Greenwood & Joyce 2001; Sroczynska *et al.* 2019). Another study on beetles at the near-natural and wide riverbed of the Tagliamento river revealed that species abundance and species richness were highest at the exposed sediment surface and channel margins (Langhans & Tockner 2014).

Some invertebrate groups, namely Coleoptera, Araneae and Formicidae shall be discussed separately as they were shown to be prey of Plovers (Leisler & Walters 1975; Boros *et al.* 2006). Boulder positively correlated with Coleopteran abundance. Cobble did not influence Coleoptera, Formicidae and Araneae abundance. One possible explanation is that the estimation of percentage cover of cobble was challenging in the field as the sizes within this granulometric category vary from 6 to 20cm which on this scale, might be a large variation to find a statistically significant effect. The quadratic term of dead vegetation positively affected Formicidae abundance. Even though the linear term negatively affected ant abundance, a positive trend can clearly be observed upon visually analysing the prediction plots but the prediction curve has a very large 95% confidence interval (Fig. 10). An outlier of 1443 Formicidae in one sample was detected which could be explained by an ant nest. As ants were abundant in the whole study area, we did not consider variables such as distance to the next ant nest in our design. In the future, such outliers can be prevented by leaving a trap inactive for a couple of days after installation as digging-in effects demonstrated in an Australian study which suggests to leave a trap inactivated for one week to minimise the effect of high ant catches after immediate installation of pitfall traps (Greenslade 1973). In respect to Araneae, dead vegetation showed a positive effect on abundance of spiders. A U-shaped relationship has been detected in relation to sand cover (Fig. 13). This may indicate that more spiders are present in habitats with either low sand cover or rather high sand cover. Yet, the confidence interval on the right is rather large and it could also well be that the one outlier on the right drives the U-shape relationship because there were not many traps with 30-70% sand cover. In contrast, large boulder affected Araneae abundance negatively (Tab. 10).

A further prediction of this study was that prey availability would be a strong driver for foraging sites as demonstrated for other wading birds (Whittingham, Percival & Brown 2001; Boros *et al.* 2006; Le Fer, Fraser & Kruse 2008; Catlin, Felio & Fraser 2012; Horvath *et al.* 2012). However, we did not encounter an effect of foraging sites. The small sample size of mapped points (n = 45 foraging points paired with pseudo-absence points), limited number of accessible foraging sites (n =7) and Plover pairs (n = 6 ± 2) could be a possible reason for not detecting any statistical effect. We would have expected foraging sites such as the artificially created ponds to yield more invertebrates as standing water in mud flats and alkaline pans have shown to boost invertebrate abundance (Boros *et al.* 2006; Le Fer, Fraser & Kruse 2008; Hunt *et al.* 2017). Only 6 of 45 foraging points were taken with use of radio telemetry. Due to this small sample size from only two birds, individual bird ID could not be considered in the analysis. The late arrival of capture permit is one of the reasons for this small number of foraging points taken by radio tracking. Moreover, the birds left 10 days after capture which impeded the assessment of further foraging points via radio telemetry.

Habitat selection on home range scale

Regarding habitat selection of home ranges, we predicted that Plovers select open and sparsely vegetated habitats as nesting sites with early successional stages and high substrate cover. We found that Plover nests were indeed located in areas of early successional stages with little vegetation where gravel and cobble dominated the habitat (Fig. 15). The compositional analysis demonstrated that Plovers preferably select for sediments compared to vegetation when settling their territories (Tab. 6, Tab. 7, Fig. 17, Fig. 18). These findings are consistent with studies on multi-scale habitat selection where they found a negative effect of woody vegetation and a positive effect of bare ground with high gravel cover in territory habitat selection of Little Ringed Plovers in Cambodia (Claassen *et al.* 2018). However, we would like to point out that our findings are only based on visual observations as it was not possible to investigate nest site selection in more depth. Low accessibility to nesting sites such as islands and our personal restraint not to disturb the breeding birds are the reasons. Moreover, the five home ranges represent a small sample size which underlines the fact that long-term studies are needed for an endangered bird such as the Little Ringed Plover. The radio telemetry data only provided six foraging points which were all located within the same home range. Given that those foraging points came from only two tagged individuals, we could not analyse the radio telemetry data in comparison to the rest of the home ranges. For further studies, distinguishing individuals by radio telemetry is crucial to define their distinct home ranges and lead to more robust results of home range habitat selection via compositional analysis for example (Apolloni *et al.* 2018). Another more general difficulty is the arbitrary definition of available habitat which is usually derived from the whole study area that in turn has been set arbitrarily (Aebischer, Robertson & Kenward 1993). In our case, the whole study we restricted it to the core study area where Plover home ranges were located. With this and the fact that only the riverbed and not the surrounding landscape were considered available habitat, we aimed to limit this arbitrary definition. Even though we have found a positive home range habitat selection towards sediments, more research is needed to identify more fine-grained characteristics of the home range habitat.

Conclusions

In this pilot study, we have shown that radio telemetry methods are applicable for small wading birds such as the Little Ringed Plover. We were able to track Plovers and study their foraging habitat with use of radio telemetry and visual observations. Additionally, systematic surveys have successfully been performed in the restored river stretch of the Rhône. During the season, six drone flights were completed, yielding six orthomosaic images of high resolution which has allowed a high precision of our survey data and therefore home range analysis of birds. In regards to foraging habitat selection and prey of Little Ringed Plover, a foraging preference for an optimal cover of 5% boulder was found. Total invertebrate abundance, Coleoptera, Staphylinidae and Elateridae all showed increased abundances in habitats with more boulder cover. As boulders may provide shelter and protection from predators, invertebrates may use them as hiding places and Plovers in turn as screens from predators. Therefore, Plovers may find prey in habitats where boulders are interspersed with other sediments of varying granulometric size. Plover's home ranges were located in areas with high sediment cover which at the same time were partly flooded as well, leading to brood loss, especially home ranges on islands.

We would like to point out that the invertebrate sampling and results thereof only provide an indirect link to the bird's foraging habitat selection. In the future, other sampling methods such as the analysis of faecal samples of captured birds as done for the Common Sandpiper (Holland 2018) could be considered for more precise information on the wading bird's prey and thus its foraging habitat selection. Methods such as sticky trap sampling have previously been employed to investigate prey of a distant cousin of Little Ringed Plovers, namely the Piping Plover *Charadrius melodus* (Catlin, Felio & Fraser 2012; Hunt *et al.* 2017). We have attempted this method in our study but the sampling time of 24h has proven to be too long as dry silt, sand and gravel stuck to the traps and impeded trapping and proper identification of invertebrates. Shortening sampling time to 30 minutes as in the studies in the US and combining sampling locations to sites where foraging events have been observed or the use of mud samples (Boros *et al.* 2006) would exemplify possible solutions to allow a direct link from foraging habitat selection to sampled invertebrates. We are aware that the dynamics of this riverine habitat poses challenges to the experimental design of such an invertebrate sampling. Flooding is not only a threat to Plover's reproductive success but also to the obtained invertebrate samples. Therefore, we recommend a thoughtful use of invertebrate sampling in such a dynamic habitat and encourage to consider other sampling methods which could more specifically target the bird's prey. The low number of this endangered wading bird pairs encountered in this pilot study emphasises the need for long-term studies on this species. With data collected over several years, more robust results can be obtained and thus, more precise habitat management measures can be devised.

Management recommendations

Our observations and analysis on foraging and home range habitat selection confirm that slow flowing areas in lateral river arms as found in the upstream area of the gravel pit of Finges and ponds upstream to Unner Pfynwald provide important constant foraging habitats even when water levels are high. More such habitats should be created and maintained dispersed throughout the whole study area. Additionally, grazing management as done in 2018 should be continued to keep vegetation low to prevent fast encroachment and providing more suitable breeding habitat for Plovers. At Iles Falcon, the habitat structure should be improved by elevating and enlarging gravel islands to offer more suitable breeding areas to Plovers. The small islands that were created or maintained in the study year were not colonised by Plovers and with good reason as all except one were flooded during high waters. The maintenance of substrate mosaics (gravel, cobble, boulder) should be promoted as this was demonstrated to play an important role for Plover presence. The three factors substrate, surface and height of islands and shores crucially influence the occurrence of Plovers (Baumann 2003). Therefore, we recommend to augment the size of artificially created gravel islands as was previously recommended by the last ornithological monitoring (Lugon 2016) and the study at the alpine Rhine (Baiker 2015) confirming that Plovers preferably colonise larger islands.

Even though human disturbance and predation were not investigated here, they are a threat to Plovers and measures to limit these threats should be taken. Reports revealed that the provision of predator-excluding cages were successfully employed and protected nests from predation in the UK (Gulickx & Kemp 2007; Gulickx *et al.* 2007) and in Switzerland (Rnjakovic 2016). Therefore, the provision of nest cages could be implemented in our study area as Plovers readily accepted these cages in gravel pits in Great Britain and Switzerland. Consequently, reproductive success may increase by actively protecting nests from predators. As previously shown by other studies, human disturbance directly affects foraging and breeding behaviour of wading birds (Burger 1994; Baumann 2003; Colwell *et al.* 2005; Baiker 2015; Schmid *et al.* 2018). Along these lines, sensibilisation work with the public needs to be done by providing information and setting up panels as done in a species promotion concept at the alpine Rhine (Schuhmacher 2017; Schmid *et al.* 2018).

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Tables

Table 1: *Granulometric classification used for mapping environmental variables of foraging points, pseudo-absence points and trap locations (r = 1.5m). Granulometric sizes according to the International Organization for Standardization (ISO).*

Substrate	**mm**
Silt and Clay	< 0.02
Sand	0.2 - 2
Gravel	6.3 - 63
Cobble	63 - 200
Boulder	200 - 630
Large Boulder	> 630

Table 2: *Environmental variables assessed both for foraging habitat selection and habitat mapping of barber pitfall traps (except water related variables). Live vegetation comprised all alive parts of plants. Dead vegetation included dead leaves, roots or other plant parts. Dead wood included sticks and larger pieces of dead wood. Turbidity was assessed by eye with estimation in percent. Water temperature was measured with a pool thermometer.*

Substrate [cover %]	**Additional variables [unit]**
Silt and Clay	Habitat type (combination of substrate and vegetation)
Sand	Vegetation type (shrubs, grass, forbs, stems)
Gravel	Maximum vegetation height [cm]
Cobble	Distance to water [m]
Boulder	Turbidity [%]
Large boulder	Water temperature [°C]
Live vegetation	Flow [s/1m]
Dead vegetation	
Dead wood	
Water	

***Table 3**: Summary statistics of the best model for the occurrence of the Little Ringed Plover during foraging activity modelled against explanatory habitat cover variables. Cover variables asine square root transformed and dead vegetation to a binary variable (presence or absence of dead vegetation).*

Explanatory variable	Estimate	Std. Error	z value	Pr(>|z|)
boulder	0.88739	0.61525	1.442	0.149212
boulder^2	-1.03281	0.42645	-2.422	0.015442 *
live vegetation	-0.08077	0.58698	-0.138	0.890557
live vegetation^2	-1.48132	0.86144	-1.720	0.085507 .
dead vegetation.bi	-1.48287	0.89647	-1.654	0.098102 .
water	1.14579	0.31110	3.683	0.000230 ***
water^2	-1.40098	0.39483	-3.548	0.000388 ***

***Table 4**: Model selection table on foraging habitat selection of Little Ringed Plover (foraging points compared to paired pseudo-absence points).*

Model	Variables	df	AICc	Δ AICc	Akaike weight
495	boulder + (boulder)^2 + dead vegetation + live vegetation + (live vegetation)^2 + water + (water)^2	8	91.1	0.00	0.168
487	boulder + (boulder)^2 + live vegetation + (live vegetation)^2 + water + (water)^2	7	91.4	0.36	0.140
496	large boulder + boulder + (boulder)^2 + dead vegetation + live vegetation + (live vegetation)^2 + water + (water)^2	9	91.8	0.76	0.115
488	large boulder + boulder + (boulder)^2 + live vegetation + (live vegetation)^2 + water + (water)^2	8	92.5	1.41	0.083

***Table 5:** Measurements and ring numbers of captured and radio-tagged Little Ringed Plovers*

Date	Location	Ring Nr	Species	Sex	Wing length [mm]	Weight [g]
16.06.2018	Gravière Finges	N 577831	*Charadrius dubius*	2	108.5	33.56 ± 0.1
16.06.2018	Gravière Finges	N577832	*Charadrius dubius*	1	114.5	33.35 ± 0.1

Table 6*: Results of the compositional analysis at the home range scale is shown per orthomosaic image, one at low water level and one at high water level. The table gives average log-ratio differences for all pairwise comparisons of proportions of habitat types between elements. Significant values from randomisation tests of the ranking matrix (Tab. 7) are shown in bold.*

Available → ↓ Used	Water	Sediments	Vegetation
a) Low water level			
Water	0	-1.888	0.432
Sediments	1.888	0	**2.242**
Vegetation	-0.432	**-2.242**	0
b) High water level			
Water	0	-0.124	0.790
Sediments	0.124	0	**0.914**
Vegetation	-0.790	**- 0.914**	0

Table 7*: Here, the ranking matrix from the comparison of habitat use of 100% minimum convex polygone (MCP) home ranges with proportion of available habitat types within the core study area is given. A sign indicating the direction of selection was used as replacement instead of each mean element of the matrix. A triple sign demonstrates significant deviations from random at alpha = 0.05. Ranked variable sequence (most to least used >>> showing significant preference over subsequent category): sediments >>> vegetation > water*

Available → ↓ Used	Water	Sediments	Vegetation
c) Low water level			
Water	0	-	+
Sediments	+	0	+++
Vegetation	-	---	0
d) High water level			
Water	0	-	+
Sediments	+	0	+++
Vegetation	-	---	0

Table 8: *Table showing proportion of flooded area per home range.*

Home range ID	Total [m^2]	flooded [m^2]	Proportion [%]
1	26214	5778	22.043
2	38779	7520	19.394
3	5273	2437	46.217
4	4206	1761	41.874
5	12819	1763	13.755

***Table 9**: Summary of the significant univariate models respective to their invertebrate groups (response variables). For linear mixed effect models (lmer) the t- values are given which is true for all response variables except for generalised linear mixed models where z- value are given (staphylinidae and heteroptera). max_veg_height = maximum vegetation height. Univariate variables with a p-value < 0.1 entered the multivariate analysis.*

Response	Variables	Estimate	Std. Error	t or z value	p-value
Total abundance	gravel	0.273	0.105	2.596	0.013
	boulder	0.211	0.123	1.723	0.093
	large boulder	-0.726	0.285	-2.544	0.016
Coleoptera	cobble	0.247	0.109	2.265	0.028
	boulder	0.351	0.134	2.626	0.012
Elateridae	gravel	0.375	0.175	2.142	0.038
	boulder	0.483	0.181	2.677	0.011
	live vegetation	-0.449	0.150	-2.993	0.003
	dead vegetation	-0.338	0.138	-2.443	0.016
	distance to water	0.321	0.155	2.073	0.041
Staphylinidae	sand	-0.437	0.258	-1.692	0.091
	cobble	0.838	0.202	4.161	< 0.001
	boulder	0.794	0.258	3.075	0.002
Heteroptera	live vegetation	1.077	0.240	4.486	< 0.001
	max_veg_height	0.953	0.258	3.687	< 0.001
Formicidae	dead vegetation	-0.311	0.131	-2.372	0.019
	max_veg_height	0.333	0.137	2.420	0.017
Araneae	silt and clay	0.204	0.109	1.858	0.071
	sand	-0.299	0.099	-3.025	0.004
	large boulder	-0.805	0.286	2.814	0.008
	dead vegetation	0.221	0.083	2.665	0.009
Collembola	gravel	0.521	0.174	2.998	0.005
	live vegetation	-0.348	0.174	-1.998	0.049

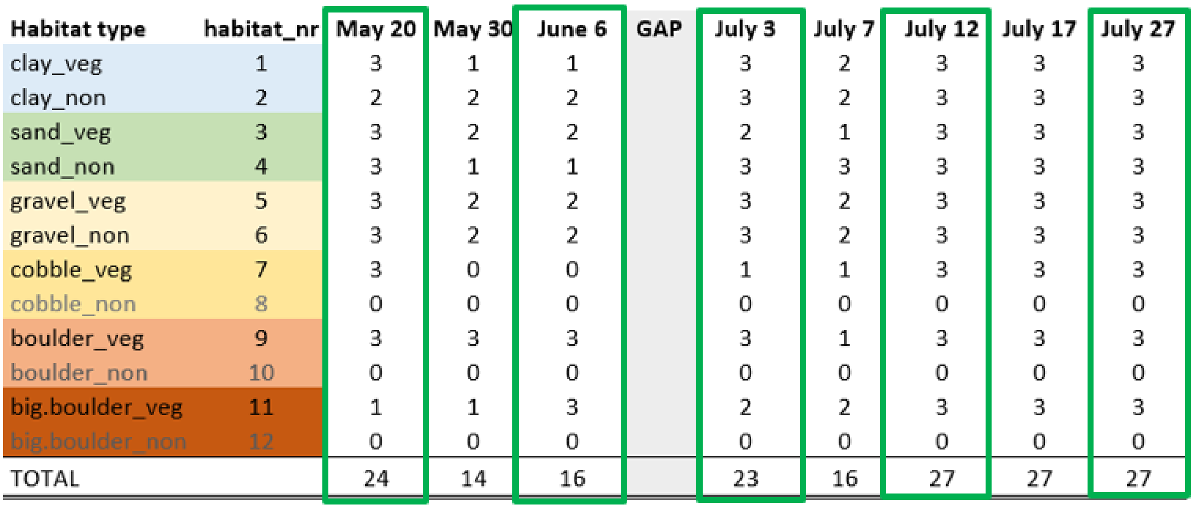
Table 10: *Model selection table presenting all models with Δ AICc < 2 including all explanatory variables. Model numbers of the selection process with "dredge" and their AICc values,* difference of AICc compared to *the first and best model, and Akaike weight are given. Abbreviations: max_veg_height = maximum vegetation height; dist_water = distance to water*

	Model	Variables	df	AICc	Δ AICc	Akaike weight
Total abundance	12	gravel + boulder + large boulder	6	290.2	0.00	0.253
	28	gravel + $(\text{gravel})^2$ + boulder + large boulder	7	290.6	0.43	0.204
	16	gravel + boulder + $(\text{boulder})^2$ + large boulder	7	290.8	0.65	0.183
Elateridae	56	boulder + dead vegetation + dist_water + live vegetation + $(\text{live vegetation})^2$	8	355.6	0.00	0.366
	64	gravel + boulder + dead vegetation + dist_water + live vegetation + $(\text{live vegetation})^2$	9	356.0	0.40	0.300
Staphylinidae	4	cobble + boulder	8	819.5	0.00	0.448
	8	sand + cobble + boulder	6	821.0	1.47	1.473
Heteroptera	4	live vegetation + dist_water	5	492.5	0.00	0.287
	3	live vegetation	4	492.8	0.31	0.246
	12	live vegetation + ma x_veg_height + dist_ water	6	493.6	1.14	0.163
	11	live vegetation + max_veg_height	5	494.4	1.87	0.113
Formicidae	8	dead vegetation + $(\text{dead vegetation})^2$ + max_veg_height	6	349.3	0.00	0.458
	6	dead vegetation + max_veg_height	5	350.1	0.78	0.310
Araneae	106	sand + $(\text{sand})^2$ + dead vegetation + large boulder	7	242.4	0.00	0.358
	42	sand + dead vegetation + large boulder	6	243.5	1.06	0.211
	108	clay + sand + $(\text{sand})^2$ + dead vegetation + large boulder	8	243.8	1.41	0.177

***Table 11**: Summary of best models investigating trap habitat mapping in relation to invertebrate sampling. Results on model selection by hand are given for Coleoptera and Collembola as these response variables had less than 3 significant explanatory variables in univariate models. Only significant quadratic effects are given. * z-values are shown for Staphylinidae and Heteroptera as generalised linear mixed models have been used for these invertebrate groups. For all other groups, the values correspond to t-values (linear mixed models).*

Response	Variables	Estimate	Std. Error	t- or z- value	p-value
Total abundance	gravel	0.261	0.094	2.769	0.008
	boulder	0.231	0.099	2.327	0.027
	large boulder	-0.756	0.257	-2.945	0.006
Coleoptera	boulder	0.350	0.134	2.626	0.012
Elateridae	boulder	0.392	0.155	2.526	0.016
	live vegetation	0.523	0.381	1.371	0.173
	$(\text{live vegetation})^2$	-0.874	0.358	-2.441	0.016
	dead vegetation	-0.454	0.136	-3.332	0.001
	distance to water	0.290	0.133	2.178	0.033
*Staphylinidae**	cobble	0.681	0.215	3.162	0.002
	boulder	0.466	0.242	1.928	0.054
*Heteroptera**	live vegetation	1.030	0.235	4.383	< 0.001
	distance to water	-0.399	0.252	-1.582	0.114
Formicidae	dead vegetation	-0.762	0.277	-2.754	0.007
	$(\text{dead vegetation})^2$	0.493	0.260	1.900	0.060
	max_veg_height	0.266	0.137	1.944	0.055
Araneae	dead vegetation	0.237	0.067	3.544	< 0.001
	sand	-0.716	0.238	-3.004	0.004
	$(\text{sand})^2$	0.437	0.235	1.857	0.068
	large boulder	-0.650	0.189	-3.445	0.002
Collembola	gravel	0.521	0.174	2.998	0.005

Table 12: *Overview of all sampling sessions. Analysed sessions are marked in green. Habitat types and their combination with vegetation (vegetated, non-vegetated) and corresponding replicate numbers of invertebrate traps are shown. Each trap was replicated 3 times according to habitat type. Note that all 12 possible habitat type combinations are listed, however for cobble, boulder and large boulder we had only vegetated traps. The indicated gap relates to the flooding period where water level was high due to snow melts and summer storms in the mountains.*



Habitat type	habitat_nr	May 20	May 30	June 6	GAP	July 3	July 7	July 12	July 17	July 27
clay_veg	1	3	1	1		3	2	3	3	3
clay_non	2	2	2	2		3	2	3	3	3
sand_veg	3	3	2	2		2	1	3	3	3
sand_non	4	3	1	1		3	3	3	3	3
gravel_veg	5	3	2	2		3	2	3	3	3
gravel_non	6	3	2	2		3	2	3	3	3
cobble_veg	7	3	0	0		1	1	3	3	3
cobble_non	8	0	0	0		0	0	0	0	0
boulder_veg	9	3	3	3		3	1	3	3	3
boulder_non	10	0	0	0		0	0	0	0	0
big.boulder_veg	11	1	1	3		2	2	3	3	3
big.boulder_non	12	0	0	0		0	0	0	0	0
TOTAL		24	14	16		23	16	27	27	27

Figures

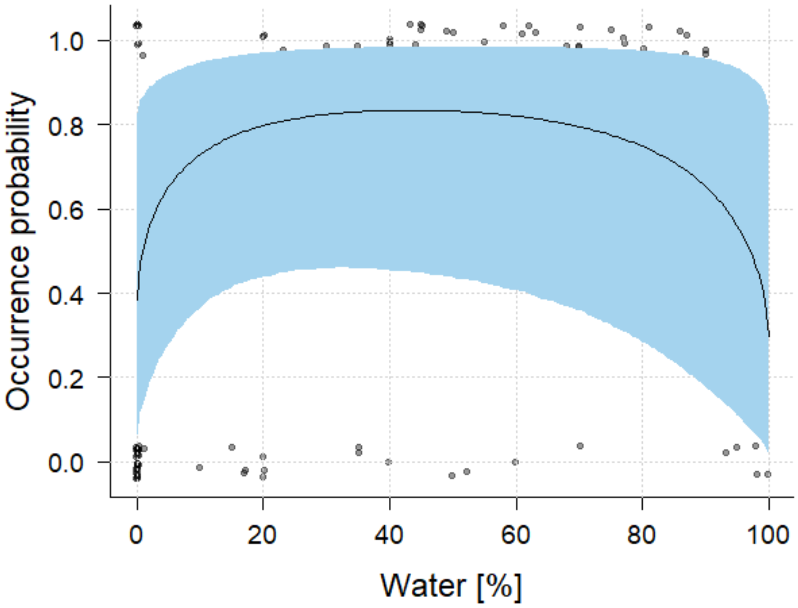


Figure 1: *Predictive plot using bayesian credible intervals (95% credible interval in blue). Response variable is the probability occurrence of a Little Ringed Plover, that is, a foraging event. The explanatory variable is water cover at the mapped foraging point.*

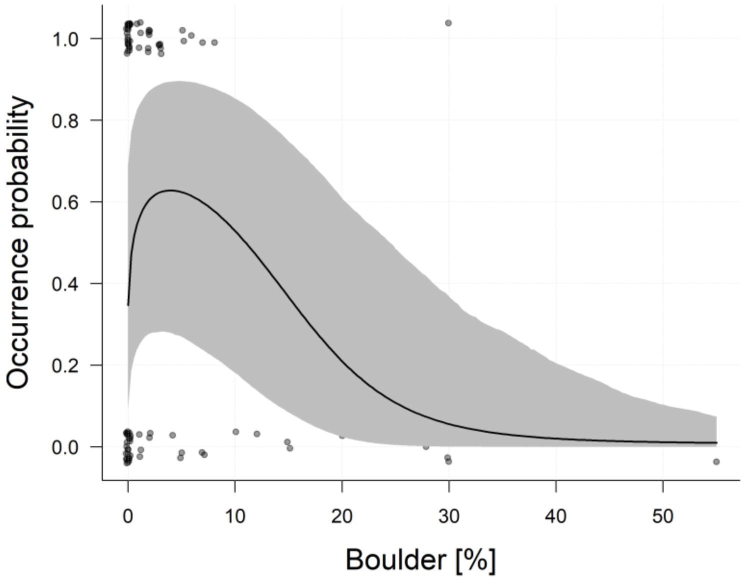


Figure 2*: Predictive plot using bayesian credible intervals (95% credible interval in grey). Response variable is the probability occurrence of a Little Ringed Plover, that is, a foraging event. The explanatory variable is the cover of boulder at the mapped foraging point.*

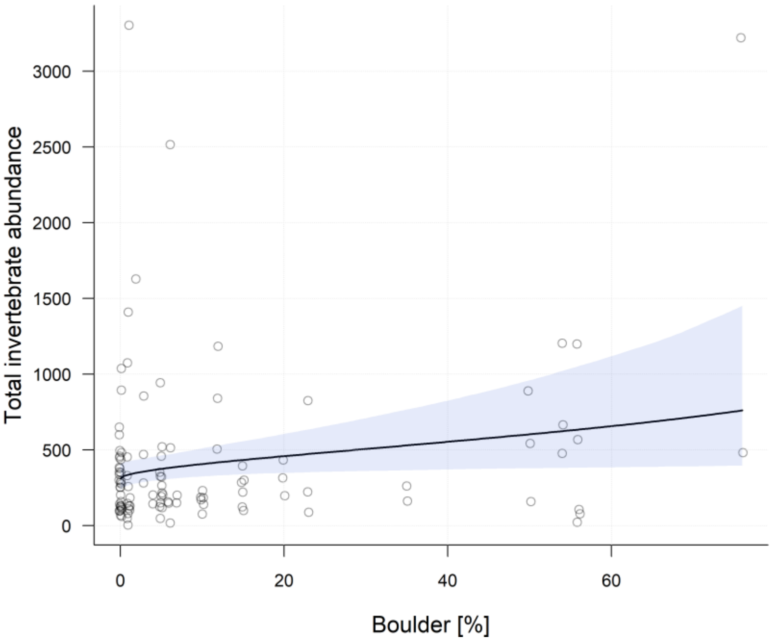


Figure 3: *Predictive plot using bayesian credible intervals (95% credible interval in grey). Positive effect of boulder on total invertebrate abundance*

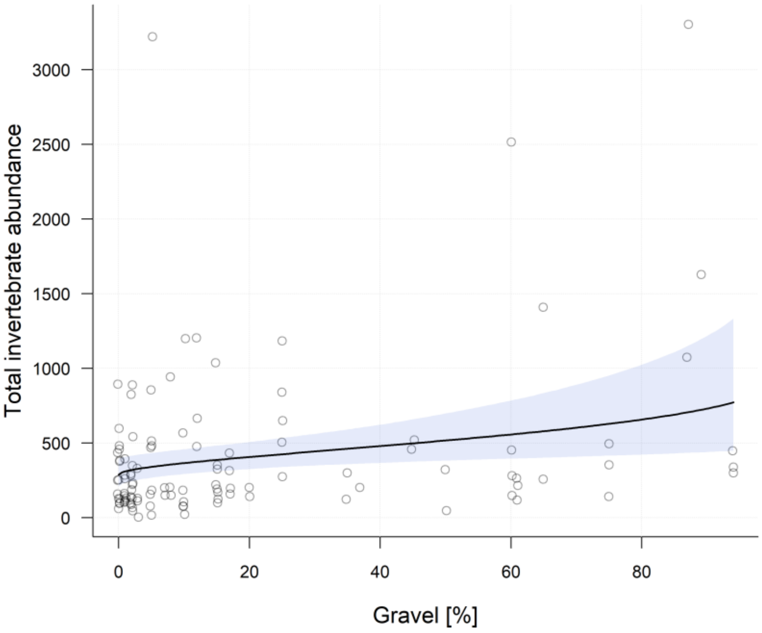


Figure 4: *Predictive plot using bayesian credible intervals (95% credible interval in grey). Positive effect of gravel on total invertebrate abundance.*

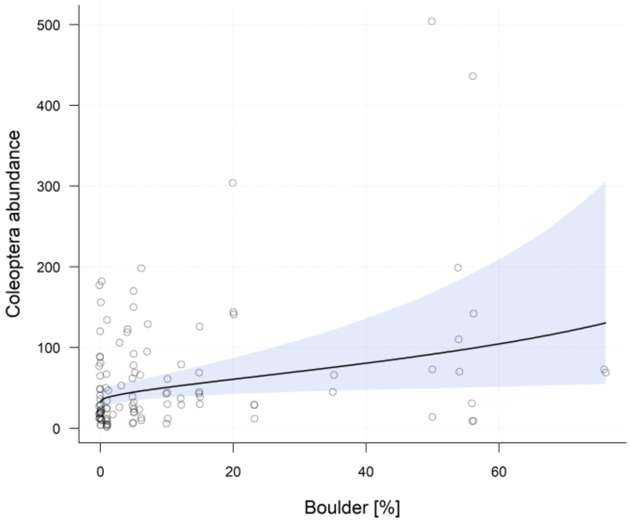


Figure 5: Predictive plot using bayesian credible intervals (95% credible interval in grey). Positive effect of boulder on abundance of Coleoptera.

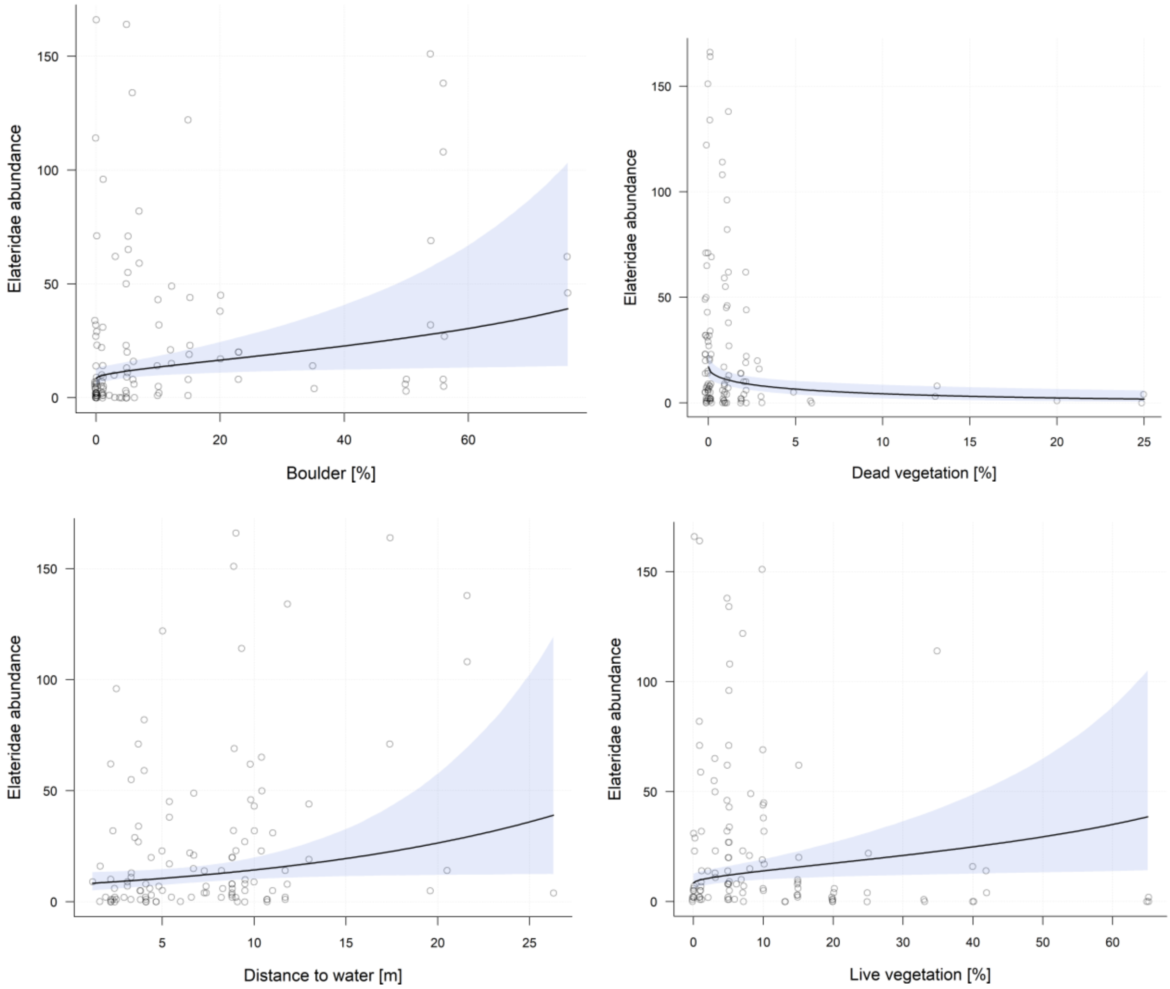


Figure 6: *Compilation of Bayesian predictive plots on Elateridae abundance (95% credible interval in grey). On the top left, boulder is showing a positive effect on Elateridae abundance. On the top right a negative trend of dead vegetation on Elateridae abundance is indicated. On the bottom left, distance to water indicates a positive effect on Elateridae abundance. On the bottom right, live vegetation is shown to affect Elateridae abundance positively.*

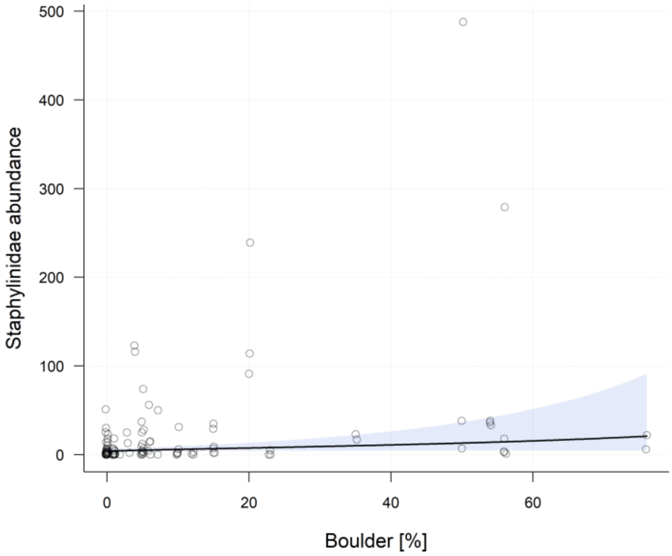


Figure 7: *Predictive plot using bayesian credible intervals (95% credible interval in grey). Positive effect of boulder on abundance of Staphylinidae*

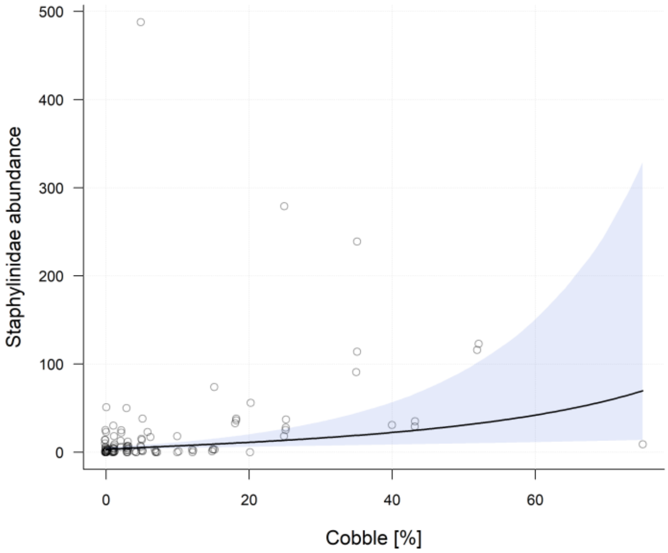


Figure 8: *Predictive plot using bayesian credible intervals (95% credible interval in grey). Positive effect of cobble on Staphylinidae abundance.*

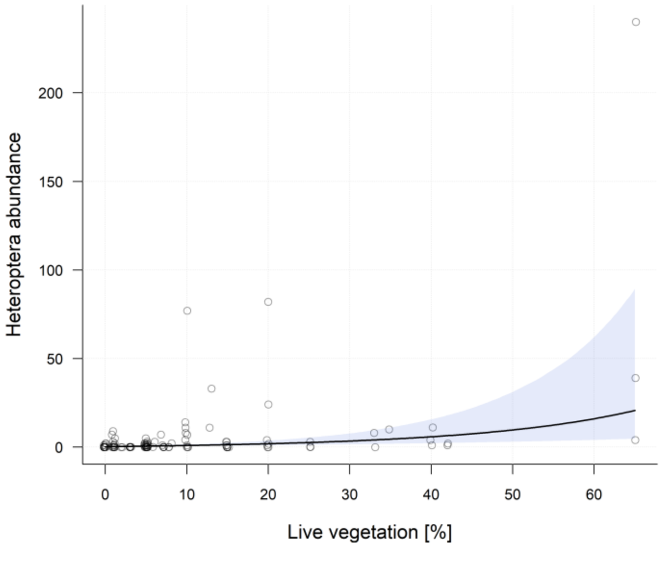


Figure 9: *Predictive plot using bayesian credible intervals (95% credible interval in grey). A positive effect of live vegetation on the abundance of Heteroptera is shown.*

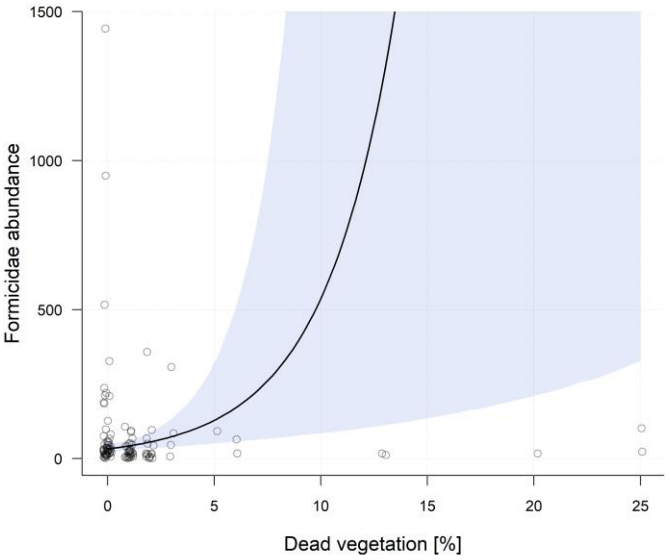


Figure 10: *Predictive plot using bayesian credible intervals (95% credible interval in grey). Positive effect of dead vegetation cover on Formicidae abundance.*

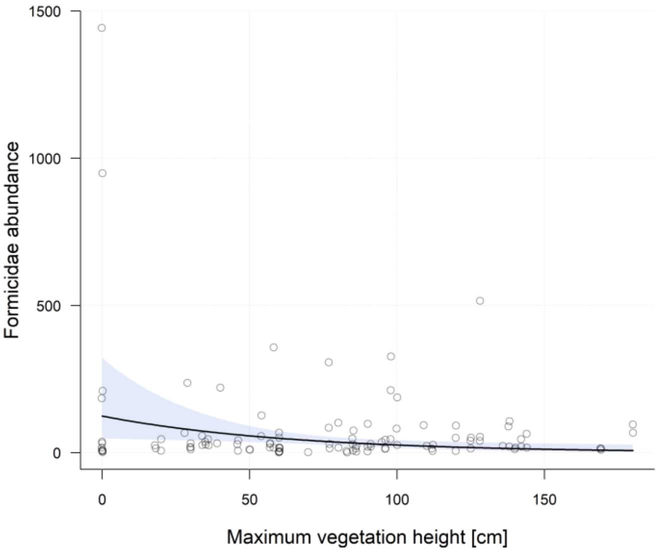


Figure 11: *Predictive plot using bayesian credible intervals (95% credible interval in grey). Positive effect of maximum vegetation height on Formicidae abundance.*

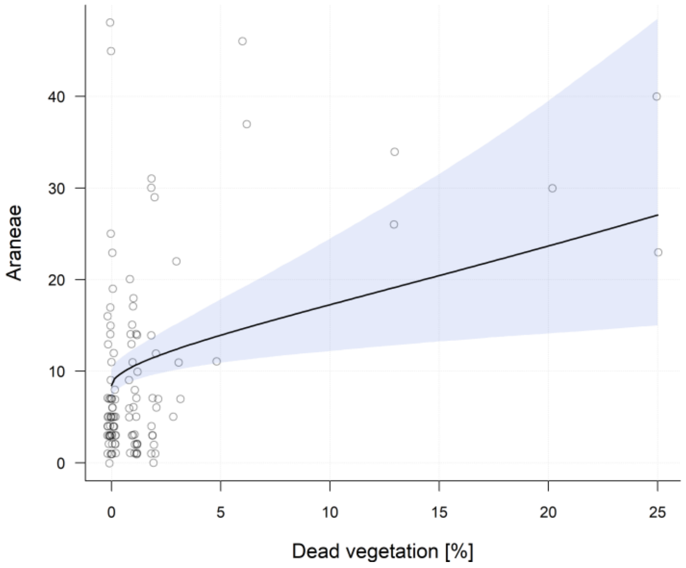


Figure 12: *Predictive plot using bayesian credible intervals (95% credible interval in grey). Positive effect of dead vegetation cover on Araneae abundance.*

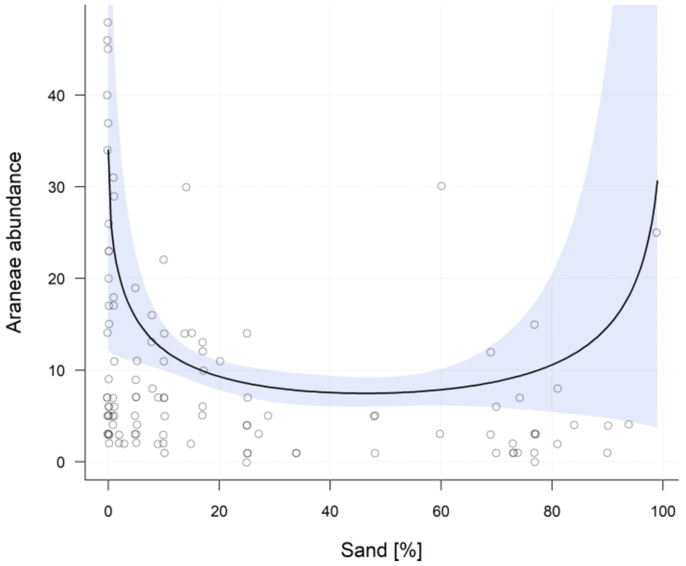


Figure 13: *Predictive plot using bayesian credible intervals (95% credible interval in grey). U-shaped relationship of sand cover on Araneae abundance.*

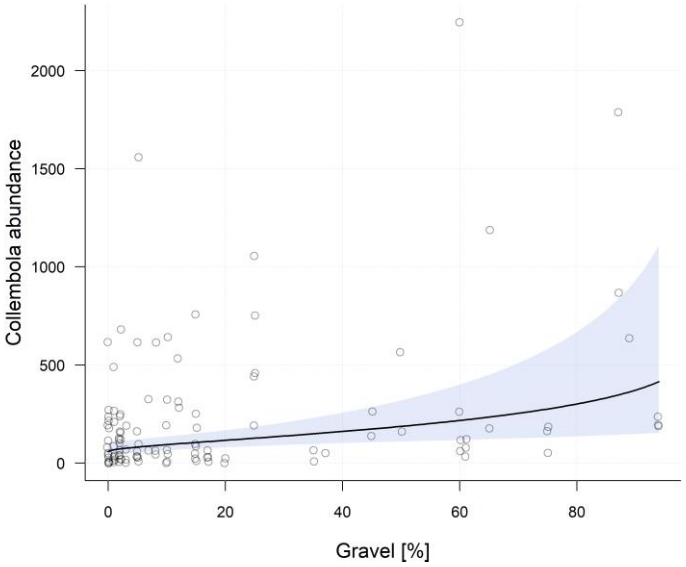


Figure 14: *Predictive plot using bayesian credible intervals (95% credible interval in grey). Positive effect of gravel on abundance of Collembola*

Figure 15: *Little Ringed Plover home ranges with flooded area. Home ranges are shown as Minimum Convex Polygons (MCP). All observation points from the Bird survey and foraging points in the core area are shown.*

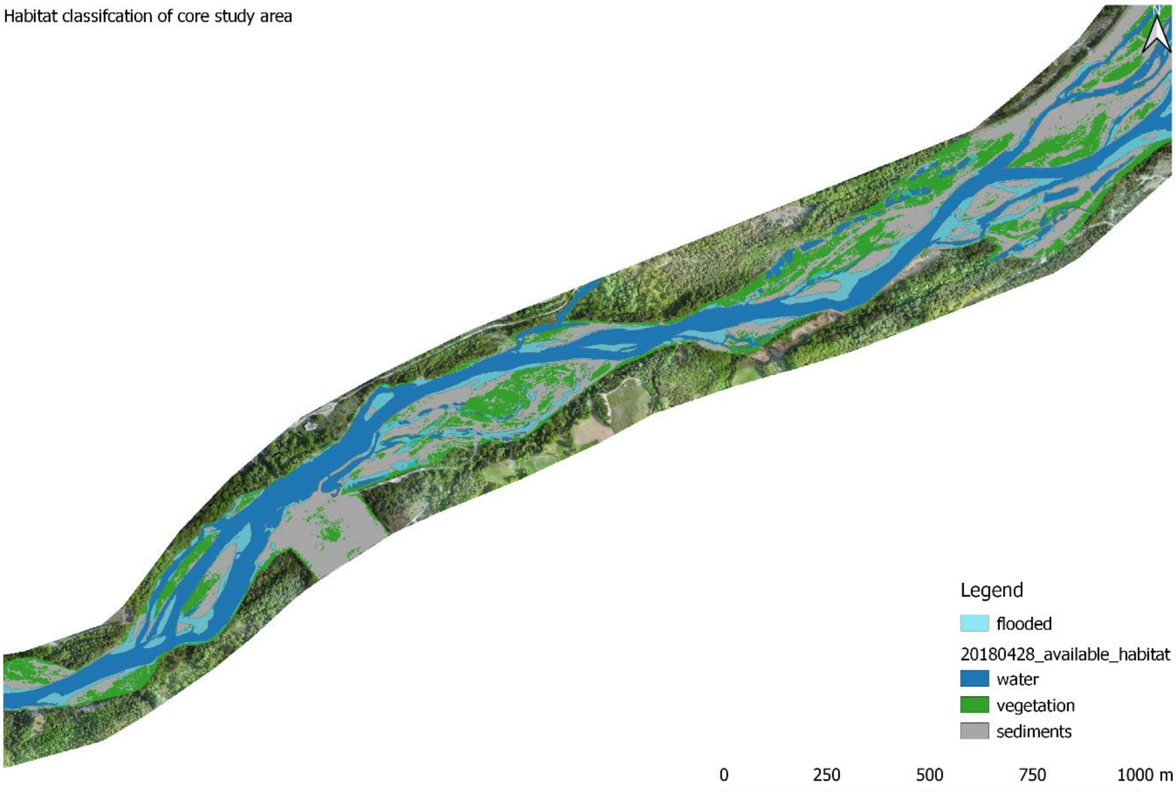


Figure 16: *Habitat classification of core study area indicating classified habitat of the riverbed (available habitat) and the flooded area. The underlying orthomosaic image is from the low water level period.*

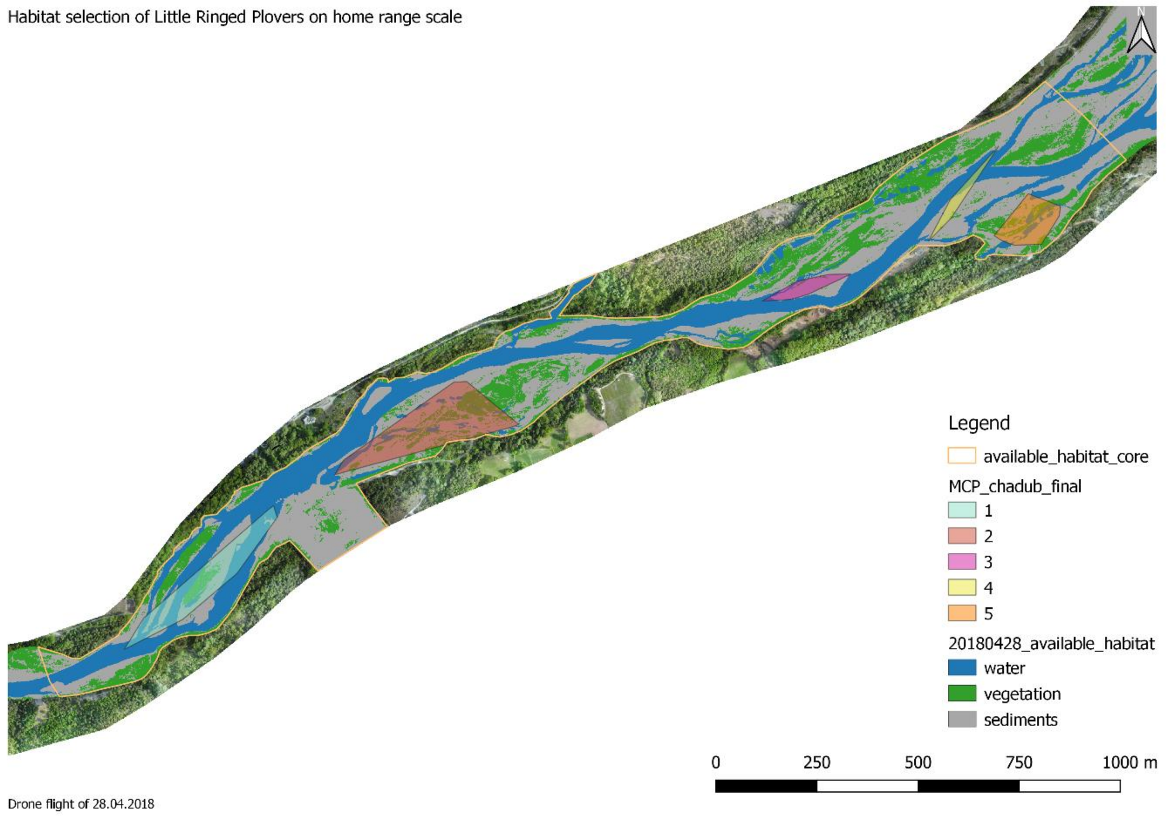


Figure 17: *Habitat selection of Little Ringed Plovers on home range scale during low water level period (April 2018). Home ranges are shown as 100% minimum convex polygones (MCP) while the available habitat is delineated by the core study area.*

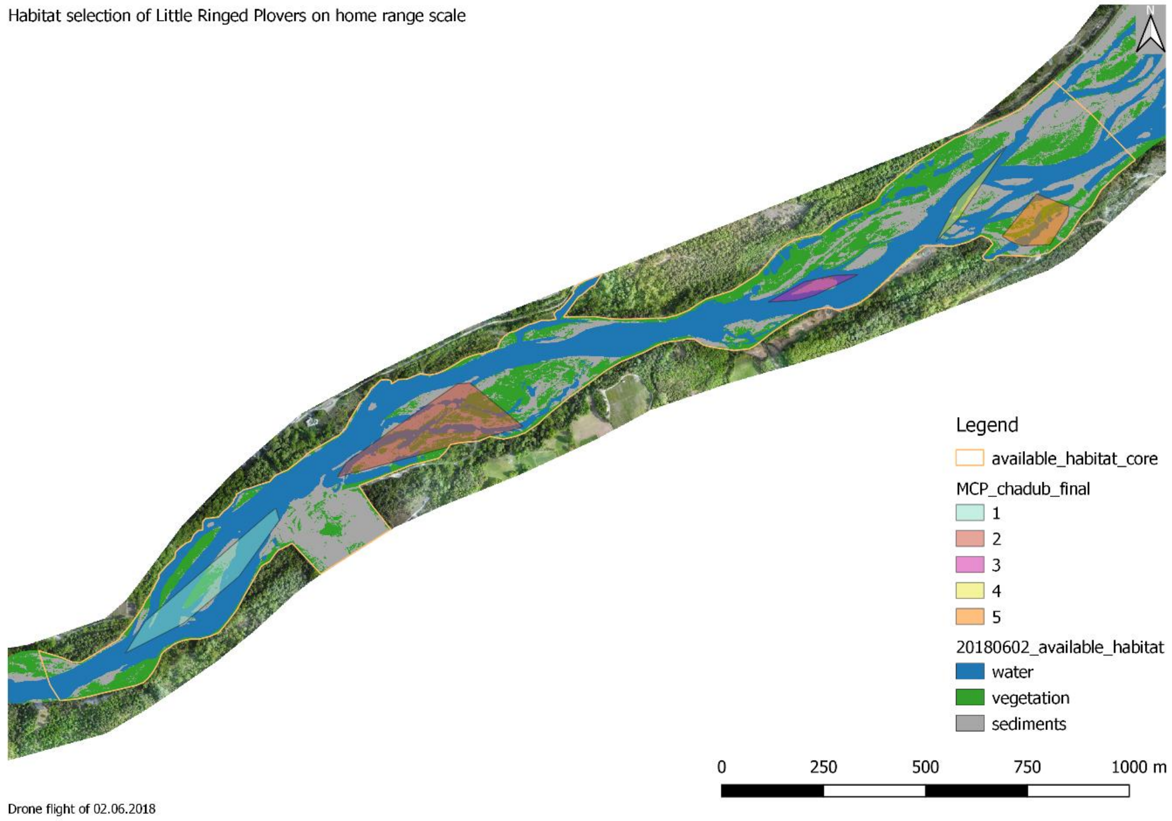


Figure 18: *Habitat selection of Little Ringed Plover on home range scale during high water level period (June 2018). Home ranges are shown as 100% minimum convex polygones (MCP) while the available habitat is delineated by the core study area.*

Appendix

Supplementary Table 1*: Habitat type combination for the pitfall sampling with presence or absence (yes/no) of vegetation. The threshold for a trap to be vegetated was set to 5% of the trap mapping area (radius 1.5m). Not all habitat type combinations were found on site.*

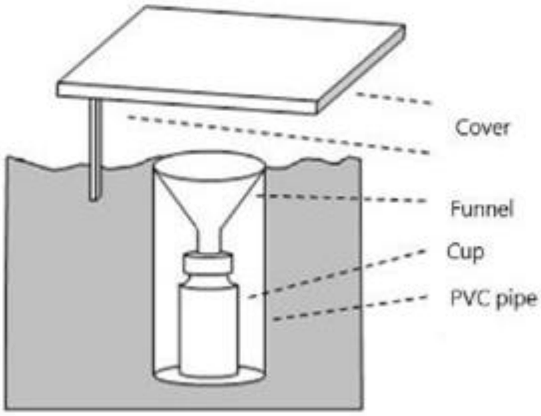
Substrate	**Vegetation (yes/no)**
Silt and Clay	Yes
Silt and Clay	No
Sand	Yes
Sand	No
Gravel	Yes
Gravel	No
Cobble	Yes
Boulder	Yes
Large Boulder	Yes

Supplementary Table 2: *Results of the compositional analysis at the home range scale. Table gives average log-ratio differences for all pairwise comparisons between elements. Available habitat is the whole study area whereas used habitat are the home ranges. Significant values shown in bold.*

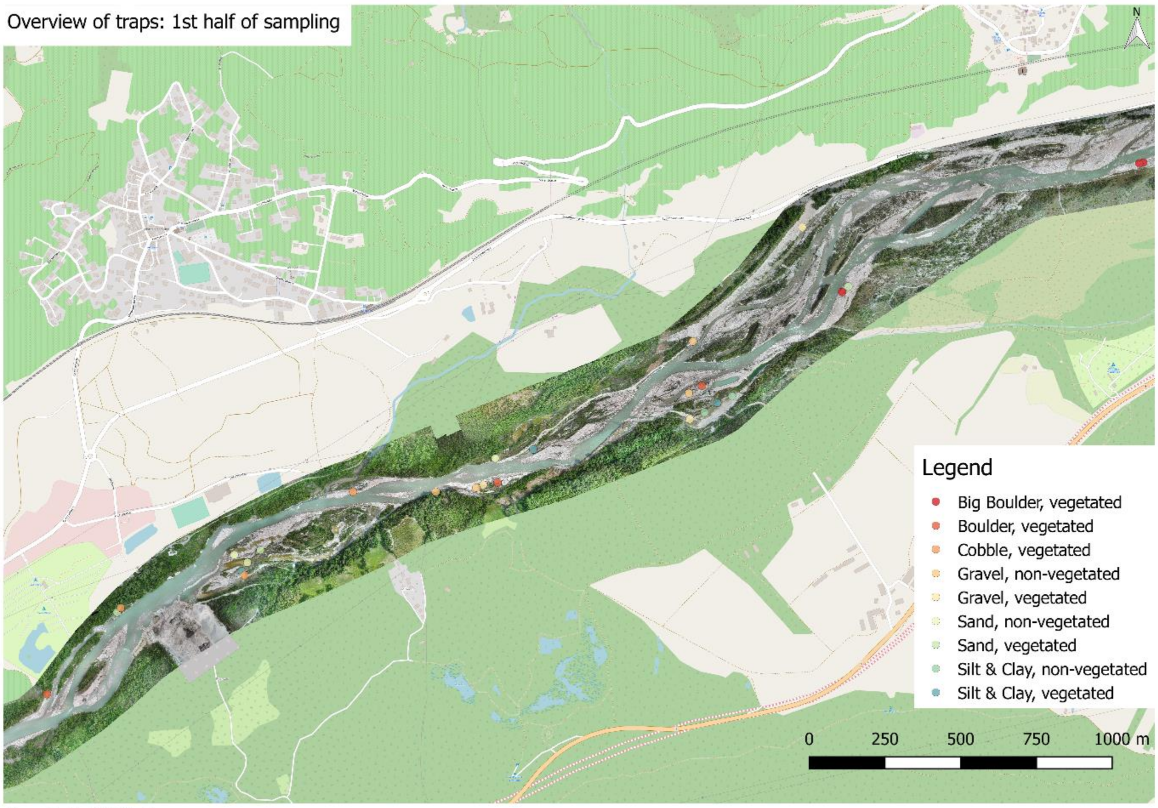
Available → ↓ Used	Water	Sediments	Vegetation
a) Low water level			
Water	0	-0.841	0.001
Sediments	0.841	0	0.842
Vegetation	-0.001	-0.842	0
b) High water level			
Water	0	-0.124	0.790
Sediments	0.124	0	0.914
Vegetation	-0.790	- 0.914	0

Supplementary Table 3: *In the same logic as above, composition analysis result is shown per orthomosaic image, one at low water level and one at high water level. Here, the ranking matrix from the comparison of habitat use of 100% minimum convex polygone (MCP) home ranges with the whole study area as available habitat. A triple sign demonstrates significant deviations from random at alpha = 0.05. Ranked variable sequence (most to least used >>> showing significant preference over subsequent category): sediments > vegetation > water*

Available → ↓ Used	Water	Sediments	Vegetation
a) Low water level			
Water	0	-	+
Sediments	+	0	+
Vegetation	-	-	0
b) High water level			
Water	0	-	+
Sediments	+	0	+
Vegetation	-	-	0

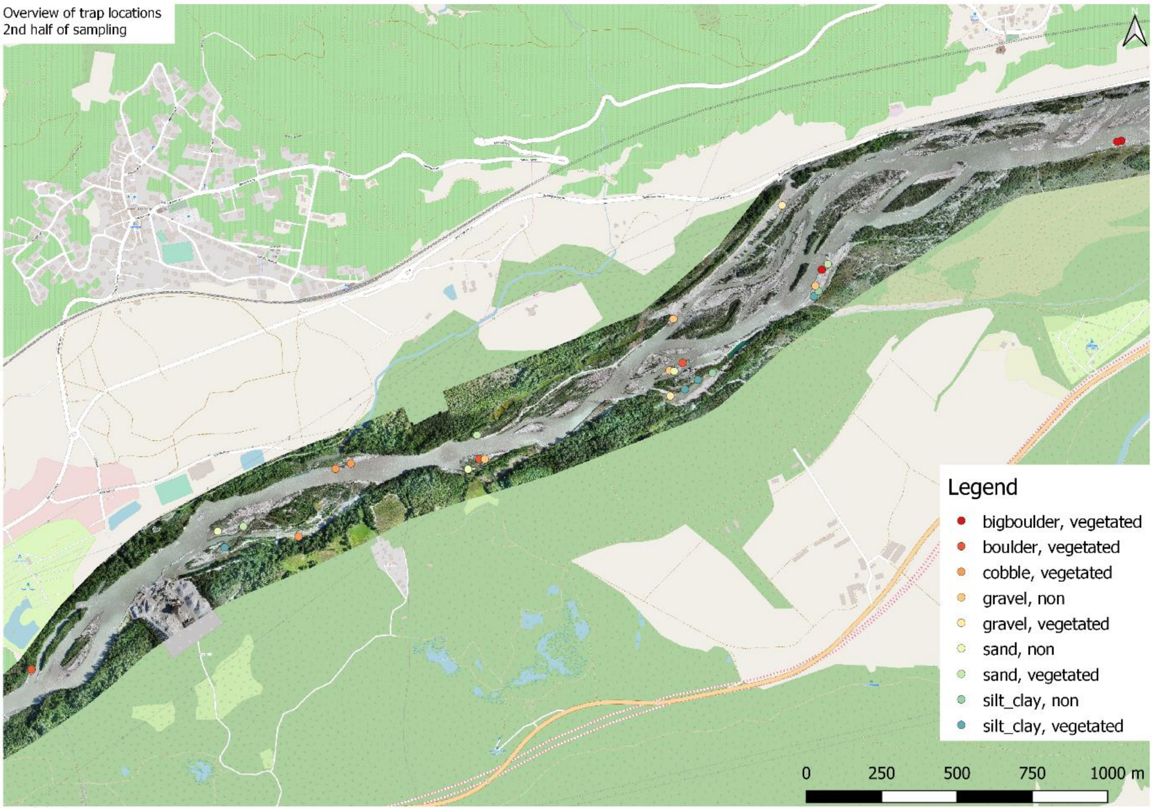


***Supplementary Figure 1**: Barber pitfall trap scheme adapted from (www.ecotech-bonn.de). A PVC pipe is burrowed into the substrate, a cup containing the propylenglycol mix placed inside and a funnel placed on top. The funnel is on the same level as the substrate. A cover is placed on top for protection from precipitation.*



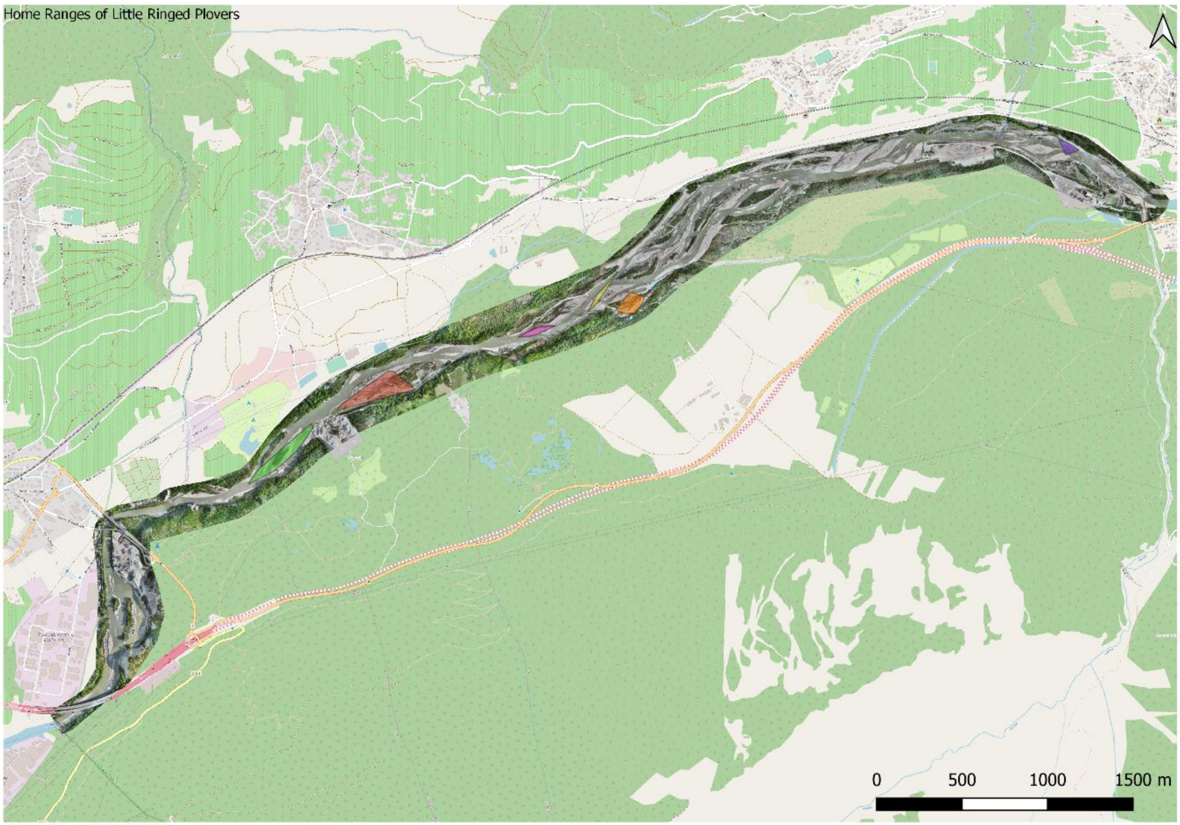
Drone flight of 19.05.18

***Supplementary Figure 2**: Trap locations with habitat type combinations in the first half of sampling period.*



Drone flight of 02.06.18

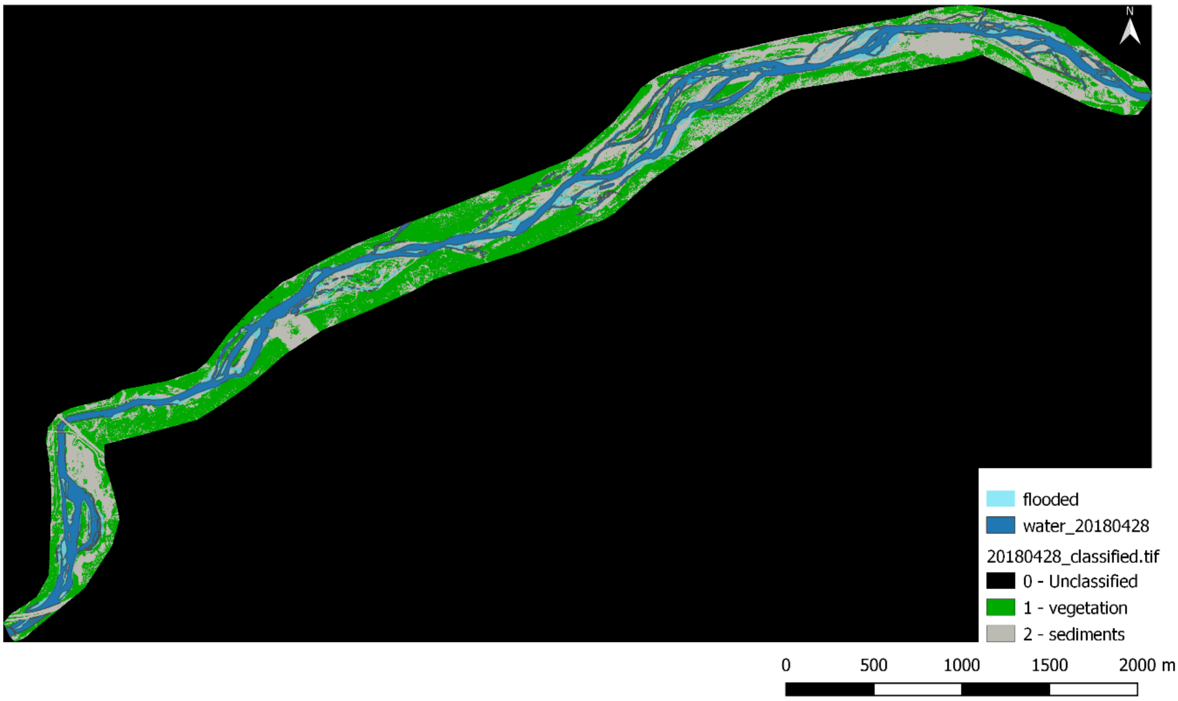
***Supplementary Figure 3**: Trap locations with habitat type combinations in the second half of sampling period.*



Drone flight of 28.04.2018

***Supplementary Figure 4**: All Minimum Convex Polygons calculated based on the bird survey and foraging points. Note that Iles Falcon on the bottom left harbours no home range of Little Ringed Plovers in 2018*

Habtiat classification of study area
Orthomosaic of Drone flight on 28.04.18



***Supplementary Figure 5:** Habitat classification of the whole study area is shown. The underlying map shows the low water level period in April while the flooded area is derived from the high water level period in June 2018.*

Declaration of consent

on the basis of Article 30 of the RSL Phil.-nat. 18

Name/First Name: Schranz, Beatrice

Registration Number: 12-921-060

Study program: Animal Ecology and Conservation

Bachelor ☐ Master ☑ Dissertation ☐

Title of the thesis: Endangered wading birds in a revitalised alpine river: Foraging habitat selection of the Little Ringed Plover Charadrius dubius curonicus and its relation to invertebrate prey

Supervisor: Prof. Dr. Raphaël Arlettaz

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