Multiscale habitat selection in two endangered waders: how targeted gravel extraction along revitalised rivers can boost these two bird species

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Faculty of Science, University of Bern

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Elisenda Peris Morente

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Supervisor

Prof. Dr. Raphaël Arlettaz

Multiscale habitat selection in two endangered waders: how targeted gravel extraction along revitalised rivers can boost these two bird species

Elisenda Peris-Morente[1], Beatrice Schranz[1], Marco Pilati[1], Yann Rime[1] & Raphaël Arlettaz[1]

[1] Division of Conservation Biology, Institute of Ecology and Evolution, University of Bern, Erlachstrasse 9a, 3012 Bern, Switzerland

Abstract

Floodplains are among the most productive ecosystems worldwide. They have thus undergone dramatic land-use changes in the historical past. In particular, levees have been erected to constrain river beds and gain land for agriculture, industry and settlements. As a result of the tremendous losses in the ecological longitudinal, lateral and vertical connectivity that characterise natural river ecosystems, biodiversity has vanished, essentially due to a lack of area and dynamics of the most valuable habitats for flora and fauna. This calls for active restoration measures in riparian ecosystems. The present study investigated Little Ringed Plover (*Charadrius dubius*) and Common Sandpiper (*Actitis hypoleucos*), two red-listed and priority bird species in Switzerland, along a restored stretch of the Rhone river (Valais, SW Switzerland), with the objective to provide habitat management recommendations. Habitat selection was studied during the reproductive period at both foraging site and home-range scales through visual observation, radiotracking and habitat mapping, with a particular attention paid to the effects of targeted gravel extraction on birds' whereabouts. At the foraging site scale, shores consisting of fine-grained sediments with little vegetation cover were the preferred features for both species. At the home range scale, both waders made a greater use, compared to availability, of the habitat characterising the interface between purely aquatic and terrestrial habitats. If Little Ringed Plover established its

territories in areas subjected to recent gravel extraction targeting biodiversity, Common Sandpiper avoided such areas, preferring zones that had not been exploited for the last seven years. Altogether, the extraction of gravel that targets biodiversity showed that management can improve the foraging conditions for the two species in the short and mid term. Habitat management should typically aim at reducing vegetation cover below 40% and at promoting foraging sites at the interface between water and terrestrial habitat, which can be achieved by the creation of new arms and shallow ponds.

Keywords: Little Ringed Plover, Common Sandpiper, Habitat selection, Riparian ecosystems, Restoration, Management, Home Range, Foraging

Introduction

Floodplains are among the most naturally productive ecosystems in the world. As a result, humans have historically exploited the diverse services they provide (Strayer & Dudgeon, 2010; Tockner & Stanford, 2002), turning the biodiversity-rich riparian habitats into agricultural land, industrial estates and human settlements. As a consequence, they hardly harbour their original flora and fauna (Báldi, Moskát, & Zágon, 1998).

Freshwater biodiversity is threatened by multiple human activities, with flow and habitat alteration directly driving species to extinction (Dudgeon et al., 2006). The construction of dams and levees reduce river connectivity and seasonal floods (Amoros & Bornette, 2002; Bunn & Arthington, 2002) that characterise unaltered riparian ecosystems (Naiman, Décamps, & Pollock, 1993). This typical disturbance regime along with the temporal and heterogeneous lateral connectivity, promote floodplains' habitats and species diversity (Amoros & Bornette, 2002; Ward, Tockner, & Schiemer,

1999). Although it is yet unknown the total biodiversity that river ecosystems can support, it has been documented that almost 70% of terrestrial vertebrates in a region use riparian habitats (Naiman et al., 1993) and 69% of the birds breed in wetlands (Tockner & Stanford, 2002).

The current and strong habitat alteration asks for active restoration of fluvial ecosystems (Naiman et al., 1993). In alpine regions such as Switzerland, for instance, 52 % of water courses are in bad conditions (Zeh Weissmann, Könitzer, & Bertiller, 2009). Nevertheless, 307 km were already revitalised between 1979 and 2014 (Kurth & Schirmer, 2014), for example the Rhone river in the Nature Park Pfyn-Finges. Since the revitalisation back in 1994, controlled gravel extractions have maintained the restored habitat and mimicked natural river dynamics (Arlettaz et al., 2011). As almost 50% of the Swiss riparian obligates are threatened (Tockner & Stanford, 2002) we aimed to analyse the effect of management actions on two bird species endangered at the Swiss level: the Common Sandpiper (*Actitis hypoleucos*) and the Little Ringed Plover (*Charadrius dubius*). Both waders are listed as national priority species (Keller, Gerber, Schmid, Volet, & Zbinden, 2010) and coexist in the revitalized section of the Rhone river. These birds are long distance migrants present in Switzerland during their breeding season between mid-April and mid-July. Long term studies have pointed out that Common Sandpipers build their nests in areas with sparse vegetation and forage along sandy shores (Dougall, Holland, & Yalden, 2010; Holland, Robson, & Yalden, 1982; Yalden, 1986). On the other hand, the Little Ringed Plover prefers bare ground habitats or even man-made structures such as gravel pits; they preferably forage in muddy substrates (Ntiamoa-Baidu et al., 2008; Parrinder, 1989). Despite these differences,

both species select large islands to establish their territories in rivers (Baumann, 2003; Heinänen & Von Numers, 2009).

Since management in the site in Finges is targeting biodiversity while maintaining some form of shallow gravel exploitation, it is of great importance to study the habitat selection of both waders and quantify their needs in our study area so at to further optimise habitat management. We focused our study at two landscape scales: (1) the foraging site selection, and (2) the home range habitat preference. A third aim of our study was to (3) analyse how does the management affect the preferred habitat types of our species, and test whether the Little Ringed Plover and the Common Sandpiper exhibit a preference for the managed areas. These results will provide evidence to support management recommendations which can improve the habitat of both endangered species. We predicted that (1) at the foraging site scale both species will select fine sediment shores to forage. (2) At the home range level, the Little Ringed Plover will prefer islands with high proportions of bare ground, and the Common Sandpiper large islands with sparse vegetation. Finally, (3) at the management level the Little Ringed Plover will prefer recently managed areas, hence pioneer habitats, and the Common Sandpiper areas managed longer ago.

Materials and methods

Study area

Field work took place in 2018 and 2019 from April to July. The study area was the Rhone river in the Pfyn-Finges Nature Park (46º18N 07º35E), between Leuk and Sierre, Valais (SW Switzerland). In this 8.8 km transect the levees were swept away after the 1990s floods and never replaced again. Furthermore, since 1994 actions to promote river

widening have taken place, simulating semi-natural river dynamics (Arlettaz et al., 2011). The current management has two main objectives: assuring people safety by avoiding dangerous floods and maintaining the habitat mosaic favouring biodiversity. Actions have focused on gravel and pebble extraction to avoid the excessive accumulation of sediments in the riverbed in mainly three intervention areas. Moreover, the surrounding habitats, which are predominantly steppe-like vegetated and pine forests, are also managed through clear-cuts and grazing.

Within the study area, we used a 15 m buffer around the high-water level polygon in 2019 to exclude the dense forest regions and include only the river and riverbed surface (Fig. 1). This allowed us to analyse just the area truly available to our bird species following the literature guidelines.

The Little Ringed Plover (*Charadrius dubius*) and the Common Sandpiper (*Actitis hypoleucos*) have been monitored in the area since 1978. After the revitalisation of the river, both species showed positive trends as *A. hypoleucos* population increased by 83% and *C. dubius* by 20% (Arlettaz et al., 2011).

Species surveys

Surveys consisted of standard transects along the water and inner ponds with one observer per river side, the two observers prospecting the river bed simultaneously. To maximize detection probability, observers alternated the observation points, separated by 400 m, between river sides and spent approximately 10 minutes in each spot. Therefore, while one observer was moving the other could detect flushed birds. We carried out six surveys per year starting just after the arrival of the species by mid-April. On average we conducted one survey every two weeks to cover the whole breeding

season of the birds. To avoid further biases, transect direction and starting points of each survey were randomised. Moreover, to even the detection probability between observers, the river side was alternated each survey. As the breeding behaviour of waders is easy to detect even when nests cannot be spotted (Heinänen & Von Numers, 2009; Parrinder, 1989), behaviour and activity of the individuals were noted down. The number of pairs per species was further studied, we estimated each home range using Minimum Convex Polygon (MCP) calculated in R version 3.6.3 (R Core Team, 2020) using the package adehabitatHR (Calenge, 2006).

Capture and radio-tracking

Individuals of both species were captured using mist nets placed close to the areas where birds seemed to have established their territories. Individuals were attracted with the playback of the species call. The capture events started at dusk and continued at night until no territorial call was heard. Captured birds were ringed with a numbered metal ring and, by the end of the season, some of them were also marked with colour rings. Birds were fitted with radio-tags (Holohil BD-2, 1.4 g, 40 pulse/minute, 7 weeks lifespan) fixed with a nylon leg-loop harness (Rappole & Tipton, 1991). Following Naef-Daenzer (1993), the whole device weighted less than the 5% limit of the body weight. Tagged birds were located using standard triangulation techniques. Radio locations were used to obtain precise foraging locations of each species and estimate a home range size. We aimed to obtain the home range and not the territory because the methodology used allows to find the birds in spots that are not necessarily defended (Anich, Benson, & Bednarz, 2009).

Foraging site selection

All individuals were observed until foraging activity was evident. At each foraging location several descriptive variables were recorded within a radius of 1.5 m from the exact feeding point (Table 1). Moreover, a pseudo-absence point was also mapped at each foraging location. The pseudo-absence point was determined with a random angle and a distance between 5 and 15 m from the foraging point, avoiding inaccessible spots. All substrate variables were recorded as percentages. Birds were tracked via triangulation covering all daylight hours with new observations every 15 min or when the individuals flew. Coordinates were extracted from Google maps with 5m precision.

The foraging site selection was assessed using Generalised Linear Mixed Models (GLMM) with binomial distribution, using the presence and pseudo-absence points as response variables. The foraging and pseudo-absence ID, the bird ID and/or the year were considered as random factors. The first step was checking collinearity between the explanatory variables with the Spearman's Rank Correlation Coefficient. A value of $|r| > 0.7$ was established as the limit of the correlation (Dormann et al., 2013). When two variables exceeded this value the most biologically meaningful was chosen for further analysis (Zuur, Ieno, & Elphick, 2010), or, in case of continuous size substrates, variables were merged as a new category. A further exploratory analysis was to test for zero inflation (Zuur et al., 2010). When a variable had more than 70% of zeros, it was transformed to binary data. All explanatory variables were standardised to mean = 0, and SD = 1 to ease the comparison between estimates (Harrison et al., 2018). Furthermore, they were tested for quadratic effects to identify any hump-shaped patterns. Finally, we included all variables and their significant polynomial terms to the function *dredge* of R package *MuMIn* (Barton, 2019) and proceeded to a model selection based on AIC corrected for small sample size. All models within delta AICc < 2

were full averaged (Grueber, Nakagawa, Laws, & Jamieson, 2011) using the function *model.avg* from the same R package (Barton, 2019). We ran the GLMM using the function *glmer* from the R package *lme4* (Bates, Mächler, Bolker, & Walker, 2015) in R version 3.6.3 (R Core Team, 2020). To obtain precise information, we run two models per species: one with all data from both sampled years plus a second using only foraging points from individuals tagged in 2019.

Home range size and habitat use

Home range of each tagged individual in 2019 was estimated using MCP. As MCP is known to rely mostly on the outer most observations (Powell, 2000), we based home range estimations on 95% of the data. We used R package adehabitatHR (Calenge, 2006) in R version 3.6.3 (R Core Team, 2020). Individuals 2 and 3 of *C. dubius* had some observations discarded. After the floods many individuals left (Fig. 3) and *C. dubius* 2 was commuting randomly across the study area so we excluded these observations. C. *dubius 3* spent the night at Pfyngut but foraged 7 km upstream during daylight until mid-May; thus, we estimated its home range using only observations from the final defended territory.

We used a Compositional Analysis (CA) to understand the habitat use at the home range level and test whether the species were using the habitat randomly (equal proportions to the available habitat) or following a ranked preference (Aebischer, Robertson, & Kenward, 1993). At this level of analysis, we combined the home ranges from tagged birds and those from the surveys to increase the sample size. We tested at two levels: second order habitat selection to check the habitat use within the study area (i.e. how the individuals establish their home range) and third order habitat selection

(i.e. how the individuals use the habitats within their home ranges) (Johnson, 1980). At the second-order habitat selection, between two individuals of the same pair we selected the bigger MCP given that the selection is at the territory level. All tests were run using the *compana* function in R package adehabitatHS (Calenge, 2006) in R version 3.6.3 (R Core Team, 2020).

Both CA designs included the same habitat types: Water, Vegetation, Sediments and Interface (flooded areas on a daily/weekly basis). The characterization of the study area was done using QGIS 3.4.10 (QGIS Development Team, 2019) (Fig. 1). Two orthophotos of the area from 2019 were used: April 2019 (before the floods) and October 2019 (after the floods). The low water level polygon was digitised by hand following the level at the spring orthophoto. Further on, sediments and vegetation were classified using the "Semi-Automatic Classification Plugin" from QGIS (Congedo, 2016). Finally, the interface area was defined as the ± 3 m buffer around the water polygon, simulating the daily and weekly tights of the water level.

For the third-order CA we needed to classify each observation according to the studied habitat types. To do so, we used the April habitat classification for all observations recorded before the 9th of June - when the flooding period started - and the October habitat classification for the observations during high-waters. The water polygon for the high-water level habitat classification was digitised by hand using the orthophoto from October 2019 and the habitat mapping done during the field season.

Management selection

We combined the management polygons from 2013 to winter 2015-2016 (Old management), and from 2016 to 2019 (Recent management). All pixels managed in

both periods were only considered in the most recent category. We also considered the area which was not managed during this time as “Never managed” (Fig. 2).

We calculated the surface of each management category within the study area and within each home range using QGIS 3.4.10 (QGIS Development Team, 2019). Then, we tested the habitat use in relation to the management categories with a CA using the R package *adehabitatHS* (Calenge, 2006) in R version 3.6.3 (R Core Team, 2020). In this case, we also ran the analysis at both orders habitat selection. Afterwards, to check whether the management categories differed between them, we compared the habitat proportions within each management category with a Chi-square test. Data was further tested with a post-hoc test using the *pairwiseNominalIndependence* function of the R package rcompanion (Mangiafico, 2020) in R version 3.6.3 (R Core Team, 2020).

Finally, to check the effect of management we examined the change in the habitat types proportions within the managed areas between 2017 & 2018 and 2018 & 2019. We used an orthophoto from April 2017 and one from April 2018. The habitat classification for 2017 and 2018 was done following the same methodology as for April 2019. To analyse the change generated by management, we used a chi-square test followed by the same post-hoc test used previously.

Results

Surveys & Breeding success

In 2018 we estimated 5 ± 3 pairs of Little Ringed Plover (*C. dubius*), and 17 – 18 pairs of Common Sandpiper (*A. hypoleucos*). Even though we observed 5 pairs of *C. dubius,* the habitat could have supported 3 more pairs based on previous surveys (pers. comm.

Lugon, A (2019); Lugon, 2016). Similarly, in 2019 we estimated six pairs of *C. dubius* and 18 pairs of *A. hypoleucos*. Of the whole population of both species in our study area only one pair of each was known to breed successfully (see Appendix 1 and Appendix 2 for more information).

Capture and radio-tracking

In total we captured and marked six *C. dubius* and three *A. hypoleucos* (Fig. 3; Appendix 1). Of the six *C. dubius* five where captured at the beginning of the field season which were mostly established on islands. The last individual was marked at the end of June and left the exact same day of the capture. *A. hypoleucos* tagged individuals mainly foraged on islands and two of them left after the floods, which led to a small sample size.

Foraging site selection

In total we gathered 183 foraging points from *C. dubius*, of which 87 were from tagged individuals. We got a mean of 34.6 foraging points per tagged *C. dubius*. Due to the shy behaviour of *A. hypoleucos* we only got six foraging points from tagged individuals of a total of 129. In total we recorded 42 observations of *C. dubius* (23 %) and 8 of *A. hypoleucos* (6 %) in inner ponds, the rest of the observations were made along the mainstream.

As cobble and boulder substrates in *C. dubius* showed high Pearson correlation index (> 0.7), we combined them into a new variable called “Coarse sediments”. The two models we ran with *C. dubius* suggested consistent results (Appendix 3). The species occurrence is positively affected by the presence of fine sediments – silt & clay and sand – and the quadratic effect of water (Fig. 4a-b). With more than 40 % of fine

sediments and more than 35 % of water the occurrence probability of *C. dubius* is higher than 0.5. In the graph we observe that a few presence points occurred at 0 % of water. Even though these observations lacked water, they were all classified as muddy substrate. On the other hand, coarse sediments and live vegetation had a negative impact on *C. dubius* presence (Fig. 4c-d). Regarding coarse sediments, a percentage higher than 35 % yields a less than 0.5 of occurrence probability to *C. dubius*. The same happens for live vegetation with values starting at 45 %.

The small sample size of observations from tagged *A. hypoleucos* limited our statistics to just one model including all recorded observations (Appendix 3). *A. hypoleucos* is affected by the amount of sand, live vegetation and the quadratic effect of water (Fig. 4f-h). Sandy substrates over 60% are positive for the occurrence probability of *A. hypoleucos*; conversely, a proportion higher than 40% of live vegetation reduces the chances of occurrence of the species. Finally, water showed the same trend as with *C. dubius.*

Home range size and habitat use

The mean home range size of the 95 % MCP of *C. dubius* was of 2.13 ha ± 1.12 ha (n = 7), and 2.54 ha ± 1 ha using only telemetry data (n = 5). For *A. hypoleucos* the size was of 2.05 ha ± 1.19 (n = 18) and 3.12 ha ± 1.54 ha for the tagged individuals (n = 3). A 91.5 % of the locations obtained with telemetry for *C.* dubius and 65 % for *A. hypoleucos* were precise.

At the second-order habitat selection, both waders established their home ranges non-randomly across the study area (*C. dubius*: $\lambda = 0.08$, $P = 0.02$; *A. hypoleucos*: $\lambda = 0.41$, $P = 0.002$) (Fig. 5a,c). The ranking matrix indicated that *C. dubius* prefers the interface zone

significantly more than the other habitat types within their home ranges (Table 2a). This habitat type represented a 30.74 ± 13.89 % (mean + SD) of the home range of the species. Secondly in the ranking we found water and sediments that represented a 20.69 ± 11.06 % and 37.38 ± 8.20 % of the home range respectively. Finally, vegetation represented a 11.19 ± 4.54 % of the area and was the last one of the ranking. *A. hypoleucos* showed similar preferences to *C. dubius* at the home range level. Nevertheless, as three individuals of *A. hypoleucos* were not selecting the habitat the same way, we excluded these home ranges from our landscape scale analysis. The interface area was ranked first; nonetheless, there were no significant differences with sediments or water, which are ranked second. Both Interface and sediments were significantly preferred to vegetation (Table 2b). On average the interface area represented a 21.56 ± 8.95 % (mean + SD) of the home range, sediments 45.83 ± 11.08 %, water 17.23 ± 9.55 % and vegetation 15.38 ± 8.72 %.

Within their home range we also found statistically significant preferences for the habitat use of both species (*C. dubius*: $\lambda = 0.14$, $P = 0.01$; *A. hypoleucos*: $\lambda = 0.35$, $P = 0.02$) (Fig. 5b,d). *C. dubius* rank matrix discloses a preference to use sediments significantly more than the interface area, and both habitats more than water, which was ranked last (Table 3a). On average, 55.34 ± 7.61 % (mean ± SD) of the observations were taken on sediments, followed by 27.95 ± 7.24 % on interface, 9.13 ± 5.35 % in vegetation and finally 7.58 ± 6.70 % in water. At the third-order habitat selection *A. hypoleucos* displayed preference for interface and sediments which significantly differed from water and vegetation (Table 3b). In proportions the observations made in the interface area represented a 40.00 ± 15.88 % (mean ± SD), followed by 41.91 ±

18.35 % in sediments and 12.41 ± 9.73 % in water. Finally, 5.67 ± 7.38 % were in vegetated area.

Management selection

In total 28.57 ha were managed since 2013 within the study area, with some targeted parts of the river managed yearly.

The second-order CA testing the preferences for a specific management category was significant for both species (*C. dubius*: $\lambda = 0.065$, p-value = 0.02; *A. hypoleucos*: $\lambda = 0.56$, p-value = 0.01) (Fig. 6). *C. dubius* showed a clear preference for recently managed areas, being significantly preferred to old management and never managed areas (Table 4a). Considering *A. hypoleucos*, the results indicate that they prefer never managed areas significantly more than old management (Table 4b).

On the other hand, within home ranges habitat use was indistinguishable from random for both waders ($P > 0.1$). This means that the proportions of management categories within the home range and the use proportions are similar, so the species had preference to use none of the categories.

As we found preferences for a certain management category to establish their territories, we analysed the differences in the proportions of each habitat type within each management category to explain the previous results (Fig. 7). We ran a Chi-square, which was significant ($P < 0.001$), as well as the post-hoc test between each management category for each habitat type (Table 5).

A last test was to check the change in the proportions of each habitat type within the managed polygons to see the direction of the effect that management has on the habitat types. We run a chi-square for each pair of years (2017-2018: $P < 0.001$; 2018-2019: $P < 0.001$), as well as the respective post-hoc (Table 6). Management decreases the amount of vegetation and sediments, whereas, it increases the interface area and water surface (Fig. 8). Extrapolating our results, we found that over six years of management water surface increased by 1.44 ha and interface by 0.25 ha in total. On the other hand, vegetation has been reduced by 1.25 ha and sediments by 0.44 ha.

Discussion

This study demonstrates that the Little Ringed Plover and the Common Sandpiper select the interface between water and fine sediments, and avoid vegetation when foraging. Regarding the management effect on the species, the Little Ringed Plover preferred recently managed areas (i.e. open habitats) and the Common Sandpiper the areas that had not been managed since 2013, i.e during the past seven years. Lastly, we could show that management improves the habitat of both species in Finges by increasing the proportion of interface habitat and decreasing the amount of vegetation.

Foraging site selection

At the foraging site scale, both species select fine sediment shores to forage, and they avoid vegetation and coarser sediments. Our results confirm the findings of existing literature that already demonstrated that both species mainly forage along the edge of the water (Dougall et al., 2010; Ntiamoa-Baidu et al., 2008; Parrinder, 1989; Yalden, 1986). Furthermore, our models reveal a preference to forage in fine sediments, finding

that Arcas (2002) already observed on the Common Sandpiper, with preferences towards sandy areas. On the other hand, Ntiamoa-Baidu et al. (2008) and Parrinder (1989) also concluded that the Little Ringed Plover mainly forages in muddy spots of fine sediments. This preference for fine sediments shorelines could be related to the diet requirements of the species. Both waders mainly feed on invertebrates (Arcas, 2004; Boros, Andrikovics, Kiss, & Forró, 2006; Yalden, 1986), whose abundance is higher in areas with shallow and permanent low velocity water flows (Jones, 2013) and decreases with distance from water (Langhans & Tockner, 2014). At the same time, low water velocity flows cannot transport coarser sediments, which our model species avoid, and it allows the deposition of finer sediments (Hjulstrom, 1935). Low water speeds also promote the arrival of nutrient particles that favour invertebrate abundance (Jones, 2013).

We believe that the difference of fine sediments selected by the Little Ringed Plover, silt & clay and sand, and the Common Sandpiper, only sand, is due to the high use of inner ponds by the Little Ringed Plover. These ponds are exposed only to periodic inundations; therefore, the finest sediments can deposit when water is stagnated (Hjulstrom, 1935), reason why we detected a selection for silt & clay. During high-water levels, both species were recorded using these areas, but during these periods, floods turned inner ponds into lateral arms with low water flow that removed silt & clay and only allowed the deposition of sand.

Home range size and habitat use

Little Ringed Plovers established their territories in areas with more interface and water surface compared to the whole study area, but sediments are the most used habitat

type. Common Sandpipers prefer areas with more interface and sediments, which are also the spots that they use the most.

The home range size we found for both species is bigger than those average sizes existing in the literature. The territory size of the Little Ringed Plover in the Mekong river is within the lower limit of the home range size in Finges (Claassen, Forester, Arnold, & Cuthbert, 2018). One explanation to these discrepancies is the difference between the concepts of territory and home range, as home ranges are always bigger than territories (Burt, 1943; Maher & Lott, 1995). For the Common Sandpiper the variations are even bigger. According to Yalden (1986) the average territory size was of 0.48 ha, compared to our 2.05 ha of the home range. Yalden (1986) also states that territories lacking neighbours might take bigger areas, as our study area case. Furthermore, the Rhone in Finges is a typical Alpine river, and as such, it presents a frequent habitat turnover (Doering, Blaurock, & Robinson, 2012) resulting from the recurrent floods that maintain a high habitat heterogeneity (Naiman, Latterell, Pettit, & Olden, 2008). This means that our study species can establish their territories in less homogeneous and favourable habitat than in other more stable floodplains.

Our results suggest high preference of the Little Ringed Plover to establish its home range in areas with greater proportions of interface and water compared to the available habitat. Water has already been assumed as one of the main habitats in the territories of the Little Ringed Plover (Simmons, 1955). The main reason to select areas with high proportions of water related to the fact that, in our study area, all home ranges from Little Ringed Plovers were established in islands, as the existing literature states (Shurulinkov, Daskalova, Michov, & Koev, 2016; Simmons, 1955). Furthermore,

territories have three dimensions, meaning that the species also defends the above land space (Simmons, 1955). What we observed was that Little Ringed Plovers mainly flew over the mainstream and lateral arms, and defended its territory using the above water area. Anyhow, one of the weaknesses of our results is that we could not differentiate between sediment grains at the home range level. As a result, we cannot know whether they need coarser grained islands to nest besides the importance of fine-grained sediment shores to forage. However, other studies have highlighted the preference to nest in egg-sized shingle, hence coarse gravel, to rely on egg crypsis for their success (Claassen et al., 2018; Sálek & Cepáková, 2006). Therefore, it is desirable to promote fine sediment shore islands with coarser sediments further from the water where they could nest .

Regarding the Common Sandpiper, we showed that they have the same preferences to establish their home range and to use it. Common Sandpipers exhibit a clear preference for the interface area, which is in line with our results at the foraging habitat selection. Nevertheless, we found that the least preferred habitat at the home range level was vegetation, which differs from existing literature that states that they nest in sparsely vegetated areas (Heinänen & Von Numers, 2009; Holland et al., 1982; Yalden, 1986). There may be many reasons why this happened. On the one hand, we focused the study on the foraging habitat selection, and, consequently, all our observations as well. Therefore, our results of the third-order compositional analysis, represent the preferences of the habitat types where they forage. Furthermore, many observations of the tagged individuals were imprecise as not all habitats allow the same detection probability (Aarts, MacKenzie, McConnell, Fedak, & Matthiopoulos, 2008), hence, many of the non-precise observations may represent the use of vegetated areas.

Even though it is claimed that second-order habitat selection has some constraints, mainly because of the arbitrary definition of “available area” (e.g. intra-species competition) (Aebischer et al., 1993), we believe that our results provide information on the main habitat type determining the establishment of the home ranges within our revitalised area. Moreover, one drawback from this study is the small sample size. Even though we aimed at having precise data using telemetry, the difficulties to capture both species and the size of the studied population limited our analysis. Therefore, the home range size should be taken with caution as most Common Sandpiper home ranges were obtained with standard surveys and the sample size of the Little Ringed Plover was scarce.

Effects of management

Management influenced the habitat preferences of both species. While the Little Ringed Plover preferred recently managed areas, the Common Sandpiper preferred regions not managed during the past seven years. All three categories differed in terms of the surface covered by each habitat type. In fact, management has been evidenced here to increase the amount of water and interface area and diminish the surface of sediments and vegetation.

Given that Little Ringed Plovers nest in bare ground spots (Claassen et al., 2018; Parrinder, 1989; Sálek & Cepáková, 2006) it was predictable that they would select recently managed areas. According to our results this management category is the one with more interface and less vegetation, thus more bare ground. One caveat of our results is that we could not disentangle the effect of the management - simulating natural dynamics - from the natural floods effect as this was an observational study. The

area is exposed to periodic floods that contribute to shape the landscape, and, when strong enough, floods maintain these areas in early successional stages by wiping out the vegetation (Amoros & Bornette, 2002).

Common Sandpipers prefer sparsely vegetated spots to build their nests (Heinänen & Von Numers, 2009; Holland et al., 1982; Yalden, 1986), so, old managed areas and never managed ones were better for them. The preference for areas not managed since 2013 is probably because the amount of area managed only between 2013 and 2016 was much smaller than in the other categories, as most of the managed regions are modified on a yearly basis. Furthermore, areas which have not been managed are still exposed to natural river dynamics promoting the habitat of the Common Sandpiper and regulating vegetation encroachment (Amoros & Bornette, 2002).

Breeding success

Of the three pairs of Little Ringed Plover that tried to breed, only one succeeded. Both pairs that failed were nesting in areas managed over winter 2018 – 2019. These areas seemed suitable to breed before the floods but were completely swept away by the water (Appendix 4). The same situation applies for many of the Common Sandpiper pairs that failed. Even though this result was expected given that floods are one of the main drivers of failure in waders (Claassen et al., 2018; Shurulinkov et al., 2016), it would be necessary to assess whether man-made structures in Finges pose an ecological trap to our study species.

Management implications

As we observed that both species mainly used large islands to breed, extraction interventions should focus on those islands. Shores with more than 35 % of coarse sediments and/or 40 % of vegetation should be specially targeted and measures to increase fine sediments and remove vegetation implemented. Maintaining a good habitat will promote the return of the same pairs to the territory every breeding season, as both species have high fidelity for their breeding areas (Dougall et al., 2010; Holland et al., 1982; Simmons, 1955).

Additionally, fine sediment interface area should be promoted with the creation of new islands and shallow ponds connected temporally to the mainstream, to permit the deposition of fine sediments. Further measures should include dead arms connected to the main water course on the lower end, to favour sand and silt & clay deposition during backflow (Amoros & Bornette, 2002). It is crucial that islands are large, as both species prefer them (Baumann, 2003; Heinänen & Von Numers, 2009) and sufficiently high to avoid being totally flooded and destroyed by river dynamics (Appendix 4). As the density of waders can mostly increase in the wider areas of the river, the aforementioned structures should be placed in these regions. Furthermore, two channelized stretches are still present in the study area: upstream from the gravel pit in Sierre and downstream from Pfyngut. River widening actions should take place on these areas to increase the riverbed area and promote fine sediments shores.

In conclusion, our results show the importance of early successional stages for the foraging habitat selection and home range establishment of both endangered waders. Consequently, it is key to encourage long-term river restauration including river

widening to promote the ocurrence of *C. dubius* and *A. hypoleucos* in alpine channelized rivers.

Acknowledgments

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Tables and figures

Table 1. Explanatory variables used to model the occurrence probability of the species at the foraging site scale. Mapped around the foraging and pseudo-absence point (r = 1.5 m). Granulometry size proposed by International Organisation for Standardisation (ISO).

Explanatory variable	Granulometry (mm)
Clay & Silt	< 0.02
Sand	0.2 - 2
Gravel	6.3 – 63
Cobble	63 – 200
Boulder	200 – 630
Big Boulder	> 630
Live Vegetation	
Dead Vegetation	
Dead Wood	
Water	

Table 2. Home range selection by a) the Little ringed Plover and b) the Common Sandpiper in the Rhone river in Finges based on compositional analysis. Ranks are from most selected (1) to least selected (4) relative to availability. Signs (+ or -) indicate greater or lesser use of the habitat in the row relative to the habitat in the column. Triple signs indicate a significant difference ($P < 0.05$).

a)

Habitat type	Rank	Interface	Water	Sediments	Vegetation
Interface	1	0	+	+++	+++
Water	2	-	0	+	+
Sediments	3	---	-	0	+++
Vegetation	4	---	-	---	0

b)

Habitat type	Rank	Interface	Sediments	Water	Vegetation
Interface	1	0	+	+	+++
Sediments	2	-	0	+	+++
Water	3	-	-	0	+
Vegetation	4	---	---	-	0

Table 3. Habitat use within the home range by a) the Little ringed Plover and b) the Common Sandpiper in the Rhone river in Finges based on compositional analysis. Ranks are from most selected (1) to least selected (4) relative to availability. Signs (+ or -) indicate greater or lesser use of the habitat in the row relative to the habitat in the column. Triple signs indicate a significant difference ($P < 0.05$).

a)

Habitat type	Rank	Sediments	Interface	Vegetation	Water
Sediments	1	0	+++	+	+++
Interface	2	---	0	+	+++
Vegetation	3	-	-	0	+
Water	4	---	---	-	0

b)

Habitat type	Rank	Interface	Sediments	Water	Vegetation
Interface	1	0	+++	+++	+++
Sediments	2	---	0	+++	+++
Water	3	---	---	0	+
Vegetation	4	---	---	-	0

Table 4. Home range management selection by a) the Little ringed Plover and b) the Common Sandpiper in the Rhone river in Finges based on compositional analysis. Ranks are from most selected (1) to least selected (3) relative to availability. Signs (+ or -) indicate greater or lesser use of the habitat in the row relative to the habitat in the column. Triple signs indicate a significant difference ($P < 0.05$).

a)

Management category	Rank	Recently	Never	Old management
Recently (2016 – 2019)	1	0	+++	+++
Never	2	---	0	+
Old management (2013 – 2016)	3	---	-	0

b)

Management category	Rank	Never	Recently	Old management
Never	1	0	+	+++
Recently (2016 – 2019)	2	-	0	+
Old management (2013 – 2016)	3	---	-	0

Table 5. Significance of the chi-square pairwise post-hoc comparing the proportion of each habitat type within the different management categories. A Bonferroni approach was used as a correction method.

Habitat type	Interface	Sediments	Vegetation	Water
Never: Old Management	9.57e-45	0.00e+00	0.00e+00	0.00e+00
Never: Recently	0.00e+00	0.00e+00	0.00e+00	0.00e+00
Old Management: Recently	0.00e+00	2.14e-59	6.58e-274	2.09e-241

Table 6. Significance of the chi-square pairwise post-hoc comparing the proportion of each habitat type before and after the management. A Bonferroni approach was used as a correction method.

Habitat type	Interface	Sediments	Vegetation	Water
2018: 2019	0.00e+00	0.00e+00	0.00e+00	0.00e+00
2017: 2018	1.52e-115	0.00e+00	4.35e-190	0.00e+00

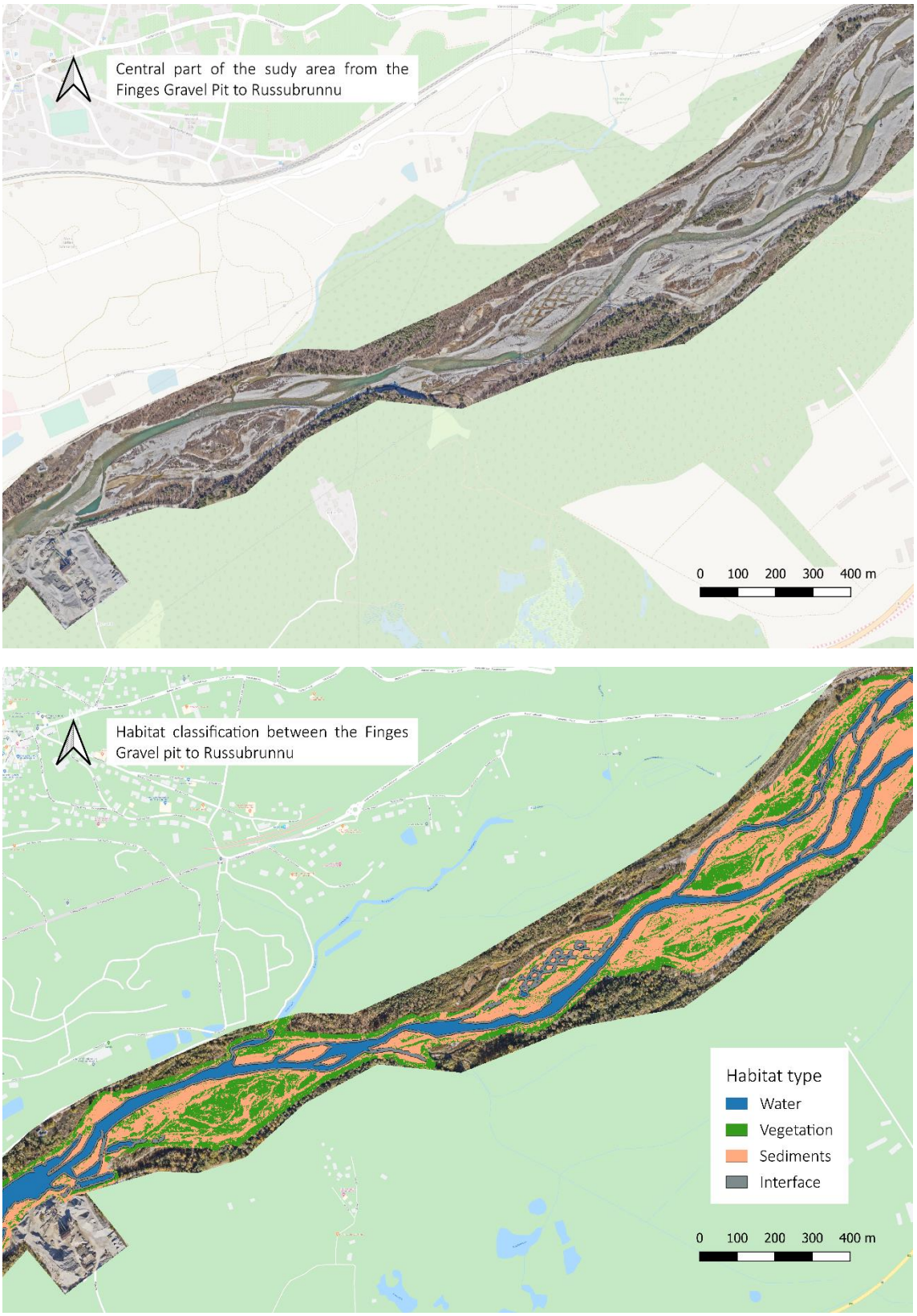


Figure 1. Above: central zone of the study area and its habitat classification for the low water level period. Below: the same habitat classification was applied along the whole river transect within the study area polygon.

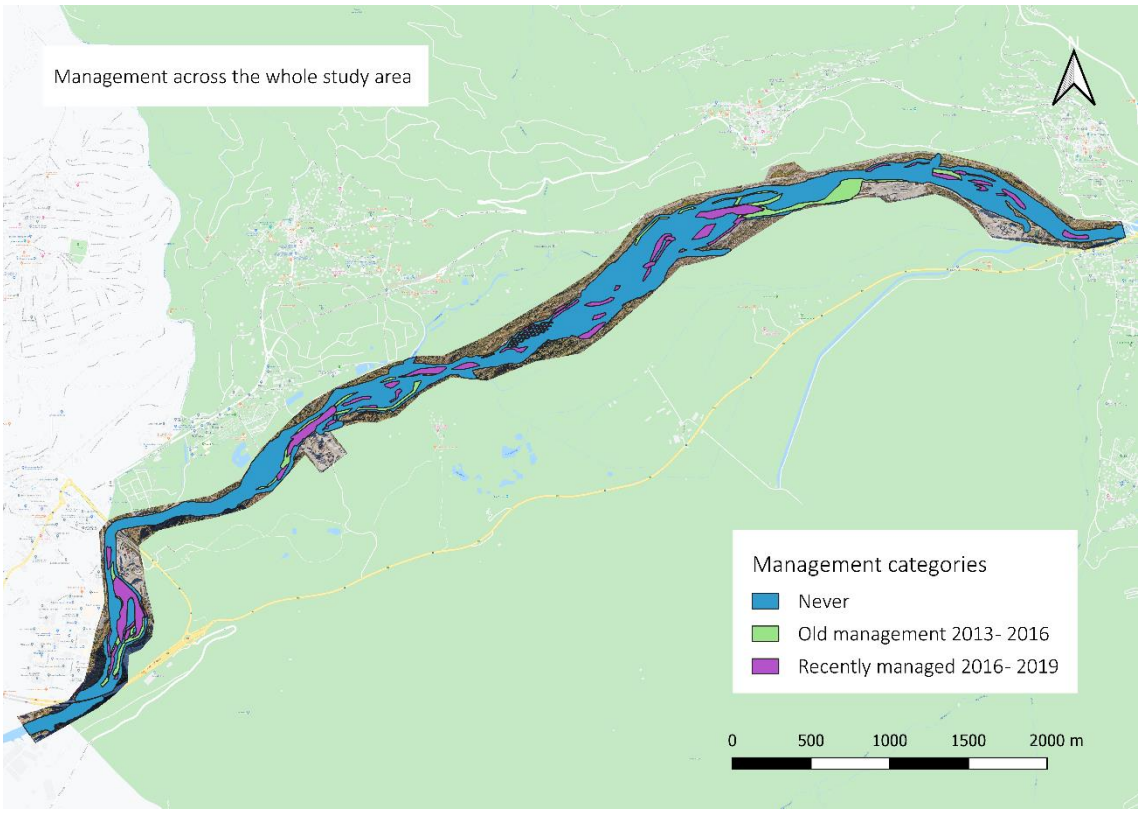


Figure 2. Management classification of the whole study area.

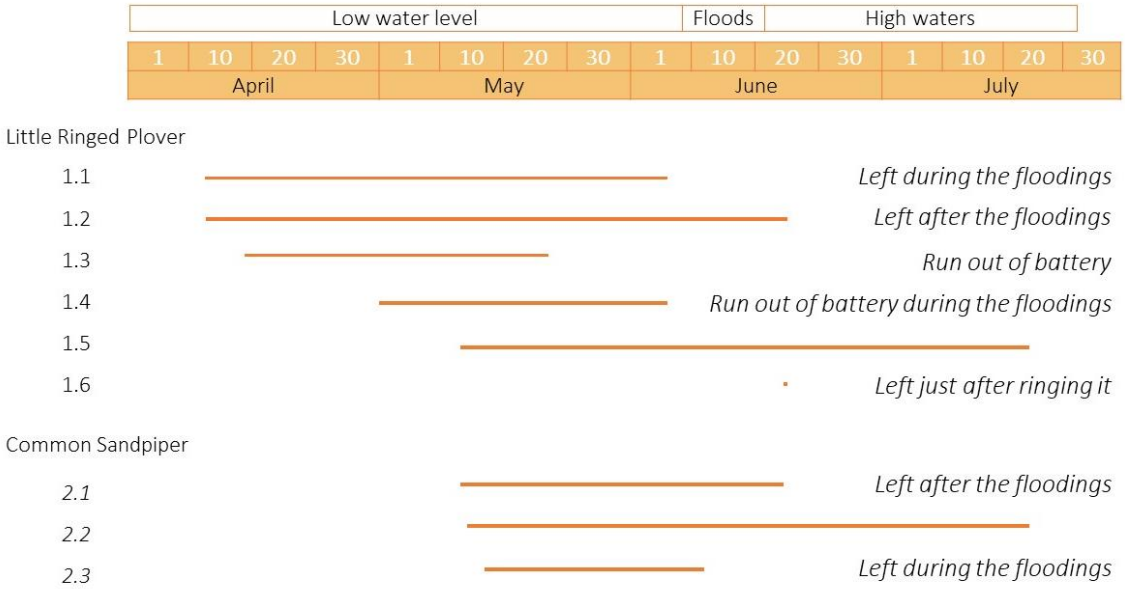


Figure 3. Scheme of the captured individuals during spring 2019. Birds with no explanation left at the end of the breeding season. Individual 1.2 was captured both in 2018 and 2019 in the same territory.

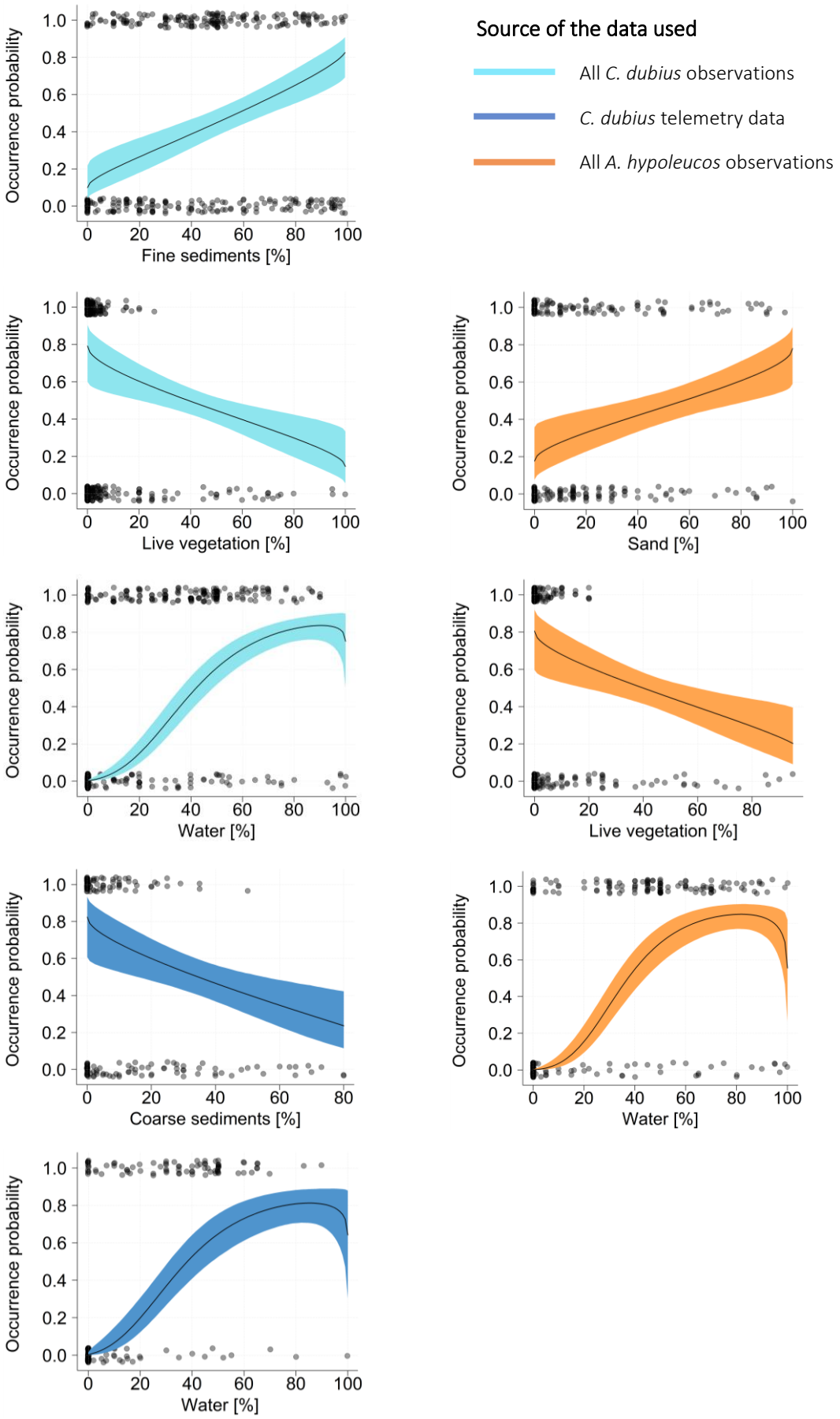

Source of the data used
All C. dubius observations
C. dubius telemetry data
All A. hypoleucos observations
Occurrence probability
Fine sediments [%]
Live vegetation [%]
Sand [%]
Water [%]
Live vegetation [%]
Coarse sediments [%]
Water [%]
Water [%]

Figure 4. Predictions from binomial models with 95%-Bayesian credible intervals (coloured areas) for the occurrence probability of *C. dubius* (all observations: dark blue; radiotracking observations: light blue) and of *A. hypoleucos* (all observations: orange).

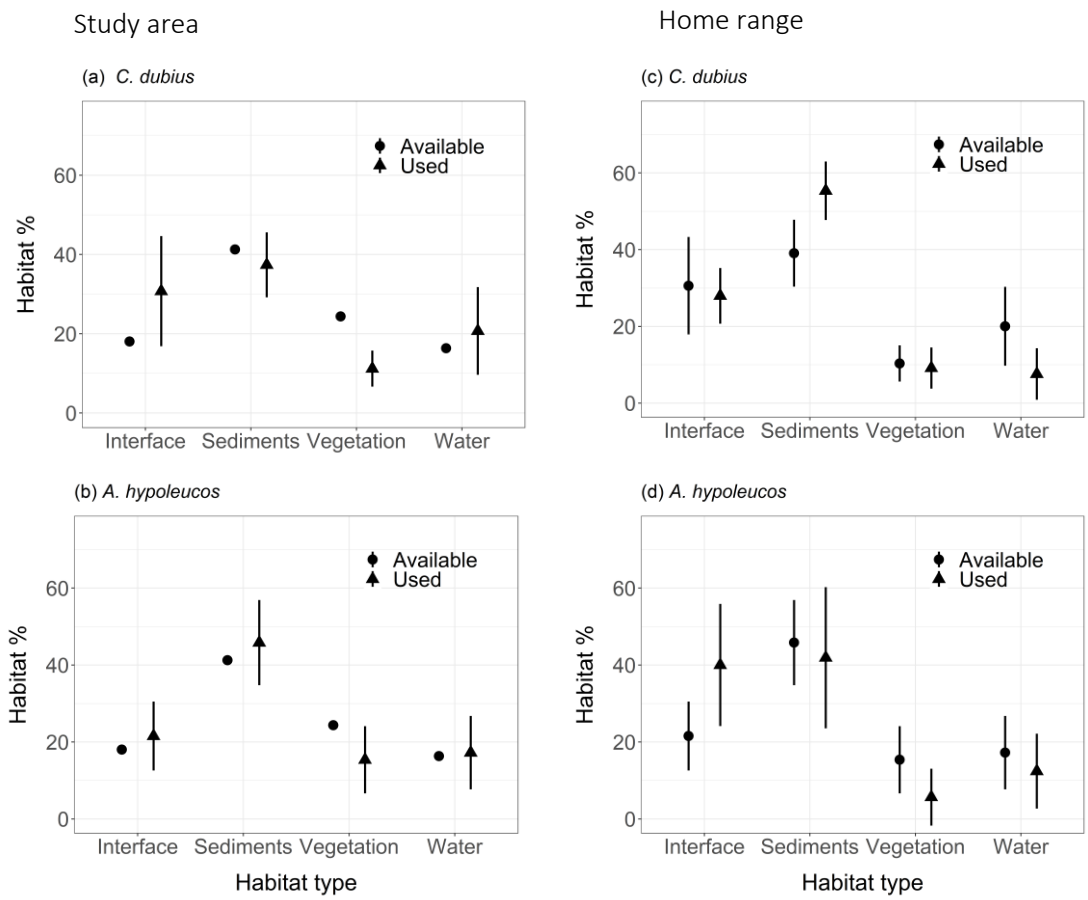


Figure 5. Habitat selection by a-b) the Little Ringed Plover and c-d) the Common Sandpiper at two landscape scales. First column – Habitat selection within the study area, where available habitat is the percentage of each habitat type within the whole study area, and used habitat is the mean percentage (± SD) of the management categories within the home range. Second column - Habitat selection within the home range, where available habitat is the mean percentage (± SD) of the habitat types within the home range, and used habitat is the mean percentage (± SD) of the locations of the individuals within each habitat type. Both home ranges obtained with radiotracking and without were used together for these analyses.

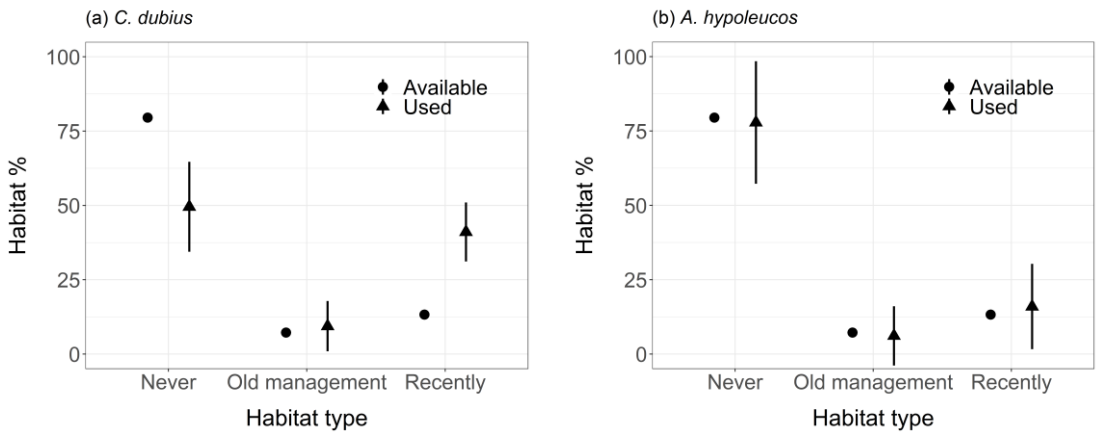


Figure 6. Habitat selection by a) the Little Ringed Plover and b) the Common Sandpiper within the study area (home range habitat selection). Available habitat is the percentage of each management category within the whole study area, and used habitat is the mean percentage (± SD) of the management categories within a home range. Both home ranges obtained with radiotracking and without were used together for these analyses.

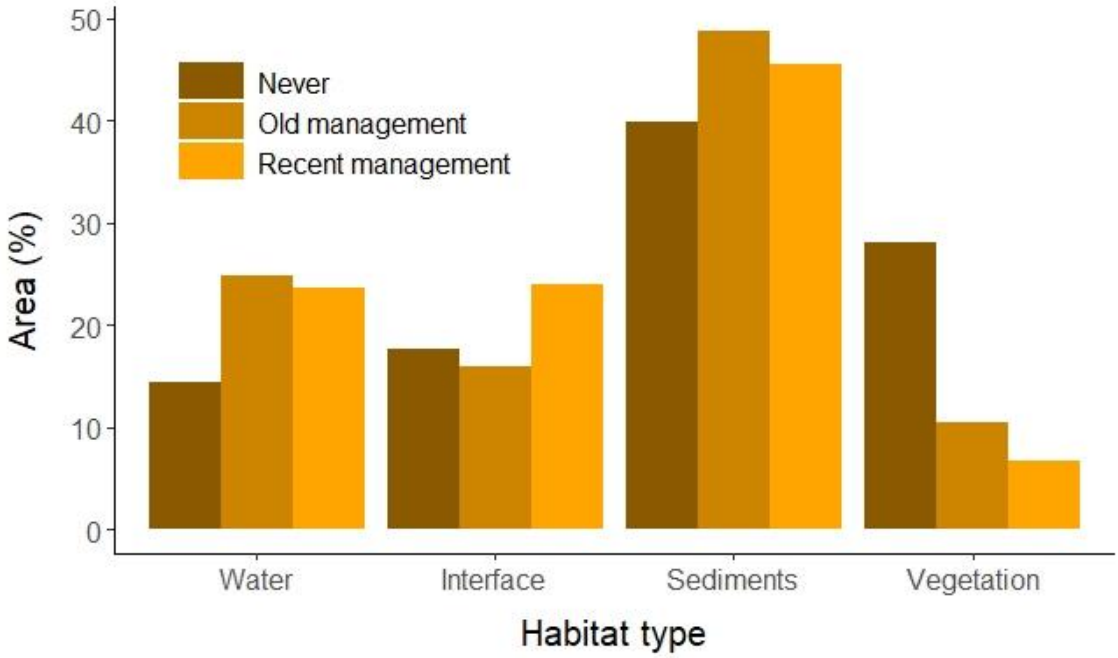


Figure 7. Habitat type percentages within each different management category for the whole study area based on the habitat classification of April 2019 (see Fig. 2 for an overview of the managed areas).

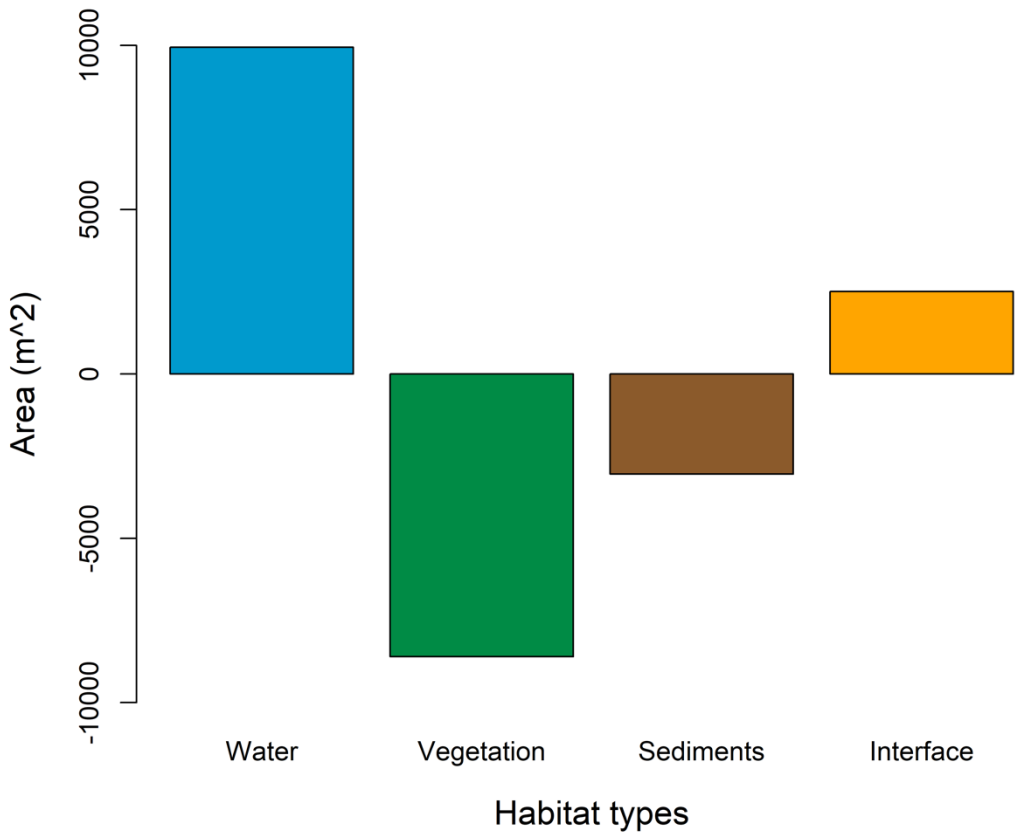
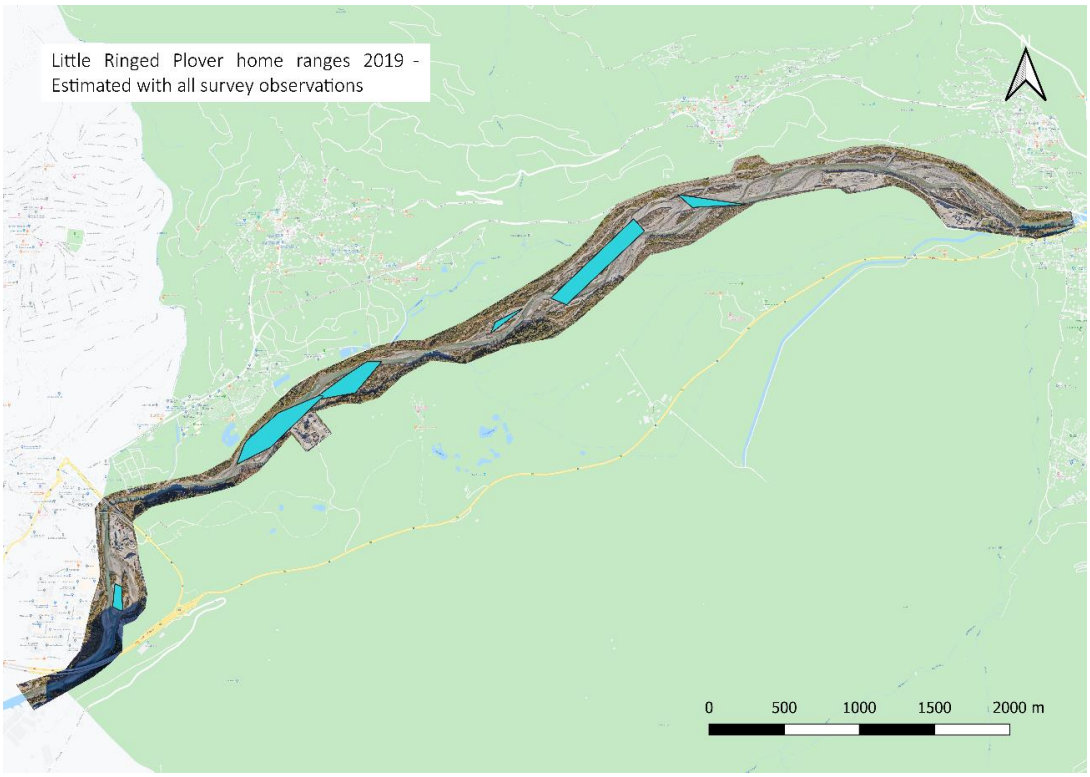


Figure 8. Average change in each habitat type due to management over a two year period.

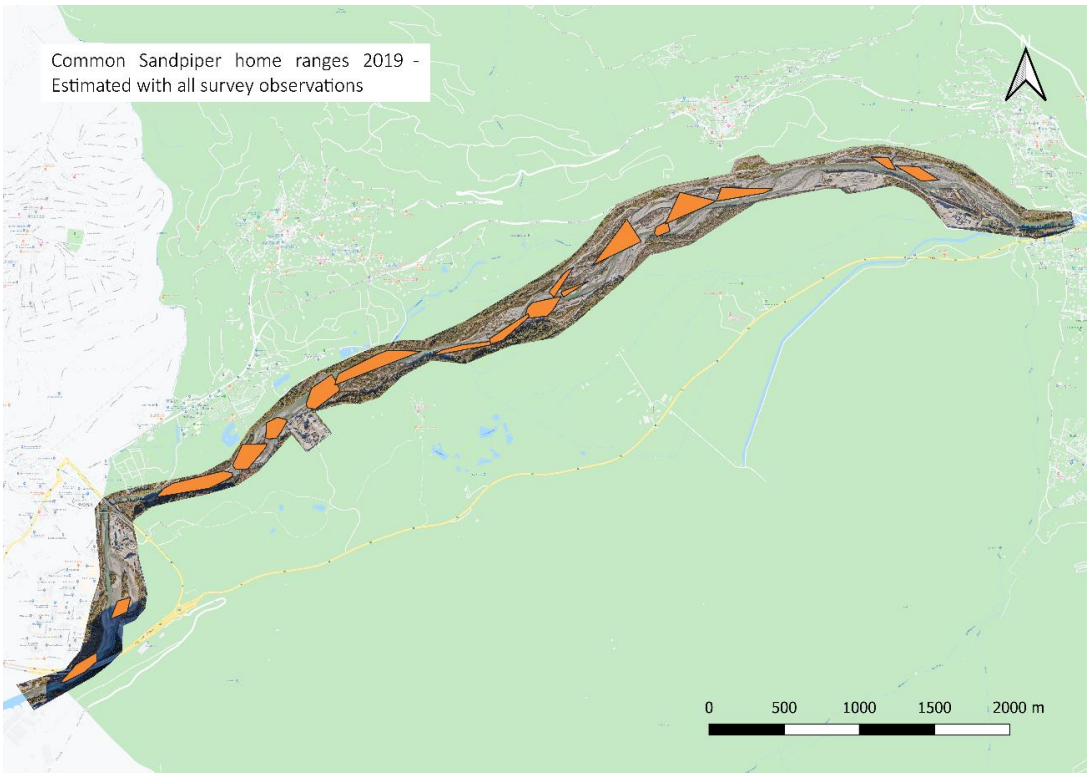
Supplementary material

Appendix 1. Maps of the home ranges of both species obtained with a-b) the surveys and c) with telemetry. Over the six surveys in 2019, 64 and 220 observations of *C. dubius* and *A. hypoleucos* were recorded, respectively. These observations belonged to six *C. dubius* pairs and an estimated 18 *A. hypoleucos*. The home ranges were further compared with the ones obtained via telemetry to investigate the overlapping: altogether seven out of eight telemetry home ranges overlapped between the two methodologies.

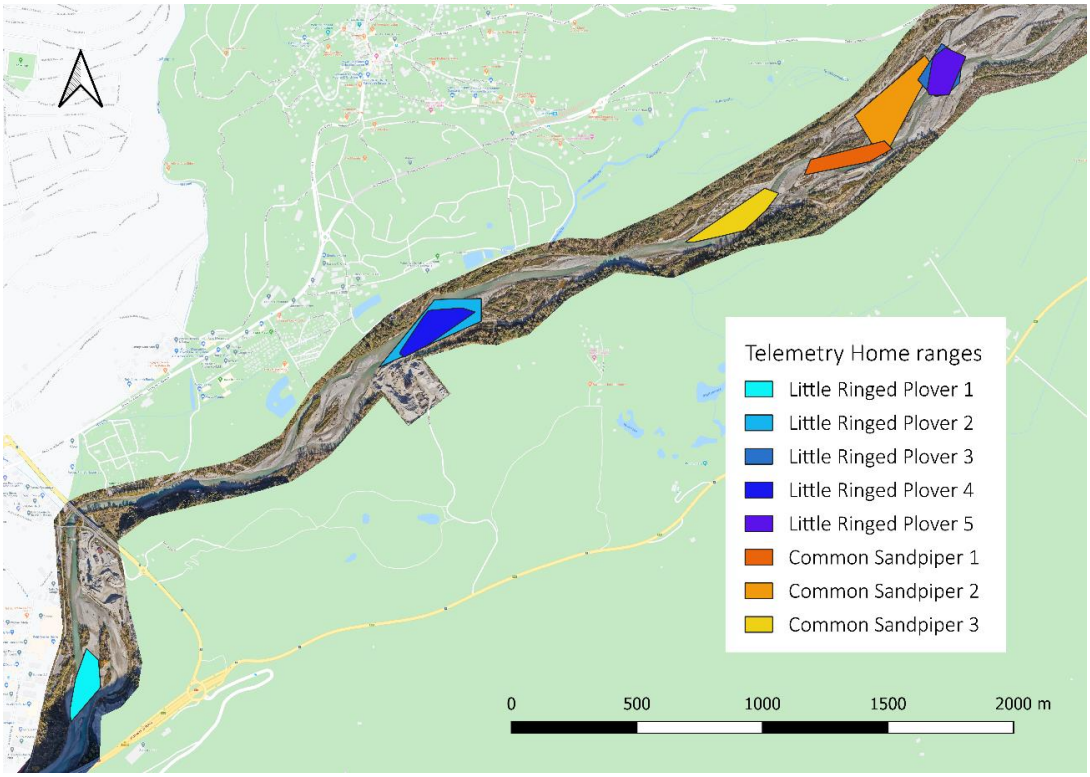
a)



b)


Common Sandpiper home ranges 2019 -
Estimated with all survey observations
0
500
1000
1500
2000 m

c)


Telemetry Home ranges
Little Ringed Plover 1
Little Ringed Plover 2
Little Ringed Plover 3
Little Ringed Plover 4
Little Ringed Plover 5
Common Sandpiper 1
Common Sandpiper 2
Common Sandpiper 3
0
500
1000
1500
2000 m

Appendix 2. Summary of the breeding success of all the tagged individuals of both species (*C. dubius* and *A. hypoleucos*) and those pairs which showed a breeding behaviour (alarming, nesting or rearing of chicks).

Species	Pair ID	Tagged	Breeding Success	Breeding code	Month	Further observations
C. dubius	0.1	No	No	Nest with eggs	Late May	Flooded nest
C. dubius	0.2	No	NA	Alarm calls	Late May	Left after the floods
C. dubius	1.1	Yes	No	Nest with eggs	Late May	Flooded nest
C. dubius	1.2	Yes	NA	Defended territory	May	Left after the floods
C. dubius	1.3	Yes	Yes	4 chicks	Start of July	Daily long-distance movements. Paired with 1.5. Only 2 chicks survived.
C. dubius	1.4	Yes	NA	Alarm calls	May	Left after the floods
C. dubius	1.5	Yes	NA	Defended territory	Start of July.	Daily long-distance movements. Paired with 1.3. Only 2 chicks survived.
A. hypoleucos	C	No	NA	Alarm calls	June	
A. hypoleucos	I	No	NA	Alarm calls	May – June	Distraction behaviour when we were too close
A. hypoleucos	J	No	Yes	Chicks observed	Late June	
A. hypoleucos	K	No	NA	Alarm calls	Start of July	
A. hypoleucos	S	No	No	Eggs hatched	Mid July	Nest highly accessible to predators. We protected the nest with a protection cage, that was removed as soon as the eggs hatched
A. hypoleucos	2.1	Yes	NA	Alarm calls	Late May	Distraction behaviour when we were too close. Left after the floods.
A. hypoleucos	2.2	Yes	NA	NA		Individual very shy
A. hypoleucos	2.3	Yes	Yes	Nest with eggs	Late May	Nest flooded. Left after the floods.

Observational notes: Individuals 1.2 and 1.4 were established around the Finges gravel pit. Both individuals alarmed for many days and one of them seemed to especially defend the small island in the east of the gravel pit. Nevertheless, during the whole study period, and mostly ends of May and during June (with high water level), the gravel pit was open and using heavy machinery in this island targeted by the bird. It is of crucial importance to avoid the use of heavy machinery outside the gravel pit during the breeding period as this may lead to failure of the breeding attempts of the species.

Appendix 3. Results of the analyses on the foraging habitat selection (occurrence probability) of *C. dubius* and *A. hypoleucos.*

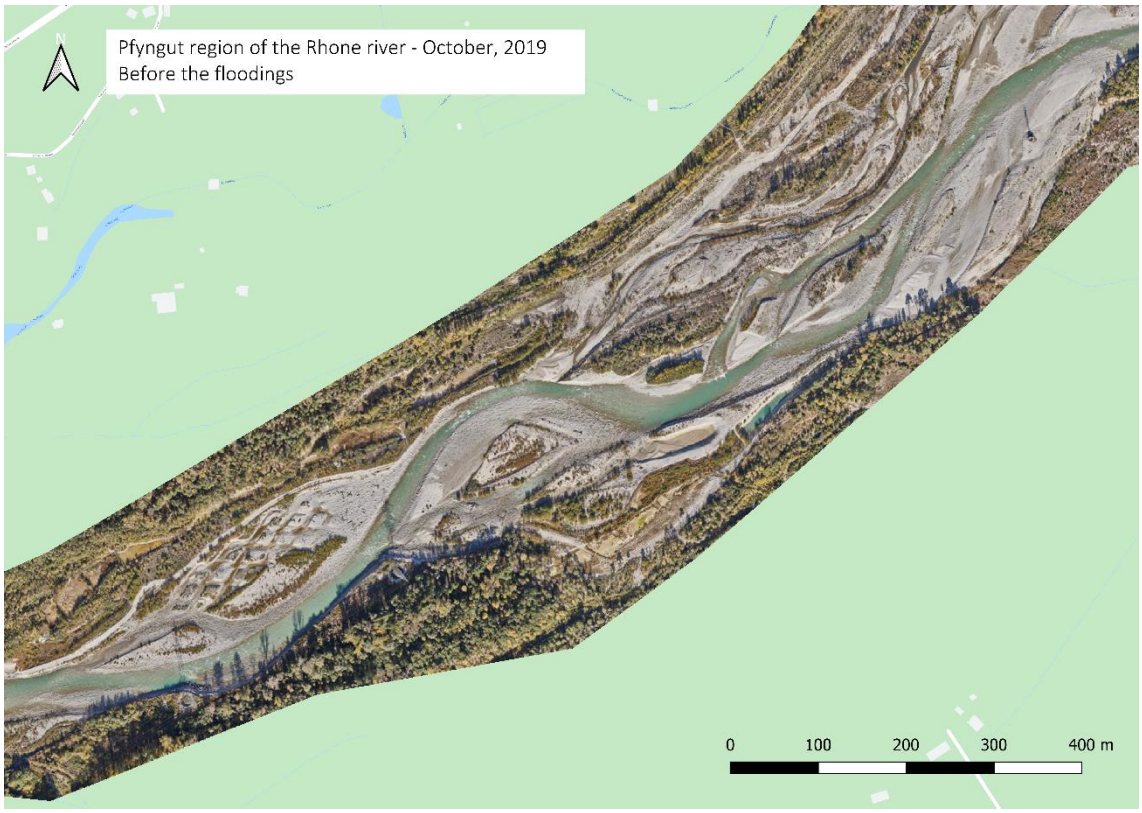
Table 3.a. Generalised linear mixed model outputs performed to analyse the effect of explanatory variables on the occurrence probability of *C. dubius* and *A. hypoleucos*. Models were run with binomial distribution. The table shows the best set of models (Δ AICc < 2) retained for model averaging.

Rank	Model	DF	logLik	Δ AICc	Model weight
a) Little Ringed Plover (all)					
1	Clay & Silt + Live vegetation + poly(water, 2)	7	-165.09	344.5	0.281
2	Clay & Silt + Gravel + Live vegetation + poly(water, 2)	8	-164.33	345.1	0.211
3	Clay & Silt + Live vegetation + Dry veegetation + poly(water, 2)	8	-164.66	345.7	0.153
4	Clay & Silt + Stone + Live vegetation + poly(water, 2)	8	-164.70	345.8	0.147
5	Clay & Silt + Big boulder + Live vegetation + poly(water, 2)	8	-165.01	346.4	0.108
b) Little Ringed Plover (tagged)					
1	Stone + Live vegetation + poly(water, 2)	6	-78.09	168.7	0.326
2	Stone + poly(water, 2)	5	-79.59	169.5	0.211
3	Clay & Silt + Stone + Live vegetation + poly(water, 2)	7	-77.99	170.7	0.121
c) Common Sandpiper (all)					
1	Clay & Silt + Sand + Gravel + Live vegetation + poly(water, 2)	9	-109.28	237.3	0.04
2	Sand + Gravel + Live vegetation + poly(water, 2)	8	-110.45	237.5	0.04
3	Clay & Silt + Sand + Live vegetation + poly(water, 2)	8	-110.59	237.7	0.03
4	Sand + Gravel + Live vegetation + Dry vegetation + poly(water, 2)	9	-109.70	238.1	0.03
5	Sand + Live vegetation + poly(water, 2)	7	-111.84	238.1	0.03
6	Clay & Silt + Sand + Gravel + Live vegetation + Dry vegetation + poly(water, 2)	10	-108.87	238.6	0.02
7	Sand + Cobble + Live vegetation + poly(water, 2)	8	-111.14	238.9	0.02
8	Sand + Gravel + Boulder + Live vegetation + poly(water, 2)	9	-110.11	239	0.02
9	Sand + Boulder + Live vegetation + poly(water, 2)	8	-111.26	239.1	0.02
10	Clay & Silt + Sand + Cobble + Live vegetation + poly(water, 2)	9	-110.19	239.1	0.02
11	Clay & Silt + Sand + Gravel + Boulder + Live vegetation + poly(water, 2)	10	-109.15	239.2	0.02
12	Clay & Silt + Sand + Dead Wood + Live vegetation + poly(water, 2)	9	-110.25	239.2	0.02
13	Clay & Silt + Sand + Gravel + Big Boulder + Live vegetation + poly(water, 2)	10	-109.17	239.2	0.02

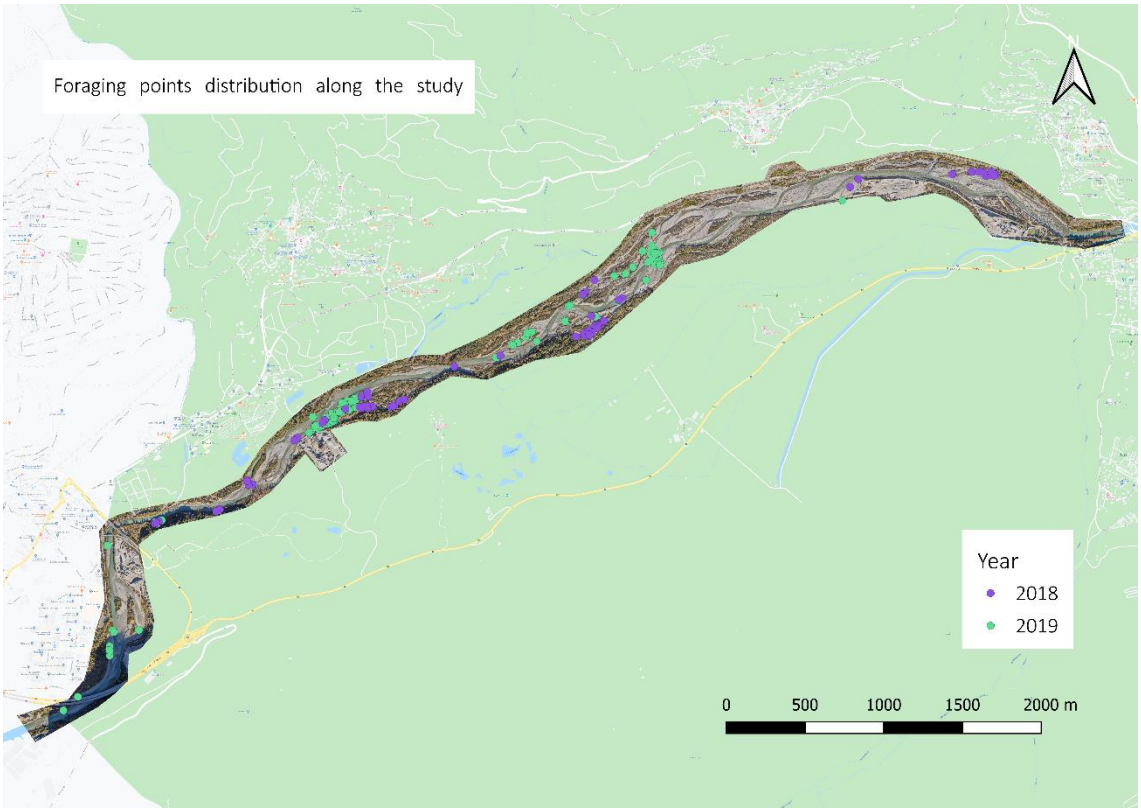
Table 3.b. Summary statistics of the best model on the occurrence probability at the micro-habitat scale of (a) the Little Ringed Plover, (b) tagged individuals of the Little Ringed Plover and (c) the Common Sandpiper. Relative importance states the total weight of the variable in the averaged models (delta < 2). Signif. Values at $P < 0.05$ are marked in bold.

Explanatory variables	Estimate	SE	Confidence interval	Relative importance	*P*-value
a) Little Ringed Plover (all)					
(Intercept)	0.468	0.206	(0.063, 0.873)		**0.024**
I(clay_silt + sand)	0.882	0.251	(0.388, 1.375)	1.00	**< 0.001**
Gravel	0.057	0.140	(-0.219, 0.332)	0.23	0.687
Stone	-0.036	0.128	(-0.286, 0.215)	0.16	0.781
Big Boulder	-0.019	0.145	(-0.304, 0.265)	0.12	0.893
Live vegetation	-0.683	0.234	(-1.143, -0.224)	1.00	**0.004**
Dry vegetation	-0.049	0.167	(-0.376, 0.278)	0.17	0.769
Water	1.787	0.242	(1.311, 2.263)	1.00	**< 0.001**
$Water^2$	-0.670	0.133	(-0.932, -0.408)	1.00	**< 0.001**
b) Little Ringed Plover (tagged)					
(Intercept)	0.590	0.267	(0.062, 1.118)		**0.029**
Clay_Silt	-0.019	0.108	(-0.231, 0.194)	0.18	0.862
Coarse sediments	-0.686	0.232	(-1.143, -0.229)	1.00	**0.003**
Live vegetation	-0.296	0.308	(-0.901, 0.309)	0.68	0.338
Water	1.488	0.240	(1.015, 1.961)	1.00	**< 0.001**
$Water^2$	-0.697	0.196	(-1.084, -0.310)	1.00	**< 0.001**
c) Common Sandpiper (all)					
(Intercept)	0.692	0.294	(0.114, 1.270)		**0.019**
Clay_Silt	0.323	0.433	(-0.527, 1.173)	0.52	0.457
Sand	0.626	0.228	(0.177, 1.075)	1.00	**0.006**
Gravel	-0.199	0.233	(-0.657, 0.260)	0.58	0.396
Cobble	-0.026	0.103	(-0.229, 0.177)	0.12	0.801
Boulder	-0.026	0.098	(-0.219, 0.168)	0.17	0.795
Big boulder	0.010	0.103	(-0.192, 0.212)	0.05	0.924
Live vegetation	-0.762	0.245	(-1.244, -0.280)	1.00	**0.002**
Dry vegetation	-0.040	0.133	(-0.301, 0.221)	0.16	0.765
Dead wood	0.007	0.052	(-0.095, 0.110)	0.05	0.886
Water	1.783	0.264	(1.264, 2.302)	1.00	**< 0.001**
$Water^2$	-0.953	0.181	(-1.310, -0.596)	1.00	**< 0.001**

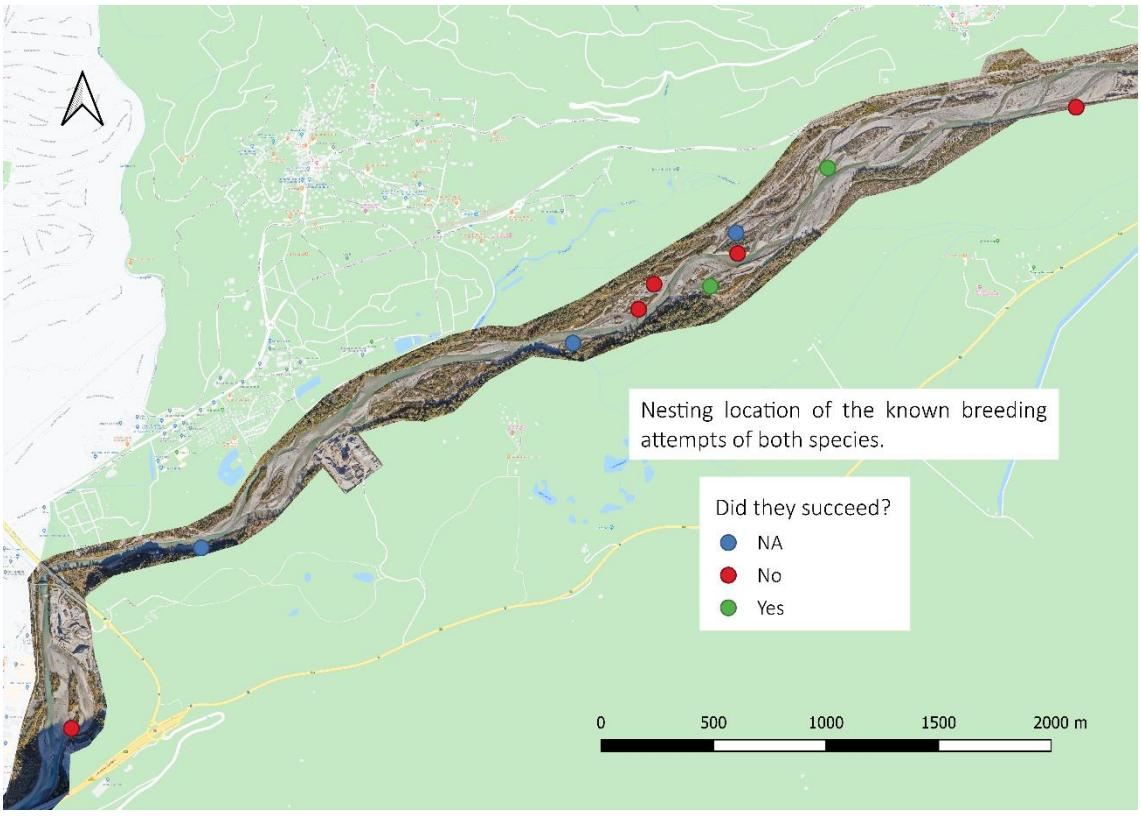
Appendix 4. Example of the river dynamics effect in the study area. Zoom to the Pfyngut area, where a pair of Little Ringed Plovers were nesting in the small islands created through management (left of the picture) but due to the floods they failed.



Appendix 5. Distribution of the foraging points recorded over 2018 and 2019 along the study area.



Appendix 6. Location of the known nests or breeding areas of both species. Each colour represents whether they succeeded or not. NA points mean that after the floods the pair did not alarm anymore but they did not leave the area.



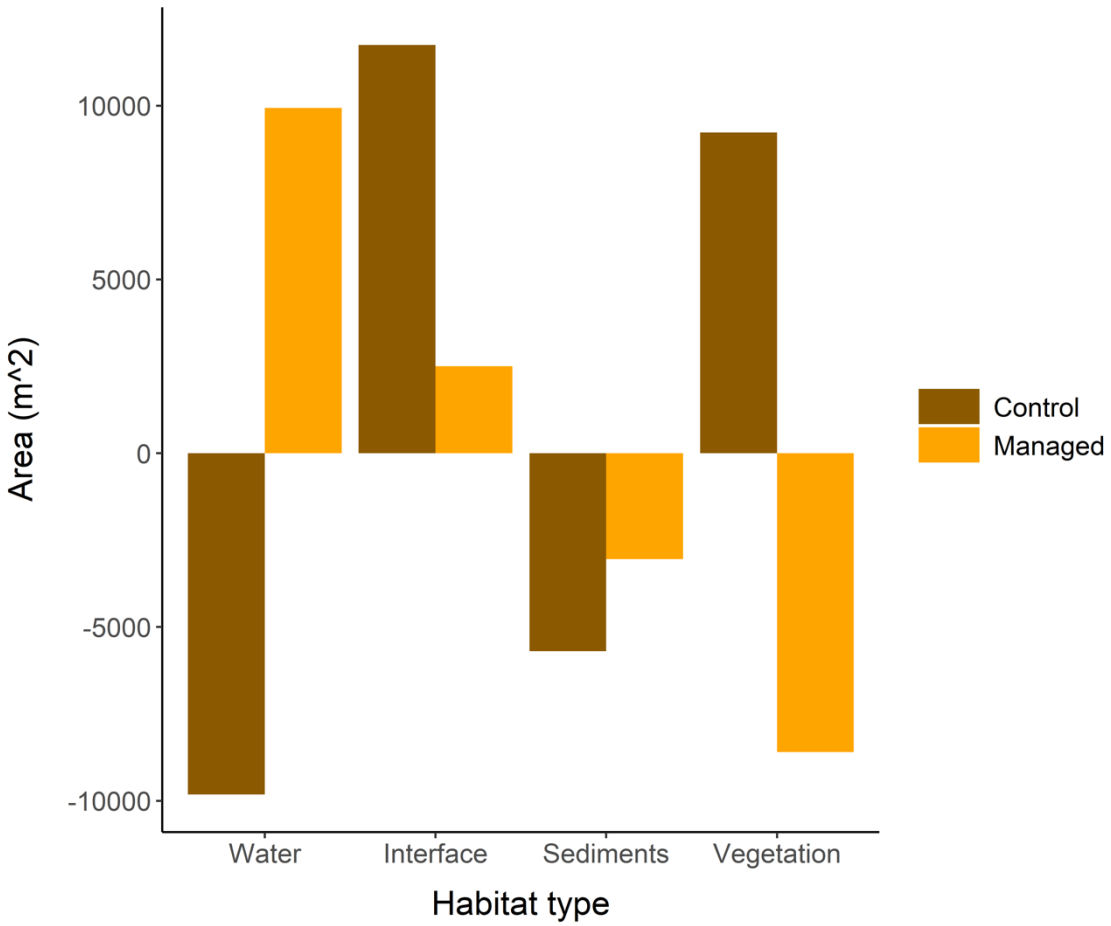
Appendix 7. Dates of the surveys

Survey number	Date
1st	14th April '19
2nd	5th May '19
3rd	19th May '19
4th	2nd June '19
5th	16th June '19
6th	8th July '19

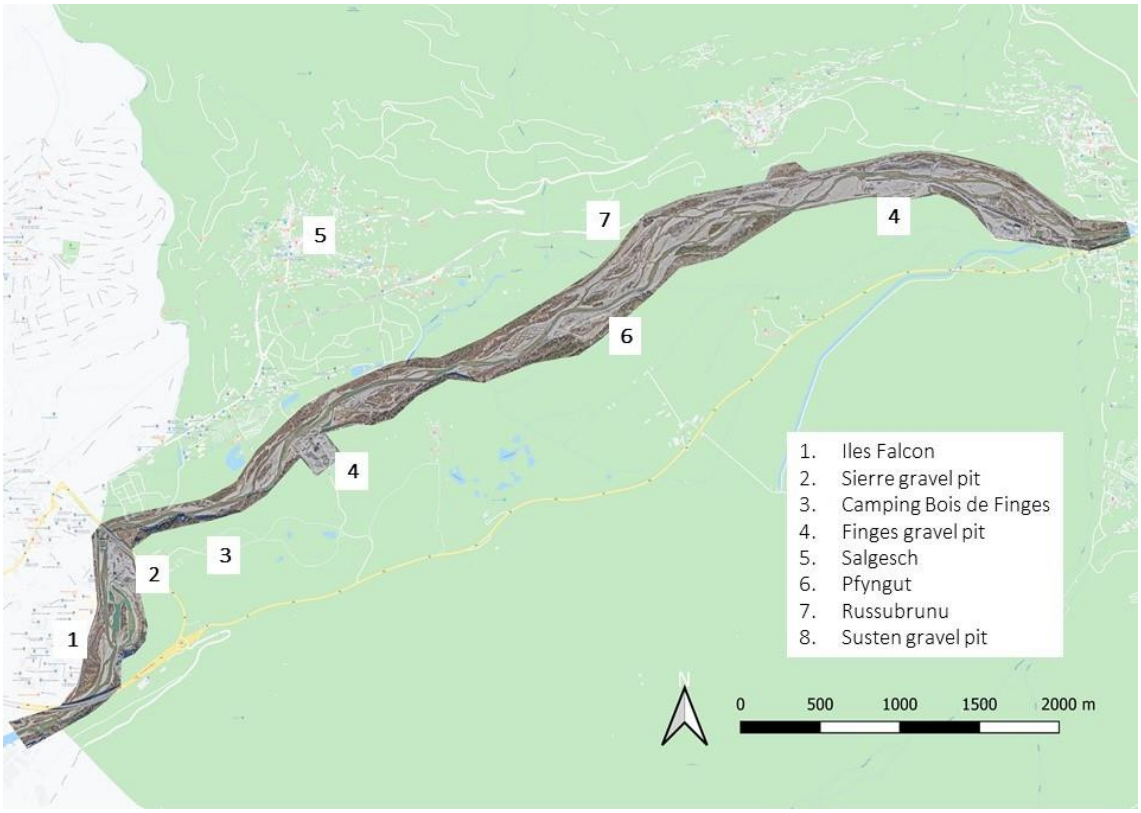
Appendix 8. In order to obtain third-order habitat selection of both species at the management level we did one further analysis. We compared, for each bird separately, the proportion of locations in each of the habitat types with the expected proportions if birds had visited these structures according to availability (Neu et al., 1974; White & Garrot, 1990). To do so we used the function *widesIII* from the R package adehabitat (Calenge, 2006). The difference between this methodology and the one used in the main paper is that Neu et al (1974) analyses the data for each bird separately and uses each observation as the sample size, and Aebischer et al (1993) tests the whole population together, to find a combined trend, with the number of individuals as the sample size. Nevertheless, this test was also non-significant (overall habitat selection: *C.* dubius *P* = 0.14; *A. hypoleucos P* = 0.98). In black in the table the significant *P*-values.

Bird ID	*P*-vaule	Bird id	*P*-value
Little ringed Plover		Common Sandpiper	
1.1	0.843	2.1	0.959
1.2	**0.021**	2.2	0.788
1.3	0.379	2.3	0.469
1.4	0.209	A	-
1.5	0.724	B	0.894
0.1	0.708	C	1.000
0.2	0.108	D	0.381
		E	0.931
		F	0.835
		G	0.508
		I	0.914
		J	-
		K	-
		N	0.636
		P	0.411
		Q	0.501
		R	-
		S	0.501

Appendix 9. To compare the effect of the management with the effect of the natural river dynamics we carried out the same chi-square analyses with the proportion of each habitat type in the non-managed area. The chi-square test was significant as well (2017 – 2018: $P < 0.001$; 2018 – 2019: $P < 0.001$) but the change in two of the habitat types was in different directions. In the following graph the average change due to river dynamics along the non-managed area compared to the average change due to management in the managed polygons is represented. Note that the non-managed area is much larger than the managed (non-managed area = 1'228'030 m^2; managed area = 97'988 m^2).



Appendix 1. Main locations of the study area.



Declaration of consent

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

Name/First Name: Peris I Morente, Elisenda

Registration Number: 18-120-097

Study program: Master in Ecology and Evolution

Bachelor ☐ Master ☑ Dissertation ☐

Title of the thesis: Multiscale habitat selection in two endangered waders: how targeted gravel extraction along revitalised rivers can boost these two bird species

Supervisor: Prof. Dr. Raphaël Arlettaz

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