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Assessment of habitat-specific food availability using human imprinted Grey Partridge (*Perdix perdix*) chicks

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There is an increasing awareness of the need to evaluate agricultural practices and the effectiveness of environmental conservation measures in order to halt the overall decline in farmland birds. One major reason for Grey Partridge population collapse in Europe is the decreased chick survival rate which directly reflects the abundance and biomass of invertebrates as essential chick food. We evaluated a new methodological design using human-imprinted Grey Partridge chicks as a biological assay to compare relative food availability (g / chick / 30 min) in five different habitat types in an arable landscape. On average, partridge chicks slightly lost weight during the trials in all considered arable habitat types, indicating a low invertebrate biomass but also indicating methodological limitations of our approach. The greatest weight loss was found in the conventional crops maize and wheat and on eutrophic grass tracks; the lowest in segetal vegetation patches within wheat fields and in wildflower crop cultivated as ecologically sound cosubstrate for biogas production. An increased defaecation rate due to the handling procedure is suggested to account for the weight loss so that invertebrate availability is discussed comparing the extent to which chicks could compensate this weight loss through food intake. Considering the discussed methodological restrictions in future studies, weight changes in human-imprinted Grey Partridge chicks provide a biologically relevant index of food availability and foraging value of farmland habitats and crops. Thus, these are suitable for evaluating and monitoring the quality of farmland habitats for the Grey Partridge.

1. Introduction

The Grey Partridge (*Perdix perdix*), a typical species of arable landscapes in Europe, used to be among the most common and characteristic farmland birds. In its entire range populations have declined dramatically but on different density levels in the course of the last 60 years. Intensification of agricultural practices, climate, predation, and changes in landscape structure are proposed as being the most important factors explaining this decline in the long term (e.g., Bro *et al.* 2001, Panek 2005, Pepin *et al.* 2008, Kuijper *et al.* 2009, Tillmann 2009b, Aebischer & Ewald 2010, Potts 2012).

One of the most important factors in the population ecology and one reason for the population collapse of the Grey Partridge is the low chick survival rate (Potts 1986, Panek 1992). This has decreased to 30% or lower across all studies (see Potts 2012 for comprehensive review).

Arthropods are an important source of essential amino acids and of protein for growth, feather development and maintenance (Green 1984, Borg & Toft 2000, Liukkonen-Anttila *et al.* 2002, Southwood & Cross 2002). A diverse and arthropod dominated diet is essential for the vitality of chicks directly influencing the resistibility to unfavourable weather conditions and predation and therefore determining the chick survival rate (Southwood & Cross 2002).

To impede the ongoing population decline of this flagship species for farmland biodiversity it is an accepted fact that the habitat of the Grey Partridge has to be improved (Buner *et al.* 2005, Draycott 2012, Faragó *et al.* 2012). Focus must be put on the conservation or creation of brood rearing habitats in sufficient quantity and quality to increase chick survival rate.

Therefore, it is necessary to be able to evaluate the quality of habitat types under the specific conditions of a landscape with regards to the food availability for partridge chicks, thereby obtaining the information necessary to define management prescriptions to address deficiencies in particular habitats or landscapes.

In various contexts in agricultural landscapes arthropod abundance has been investigated, often comparing habitat-types, crops and agricultural regimes (Holland *et al.* 2005, Frampton & Dorne 2007, Ivask *et al.* 2008, Smith *et al.* 2008, Batary *et al.* 2012). Such studies are often consulted to classify habitats regarding their quality for insectivores (for reviews see Holland *et al.* 2006, Vickery *et al.* 2009). Fewer studies have directly focused on estimating habitat-specific arthropod biomass, indexing them as to their suitability for the ground dwelling broods of galliform birds (Stuen & Spidso 1988, Picozzi *et al.* 1999, Park *et al.* 2001, Hagen *et al.* 2005, Randel *et al.* 2007, Wegge *et al.* 2010, Holland *et al.* 2012).

Methods commonly used to assess relative arthropod abundance and diversity are insect traps, sweep nets or suction samplers (see Potts 1986 for the Grey Partridge). However, these entomological methods were found to be unsatisfactory as explained in detail by Palmer *et al.* (2001) and Smith & Burger (2005) not reflecting the spectrum actually chosen by or available to galliform chicks as they select their prey in terms of taxon, behaviour and colour (Moreby *et al.* 2006). Moreover, the availability of arthropods for partridge chicks is limited by their reachability, activity concerning time of day and weather conditions.

In order to gain more realistic results the observation of human-imprinted chicks can be a reasonable approach for assessing the suitability of brood-rearing habitats. Foraging success of human-imprinted Grey Partridge chicks may provide a more ecological relevant method for ranking habitat patches according to their food supply (Kimmel & Healy 1987). Palmer *et al.* (2001) state that in contrast to standard arthropod sampling techniques human-imprinted chicks are more likely to sample arthropods in the physical space available to wild chicks; select arthropods suitable for wild chicks; and interact with the environmental factors in a similar manner to wild chicks. To rank habitat types with regards to their quality for foraging human-imprinted chicks of various galliform species have either been (1) observed in close contact to determine which foods were eaten and to determine feeding rates (pecks / min.) (Kimmel & Healy 1987, Palmer *et al.* 2001) as well as their mobility in the respective vegetation (Doxon & Carroll 2010); (2) have been monitored regarding the mass change per time unit (Palmer *et al.* 2001) and their feather growth (Huwer *et al.* 2008); or (3) have been euthanised after standardised foraging trials in habitat patches to then analyse crop-gizzard contents (Palmer *et al.* 2001, Smith & Burger 2005, Burke *et al.* 2008, Doxon & Carroll 2010). To our knowledge, Erpelding *et al.* (1987) were the first to imprint Grey Partridge chicks on the investigators to study the diet and feeding behaviour by closely observing individual imprinted chicks comparing six habitat types in the US where this species is allochthonous. In one further study Herrmann and Fuchs (2006) compared the foraging rates and the mass changes of 9 imprinted partridge chicks in organically and conventionally grown crops.

The purpose of this present study was twofold:

(1) As methods applied using human-imprinted chicks vary considerably, one aim was to evaluate a study design which is practical, stand-

ardised and repeatable across different habitats and allows for comparisons of different studies and comparisons in time.

(2) Evaluation of five habitat types of an arable landscape with regard to their foraging quality for Grey Partridge chicks and with a special focus on a perennial "wildflower crop".

2. Material and methods

2.1. Study area

This study was conducted approximately 20 km southeast of Hannover, in the state of Lower Saxony, Germany, on a privately owned conventional farm and on the conventional research farm of the University of Veterinary Medicine Hannover, an arable farmland-region in the "Hildesheimer Börde", with fertile Chernozem soils. This area has an altitude of 60–70 m above sea level, having favourable climatic conditions with an average annual temperature of 8.9°C and average annual precipitation of 633 mm / year. Agriculture is intensive, this being indicated by an average harvest of 8.7 t / ha for wheat and 65.4 t / ha for sugar beet. Winter wheat (*Triticum aestivum*) accounted for ca. 40%, sugar beet (*Beta vulgaris*) for 35% and maize (*Zea mays*) for 20% of the crop cover. Within the framework of another study on the effects of the increasing share of maize cultivation, Grey Partridge breeding pair densities were determined on a 293 ha large section of this arable landscape including the habitat types sampled here. Breeding pair densities were found to be 0.7 breeding pairs / 100 ha in 2008, 0.5 breeding pairs / 100 ha in 2009 and 1.5 breeding pairs / 100 ha in 2010 (Tillmann 2011) and thus represent the average low densities in German agricultural landscapes as described in Tillmann *et al.* (2012).

2.2. Chick care and handling

We chose to use commercially produced chicks as in the Northern Bobwhite (*Colinus virginianus*) no difference in chick behaviour or condition was found when comparing genetically wild and domesticated chicks in similar field studies as conducted here (Smith & Burger 2005). Sixty Grey Partridge chicks were purchased at hatch on 24 June 2011. This date was chosen as it is also a realistic hatching date for a late first clutch of wild Grey Partridges and therefore hand-reared chicks would meet similar environmental conditions during the field trial as wild coveys. The incubator-hatched chicks were divided into three groups with 20 individuals in each and imprinted to humans by exposure to the investigators immediately after hatching. The groups were chosen to simulate coveys in the field trials and therefore were kept separately during the whole study. The first two days after hatch the investigators spent most of the daylight hours either interacting with the chicks or in the direct vicinity of the boxes, periodically emitting "put-put-put" calls to facilitate chick-human imprinting.

Each group was kept in an open box (1 × 1.5 × 0.6 m) equipped with an electric brooder hen ("Schuhmacher"-Wärmeplatte, 220 V), maintaining an air temperature of 38°C (± 1°C) underneath. All chicks were fed a commercial turkey starter feed which was ground for the first week after hatching (27% crude protein; without cocidiostat) and water ad libitum. On an irregular basis, larvae of *Tenebrio molitor, Acheta domesticus*, Aphidoidae and imagines, larvae, pupae and eggs of Formicidae and further arthropods were fed. The imprinting procedure resulted in a strong bond between the partridge chicks and the investigators. The regular handling of the chicks (touching, relocating, capturing, weighing) proved uncomplicated and the chicks did not seem to mind being handled. The chicks could be called in the pens to capture them after a trial in a short amount of time and disoriented chicks could be reassured uttering the commonly used "put" call.

The partridge chicks began searching for arthropods as soon as they were released into the pens. On 5 occasions the trial had to be stopped due to unfavourable weather conditions (i.e., rain, low temperatures) which caused obvious discontent, huddling, inactivity among the chicks and abandoning of searches for food.

When the partridge chicks reached the age of 17 days the foraging trials were stopped as the increasing ability to fly impeded efficiently handling the chicks, given the necessity to weigh them in a short time frame.

From the third day after hatching until 10 July the field trials were conducted, depending on weather conditions, between 08:35 CET and 18:45 CET. When not in the field, chicks were held in indoor boxes.

All chicks were marked with an individual code by means of nail varnish put on the three forward-pointing toes using one colour per group. Due to abrasion the nail varnish had to be renewed every second day.

2.3. Foraging trials

Foraging trials were conducted in five representative arable habitat types under the precondition of moderate to dry weather conditions:

(1) Maize (vegetation cover 5–20% at 5 cm height; two fields)
(2) Winter wheat (vegetation cover 25–55% at 5 cm height; two fields)
(3) A perennial "wildflower crop" which was the focus of a study evaluating the agronomical and ecological benefit as alternative substrate for maize in the biogas production. The respective field was in its second year after sowing with the dominant species *Tanacetum vulgare, Melilotus officinalis, Melilotus albus, Artemisia vulgaris, Urtica dioica* and *Cirsium arvense* (vegetation cover 40–75% at 5 cm height; one field).
(4) Grass tracks between fields (vegetation cover 65–95% at 5 cm height; three grass tracks) with usually dense vegetation of nitrophilous grass species such as *Dactylis glomerata*, *Lolium perenne* and *Elymus repens*.
(5) Failed crop patches within the edges of wheat fields with arable plant communities dominated by *Capsella bursa-pastoris, Matricaria* spec., *Polygonum* spec., *Atriplex* spec. and others (vegetation cover of 20–60% at 5 cm height; two fields) hereafter referred to as "segetal vegetation patches" were evaluated.

A total of 41 foraging trials à 30 min. were conducted (7 × maize, 7 × wheat, 9 × wildflower crop, 9 × grass track, 2 × segetal vegetation patches within wheat fields and 7 × indoors under optimal conditions and ad lib. feeding and water supply). As indicated above, predominantly for logistical reasons only one to three sites per habitat type were selected for the trials preferably in direct vicinity to each other. Field size ranged between 2–6.5 ha. The sampling locations in the four crops were selected randomly within the crop edge i.e., 0–2.5 m from the field margin. The complete margin of each field was covered as trial sites so as to guarantee a broad variety in site conditions; i.e., exposition, soil characteristics, vegetation characteristics etc. The crop edges were chosen as partridges preferentially forage with their chicks within the crop edge and the field margin (Itämies *et al.* 1996, Chiverton 1999) and food availability for galliform chicks has been shown to decline as the distance from the field edge increases (e.g., Smith & Burger 2005, Holland *et al.* 2012). For each trial per habitat type three mobile round wire fence pens, 6.5 m^2 ($r \approx 1.45$ cm) in size with a mesh width of 1 cm and 0.8 m in height were erected. Attention was paid to keeping disturbance of the sampled plots as low as possible in order not to influence arthropod movements. The distance between the three pens ranged between 0.5 and 3 m to ensure similar environmental conditions.

In order to gain evidence of the potential food intake the foraging trials were also conducted indoors in cages, feeding and watering the partridge chicks *ad libitum* while adhering to the same standardised procedure used in the field trials.

To weigh the chicks with portable digital scales (DIPSE Germany, TP-Series, 200 g 0.01 g, 10 × 10 cm, precision of ± 0.01 g) they were placed in a transparent plastic box (8 × 8 × 20 cm) as intransparent boxes were found to agitate the chicks.

The chicks were transported in an air-conditioned van with an auxiliary heating system allowing the chicks to be warmed up between the foraging trials. The partridge chicks were fasted (i.e., by removing food and water from the transport boxes) forty minutes prior to the first foraging trial. Immediately before groups of 15 chicks were released into each of the three pens each individual was weighed. After recording their weight the chicks were released into the pens for 30 min. During this phase at least one investigator monitored the chicks and had contact to them uttering "putputput" calls.

To determine the pecking rate the frequency of pecks of randomly chosen chicks was recorded using mechanical tally counters (Voltcraft, type 100814). The pecking rate was recorded for an in-

Table 1. Model selection of the random effects for the linear mixed effect model based on restricted maximum likelihood estimation. The model was of the general form: weight change = Habitat + random structure. The design of the experiment included the nested effect plot in trial and a crossed Chick ID. Model selection was performed on preselected variants of including the day the experiment was performed (equivalent to age of chicks in days).

Fixed effect	Random effect	df	AIC	ΔAIC
Habitat	(day – 1 | trial / plot) + (day – 1 | Chick ID)	9	1.23	0
Habitat	(day + 1 | trial / plot) + (day – 1 | Chick ID)	13	8.38	7.15
Habitat	(1 | trial / plot) + (day – 1 | Chick ID)	9	10.87	9.64
Habitat	(day + 1 | trial/plot) + (day + 1 | Chick ID)	15	11.88	10.65
Habitat	(1 | trial / plot) + (day + 1 | Chick ID)	11	14.80	13.57
Habitat	(1 | trial / plot) + (1 | Chick ID)	9	46.46	45.23

terval of three minutes to then proceed with recording the pecking rate of further chicks. Up to four investigators recorded the pecking rates during the foraging trials in the three pens. 764 pecking rates [pecks / min] at three min intervals were determined.

After 30 min all partridge chicks were captured by hand and immediately weighed to determine weight changes. The whole procedure was shifted 10 min for the three groups per trial. Subsequently, for 40 min the partridge chicks were fed and watered *ad libitum* under standardised climatic conditions in their transport boxes to then proceed with the 40 min fasting period before the following foraging trial in a different habitat type. This time was used to erect the mobile pens again at the new location.

On average 4 foraging trials (range = 2–5) à 30 min were conducted per day. Trials were not conducted in unfavourable weather conditions (temperatures below 15°C, rain, wet soil and vegetation). In mornings with such condition the trials were not even started. The trials were conducted in a narrow window of moderate environmental conditions preventing the chicks from freezing and huddling together. This approach guaranteed a comparable chick and also invertebrate activity to distinguish the effects of the habitat but also reduced the likelihood of finding dependencies of environmental parameters.

In the context of the foraging trials 4,326 body weight measurements were taken, resulting in 2,163 weight changes being determined as the difference of the individual weight after and before the foraging trials. 291 measurements representing 6 field trials were excluded *a posteriori* from further analysis as under certain environmental conditions comparability was not ensured. Particularly, results were obviously biased with moist soil conditions leading to weight gain by mudballing the chicks' feet.

2.4. Statistical analysis

All statistical analyses were conducted with the software R (R version 3.1.2, R Core Team 2014). An initial analysis showed that chicks in the indoor trials gained more weight and showed higher pecking rates than in all considered arable habitats ($p < 0.001$, respectively). Subsequently, all indoor trials were dropped from further analyses. The dependent variable "weight change" was found to be normally distributed. To analyse the effect of agricultural crops on weight change a linear mixed model was conducted with the R package lme4 (Bates *et al.* 2014). Model fit of random effects was assessed by AIC comparisons of 6 preselected random effect specifications using REML (restricted maximum likelihood) estimation (Table 1). The winning model based on AIC, adopted a partially hierarchical design with the three plots as replicates nested within every trial, dependent on the day as random slope term, forcing the slope through origin. Since chicks were randomly chosen between crops and plots within crops we accounted for the growth of chicks by adding a second, crossed random term "chick", again allowing for the day as random slope forcing the intercept through origin (Eq. 1). Weight changes increased with age and concordantly variance, whereas variance at origin approaches zero, which causes un-

Table 2. Model selection of the random effects for the generalized linear mixed effect model based on restricted maximum likelihood estimation. The log-linear Poisson model was of the general form: Number of pecks = Habitat + log(time observed) + random structure. The design of the experiment included the trial and a crossed Chick ID. Model selection was performed on preselected variants of including the day the experiment was performed (equivalent to age of chicks in days).

Fixed effects	Random effects	df	AIC	ΔAIC
Habitat + log(time observed)	(1 | trial) + (day + 1 | Chick ID)	10	13416.4	0
Habitat + log(time observed)	(day + 1 | trial) + (day + 1 | Chick ID)	12	13419.2	2.7
Habitat + log(time observed)	(day – 1 | trial) + (day + 1 | Chick ID)	10	13430.9	14.5
Habitat + log(time observed)	(1 | trial) + (1 | Chick ID)	8	14302.0	885.6
Habitat + log(time observed)	(1 | trial) + (day – 1 | Chick ID)	8	14348.7	932.3
Habitat + log(time observed)	(day – 1 | trial) + (day – 1 | Chick ID)	8	14358.6	942.2

identifiable variances at origin. Consequently, a simplification of forcing the random slope through origin seems a justifiable simplification. Degrees of freedom and *p*-values were estimated with the Satterthwaite approximation in the package lmerTest (Kuznetsova *et al.* 2014).

E[weight change] = habitat + re(day – 1 | trial / plot) + re(day – 1 | ChickID) (1)

The number of pecks as count data were calculated as generalised linear mixed model (GLMM) using Poisson distribution in the package lme4 (Bates *et al.* 2012). In a few cases it was impossible to count the chick for 3 min, however the relationship of time observed and pecks was not strictly linear thus we estimated log(time observed) as fixed effect instead of an offset parameter. Again model fit of random effects was assessed by AIC comparisons of 6 preselected random effect specifications using restricted maximum likelihood estimation (REML, Table 2), which resulted in almost identical specifications to the weight change analysis. However, since replication within plots was sometimes low we ran into convergence errors and had to omit the plot level from the random effects. The AIC-value indicated a better fit, when omitting the random slope term “day” within the “trial” part of the random effect. The fixed effect habitat was tested against the null models in likelihood ratio tests for both models. To test whether a relation between the number of pecks and weight change existed, a Spearman rank correlation was calculated.

E[(no. of pecks)] = habitat + log(time observed) + re(trial) + re(day | ChickID) (2)

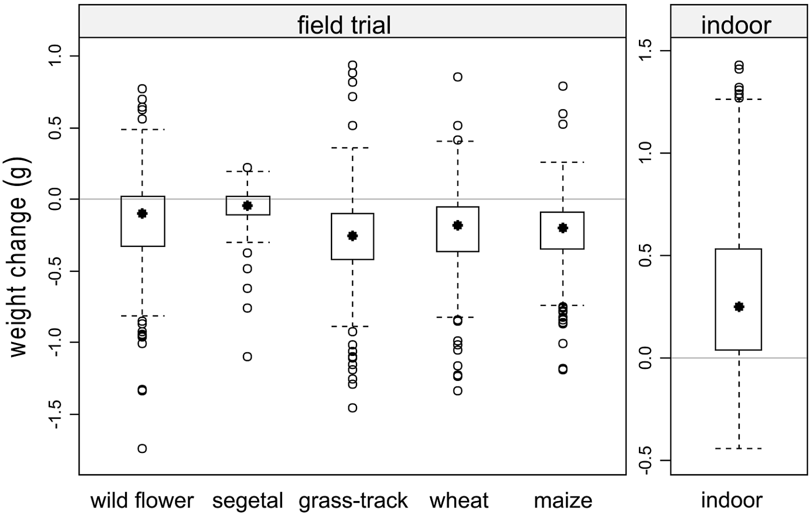

Fig. 1. Boxplots of weight changes per habitat type. Note different scales for Y-axis in field trials compared to indoor trials. Zero weight change is shown by the grey, horizontal reference line. A number of 392, 321, 90,349, 375 and 321 individual weight changes were recorded for the habitat types grass track, maize, segetal, wheat, wildflower and indoor respectively.

Table 3. Results of the linear mixed effect model testing the effect of "habitat" on "weight change" of grey partridge chicks: a) Variance partition in random effects, b) Estimates of fixed effects.

a) Random effects

Groups		SD
Plot in trial	random slope of day	0.011
Chick ID	random slope of day	0.010
Trial	random slope of day	0.018
Residual	–	0.221

b) Fixed effects

	Estimate	SE	df	*t*-value	*p*-value
Intercept (grass track)	–0.217	0.050	25.35	–4.381	0.000
Maize	0.035	0.060	28.12	0.593	0.558
Segetal	0.161	0.058	35.67	2.771	0.009
Wheat	0.087	0.056	30.14	1.561	0.129
Wildflower	0.129	0.060	28.02	2.159	0.040

3. Results

3.1. Weight change

During all foraging trials in the field Grey Partridge chicks lost weight on average (Fig.1). Only during the indoor foraging trials with *ad libitum* food and water supply Grey Partridge chicks gained weight (mean change = 0.330 ± 0.021 g; N = 320). With a mean weight loss of –0.159 g (SE = 0.016; N = 375) for the "wildflower crop" and –0.055 g (SE = 0.013; N = 90) for the "segetal vegetation patches" in these two habitat types compensation for weight loss was the highest and therewith the food availability compared to the conventional crops and the grass track potentially higher (maize Mean = –0.230 ± 0.013 g; N = 321, wheat Mean = –0.230 ± 0.016 g; N = 349, grass track Mean = –0.275 ± 0.015 g; N = 392). The linear mixed model confirms these findings. The habitat type has a significant effect on weight change (likelihood ratio test: χ^2 = 12.092, df = 4, p = 0.017) with chicks in the wild flower crop and segetal patch compensating significantly better for weight loss than on grass tracks (p = 0.040, p = 0.009 respectively) (Table 3). Maize and wheat showing slightly higher net weight losses than wild flower and segetal vegetation patches, but less than on grass track; however, these differences were not significant ($p > 0.1$) (Table 3).

In order to interpret the weight changes during the field trials the weight of faeces was taken when the chicks were 7 days old. The median of the 50 samples was 0.04 g (q25 = 0.03; q75 = 0.08).

3.2. Pecking rate

764 pecking rates at three min intervals [pecks / min] were determined. The highest pecking rates were found in the indoor trials. Chicks in wheat and wild flower fields pecked more frequently than in the other habitats (17, 10–24 and 15, 9–23 pecks per min; for the median and interquartile ranges, respectively, Fig. 2). The likelihood ratio test against the null model showed highly significant effects of habitat (χ^2 = 19.18, df = 4, $p <$ 0.001) and self-evidently for the effect of time observed (χ^2 = 2,040.61, df = 1, $p < 0.001$). Chicks on maize showed somewhat lower pecking rates (p = 0.075) than chicks on grass tracks, however this difference was not significant in the generalised linear mixed model (Table 4). From all outdoor trials chicks on wild flower patches pecked most frequently (p = 0.018 compared to grass track). In segetal vegetation patches, which were sampled

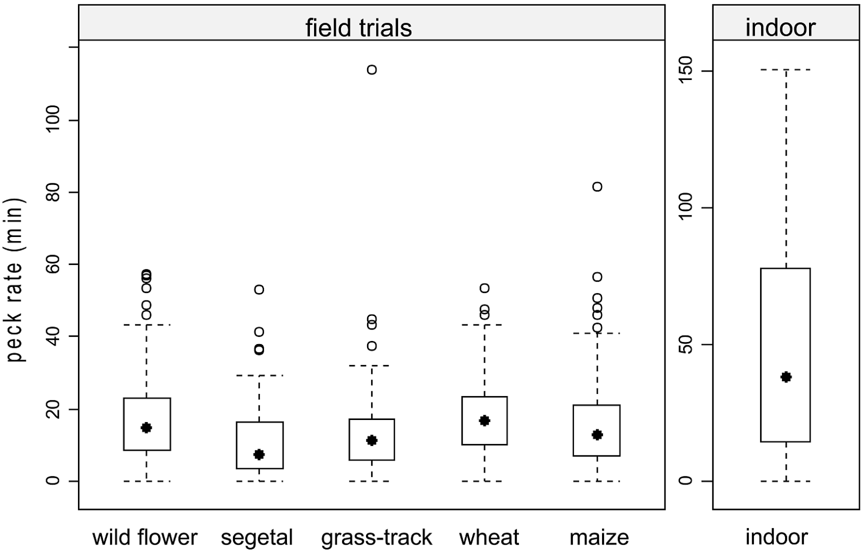

Fig. 2. Boxplots of pecking rates per habitat type. Note different scales for Y-axis in field trials compared to indoor trials. A number of 186, 203, 40,164, 181 and 180 individual pecking rates were recorded for the habitat types grass track, maize, segetal, wheat, wildflower and indoor respectively.

within the first two days only, chicks showed on average lower peck rates (12 and 5–20 pecks per minute for the median and interquartile range). The estimates (Table 4) for segetal however show relatively high pecking rates. Since day was accounted for in the model, when comparing the pecking rates among the first two days, segetal patches had the highest pecking rates (median: 15, compared to 7, 12 and 15 in the habitat types maize, wheat and wildflower respectively). These differences were however not significant in the generalised linear mixed model (Table 4).

No relation between the pecking rate and the weight change was found (Spearman rank correlation: $\rho = -0.07$, $p = 0.069$).

4. Discussion

As sensitive indicator species, population trends and habitat preferences of the Grey Partridge are often monitored in order to assess conservation effort and wildlife friendliness of agricultural practices, respectively (Buner *et al.* 2005).

Here we used human-imprinted Grey Partridge chicks as biological assay to compare relative food availability in five different habitat types in an arable landscape and moreover to evaluate a new standardised methodological study design. As stated by Kimmel & Healy (1987) and Potts (2012) foraging behaviour is innate and not learned from adult partridges. Accordingly, with suitable weather conditions our human-imprinted chicks started searching for invertebrates straight after being released into the mobile pens and clearly avoided unpalatable invertebrates like for example bees (*Apis mellifera*), wasps (*Vespula* spec.) or ladybird beetles (*Harmonia axyridis* and *Coccinella septempunctata*).

On average partridge chicks slightly lost weight during the 30 min. trials in all considered arable habitat types. The significant weight gain during the indoor trials with *ad libitum* food and water supply compared to the field trial provides evidence of the potential food intake of partridge chicks within the same methodological framework. The observed average short-term weight loss in all field trials results from an increased defaecation rate during the trial procedure after weighing the chicks (for further discussion, see below). Therefore, food availability in the five considered habitat types has to be discussed, comparing the extent to which chicks could compensate this weight loss through food intake. Hence, the determined significant differences in weight change of the chicks in the five habitat types allows for discussion on the habitat-specific food availability as weight loss due to increased defaecation is assumed to be the same in all habitats on average.

The determined food availability based on compensation for weight loss was highest in the

Table 4. Result of the generalized mixed effect model testing the effect of "habitat" on "pecking rate" of grey partridge chicks: a) Variance partition in random effects, b) Estimates of fixed effects.

a) Random effects

Groups	SD	Correlation
Chick ID	0.569	–
Day	0.068	–0.910
Trial	0.323	–

b) Fixed effects

	Estimate	SE	*z*-value	*p*-value
Intercept (grass track)	2.7829	0.1004	27.72	< 0.001
Maize	–0.261	0.147	–1.780	0.075
Segetal	0.268	0.253	1.060	0.290
Wheat	0.150	0.149	1.010	0.313
Wild flower	0.311	0.132	2.360	0.018
Log(time observed)	0.738	0.018	41.930	< 0.001

segetal vegetation patches with volunteer vegetation and in the wildflower crop exemplarily cultivated for biogas production. The latter is studied as an ecological sound alternative to maize. With our results it can be hypothesized that the edges of wildflower crops provide an increased invertebrate availability due to (a) the sown diversity of flowering plants as host for invertebrates, (b) additional volunteer plants as host for invertebrates, (c) the fact that no pesticides are applied and (d) the fact that this crop is supposed to remain for up to 5 years (here in the second year) without soil tillage, which causes an accumulation of ground debris and allows invertebrate species otherwise sensitive to soil tillage to establish themselves. However, in this habitat type food availability as a function of invertebrate abundance and its reachability must result from a comparatively increased invertebrate abundance as the vegetation is rather dense and the chicks were observed not being able to penetrate the vegetation unrestrainedly. Radio-tracking partridge broods to analyse habitat preferences and the diet of chicks Itämies *et al.* (1996) also came to the conclusion that the real availability of different invertebrates depends on the structure of the habitat used by the broods. Our findings support the approach to cultivate wildflower crops in order to mitigate negative effects of field exceeding maize cultivation for biogas production. In the case of partridge broods the focus should be put on increasing the edge density, meaning wildflower crops should be cultivated in strips as the interior part of field patches fails to serve as brood habitat from the second year onwards. Supporting our findings an increased invertebrate abundance in various types of sown wildflower strips has been found in many entomological studies as reviewed by Haaland *et al.* (2011).

Our results for the considered segetal vegetation patches within the edges of wheat fields indicate a higher invertebrate biomass compared to the conventional crops due to the diversity of volunteer plants as host for invertebrates and a beneficial microclimate, as well as to better prey detectability and accessibility in these sparsely vegetated patches. Our findings confirm various studies on the beneficial value of segetal vegetation increasing food resources also for insectivorous birds and support nature conservation approaches such as 'conservation headlands' (e.g., Moreby & Southway 1999, Vickery *et al.* 2009, Ewald *et al.* 2010).

Unexpectedly, on grass tracks the food availability was the lowest. This can be explained by the dense vegetation with 65–95% vegetation cover at 5 cm height – the highest vegetation cover within the considered habitat types impeding the penetrability of the vegetation with a comparatively unfavourable moist microclimate.

Similar to the grass track, compensation for weight loss in the conventional crops maize and wheat was somewhat lower than in the segetal vegetation patches and the wildflower crop (Fig. 1). In the case of maize, aphids on the base of the maize stems were the only obvious food items the chicks found in this habitat.

However, our general result that partridge chicks lost weight on average in all habitat types with our methodological approach might be biased due to the following reasons:

(a) The abundance of invertebrates varies on the broad scale but also on the scale of microhabitats (Honek 1997, Panek 1997, Meek *et al.* 2002, Holland *et al.* 2005, Holland *et al.* 2012). Taking the example of ants as an important chick food (see review in Potts (2012)) this becomes most obvious with very high abundances where nests are present. Additionally, the adult birds open ants' nests, pecking and scratching to provide access for the chicks to the various development stages, being otherwise hidden in the soil nest. Here, sampling plots were randomly selected at the edges of fields. As described above field edges were chosen as most preferred brood rearing habitats of Grey Partridges providing the preferred resources including higher invertebrate diversity and biomass (Green 1984, Smith & Burger 2005). Within the field edges as our focus areas special features indicating higher food availability were not preferentially selected. Therefore, the micro-spatial behaviour of brood rearing partridge pairs was only copied in a general way, choosing the preferred field edges. However, microhabitat selection could not be simulated and therefore results are likely to be biased towards reduced food availability as partridge pairs guide their chicks selectively to those patches with high food availability.

(b) The study design restricted the available foraging area to 6.5 m^2 and to 30 min foraging time for 15 chicks. Dahlgren (1987) found that chicks moved 0.9 m / min in weedy cereals and 2.35 m / min in sprayed cereals. Taking the chick moving distances from 0.9–2.35 m / min, 20 min activity per half an hour and the number of chicks in the pen (*n* = 15), they may move between 270–700 m during a trial in the small pen. Therewith a fast depletion of suitable invertebrates during a trial is very likely impeding the chicks to compensate the weight loss due to an increased defaecation.

Especially in areas with poor chick food supply, broods range more widely than in habitats with sufficient invertebrate abundance (Rands 1986). Thus, the "stocking rate" applied here should be reduced in future studies by reducing the number of chicks, but to not less than 10 to avoid stress because of loneliness, and by increasing the pen size. 30 min as foraging time should be the minimum duration of a trial as partridge broods are found to be active during the daylight hours with alternating periods of resting (on average 18 min) and of activity (11 min) (Green 1984).

(c) An increased defaecation rate can be found when adult Grey Partridges are disturbed (Tillmann 2009a). We assume that although the chicks were human-imprinted the handling procedure of being taken out of the transport box, being weighed and then released into the novel environment of the mobile outdoor pens but also being released in the boxes for the indoor trials very likely provoked higher defaecation rates as stress reaction. The droppings of 7 day-old chicks weighed an average of 0.04 g. Conveying a defaecation rate of up to 4 droplets defaecated by adult partridges directly upon disturbance (Tillmann 2009a) in this trial situation partridge chicks potentially excreted up to 0.16 g faeces due to the handling procedure. This weight loss clearly reflects the average weight loss of the partridge chicks determined in wheat (0.18 g), maize (0.17 g) and the grass track (0.26 g). To compensate for a weight loss of 0.16 g, for example, ca. 40 ant pupae of the common ant (*Lasius niger*) à 3.91 mg (Boomsma and Isaaks 1985) or 107 individuals of the aphid *Sitobion avenae* à 1.5 mg (Debarro *et al.* 1995) would have to be consumed. Comparing these numbers with the number of invertebrates found in the crops and gizzards of chicks as reviewed in Potts (2012), i.e., on average approx. 175 per chick or even more than 1,000 recently eaten aphids, the number of insects which would have had to be

> eaten to at least compensate for the weight loss during the field trials appears relatively low. This exemplary calculation affirms the overall scarceness of invertebrates as food for chicks in the considered habitats.

In addition to the analysis of weight changes, the pecking rate as pecks per minute was recorded to intentionally index feeding behaviour as a function of prey abundance, detectability and accessibility in the five habitat types. Although there was no direct correlation between pecking rate and weight change, from an ecological point of view the comprehensible pattern found with the weight changes was similarly reproduced by the pecking rate. The wild flower crop was the overall best habitat with relatively high compensation for weight loss and the highest pecking rates. Grass track and maize performed worst in both respects and wheat was somewhat intermediate. Segetal was under sampled; thus results should be taken with care. Identifying eaten food items was not possible because of their often small size, rapid movement of chicks and/or foraging in dense vegetation. Erpelding *et al.* (1987) found it difficult to identify food items of chicks older than two weeks despite the increasing size of food items with increasing age of the chicks. The same authors found that chicks from two weeks on became more proficient at capturing invertebrates. However, little is known as to how efficiently chicks can find and catch different prey items in various habitats (Itämies *et al.* 1996). This finding explains, to a certain extent, the unsuccessful pecks of our less than two-week-old chicks. Additionally, a higher degree of explorative pecks of young chicks then leads in the field trials to a disassociation of pecks and weight change in contrast to the indoor trials. Moreover, only one peck can result in significant weight increase if the prey is large.

The method using weight changes in human-imprinted partridge chicks to index habitat-specific food availability is significantly more labour intensive but has the potential to provide a more biologically relevant index of invertebrate abundance and availability than classical entomological sampling techniques. Nonetheless, with the limitations found in the methodological design evaluated in this study further adaptations as described above have to be tested and optimised in order to develop a suitable method for analysing the quality of habitats for brood rearing in the Grey Partridge.

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Ravinnon määrän arviointi eri elinympäristöissä käyttäen ihmisiin tottuneita peltopyyn (*Perdix perdix*) poikasia

Maatalouden toimintatapojen ja ympäristönsuojelutoimien arviointi tiedostetaan yhä tärkeämmäksi maatalousympäristöjen lintujen taantuman pysäyttämisen kannalta. Yksi pääsyistä peltopyykannan romahdukselle Euroopassa on ollut poikasten elossasäilyvyyden heikentyminen, mikä on suoraan yhteyksissä ravintona käytettyjen selkärangattomien määrään ja biomassaan.

Arvoimme uutta menetelmää, jossa ihmisiin tottuneita peltopyyn poikasia käytetään vertaillessa suhteellista ravinnon saatavuutta (g / poikanen / 30 min) viidellä eri elinympäristötyypillä viljellyillä pelloilla. Keskimäärin poikasten paino laski hieman kokeiden aikana, mikä kertoo alhaisesta ravinnon määrästä ja toisaalta menetelmän rajoitteista. Poikasten paino laski eniten perinteisillä maissi- ja vehnäpelloilla sekä rehevillä ruohokäytävillä. Vähiten poikasten paino taas laski vehnäpelloilla sijaitsevilla rikkaruohostoilla ja luonnonkukkaviljelmällä, jota viljellään ympäristöystävälliseksi ainesosaksi biokaasun tuotantoon.

Painon laskun syyksi ehdotetaan tihentynyttä ulostamista ja ravinnon määrän oletetaan vaikuttavan siihen, kuinka paljon poikaset kompensoivat laskenutta painoa. Kun menetelmän rajoitteet otetaan huomioon tulevissa tutkimuksissa, ihmisiin tottuneiden peltopyyn poikasten painonmuutoksia voidaan pitää merkityksellisenä indeksinä ravinnon saatavuudesta ja eri maatalousympäristöjen ja kasvilajikkeiden arvosta ruokailuympäristöinä.

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