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*Short research contribution*

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# GRANIVORY OF BIRDS AND SEED DISPERSAL: VIABLE SEEDS OF *AMARANTHUS RETROFLEXUS* L. RECOVERED FROM THE DROPPINGS OF THE GREY PARTRIDGE *PERDIX PERDIX* L.

ABSTRACT: The droppings of the Grey Partridge *Perdix perdix* L. wintering on a set-aside field were found to contain 99.3% of *Amaranthus retroflexus* and 0.7% of *Chenopodium album* seed coat fragments. A bird consumed on average 3008 (± 95% CL = 2699–3317) weed seeds per 1 g of droppings. The excreted seed coat remnants made up *c.* 21% of the swallowed seed mass. Approximately 0.3% of the ingested seeds passed undamaged through the gut. The number of undamaged seeds in the droppings was not significantly correlated with the weight of droppings and the amount of the excreted sand grains, seed coat fragments and other plant parts. After over 1.5 years of storage, 3 out of 18 sown undamaged seeds of *A. retroflexus* germinated. The average germination time of the excreted seeds was 10 days, while for the fresh ones it amounted to 8.5 days. Our results shows that the Gray Partridge is poor seed disperser and it play important role as predator of *A. retroflexus* seeds.

KEY WORDS: *Amaranthus retroflexus*, dicotyledonous weeds, *Pedrix pedrix*, seed digestion, weed dispersal

Weed seeds form the staple diet of many species of farmland wildlife (Marshall *et al.* 2003), including numerous seed-eating birds (Wilson *et al.* 1999, Holland *et al.* 2006). The availability and high density of weed seeds is a factor allowing the survival of many birds, especially in the autumn-winter period, when the diet of most of the farmland species wintering in the temperate northern hemisphere is exclusively granivorous (Moorcroft *et al.* 2002).

The Grey Partridge *Perdix perdix* is a species with the negative abundance trend in most European countries (Tucker and Heath 1994, Donald *et al.* 2006). In the autumn-winter period the diet of Grey Partridge, inhabiting temperate and cold parts of Europe, is based exclusively on plant matter, mainly the green mass of cultivated plants and seeds of cereals and arable weeds (Oko 1963, Glutz von Blotzheim 1973, Cramp 1998).

Birds and mammals can contribute to the long-distance seed dispersal (LDD) of some plants (Dean *et al.* 1990, Higgins *et al.* 2003). Long-distance dispersal events are very rare and difficult to investigate, because of their low frequency. Quantifying LDD has been always very difficult task but the rule is that the long-distance dispersal is very rare (Ouborg *et al.* 1999). There is a great need for better dispersal data in many areas of applied ecology (Cain *et al.* 2000). The issues of seed dispersal by vertebrates regarding species with fleshy fruits (Izhaki *et al.* 1991, Debussche and Isenmann 1994), including invasive flora (Williams 2006) and aquatic plants (Green *et al.* 2002) were discussed quite often (Traveset 1998). Dispersal as the consequence of herbivory (Pakeman *et al.* 2002, Cosyns *et al.* 2005, Bruun and Poschold 2006) was often studied as well, but active seed predation may also accomplish dispersal but with substantial mortality of seeds (Tiffeney 2004). There is currently a shortage of studies dealing with long-distance dispersal of invasive arable weed seeds by farmland wildlife in Europe (e.g. review for genus of *Amaranthus* in Costea *et al.* 2004). Analysis of rare dispersal events connected with granivory may et least partially explain the nature of weed invasion.

The aim of the present study is to determine the potential role of Gray Partridge in the long-distance dispersal of invasive arable weeds occurring in the crop fields of south-western Poland. We discussed the effectiveness of this disperser (sensu Schupp 1993). The paper presents detailed information on digestion and viability of the excreted weed seeds while also describing the relation between undamaged seeds and other components of the droppings as well as their weight.

The analysis of the digestibility of weed seeds and their viability was made with the use of Grey Partridge droppings (n = 23) collected in the vicinity of Wrocław (south-western Poland) on January 2004. The samples were taken from a set-aside field (approximate location: 51°01´N, 17°04´E), heavily overgrown with *Amaranthus retroflexus* L., where potatoes had been cultivated. The collection of droppings was preceded by the observation of flock of 4 individuals of Grey Partridge. The total weight of droppings, dried over three weeks by a heat emitter amounted to 2.556 g (mass of one dropping varied between 0.023 and 0.240 g).

The laboratory analysis of the collected material was resumed in October and November 2006. The initial examination with the use of binocular revealed the presence of some whole, intact seeds. In order to separate them, the droppings were first dissolved in water. After the removal of seeds the rest of material was then soaked in 0.25 M solution of $Na_2CO_3$ in order to dissolve mucus and acid as well as to separate the food particles glued together. 24 hours after soaking the samples were boiled and drained (Ralph *et al.* 1985). The seed coat fragments were then divided into species and counted under the microscope (×40), sand grains and other plant parts were also counted.

The whole seeds, separated from droppings, were cooled in the refrigerator for 14 days at the temperature of *c.* > 0–1°C. They were subsequently sown on Petri dishes lined with the damp filter paper and watched over 30 days. The viability of these seeds was compared to that of the fresh seeds of *A. retroflexus* collected at the beginning of February 2007 (3 samples; 100 seeds each), which had also been cooled over 14 days at the temperature of around 0°C. Mean time of germination ($T_G$) was calculated in the following way (Lityński 1982):

$$T_G = \frac{\sum (D \times N_D)}{TG}$$

where, (*D*) subsequent day of germination, ($N_D$) percent of seeds germinated on particular day, (*TG*) total germination, germinated seeds as the percentage of the total number of sown seeds.

The weed seed digestibility, defined as the number of whole seeds needed to produce a given number of coat fragments was calculated on the base of the relation between the total weight of seed coat fragments found in the droppings and the weight of mean dry mass of the whole seed coat. The whole seed coats were collected after germination of seeds in the greenhouse, they were dried and weighted (30 coats of *A. retroflexus* and *C. album*). The mean weight of a coat fragment was calculated for 600 (3 × 200) randomly selected fragments. Ultimately, the number of coat fragments per number of consumed seeds per 1 g of droppings was calculated. Weight of one seed of *A. retroflexus* (0.44 mg), based on the mean weight of 500 dried seeds (5 × 100) was used to calculate the ratio of the weight of consumed *vs*. excreted seeds. The obtained mean values were given with (±) 95% confidence limits (CL).

Table 1. Spearman rank correlation coefficients between the number of undamaged seeds of *Amaranthus retroflexus* ($n$ = 18) and features of extrected material contained in the droppings of the Grey Partridge *Perdix perdix*. [1]Fragments of seed coats and seeds with damaged coat. [2]Fragments of inflorescences, stems and leaves. Asterisks denote the significance level: * – $P$ <0.001; (ns) – not significant ($P$> 0.05).

| Effect | Number of undamaged weed seeds | Number of other plant parts[2] | Number of weed seed fragments[1] | Number of sand grains |
|---|---|---|---|---|
| Weight of droppings | 0.24 | 0.68* | 0.92* | 0.17 (ns) |
| Number of sand grains | –0.31 (ns) | 0.09 (ns) | 0.02 (ns) | – |
| Number of weed seed fragments[1] | 0.13 (ns) | 0.69* | – | – |
| Number of other plant parts[2] | 0.19 (ns) | – | – | – |

The relationship between the number of undamaged weed seeds of *Amaranthus retroflexus* (n = 18) found in the droppings, their weight and the content of exctrected material (sands, seed coats and seeds with damaged coat, fragments of stems and inflorescences) were tested with a Spearman rank correlation coefficient in software Statistica 6.0 (StatSoft 2006). Results with probability $P$ ≤0.05 were treated as statistically significant.

A total of 118 480 (99.3%) seed coat fragments of *Amaranthus retroflexus* and 874 (0.7%) of *Chenopodium album* were found in the studied droppings. The remaining content was made up of parts of inflorescences and other plant fragments, mainly stems and leaves ($n$ = 9 685) as well as grains of sand ($n$ = 7 811).

The mean weight of a coat fragment found in droppings was 0.0054 mg, and the mean of weight of the whole coat – 0.209 and 0.089 mg for *A. retroflexus* and *C. album* respectively. In the digestion process one whole seed coat fell apart into average of 16.2 (*A. retroflexus*) and 38.1 (*C. album*) fragments. An average (± 95% CL) of 3008 (2699–3317) seeds of both weed species was consumed by a partridge to produce 1 g of faeces. The total weight of all consumed weed seeds ($n$ = 7 365) amounted to *c.* 3 249 mg., whereas the excreted seed coat fragments weighed jointly *c.* 670 mg. The excreted seed coat fragments constituted therefore *c.* 21% of the swallowed seed mass.

In 9 (39%) out of all droppings 18 undamaged seeds of *A. retroflexus* and 1 seed of *C. album* were found. In these droppings between 1 and 5 undamaged seeds were found and the share of undamaged seeds ranged from 0.3 to 1% (mean ± 95% CL = 0.6% ± 0.4–0.8%) of all consumed seeds. The proportion of the undamaged seeds to the total number of all consumed seeds ($n$ = 7 365) amounted to *c.* 0.3%. The number of undamaged weed seeds was not significantly correlated with any analysed feature of the droppings (Table 1).

Three out of 18 sown undamaged seeds of *A. retroflexus* germinated. They sprouted respectively on the day 5, 9 and 16, which gives the average germination time ($T_G$) of 10 days. As a comparison, the average time for fresh seeds of *A. retroflexus* (49% seeds germinated) amounted to 8.5 days.

On the basis of our results, which found that the number of undamaged seeds in droppings of Grey Partridge is very low, we should define, that Grey Partridge is not an effective dispersal vector for *A. retroflexus*. According to Schupp (1993) dispersal agents differ in their effectiveness quantitatively (number of dispersed seeds, distance of dispersal) and qualitatively (treatment and the place of deposition of seeds). In the case of Grey Partridge number of viable seeds found in droppings was low, what is fully understandable in the case of granivory. Distance of dispersal is also probably low, because all droppings were found in the close vicinity of feed source. However some bird species (The Yellow-vented Bulbul *Pycnonotus xanthopygos* [Hemprich and Ehrenberg 1833] and The Blackbird *Turdus merula* L.) have not defecated seeds which had been swallowed together at the same time, but they were gradually dispersed. This pattern of temporal seed deposition is thought to have a positive implication on seed dispersal in space (Barnea *et al.* 1992). Although we have no data concerning the presence of temporal deposition in the case of Grey Partridge and the other species, we can not exclude absolutely the probability of presence of this process. As regards qualitative components of the dispersal effectiveness (the majority of seeds was destroyed during passage through the partridge gut) seed passage also lowers the germination ability of seeds in comparison with uningested seeds. However the probability of placement of alive seeds in germination safe site seems to be quite high, because of the type of habitats penetrated by the birds.

*A. retroflexus* as a neophytic weed is one of the most expansive species in central Europe. It has become a dominant weed, especially in root crops and represent a serious problem for several plants of economic importance, where controls with post-emergence herbicides have been shown to be not effectives (Rola *et al.* 2002, Lososova *et al.* 2004). The densities of *A. retroflexus* can reach 100 plants $m^{-2}$, and the seed production can climb to 1 900 000 diaspores per plant (Costea *et al.* 2004). It should be underline, that the Grey Partridge is, rather than disperser, a strong predator of *A. retroflexus* seeds and play with other granivorous birds important role in biological control of invasive weed species in Europe (e.g. Holmes and Froud-Williams 2005). In the 1960s in central Poland up to 141.6 kg of *A. retroflexus* seeds per 1 $ha^{-1}$ of crops were produced, as much as 50% of which were consumed by House Sparrow *Passer domesticus* L. and Tree Sparrow *P. montanus* L. (Pinowski and Wójcik 1968). Although, as the present paper shows, *c.* 0.3% of seeds passed through the partridge gut undamaged, this value is just a tiny fraction of all ingested seeds. Much smaller granivorous birds (e.g Reed Bunting *Emberiza schoeniclus* L.) digest all swallowed seeds (Orłowski and Czarnecka 2007). However the high potential of *A. retroflexus* to be dispersed by herbivores and granivores is worth underlining. Round seed shape, small size, high abundance and longevity of seeds are features of species germinated from herbivore dung (Pakeman *et al.* 2002, Bruun and Poschold 2006). *A. retroflexus* create persistent seed bank (longevity index is 0.94; calculated according to Thompson *et al.* 1998 based on data from Thompson *et al.* 1997) and adaptation required to survive ingestion and transport through the gut are thought to be similar to those needed to survive in the seed bank (Pakeman *et al.* 2002).

Even a small amount of seeds which passed intact through digestive system of bird can be extremely important in the long-distance dispersal (Lambert 1989). Rare events of dispersal (like described in this paper) may be potentially important especially in the context of biological invasions. Long-distance dispersal events are especially important for invasive plants because they affect colonization probabilities and probabilities of population persistence in fragmented habitats (Ouborg *et al.* 1999). The described viability of excreted *A. retroflexus* seeds points to the role of Grey Partridge as a factor contributing to the long-distance dispersal of this weed species, although this bird is sedentary (Cramp 1998) thus the potential spread of seeds is limited only to the small landscape scale. The lack of similar studies and the modest sample analysed in the present paper imply however the need for further research on the dispersion of invasive arable weeds by farmland wildlife in Europe.

The results of the present study showed that the food of partridges wintering in some habitats of South-western Poland was made up in over 99% by the seeds of *A. retroflexus*. It is a new finding related to the Grey Partridge ecology, as there are no reports published so far about domination in diet of this weed species (Oko 1963, Steenfeldt *et al.* 1991, Cramp 1998, Holland *et al.* 2006). In 1960s in western Poland the share of seeds of *A. retroflexus* in food of the Grey Ppartridge (for 420 individuals hunted in year cycle) was the highest in late autumn, and amounted in October to 5%, in November 6%, in December 17% and in January 0.5%, in the rest of months the share not exceed 0.4% (Oko 1963). Consequently, local abundance of *A. retroflexus* certainly boosts the food resources for granivorous birds. Its seeds were also mentioned recently as one of the main diet ingredients (up to 46%) of Reed Bunting *Emberiza schoeniclus* wintering in various crops in south-western Poland (Orłowski and Czarnecka 2007).

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