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SHORT COMMUNICATION

Establishment of *Rhinanthus angustifolius* in a successional hayfield after seed dispersal by mowing machinery

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SUMMARY

The role of seed dispersal by mowing machinery in the invasion into a hayfield under restoration management was investigated for the annual hemiparasite *Rhinanthus angustifolius* (C.C. Gmelin). Therefore, all plants of *R. angustifolius* in a hayfield were removed before seed production in 1994. As *R. angustifolius* seeds rarely survive for more than 1 year this would almost entirely prevent establishment of seedlings in 1995. In August 1994 the hayfield was divided into three parts. Under fair-weather conditions two of these parts were mown by a clean tractor disk mower combination and a tractor disk mower combination previously contaminated with *R. angustifolius* seeds, respectively. The third part was mown under rainy conditions by a contaminated caterpillar mower. In June 1995 all established *R. angustifolius* plants within the three parts were mapped.

In both parts mown by contaminated machinery more plants of *R. angustifolius* were found as compared to the part mown with clean machinery. The part mown under wet-weather conditions by the caterpillar mower, in particular, contained many established plants of *R. angustifolius*. The results suggest that spatial patterns of establishment are induced by machinery.

The conclusion of the experiment is that mowing machinery acted as a dispersal agent of *R. angustifolius* seeds in 1994. This probably applies to other hayfield species as well. Machinery may therefore play a major role in seed dispersal within the nature reserve, enhancing the speed of succession within hayfields. The circumstances under which the experiment took place did not allow us to conclude on separate effects of machinery type or weather conditions on seed dispersal. However, both effects may exist.

Key-words: agestochory, *Rhinanthus angustifolius*, succession, seed dispersal, mowing machinery, species establishment, restoration.

INTRODUCTION

Agestochory, the dispersal of seeds by vehicles, sometimes plays an important role in long-range dispersal of plant species. In arable fields combiners are an important dispersal vector of weed seeds (Ghersa *et al.* 1993; Howard *et al.* 1993; Mortimer *et al.* 1993). In hayfields machinery may also act as dispersal agents (Bakker & De Vries 1988; Strykstra & Verweij, in press). This is of special interest when species-rich hayfield plant communities are being regenerated by hay-making without application of fertilizer (Bakker 1989; Bakker & Olff 1995).

Hayfield succession in the Drentse A nature reserve induced by this type of management follows a well defined pathway of change in species composition (Olff & Bakker 1991; Bakker & Olff 1995). Single species dominate early successional stages. Of these species the grass *Holcus lanatus* is the first to appear, dominating the first years of succession, after which *Rhinanthus angustifolius* (C.C. Gmelin), a hemiparasite appears and becomes dominant. The establishment of a population of *R. angustifolius* can be very explosive (De Hullu *et al.* 1985; Ter Borg 1985). As *R. angustifolius* has a transient seed bank, i.e. seeds in or on the soil have a very short lifetime (De Hullu *et al.* 1985; Ter Borg 1985; Thompson *et al.* 1996), this cannot be attributed to emergence from an existing soil seed bank.

The rapid way of establishment, therefore, suggests a very efficient dispersal of seeds between and within hayfields. It has been demonstrated that seeds of *R. angustifolius* are transported and probably dispersed in large amounts by hay-making machinery (Bakker & De Vries 1988; Strykstra & Verweij, in press). The fast population growth (De Hullu *et al.* 1985) may also be attributed partly to dispersal by hay-making machinery (Ter Borg 1985). However, although it is expected, it has never been shown that it is actually the dispersal of seeds by mowing machinery that leads to establishment of *R. angustifolius* in new fields added to the reserve.

This paper describes a small experiment carried out to investigate if it is possible that the establishment of new populations of *R. angustifolius* is initiated through seed dispersal by mowing machinery. This is done by mowing a target field in an early successional stage with machinery deliberately contaminated with *R. angustifolius* seeds from an adjacent, later successional field in a way which corresponds to the management practice.

METHODS

From June 1994 until the mowing date in the beginning of August 1994, in the experimental field a small number of *Rhinanthus angustifolius* plants were found, indicating that establishment of this species was possible. These plants were systematically removed before seed rain. Since *R. angustifolius* has a transient seed bank we assumed that this would largely prevent re-establishment in the next year within this field.

In the beginning of August 1994 a large part of the experimental field was subdivided into three sections, which received different mowing treatments. The fringe of the experimental field and section 1 were mown by a tractor with disk mower of which all plant material was carefully removed before it entered the field (clean machine). Section 2 was mown by a similar machine which first visited and mowed part of a hayfield with a dominance of *R. angustifolius* bearing seeds (dirty machine 1). In the sections mown

by the disk mower the mown material was picked up by clean machinery. Section 3 was mown by the caterpillar mowing machine, which immediately picks up the material and deposits it in a container at the back of the machine. This machine also visited and mowed part of the same field as the machine that mowed section 2 (dirty machine 2). After contamination with seeds the dirty machinery had to drive about 300 m over a sandy road. Originally, the aim of the experiment was to distinguish between the effect of two different types of machinery. It is known that different types of harvesting machinery may differ in weed seed dispersal capacity (Ballare *et al.* 1987). This can be expected for mowing machinery as well. However, the two types of machinery had to operate under different weather conditions. The disk mower, both clean and dirty (sections 1 and 2) operated under dry weather conditions. The next day, when section 3 was mown with the caterpillar mower, it was raining. It was observed that wet plant material adheres to machinery very well, whereas dry plant material does not, and this was expected to influence the results to a large extent. However, the amount of adhering material was not quantified.

The driving direction of the machinery was along the long axis of the sections, starting at the higher end at the left side. The narrowness and the presence of a ditch caused the machinery to do some manoeuvring at the lower end in all three sections.

In July 1995 all *R. angustifolius* plants in the three experimental sections were counted and mapped. Clusters of plants very close to each other were mapped as one spot, but counted as separate plants.

RESULTS

Figure 1 shows the distribution of the spots in the target field. In section 1 a small number of *R. angustifolius* plants within few spots were found. In section 2 more spots were found, which were located at the lower end of the section. In section 3, however, a large number of spots and plants were found over the whole area.

Figure 2 shows the cumulative number of *R. angustifolius* plants against the distance to the left side of section 3. In this figure at certain distances a sudden increase in number of plants can be seen. Towards the right side of the section the distance between those sudden rises, which was about 2·3 m, corresponds to the distance between the tracks of the number 2 mowing machine. Towards the left side, where the mowing started, this pattern is somewhat irregular, although the 2·3 m distance can be roughly found between some of the rises. Therefore, the pattern of the spots seems to match the movements of the machine.

DISCUSSION

The results show that *R. angustifolius* plants emerged in section 3, which was mown using a dirty caterpillar mower under rainy weather conditions. A small number of those plants may have derived from seeds that were shed in 1993 or 1994 as some plants were found in section 1. The establishment of mature *R. angustifolius* plants from sown seeds in a similar vegetation was found to be 0·54% (De Hullu & Ter Braak 1985). Demographic data from another study by De Hullu *et al.* (1985) show percentages of establishment from seed of about 1%. The number of mature plants found within section 3 therefore suggests that thousands of seeds were deposited in section 3.

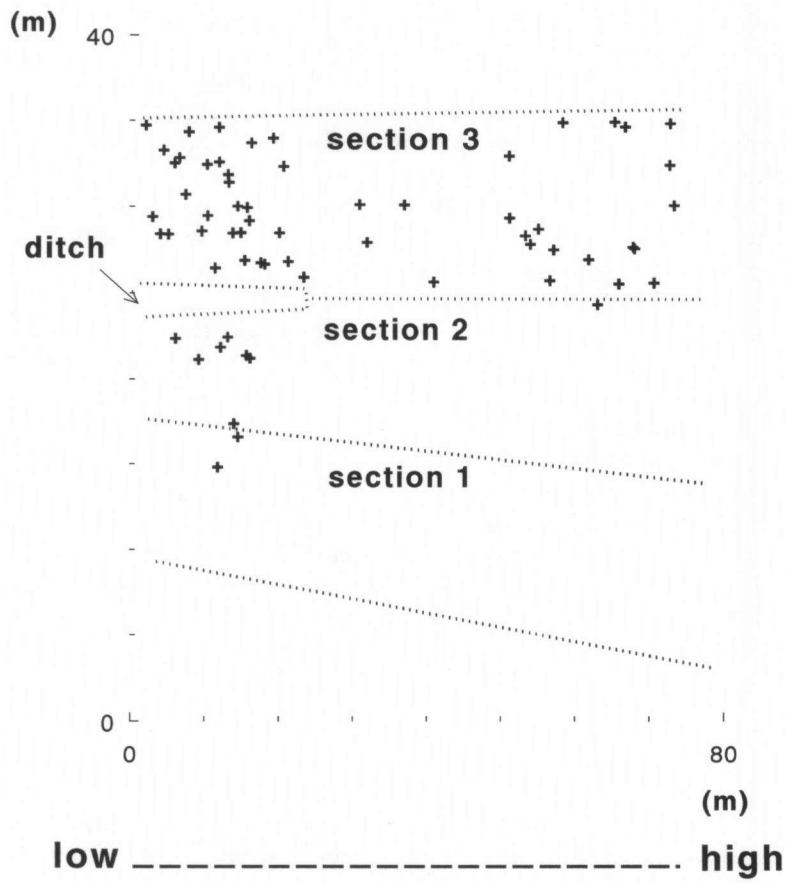

Fig. 1. The spatial distribution of spots in the experimental sections recorded in 1995, the year after mowing. Section 1: mown by clean disk mower combination. Section 2: mown by dirty disk mower combination, contaminated with *Rhinanthus angustifolius* seeds. Section 3: mown by caterpillar mower, contaminated with *R. angustifolius* seeds.

This leads to the main conclusion that, like other vehicles including cars (Clifford 1959; Lonsdale & Lane 1994) and harvesting machinery in arable fields (Ghersa *et al.* 1993; Howard *et al.* 1993; Mortimer *et al.* 1993) mowing machinery can be a very effective dispersal agent both in terms of seed numbers and in distance. It is shown to be capable of initiating new populations of *R. angustifolius.*

The results of the experiment show a marked difference between section 2 and 3, mown by the two different types of dirty machinery. The disk mower led to some establishment of *R. angustifolius*, but far less than the caterpillar mower. No firm conclusions about what caused this difference can be drawn from the results of the experiment. Arable weed seed dispersal is known to be related to harvesting methods including machinery type (Ballare *et al.* 1987). The caterpillar mower seems to have a somewhat larger adhesive surface, for instance, considering the size and construction of the tracks. However, it seems unlikely to us that this difference in machine structure would lead to such a large difference found in establishment of *R. angustifolius.* More likely, the different weather conditions under which the two types of machinery operated

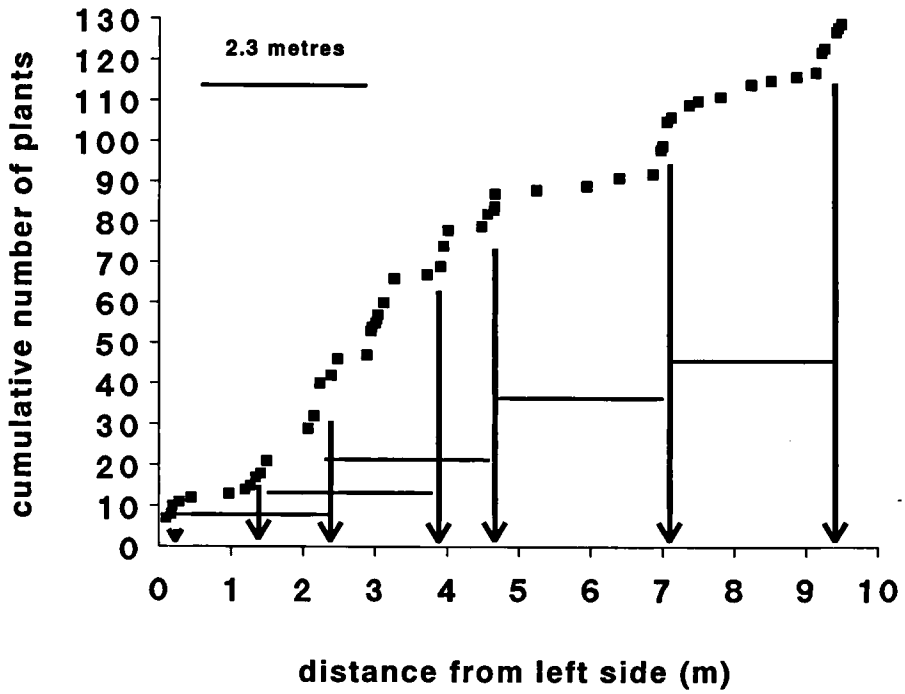

Fig. 2. Cumulative number of *Rhinanthus angustifolius* plants recorded in section 3 in 1995 at separate distance from the left side of the section, the first year after mowing. The horizontal bars in the figure represent the 2·3 m distance between the tracks of the caterpillar mower.

during the experiment played an important role. The adhesion of seeds was observed to be better on the caterpillar mower operating under wet conditions. A new and more elaborate experiment would be necessary to distinguish between the effects of weather conditions and machinery.

It has been shown that machinery may initiate establishment of *R. angustifolius* within a large area within one season. This may lead to an explosive invasion by *R. angustifolius* in newly acquired fields. In practice this can be observed in the Drentse A reserve (De Hullu *et al.* 1985; Ter Borg 1985). The speed of expansion within a field may also depend on machinery action.

The direction in which machines drive may influence the spatial pattern of weed invasion (Fogelfors 1985) and dispersal within fields (Mesa Garcia *et al.* 1986; Ghersa *et al.* 1993; Howard *et al.* 1993) in arable land. Considering the results presented in this paper it can be concluded that spatial patterns induced by machinery may occur between and within hayfields.

In an earlier experiment, which investigated the presence of seeds on a disk mower (Strykstra & Verweij, in press), we found that the mower was an efficient carrier and probably a dispersal vector of many species between and within hayfields. Populations of many other species besides *R. angustifolius* may actually be initiated by agestochory. Most grassland species do not have persistent soil seed banks (Thompson & Grime 1979; Pfadenhauer & Maas 1987; Bakker 1989; Thompson *et al.* 1996). This implies that mowing machinery may be very important as an interconnecting agent, enhancing the establishment of new species in hayfields under restoration management.

The lack of any connection to seed sources could explain slow succession, which is often observed in isolated hayfields. For instance, Oomes (1990) found no increase in species number or richness although the decrease of biomass production was similar to that in the Drentse A hayfields. The dispersal by hay-making machinery is certainly part of the explanation for the fast and predictable succession (Olff & Bakker 1991; Bakker & Olff 1995) in parts of the Drentse A reserve, where older and younger fields with respect to restoration management history are interconnected by machinery routes.

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