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## Predicting Arable Weeds' Competitive Abilities From Plant Traits.

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### Summary

Little is known about the competitive response of plants in comparison with competitive effect. The present study measures the relative competitive ability of herbaceous plant and tests whether it is correlated with simple measurable plant traits. 14 arable weeds were collected in cereal fields and tested against a phytometer, *Triticum aestivum* var. Darius. The aims of this experiment were primarily (i) to identify plant traits to predict competitive ability of arable weeds against a domesticated species and (ii) to apply our results to predict competitive ability of arable weeds. Simple regressions showed a predictive relationship between plants traits and competitive ability. The biomass of the phytometer was correlated with several traits, but most strongly with the allocation of biomass to the stems of the test species. General implications of these results are that competitive ability of arable weeds could be easily predicted by measuring plant traits with a simple experimental design.

### Introduction

Historically, two opposing directions can be distinguished in the research on weed communities of arable fields: (i) the principle objective of the research of the agronomists and weed researchers has been the understanding of the population dynamics of weed species, with the aim of being able to control the expansion of these species, using culture practices and herbicides because arable weeds compete with the domesticated species for water, mineral elements, space and light (Firbank *et al.*, 1991); (ii) the work of ecologists also aims to understand the dynamics of the weed populations, but with a goal of conserving species threatened by the intensive usage of weed killers (Aymonin, 1962; Jauzein, 1995). These two fields of research have existed in isolation for a long time. However, over the last few years, work has appeared in which the aim is the control of weed populations by the use of better identification of the most competitive species (Dekker, 1997). This identification allows the use of better targeted weed killers, and is thus more respectful of the biodiversity of arable fields because certain weed species are currently in strong decline or are threatened in France (Montegut, 1997).

The majority of research carried out on the competition in large-scale agriculture systems takes into account the population density of the weed species (Firbank & Watkinson, 1990; Wilson & Wright, 1990). However, this parameter can mask variations which result from other factors, for example, the plant size (Weiner & Thomas, 1986). Our study has therefore been based on a single density, with constant distances and angular dispersion of plants. The effect of other parameters may be clearly identified in this way (Gaudet & Keddy, 1988). Further, most research has been carried out in agricultural systems where high level of chemical fertilisers are used (Firbank *et al.*, 1990). The substrates used therefore contain a high concentrations of mineral material (Iqbal & Wright, 1997, Chachulski *et al.*, 1999). We have instead chosen to work in the south-east of France, where there is extensive agriculture where low levels of chemical fertilisers are used, and an important weed flora still exists, including species of high national heritage value (Filosa, 1985; 1997).

The different objectives of this study are therefore: (1) to identify the most relevant morphological traits to determine the capacities of arable weed species in competition with a domesticated species cultivated at a large scale; (2) to validate the method of cultivation with interspecific competition; (3) to use the results obtained to predict the competitive ability of arable weed species; and (4) to discuss the results from a viewpoint of the conservation of certain rare arable weeds.

## Material and methods

### Study site

Seeds from the fourteen weed species studied were collected from cereal fields in the Luberon natural park in Upper-Provence, province of Vaucluse. Cultivated land in this region still contains a large number of weed species, including several of high national value, as they are rare or in the process of disappearing in France (Guende & Olivier, 1997). This richness is a result of the continuation of traditional agricultural practices, and the absence of the use of fertilizers or weed killers (Maillet & Godron, 1997).

### Experimental layout

Seeds of the weed species and wheat were germinated at high density in plastic culture pots of 3 dm<sup>3</sup>. At the stage of the appearance of the first leaf, surplus individuals were removed so that a single individual of wheat was retained. This will be henceforth termed the "phytometer" (Gaudet & Keddy, 1988). Four individuals of one of the arable weed species were also retained in each pot. The distribution and distances were identical across all the pots. For each weed species, five replicates were used (5 x 1 phytometer + 4 weeds). The chosen density was based on that observed in the sample area (Dutoit *et al.*, 1999). As a control, the phytometer was cultivated on its own, as a single individual placed in the centre of a pot (5 x 1 phytometer), and also with four individuals of the same species, in order to test the effects of intraspecific competition (5 x 1 phytometer + 4 phytometer). In total, 80 pots were used during the experiment, 70 for the 14 weed species investigated, 5 for the control and 5 for the intraspecific competition. The seeds of the weeds and the phytometer were planted in March 1998 and placed in a greenhouse. Plant growth was maintained between March 1998 and May 1998, until the phytometer matured, i.e. at fruiting and seed maturity.

The pots were filled with soil taken from an agricultural plot situated in the town of Rustrel (5°26'E, 43°55'N) in the Luberon. The agricultural exploitation of this plot is representative of that practised in the majority of fields in the region (Dutoit *et al.*, 1999). In this region, sowing takes place at the start of November, at a level of 170 kg of winter wheat (*Triticum aestivum* var. Darius) seeds per hectare. No chemical or mechanical weed killing is carried out. Organic fertilisers are added during October in the form of 10 tonnes of manure per hectare. Harvesting occurs toward the end of July, and the average production is 45 hundredweight/ha.

### Morphological traits

In May 1998, all individuals were cut at one cm from the neck. The different morphological characteristics were measured on the fresh material, before drying the samples in an oven, to obtain dry biomass measurements. Drying was carried out at 65°C until a constant weight was reached, taking approximately 48 hours depending on the plant part.

The morphological characteristics measured included: the height of the longest stem (principle axis), the number of leaves and of seeds, the height of the wheat-straw and of the inflorescence (the ears) of the phytometer. The values were averaged for the four weed individuals and across the five replicates. Biomass was measured as dry weight of the roots, stems, leaves and fruits (with seeds). These were weighed separately in order to calculate the above-ground biomass (stems + leaves + fruits), the below-ground biomass (roots) and the total biomass (stems + leaves + fruits + roots) of each individual. The biomass of each different plant organ was then compared against the total biomass of each individual in order to calculate the allocation of each part to the overall biomass.

### Statistical analyses

Correlations between the morphological characteristics of the weed species and the phytometer were examined using simple linear regression (program: Statview). After regrouping the values into five classes, a correspondence analysis (CA) was carried out (program: Statos) on the table/results of the 8 morphological traits measured for the phytometer and the 7 measured for the weed species (excluding the ear length), for each of the 16 situations (14 weed species, phytometer alone, phytometer + 4 phytometer). This gave a matrix of 40 variables (8 phytometer characteristics x five classes) and 51 individuals (7 characteristics x 5 classes + 16 species).

## Results

### Linear regressions

210 linear regressions were carried out between the different morphological traits measured for the phytometer and those measured for the 14 weed species, the phytometer in intraspecific competition and the single phytometer. For the number of variables/modalities (16) and for  $p < 0.0001$ , the level of significance for  $r^2$  has been calculated at 0.410 (Baillargeon, 1984). 33 of the linear regressions showed significant correlations between the morphological characteristics of the weeds and those of the phytometer. Negative correlations were obtained for all regressions between the phytometer morphological traits and the following characteristics of the arable weed species: total or above-ground biomass, stem biomass or height and a high allocation of biomass to the stem (Table 1).

Table 1. Significant correlations between traits of 14 arable weeds and traits of the phytometer (*Triticum aestivum* var. Darius).  $r^2 = 0,410$  and  $p < 0.0001$ . Correlations are simple linear correlations with the traits of the phytometer.

Arable Weeds	Phytometer	Correlation
Allocation to stems (%)	Biomass, above ground (g)	0,653
Allocation to stems (%)	Biomass, ear (g)	0,647
Allocation to stems (%)	Biomass, total (g)	0,640
Allocation to stems (%)	Biomass, stems (g)	0,626
Biomass, stems (g)	Biomass, leaves (g)	0,607
Allocation to stems (%)	Biomass, leaves (g)	0,581
Biomass, stems (g)	Biomass, stems (g)	0,571
Height (cm)	Height, ear (cm)	0,569
Allocation to stems (%)	Height, ear (cm)	0,565
Allocation to stems (%)	Allocation to the ear (%)	0,530
Allocation to stems (%)	Seed number	0,521
Biomass, total (g)	Biomass, total (g)	0,514
Biomass, total (g)	Seed number	0,514
Biomass, total (g)	Biomass, above ground (g)	0,513
Biomass, stems (g)	Biomass, above ground (g)	0,510
Biomass, stems (g)	Biomass, total (g)	0,509
Height (cm)	Biomass, stems (g)	0,499
Biomass, above ground (g)	Biomass, total (g)	0,490
Biomass, above ground (g)	Seed number	0,490
Biomass, above ground (g)	Biomass, above ground (g)	0,487
Biomass, above ground (g)	Biomass, leaves (g)	0,487
Allocation to stems (%)	Allocation to leaves (%)	0,483
Biomass, total (g)	Biomass, leaves (g)	0,480
Biomass, stems (g)	Height, ear (cm)	0,468
Biomass, stems (g)	Seed number	0,468
Height (cm)	Biomass, above ground (g)	0,463
Biomass, total (g)	Biomass, stems (g)	0,458
Height (cm)	Biomass, total (g)	0,458
Biomass, above ground (g)	Biomass, stems (g)	0,450
Height (cm)	Seed number	0,446
Biomass, stems (g)	Height, ear (cm)	0,445
Height (cm)	Biomass, leaves (g)	0,439
Height (cm)	Height, ear (cm)	0,431

Table 2. Correlations between traits of 14 arable weeds and biomass of the phytometer (*Triticum aestivum* var. Darius). \*\*\* $p < 0,0001$ . Correlations are simple linear correlations with phytometer biomass.

Plant traits	Correlation with phytometer biomass
Allocation to stems (%)	0,640***
Biomass, total (g)	0,514***
Biomass, stems (g)	0,509***
Biomass, above-ground (g)	0,490***
Height (cm)	0,458***
Biomass, leaves (g)	0,361
Leaf number	0,333
Biomass, below-ground (g)	0,306
Biomass, fruits (g)	0,235
Allocation to leaves (%)	0,088
Allocation to fruits (%)	0,086
Allocation to roots (%)	0,083
Shoot to root ratio (g/g)	0,064
Seed number	0,018

The total biomass value of the phytometer is normally considered as the best indicator of the effects of competition (Gaudet & Keddy, 1988). For this parameter, our results show that with increases in (i) the allocation of biomass in the stem, (ii) total, above-ground and stem biomass values and (iii) height of the principle axis, there is a reduction in the total biomass value of the phytometer (Table 2).

#### Correspondence analysis

The inertia percentages of the first two axes of the CA explain more than 60 % of the information/variation: 45.31 % on the first axis and 15.77 % on the second axis. The contributions of the variables and the individuals to the first axis of the CA show that strong values (class 5) measured for the phytometer morphological traits (Figure 1a), e.g. the biomass of the leaves or the wheat-straw (equal contribution: 13.4%), the number of seeds (10.7%) and the height of the ear (9.8%), are clustered with weak values (class 1) of the weed species morphological traits (Figure 1b), e.g. the stem biomass (14.8%), the height of the principle axis (9%) and the number of leaves (8.6%). The high values recorded for the traits of the phytometer cultivated alone, explain its strong contribution to the first axis (11.1%) and its place on the CA ordination diagram (Figure 1b).

Figure 1. CA carried out on the 5 classes (1-5) of traits measured for the phytometer (a) and 14 arable weeds (b). (BG biomass, below-ground; BS biomass, stems; BL biomass, leaves; BF biomass, fruits; HS Height, stem; NL Leaf number; NS, seed number; HE height, ear of the phytometer only).

FIGURE 1(a)

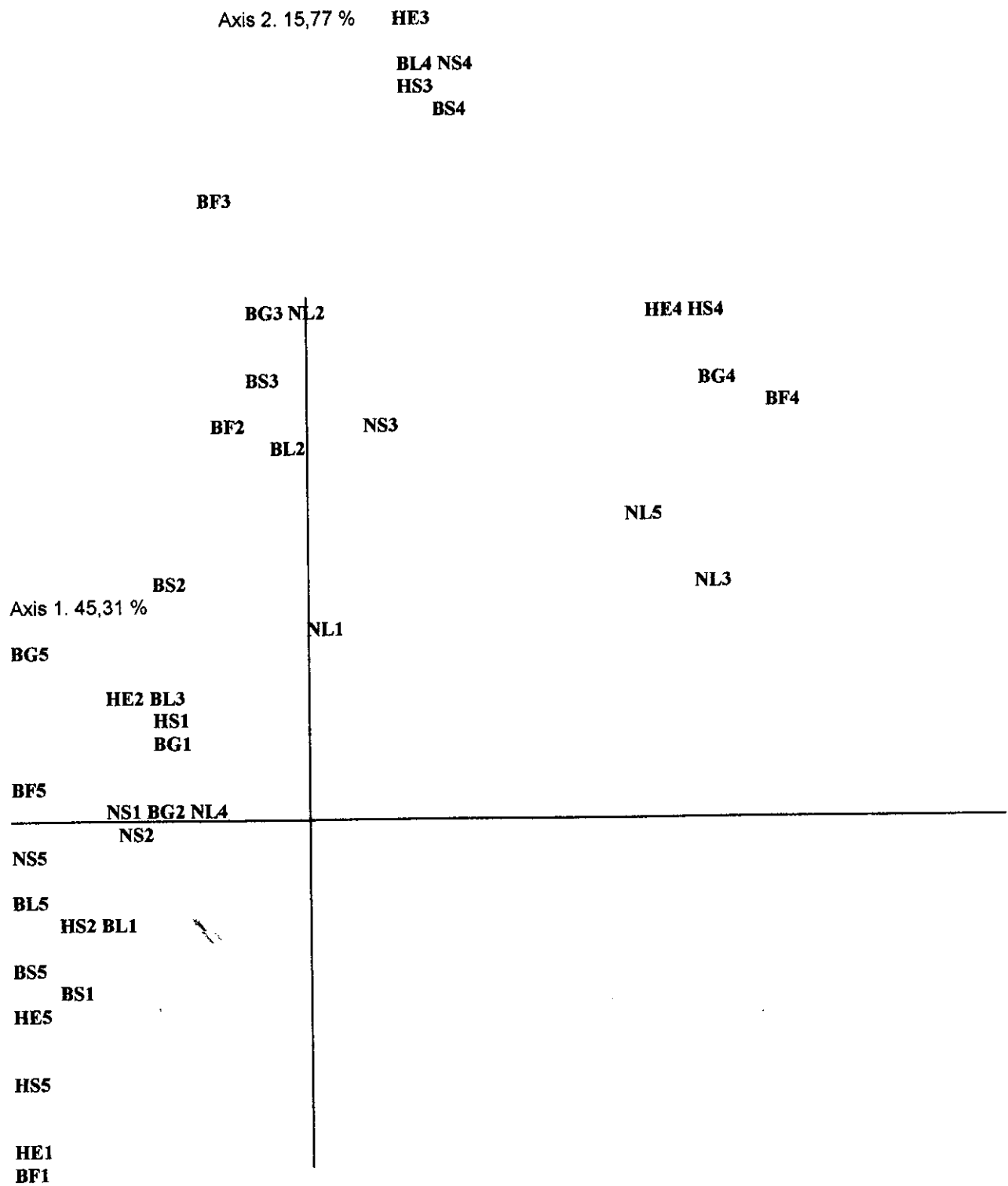
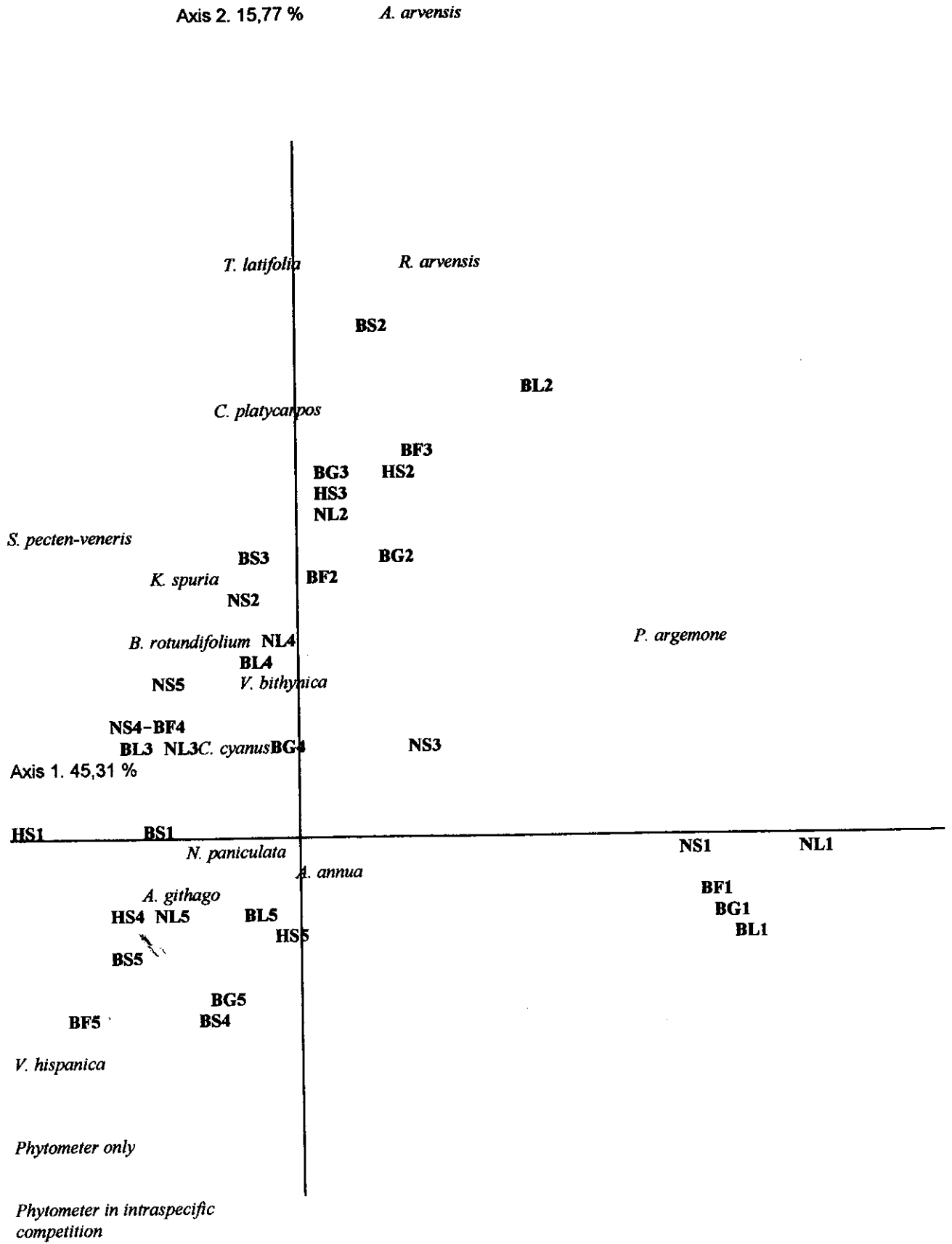


FIGURE 1(b)



Low values recorded for phytometer morphological traits, e.g. the biomass of the ear (3.1%), the wheat-straw (2.2%) and the leaves (2.1%), and the number of seeds (2.7%), are situated in the opposite direction on the first axis of the CA ordination diagram. These are grouped with high values of the weed morphological traits, e.g. Biomass of the fruits (4.2%), stems (2.8%) and the roots (3.8%). The very low values obtained for the morphological traits of the phytometer in intraspecific competition (1 phytometer + 4 phytometers) explain its low contribution to the first ordination axis (2%), and its position on the ordination diagram (Figure 2b).

The different weed species tested are spread along the first axis on a gradient from the most competitive species (Figure 2b), e.g. *Vaccaria hispanica* (1.9%), *Agrostemma githago* (0.8%), *Bupleurum rotundifolium* (0.5%), *Neslia paniculata* (0.4%), *Caucalis platycarpos* (0.3%), *Turgenia latifolia* (0.2%) and the phytometer in intraspecific competition, to the less competitive species, e.g. *Scandix pecten-veneris* (3.7%), *Papaver argemone* (0.8%), *Ranunculus arvensis* (0.1%), *Anagallis arvensis* (0.1%) and, obviously, the single phytometer used as a control.

## Discussion

Our results clearly show that competitive capacity of plants may be predicted using simple criteria such as their morphological traits. This process, applied to 14 species of weeds of large wheat cultures, shows that the competitive aptitude of the weed species in relation to the cultivated species is best explained by the allocation of biomass to stems, but also by the different biomass (stems, ears, total) and, to a lesser degree, the height of the principle axis. Although this experiment was carried out at a single density and with a single soil type, these results are representative of the majority of large-scale cultivated fields in the Mediterranean basin (Barbero *et al.*, 1984).

In our study, tall weed species which develop strongly have the greatest competitive effect on the total level of wheat biomass. For agricultural applications, it is important to note that these tall weeds with a high proportion of stem biomass will significantly affect the agricultural production of wheat by reducing the size and biomass of the ears, as well as the number of seeds in the ear. Of the species tested, six (*V. hispanica*, *A. githago*, *B. rotundifolium*, *N. paniculata*, *C. platycarpos*, *T. latifolia*) appear to be predominantly/relatively competitive with the resources invested in the stems (height or biomass), and the above-ground vegetative apparatus (biomass or number of leaves). Few results have been previously obtained for the other eight species (*A. annua*, *A. arvensis*, *R. arvensis*, *C. cyanus*, *K. spuria*, *P. argemone*, *S. pecten-veneris*, *V. bithynica*). This is because they are either very rare in the intensive cultures in the north-west of Europe (Jauzein, 1995), or they are essentially only present in the Mediterranean basin where agricultural practices with a strong traditional component still exist. These results confirm the potential of the method of cultivation with interspecific competition between weeds and the domesticated species, for the conservation of certain taxa which are currently in decline in cultivated fields. After identifying less competitive species, these may be spared by the use of selective herbicides, with no significant reduction in the production of the cultivated species.

## Conclusion

The application of the method of cultivation with interspecific competition using 14 arable weeds and wheat has shown that the best morphological traits to predict the competitive ability of the weeds are: the percentage of allocation of biomass to the stem, the above-ground and total biomass and the height of the principle axis. The application of this method to highly artificial ecosystems, such as cultivated field, is possible, with important implications. In agronomy, this will allow an improved application of herbicide treatments. In conservation biology, this will allow the preservation of certain weed species currently in serious decline in the national territory.

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