UNIVERSIDADE DE ÉVORA

COLONIZAÇÃO DE BERMAS DE ESTRADAS DO SUL DE PORTUGAL POR *Dittrichia viscosa* L. E SEUS EFEITOS NA DIVERSIDADE FLORÍSTICA DAS BERMAS

CINTIA SOARES DE SOUZA

Dissertação apresentada para a obtenção do grau de mestre
em Biologia da Conservação.

Orientador: Profª Drª Maria Paula Simões

Co-orientadora: Profª Drª Anabela belo

Évora, 2009

Esta dissertação não inclui as críticas e sugestões feitas pelo júri.

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O caminho para realização dos nossos sonhos, requer muita determinação, entusiasmo, persistência, muita força de vontade, principalmente para vencer os obstáculos. Porém caminhar sozinha é impossível.

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ÍNDICE GERAL

COLONIZAÇÃO DE BERMAS DE ESTRADAS DO SUL DE PORTUGAL POR *Dittrichia viscosa* L. E SEUS EFEITOS NA DIVERSIDADE FLORÍSTICA DAS BERMAS

RESUMO

A distribuição da espécie *D. viscosa*, nativa em Portugal, foi avaliada ao longo da berma de duas estradas, do sul do país. A composição florística e a percentagem de cobertura do solo das diferentes espécies foram amostradas em áreas de berma com e sem a influência de *D. viscosa*, para avaliar o seu efeito nas comunidades das bermas. O efeito do corte dos arbustos foi também estudado. A espécie em estudo apresentou uma clara preferência pelas bermas, comparativamente com as áreas envolventes. Os resultados sugerem que a presença dos arbustos provoca uma diminuição na biodiversidade das bermas. As estradas estudadas devem, portanto, ser alvo de controlo da distribuição desta espécie, para impedir a sua invasão. Com base nos resultados, sugerimos que o controlo deve ser efectuado através de dois cortes, no meio da primavera para impedir a propagação de incêndios e no final do verão, para prevenir a dispersão das sementes.

COLONIZATION BY *Dittrichia viscosa* L. OF ROAD VERGES OF SOUTHERN PORTUGAL AND ITS EFFECTS ON VERGE PLANT DIVERSITY

ABSTRACT

The distribution of the native species *D. viscosa* was evaluated along the road verges of two roads in southern Portugal. The plant species composition and cover were surveyed within the roadside habitats, in areas with and without *D. viscosa*, to evaluate its effect on road verge communities. The effect of mowing on *D. viscosa* shrubs was also assessed. Shrubs showed a clear preference to verges relative to the surroundings, indicating that *D. viscosa* seems to be invading the study road verges. Results also suggest that the presence of the shrubs decrease the plant diversity of road sides, with potential effects on animals as well. Therefore, the study roads should be considered as important targets of local and regional efforts to prevent invasions of this species. Based on our results, we suggest that to prevent *D. viscosa* invasion within roadside ecosystems, the control should be based on two mowings, in mid-spring to prevent fires and in late-summer to prevent seed dispersal.

INTRODUÇÃO

As vias de comunicação e as rodovias, em particular, são condição incontornável do desenvolvimento sócio-económico (Forman & Alexander, 1998 e Karim, and Mallik, 2008). A construção de estradas, ao fragmentar o espaço, provoca uma grande ameaça ao ambiente, porque condiciona a disponibilidade de habitat adequado para muitas espécies (Tilman et al. 1994; Leach and Givnish 1996; Van Groenendael et al.) e contribui para diminuição de populações de plantas e animais (Andrén, 1994; Fahrig, 2003).

Por conseguinte, o habitat linear (berma), resultante do impacto ambiental da construção da rodovia, tornou-se especialmente importante para a conservação da biodiversidade e pode desempenhar um papel crucial como refúgio e corredor ecológico para fauna e flora (Tikka et al. 2001; Smart et al. 2006). Relativamente à flora, a berma pode ser um importante habitat de plantas raras (Hopwood, 2008). No entanto, é muito mais predominante nesse habitat crescimento e propagação de espécies invasivas (Flory and Clay, 2006). Daí a importância do conhecimento deste tipo de habitat. Este está relacionado com a destruição e fragmentação de habitats.

A intensificação agrícola, o crescimento das áreas urbanas, entre outras actividades antrópicas, contribuem para a alteração da paisagem original. Mas o objecto deste estudo são os espaços intersticiais das estradas que, de facto, podem funcionar como local de conservação da biodiversidade vegetal, ou, e ao inverso, de propagação de plantas invasivas.

Neste sentido, o problema é particularmente crítico relativamente à sobrevivência das espécies endémicas a áreas restritas e que são difíceis de identificar antes que as actividades humanas as ponham em perigo irreversível. Por não existirem populações em outros locais, estas espécies não poderão ser recuperadas, uma vez perdidas (Lugo e Brown, 1996). Adicionalmente, as estradas são caracterizadas por frequentes perturbações (Trombulak & Frissell, 2000), dentre as quais, uma das mais importantes é o tráfico, em particular as deslocações de ar e os gases de escape. Embora, naturalmente, ocorram nas bermas plantas nativas que têm alto potencial para sobreviver e regenerar em habitats perturbados (Prach e Pysek, 2001) existe, contudo o risco de espécies não indígenas ameaçarem a biodiversidade nativa, alterando as características dos habitats, bem como a diversidade florística (Greenberg et al. 1997).

Evidentemente que as actividades humanas de manutenção podem facilitar processos biológicos tais como a dispersão.

Neste estudo, investigamos a relação da *D. viscosa*, ao longo das estradas no Sul de Portugal, uma espécie arbustiva naturalmente distribuída em volta da bacia mediterrânica (Brullo and Marco, 2000). Segundo, Wacquant (1990) refere-se que esta espécie cresce em habitats ruderais, tornando-se, por vezes, infestante, com capacidade de evolução e crescimento invasivo. Nos últimos anos a expansão tem sido observada em vários países mediterrânicos, possivelmente devido á diminuição da actividade humana em áreas ruderais.

Em Portugal, muito poucos estudos ecológicos têm incidido sobre os impactos da estrada sobre a vegetação, mas, em outras partes do mundo, Austrália, Nova Zelândia e América do Norte, e outros países europeus as estradas são considerados excelentes habitats para estudar a vegetação e as espécies como respostas às mudanças no ambiente (Lausi e Nimis, 1985; Ullmann e Heindl, 1989; Heindl e Ulmann, 1991, Wilson et al. 1992; Ullmann et al. 1995). Em Portugal há alguns estudos de fauna (Ascensão e Mira, 2006; Santos, et al. 2007). Porém sobre vegetação na berma e *D. viscosa,* em particular desconheço em absoluto.

A *D. viscosa* é uma espécie de porte arbustivo, que facilmente ultrapassa os 100 cm de altura. É claramente dominante em primeiras etapas de sucessão dos campos abandonados. Outra característica de estratégia competitiva consiste no papel do sistema fotossintético, radicular e um período vegetativo marcadamente estacional e prolongado. Assim, trata-se de características que tendem a maximizar o crescimento da planta e por tanto, a facilitar a aquisição de uma habilidade competitiva maior do que outras espécies em campo (Soria, 1980).

A vegetação nas bermas cresce rapidamente devido à disponibilidade de luz, água e nutrientes, predominando espécies herbáceas. A invasão da *D. viscosa* planta arbustiva, precisamente, diminui a área disponível tanto de herbáceas como de arbustivas, o que condiciona a variedade de espécies numa determinada área e, bem assim, a biodiversidade. O espaço físico é o único recurso comum pelo qual todas as espécies competem em conjunto. A necessidade por luz, água e nutrientes, no entanto, significa que a competição por vários factores é inevitável, apesar da quantidade de recursos requerida por cada espécie pode variar (Turkington e Mehrhoff, 1990).

Desta forma, torna-se evidente a necessidade conhecer os parâmetros para prescrever acções de maneio, visando a conservação, a manutenção, enfim, o planeamento de estratégias diversificadas para a conservação da biodiversidade nas bermas da estrada. No mínimo a necessidade de maneio é evidente, pois a maior parte da vegetação nas estradas são submetidos a poda, em virtude da necessidade de assegurar as melhores condições de segurança à circulação rodoviária. Por outro lado, tal tende a comprometer a sustentabilidade das populações de plantas e animais.

COLONIZATION BY *Dittrichia viscosa* L. OF ROAD VERGES OF SOUTHERN PORTUGAL AND ITS EFFECTS ON VERGE PLANT DIVERSITY

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ABSTRACT

The distribution of the native species *D. viscosa* was evaluated along the road verges of two roads in southern Portugal. The plant species composition and cover were surveyed within the roadside habitats, in areas with and without *D. viscosa*, to evaluate its effect on road verge communities. The effect of mowing on *D. viscosa* shrubs was also assessed. Shrubs showed a clear preference to verges relative to the surroundings, indicating that *D. viscosa* seems to be invading the study road verges. Results also suggest that the presence of the shrubs decrease the plant diversity of road sides, with potential effects on animals as well. Therefore, the study roads should be considered as important targets of local and regional efforts to prevent invasions of this species. Based on our results, we suggest that to prevent *D. viscosa* invasion within roadside ecosystems, the control should be based on two mowings, in mid-spring to prevent fires and in late-summer to prevent seed dispersal.

Keywords: disturbance, *Dittrichia viscosa*, invasive plants, mowing, road verges, verge management.

Introduction

Roads are artificial structures in the natural landscape (Karim, 2008), which can have both positive and negative impacts on species, habitats and landscapes. In fact, potential biological value of road verges has long been recognized (Way, 1977), with possible contribution to the conservation of flora and fauna. In human dominated areas such as intensive agricultural landscapes, where non-agricultural habitats (e.g. edges) are critical to the conservation of biological diversity and ecological processes (Burel, 1996), this marginal habitat becomes especially important for the conservation of biodiversity (Hopwood, 2008). They can act as corridors that allow optimal dispersal, minimizing the problem of dispersal limitation (Wilson et al., 2000; Santos et al., 2007). Recent studies have reported that road verges could play a crucial role as food resource and refuge, as well as ecological corridors for some species, mainly animals, like butterflies (Valtonen et al, 2006), bees (Hopwood, 2008), ants and beetles (Keals and Majer, 1991; Vermeulen, 1993), spiders (Viol, et al; 2008), and birds and small mammals (Adams, 1984; Camp and Best, 1994; Santos et al., 2006). It has also been suggested that road verges have potential conservation value to wild plants (Way, 1977). They have relatively high plant species richness (Bennett, 1991; Zwaenepoel, 1997 in Forman and Alexander, 1998) and can be important habitats for rare plants (National Research Council, 2005). In fragmented landscapes road verges play a crucial role as a refuge and as ecological corridors, changing the degree of isolation of animal and plant populations (Saunders and Hobbs, 1991).

Roads can, however, have a significantly negative impact on the environment by traversing areas of suitable wildlife habitat, being hence among the most relevant structures involved in the fragmentation of (semi-) natural habitats (Zwaenepoel et al., 2006; Santos et al., 2007). Moreover, road verges promote invasion by non-indigenous species (Viol et al., 2008), providing corridors for habitats that are suitable for exotic plants (Forman and Alexander, 1998). Road verges disturbed habitats have often formed footholds for invasive plant species (Trombulak and Frissell, 2000; Prach and Pysek, 2001), and in some parts of the world the composition of invasive species is commonly higher along road edges than within natural habitats (Wester and Juvik, 1983; Ullmann and Heindl, 1989; Benninger-Truax et al., 1992; Ullmann et al., 1995). Since biological invasions can permanently alter ecosystem structure and function (Jonathan and Jayne, 2003), the contribution of road verges to the spread of invasive plants is one of the major roadside negative effects on ecosystems.

Besides exotic, naturally occurring native species might also have high potential to survive and regenerate in roadside. On continents, native ruderal predominate along roads, and the species richness of these groups is commonly higher along road verges than in surroundings (Ullmann and Heindl, 1989; Benninger-Truax et al., 1992; Ullmann et al., 1995). Roadsides are characterized by frequent disturbance, nutrient rich soil and exposure to sunlight. Invasion occurs when all "barriers" that previously excluded a plant species are removed (Johnstone, 1986). Traffic and human maintenance activities may also facilitate some biological processes such as dispersal. The vehicle traffic along roads facilitates the easy movement of wind, water, and animals that transport seeds. In addition, the seeds often respond to a combination of different environmental factors such as light, temperature and soil moisture that are most favourable to their establishment. Mowing is another human impact on roadside vegetation. Roadsides are regularly mown in order to ensure visibility and thereby improve traffic safety (Jantunen et al., 2006) and cuttings may be removed or left behind, with different consequences for nutrients cycling. On one hand, mowing roadside verges may favour exotic plant species that are less sensitive to clipping than native flora (Forman and Alexander 1998), but on the other hand, mowing prevents the establishment of woody species on roadsides which is considered to enhance diversity (Bakker, 1989; Bakker and Olff, 1995; Fenner and Palmer, 1998).

D. viscosa L. is a shrub mainly distributed in the Western Mediterranean areas, which present a high competitive potential (Brullo and Marco, 2000). Since the 1960, *D. viscosa*, have become an invader in the north-western part of the Mediterranean basin, also in urban areas and fallows (Wacquant, 1990). Contemporary human disturbance, by favouring expansion of *D. viscosa* as ruderal, has possibility led to invasion of natural and crop communities. Nowadays, *D. viscosa* aggressively occupy disturbed areas, like roadsides, abandoned fields and removed lands (Levizou, 2004; Catalan, 2007). It rapidly spread worldwide and become a weed in many countries in different continents, Morocco, Algeria, Tunisia, Yugoslavia, Albania, Sicily, Italy, Corse, Sardinia and Australia, among others (Brullo and Marco, 2000). The rapid spread of this plant along road sides can alter the competitive interactions in this habitat, threaten the biodiversity and cause other environmental damages. Since roadside vegetation is a permanent part of the landscape, any potential loss of biodiversity due to invasion is a cause for concern (Forman and Alexander, 1998; Karim and Mallik, 2008).

In Portugal, although some attention has been paid to animal species (e.g., Santos et al. 2006, 2007), knowledge on verge vegetation is still lacking. Therefore, understanding the invasion processes of *D. viscosa* on road verges and evaluating its potential effects on biodiversity is fundamental to lay down guidelines for proper management of this habitat, in order to control its dispersal and the threats for biodiversity. In this context, a study was conducted in southern Portugal to determine i) the role of road verges in *D. viscosa* dispersal; ii) the effects of *D. viscosa* on verge plant communities; and iii) the effect of mowing in the development of *D. viscosa.* Answers to these questions will hopefully provide a first indication of the role of roads and roadsides in the conservation of biodiversity in southern Portugal and will help to develop a predictive framework for better management strategies.

Materials and methods

Study area

The study area is located in southern Portugal, close to Évora (38° 34' N; 07° 54' W). The climate is typically Mediterranean, with dry and warm summers extending from May to September and mild rainy winters. Annual mean, maximum and minimum temperatures are 15.7, 20.6 and 10.9°C, respectively, and annual mean rainfall is 625 mm yr^{-1} (1961-1990, INMG, s/d). In terms of the bioclimatic typology the study area is located in the Mesomediterranean, lower dry to subhumid belt of the Mediterranean pluviseasonal-oceanic bioclimate (Rivas-Martínez *et al*, 2004), and biogeographically stands as the Lusitan-Extremadurean Province (Marianic-Monchiquensean Sector) of the Mediterranean region (Rivas -Martinez, et al 2002). Soils in the study area are mostly dystric Leptosols and Cambisols (WRB, 2006), occupied by a multi-purpose agro-pastoral system dominated by sparse oak trees (*Quercus suber* L. and *Q. rotundifolia* Lam.).

Vegetation sampling of roads verges was accomplished along two paved two-lane roads: the Municipal Road (CM 1075) between Valverde (38° 31' N; 08° 01' W) and Guadalupe (38° 34' N; 08° 01' W) and the National Road (N114) between Évora (38°

34' N; 07° 54' W) and Montemor-o-Novo (38° 38' N; 08° 13' W), hereafter named road V and road M, respectively. Both selected roads have verges 1-4 m width from paved edge to fences limit, but differed in levels of traffic intensity and in verge management practices. Average daily traffic is low on road V and moderate on road M (below 1,000 and 7,500-8,000 vehicles, respectively, EP, 2005). Verges of both roads were mown to the ground in spring, for fire prevention and road safety sake, and verges of road M were mown again in autumn

Study species

Dittrichia viscosa (L.) W. Greuter is a perennial shrub of the sunflower family, 40-130 cm in height (Ball, 1976), widely distributed in the Mediterranean area (Brullo and Marco, 2000). The species is a remarkable pioneer, able to colonize soils chemically very diverse from calcareous to acidic soils (Wacquant and Bouab, 1983), and releasing substances that inhibit the germination of neighbouring plants (Levizou *et al.*, 2002). The species has been observed to be expanding in various circumediterranean countries, and nowadays it became a common ruderal throughout the Iberian Peninsula, usually found on road edges, land clearings and waste places (Wacquant, 1990; Silva *et al.*, 2005). Each plant produces several individual stems, woody near the ground, covered with abundant glandular, sticky hairs and dense spatuled leaves (Soria, 1980; Brullo and Marco, 2000). Roots, from which new stems sprout each year, are quite substantial in comparison with aboveground biomass (Brullo and Marco, 2000). Maximum vegetative growth occurs during late-spring and summer, and flowering in late-summer and autumn. Vegetative inactivity and leaf fall occur in winter (Wacquant, 1990).

Measurements and Sampling

Sampling design

Vegetation sampling was conducted along two 4 km stretches with *D. viscosa* patches on study roads, providing that they both had the same orientation and exposition. On the basis of surrounding vegetation analysis through ArcView GIS 3.2, both stretches were bordered mainly by grassland vegetation with a few shrubs (1,700 m on road V and 1,600 m on road M) and also with sparse trees (2,300 and 2,400 m, respectively). Since the development of *D. viscosa* was similar on both verges of each road, only one roadside per road was chosen for sampling purposes. Each verge stretch was divided into sectors of 100 m length, providing a total of 40 sectors per road. Starting from one end of each stretch, the first *D. viscosa* that in each sector had at least 25% cover of a 2x0.5 m^2 quadrat was defined as the initial patch. Surveys were accomplished between mid-March and mid-April 2008, right before verges was mown.

D. viscosa *abundance and distribution*

To determine the abundance and distribution of *D. viscosa*, two 10x1 m^2 perpendicular transects starting from the centre of the initial patch were established, one parallel to the road and another towards the surrounding landscape. Each transect was divided in ten 1 m sequential sections, and for each section the number of *D. viscosa* plants and their individual height, canopy diameter, projection cover (0-100%) and phenophase were recorded.

Floristic diversity of verge communities

To evaluate the floristic diversity along verges, a 2x0.5 m^2 quadrat was placed in each sector parallel to the road and starting from the centre of the initial patch. In each quadrat, plant species composition was surveyed and their individual abundance was estimated with projection cover. Additionally, we divided the species in families and raunkiaer life-forms. Total green cover, litter cover and bare ground were also estimated. The same procedure was carried out on a 2x0.5 m^2 quadrat located adjacently or on the closest quadrat with a negligible abundance (less than 5%) of *D. viscosa.*

D. viscosa *biomass production and allocation*

Mowing of verge vegetation on both roads in spring, by the entities responsible for road management, prevented the evaluation of *D. viscosa* biomass in the studied road verges. Therefore, this evaluation was carried out in an equivalent area nearby, at the same time and with the same methods used to verges clearance work. In spring

(April), ten similar *D. viscosa* shrubs were randomly selected and each plant height was measured; the largest width of the canopy and its perpendicular axis were also measured, to estimate the canopy cover projected on the ground. Shrubs were then divided into two five plant groups. Plants of one group were individually tagged for autumn evaluation and plants of the other group were cut to the ground to evaluate current aboveground standing biomass. Shrub biomass was harvested and separated into green leaves, green stems, live woody stems, senescent leaves, dead stems, and flowering heads. After drying (80ºC) until constant weight, all biomass components were weighed separately. The projected leaf area was measured on fresh green leaf samples, using a leaf area meter (LI-COR Mod. Li-3000A). In autumn (October), biomass estimation was accomplished, through the same method, in both five shrub groups: those which have been mown in spring (mSpr) and those which have been tagged (umSpr). Before cutting, all plants height and canopy diameter were individually measured. In addition to biomass estimates, seed production was quantified. For this purpose, the number of heads produced by plants of both shrub groups (mSpr and umSpr) was counted individually. Seed number contained in five heads collected from each shrub was also counted.

Seed germination

Germination experiments were settled in laboratory to ascertain germination rate of the population. Mature seeds from 200 heads were randomly collected from ten plants located at the substitution area and thoroughly mixed. Altogether, 100 of those seeds were separated in five replicates of 20 seeds each, and placed in 9 cm diameter Petri dishes with two layers of filter paper (no.1; Whatman International, Maidstone, UK). Petri dishes were moistened daily with distilled water, sealed with Parafilm and kept for 27 days in an incubator at fluctuating day/night temperatures of 24/19°C in 16 h/8 h light/dark conditions. Seeds were considered successfully germinated when radicula length exceeded seed length.

Data analysis

Species abundance data were organized into a species x surveys matrix and transformed into a similarity matrix by calculating Bray-Curtis similarity index between all survey-pairs (sites with and sites without *D. viscosa*). The average number and coverage of species of the quadrats in each site were determined. The total plant species richness (total number of species observed), the Shannon's diversity index and evenness were also determined for each site. A cluster analysis was then performed to detect similarity between plant assemblages, followed by a non-metric multi-dimensional scaling (MDS) analysis. This displays a graphical representation of the degree of similarity, between surveys. Additionally, a non-metric, one-way, pair-wise analysis of similarity (ANOSIM) was performed to determine if differences in community species composition were significant (Clarke and Warwick 2001). A non-metric similarity of percentages (SIMPER) analysis was made to determine individual species contribution to the similarity/dissimilarity (Clarke and Warwick 2001). Species summing up at least 50% similarity were considered the most important in community structure.

Differences in species richness, floristic diversity, percentage cover, raunkiaer life-form and family composition between paired verges (with and without *D. viscosa*) in each road were determined through non-parametric Sign tests (paired samples). The same approach was used to compare *D. viscosa* abundance between parallel and perpendicular transects in each road. Values of shrub height, canopy area, biomass components and LAI were compared through one-way ANOVA and Scheffé tests for multiple comparisons. Two sample Student's *t*-tests were performed to assess differences regarding head and seed production. Some of the data were transformed (natural log) for homogeneity of variances. MDS, ANOSIM and SIMPER were accomplished using Primer v.6 (Primer-E Ltd. Plymouth, UK). All other statistical analyses were performed with SPSS 16.0 for Windows (Statistical Package for the Social Sciences).

Results

D. viscosa *abundance and distribution*

The presence of *D. viscosa* was observed in 9 (road V) and 17 (road M) out of 40 sectors per road. Individuals mean height was 0.45±0.01 m and canopy area was

0.28±0.03 m^2. Although more frequent in road M than in road V, shrub density was similar in both roads (0.8 plants per m^{-2}), if only sectors with *D. viscosa* are taken in account. Shrub distribution between transects parallel to and those perpendicular to the roadside was also similar in both roads. Plant density was significantly ($P<0.001$) higher in locations near the road (1.2-1.3 plants per m^{-2}) than in those far from the road (0.3-0.4 individuals per m^{-2}) (Fig. 1). Moreover, considering the variation of shrub abundance along sectors from each initial sampling quadrat, two distinct distribution patterns were observed. In parallel transects mean shrub density varied between 1 and 1.2 plants per m^{-2}, while in perpendicular transects there was a pronounced drop of shrub density with increasing distance to road. Starting at 3-4 m from the road side, no further shrubs were observed (Fig. 1).

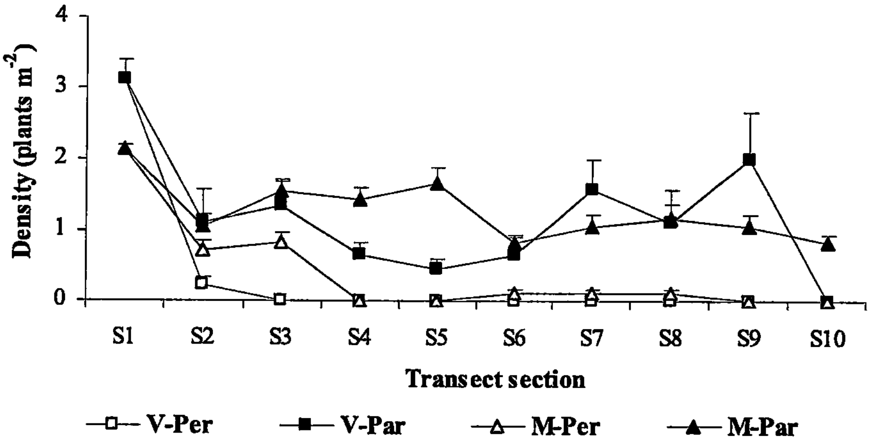

Fig. 1 – Density of *D. viscosa* along the road side (S1 to S10 – ten 1 m sequential sections from initial sampling quadrat; V-Per – perpendicular transects in road V; V-Par – parallel transects in road V; M-Per – perpendicular transects in road M; M-Par – parallel transects in road M). Bars represent the standard error of the mean.

Floristic diversity of verge communities

D. viscosa cover on *Dittrichia* verges was similar in both roads (between 25 and 60%), but cover of other plant species was markedly higher on non-*Dittrichia* verges, either for road V or road M (Table 1). In road M total species richness, Shannon's diversity index and evenness were also higher on areas without *D. viscosa*, indicating not only a greater species number, but also a greater similarity in species abundance. In road V, although the same trend was observed, differences were not significant.

Table 1 – Differences in community cover and diversity, in Valverde (V) and Montemor (M), between the *Dittrichia* (D) and non-*Dittrichia* (N) verges.

	VD	VN	*p*	MD	MN	*p*
Dittrichia cover	39±4	-	-	37±3	-	-
Other plant cover	62±5	89±5	**	61±5	83±6	**
Total species richness	32	34	ns	38	45	**
Species per m^2	12±1	12±1	ns	15±1	18±1	ns
Shannon's diversity index	1.9±0.1	2.0±0.2	ns	1.9±0.1	2.3±0.1	*
Evenness	0.8±0.0	0.8±0.0	ns	0.7±0.0	0.8±0.0	*
Green cover	88±4	84±3	ns	74±4	75±4	ns
Litter	54±8	42±10	ns	46±6	53±6	ns
Bare Ground	12±3	15±4	ns	13±5	9±3	ns

Values are mean±S.E. Significance of Sign tests are reported. *** $P<0.001$, ** $0.001 \leq P<0.01$, * $0.01 \leq P<0.05$, ns=not significant.

Besides *D. viscosa*, a total of 64 plant species were recorded in roadside verges (supplementary data). Most species were included in Leguminosae (25-42% cover), Compositae (16-18%) and Gramineae (8-19%). Cover of main families (cover higher than 2.5% at least in one of the four sites) was higher in areas without than in those with *Dittrichia*. This trend was observed for both roads, although differences were significant (P<0.05) for Gramineae in road M only (Fig. 2). Moreover, some families (e.g. Primulaceae) were registered only in non-*Dittrichia* verges).

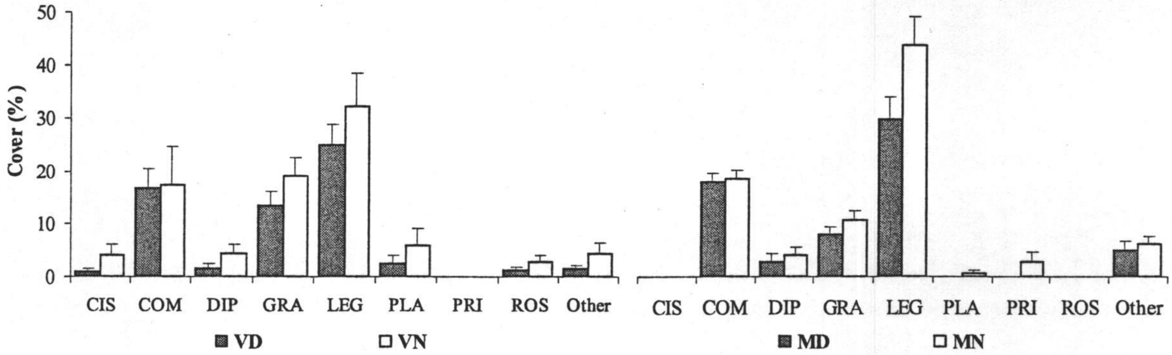

Fig. 2 – Percentage cover of main families (CIS – Cistaceae; COM – Compositae; DIP – Dipsacaceae; GRA – Gramineae; LEG – Leguminosae; PLA – Plantaginaceae; PRI – Primulaceae; ROS – Rosaceae; Other – other families) in Valverde (V) and Montemor (M), on *Dittrichia* (D) and non-*Dittrichia* (N) verges. Bars represent the standard error of the mean. Asterisk indicates values significantly different ($P<0.05$).

If *D. viscosa* is not taken in account, therophytes were the prevailing raunkiaer life-form in all sampled verges (between 61 and 81% cover), followed by hemicryptophytes (11-36%) (Fig. 3). Proto-hemicryptophytes (6-8%) were registered in road V only and chamaephytes (3-4%), although found in both roads, were exclusive of non-*Dittrichia* verges. A general trend to higher cover on non-*Dittrichia* compared to *Dittrichia* verges was observed for all life-forms, in both roads, but significant differences (P<0.05) were found for hemicryptophytes in road M only (respectively, 36 and 33%).

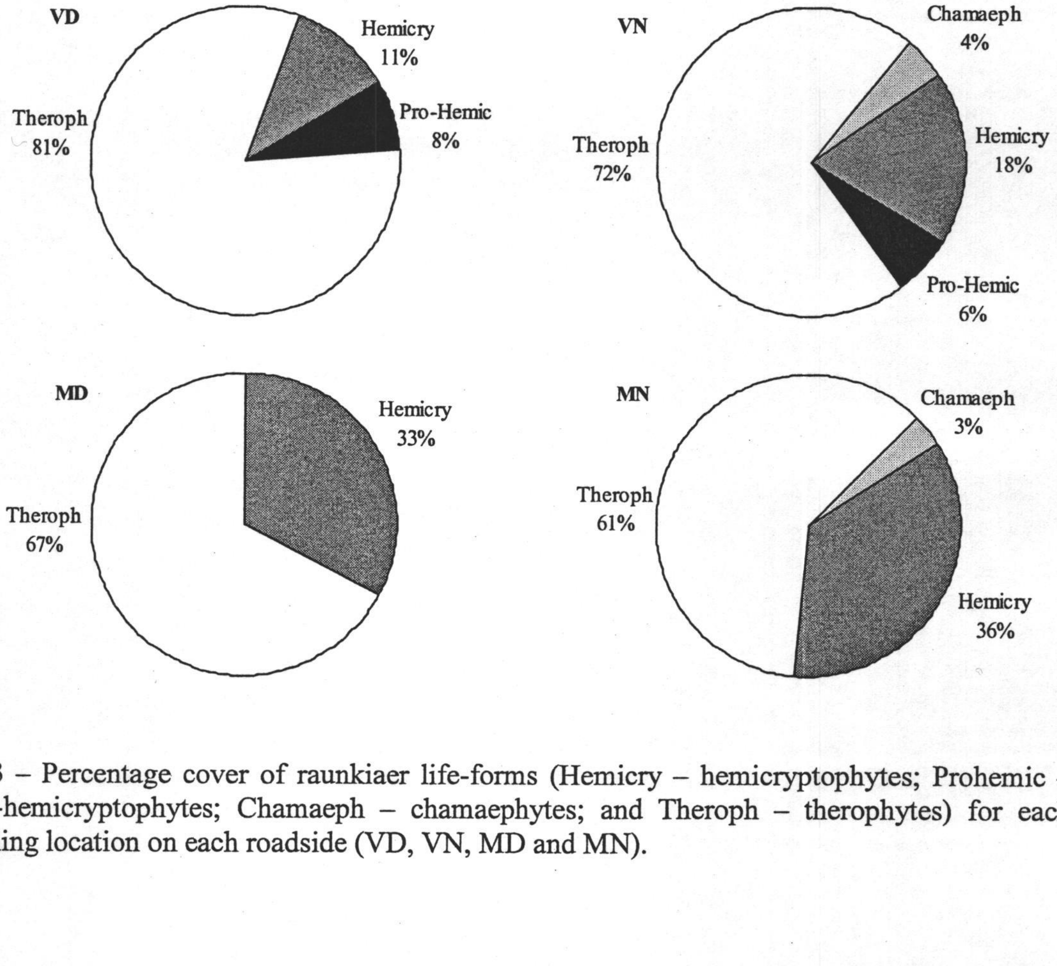

Fig. 3 – Percentage cover of raunkiaer life-forms (Hemicry – hemicryptophytes; Prohemic – proto-hemicryptophytes; Chamaeph – chamaephytes; and Theroph – therophytes) for each sampling location on each roadside (VD, VN, MD and MN).

The three-dimensional MDS plot, with a stress value of 0.17, is not shown for lack of clarity and in alternative the two-dimensional solution, with a stress value of 0.24, is presented. This MDS analysis showed different spatial distribution of the four surveyed sites (Fig. 4). The *Dittrichia* verges were clustered, whereas the non-*Dittrichia* verges were scattered over the ordination space. Within the latter, possible subgroups existed with most transects of road M falling to the left, and most transects of road V falling to the right of the ordination space. The ANOSIM analysis indicated significant differences between the stretches (Global R=0.58, *p*=0.1%), revealing dissimilarities between communities of the *Dittrichia* (VD and MD) and the non-*Dittrichia* (VN and MN) verges (Table 2). In what comparison between the two roads is concerned, ANOSIM analysis showed that although there were significant differences between communities of the non-*Dittrichia* (VN and MN) verges, revealing distinct assemblages corresponding to the different roads, no significant differences were observed between the assemblages from *Dittrichia* verges (VD and MD).

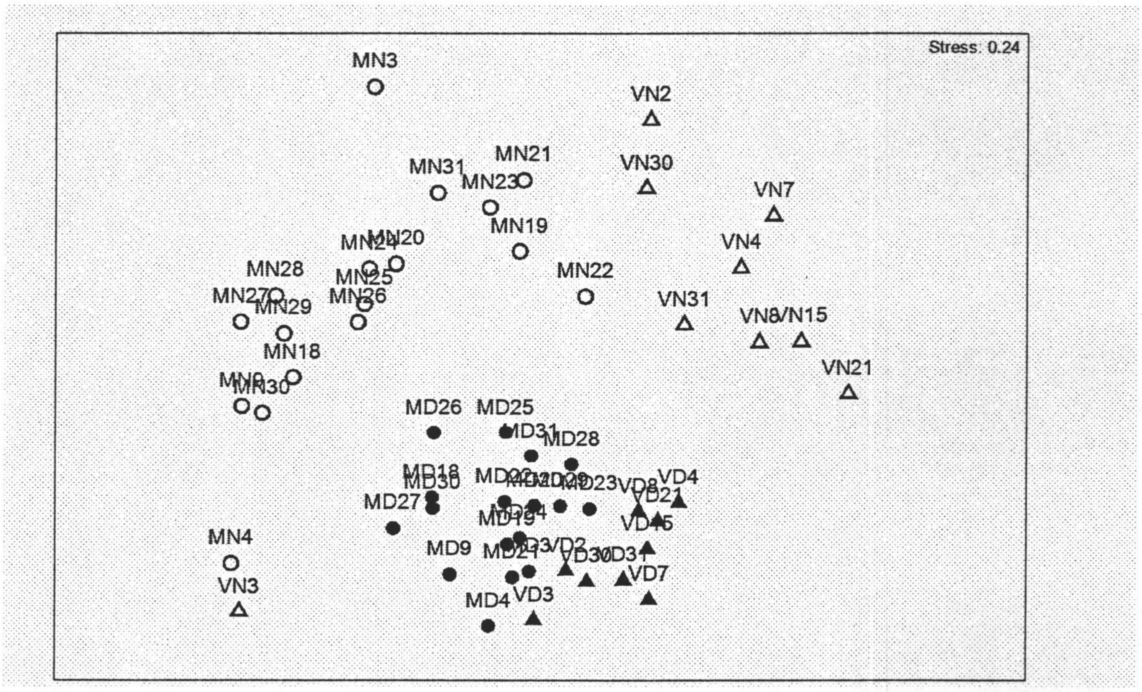

Fig. 4 – Non-metric multidimensional scaling (MDS) plot based on species density and composition from all sampling locations. Sites are coded by site location and transect number, example: Montemor Non-*Dittrichia* verge Transect 3 = MN3. The *stress value* indicates the ease with which all data points were fitted into two dimensions.

Table 2 – Results of one-way analysis of similarities (ANOSIM) for the communities of all sampling locations (VD, VN, MD and MN).

Groups	R statistic	Significance level (%)	Significant difference	Possible permutations	Actual permutations	Number ≥ observed
VD, VN	0.493	0.1	YES	24310	999	0
MD, MN	0.598	0.1	YES	Very large	999	0

VD, MD	0.318	0.2	NO	3124550	999	1
VN, MN	0.615	0.1	YES	3124550	999	0

According to the SIMPER analysis (Table 3) one species (*D. viscosa*) was enough to explain the within-group similarity (69.02 and 70.27%, on VD and MD, respectively) in the *Dittrichia* verges, while 4 to 6 species were indicative of the non-*Dittrichia* verges. In VN, *Hypochaeris glabra* made the highest contribution to the within group similarity (12.74%) along with the *Vicia lutea* (10.15%), *Trifolium arvense* (9.08%) *Avena sterilis* (8.80%), *Scabiosa atropurpurea* (7.11%) and *Agrostis castellana* (6.68%), while in MN the similarity resulted from the presence of *Anthylis gerardi* (30.04%), *Sonchus oleraceus* (11.61), *Andryala integrifolia* (5.25%) and *Ornithopus compressus* (4.62%).

Table 3 – Species determined by SIMPER analysis as those most responsible for contributing for the similarity within groups (VD, VN, MD, MN). Species are listed in ascending order according to percent contributions to respective similarity. Numbers to the right reflect cumulative percent contribution for each species.

Verges of road V			Verges of road M		
VD			MD		
Average similarity: 46.71			Average similarity: 44.98		
Species	Cont. (%)	Cum. (%)	Species	Cont. (%)	Cum. (%)
Dittrichia viscosa	69.02	69.02	*Dittrichia viscosa*	70.27	70.27
VN			MN		
Average similarity: 18.72			Average similarity: 26.16		
Species	Cont. (%)	Cum. (%)	Species	Cont. (%)	Cum. (%)
Hypochaeris glabra	12.74	12.74	*Anthylis gerardi*	30.04	30.04
Vicia lutea	10.15	22.89	*Sonchus oleraceus*	11.61	41.64
Trifolium arvense	9.08	31.97	*Andryala integrifolia*	5.25	46.89
Avena sterilis	8.80	40.77	*Ornithopus compressus*	4.62	51.52
Scabiosa atropurpurea	7.11	47.88			
Agrostis castellana	6.68	54.56			

The SIMPER analysis also showed *D. viscosa* to be most responsible for dissimilarities between communities of *Dittrichia* and non-*Dittrichia* verges, in both roads (24.89% in road V and 25.83% in road M) (Table 4). In road V, *Hypochaeris glabra* (7.23%), *Vicia lutea* (5.41%), *Avena sterilis* (4.27%), *Medicago nigra* (4.26%) and *Plantago coronopus* (4.06%) also contributed to the dissimilarity between VD and

VN communities. In road M, besides *D. viscosa*, four species were primarily responsible for the dissimilarity between MD and MN, *Anthylis gerardi* (14.25%), *Medicago nigra* (4.76%), *Scabiosa atropurpurea* (3.65%) and *Vicia villosa* (3.58%). Most responsibility (around 50%) for the dissimilarity between VD and MD was shared by ten species, varying their contribution between 10.05 and 2.96%. The dissimilarity between VN and MN was predominantly due to the presence of *Anthylis gerardi* (11.72%), along with ten additional species (the contribution of which varied between 6.80 and 2.78%).

Table 4 – Species determined by SIMPER analysis as those most responsible for contributing for the dissimilarity between groups. Species are listed in ascending order according to percent contributions to respective dissimilarity. Numbers to the right reflect cumulative percent contribution for each species.

Road verges			Road verges		
VD and VN			MD and MN		
Average dissimilarity: 82.26			Average dissimilarity: 80.70		
Species	Cont. (%)	Cum. (%)	Species	Cont. (%)	Cum. (%)
Dittrichia viscosa	24.89	24.89	*Dittrichia viscosa*	25.83	25.83
Hypochaeris glabra	7.23	32.13	*Anthylis gerardi*	14.25	40.08
Vicia lutea	5.41	37.54	*Medicago nigra*	4.76	44.84
Avena sterilis	4.27	41.81	*Scabiosa atropurpurea*	3.65	48.49
Medicago nigra	4.26	46.07	*Vicia villosa*	3.58	52.07
Plantago coronopus	4.06	50.13			
VD and MD			VN and MN		
Average dissimilarity: 60.03			Average dissimilarity: 89.25		
Species	Cont. (%)	Cum. (%)	Species	Cont. (%)	Cum. (%)
Dittrichia viscosa	10.05	10.05	*Anthylis gerardi*	11.72	11.72
Anthylis gerardi	8.00	18.05	*Hypochaeris glabra*	6.80	18.52
Vicia lutea	5.79	23.84	*Medicago nigra*	5.29	23.81
Hypochaeris glabra	5.53	29.37	*Plantago coronopus*	4.07	27.88
Lupinus angustifolius	4.36	33.73	*Vicia lutea*	3.95	31.83
Medicago nigra	4.30	38.03	*Scabiosa atropurpurea*	3.72	35.54
Bromus diandrus	3.39	41.43	*Avena sterilis*	3.67	39.22
Avena sterilis	3.31	44.74	*Trifolium arvense*	3.42	42.64
Scabiosa atropurpurea	3.06	47.80	*Bromus diandrus*	3.24	45.88
Vicia villosa	2.96	50.76	*Biserrula pelecinus*	3.09	48.97
			Sonchus oleraceus	2.78	51.76

D. viscosa *biomass production and allocation*

The increment of shrub height was significantly lower ($P<0.01$) for shrubs mown (0.08 m) than for shrubs unmown (0.38 m) in spring. The difference found for the canopy area was even greater ($P<0.001$), because while for shrubs mown in spring there was a decrease of 0.07 m^2, for those unmown an increase of 0.15 m^2 was observed (Table 5).

Table 5 – Variation of shrub height (SH), canopy area (CA) and leaf area index (LAI) between spring and autumn of *D. viscosa* shrubs (mSpr – shrubs mown in spring; umSpr – shrubs unmown in spring).

	SH (m)	CA (m^2)	LAI
Spring	0.53±0.04 ^{a}	0.29±0.03 ^{a}	1.23±0.08 ^{a}
Autumn-mSpr	0.58±0.04 ^{a}	0.23±0.03 ^{a}	0.63±0.10 ^{b}
Autumn-umSpr	0.94±0.10 ^{b}	0.44±0.04 ^{b}	0.38±0.06 ^{b}

Values are mean±S.E. Means in the same column with different letters are significantly different ($P<0.05$). *nd*, not determined

The time course of one growing season was not enough for shrubs to regenerate standing aboveground biomass after spring mowing, and thus by autumn the mean total biomass, as well as, both live biomass and necromass differed significantly between shrubs mown and unmown in spring (Fig. 4). In contrast, reproductive organ production was similar. Comparisons of the biomass proportions allocated in autumn to live vegetative biomass and necromass also revealed significant differences ($P<0.05$) between mown (68 and 19% of the total, respectively) and unmown (46 and 47%) shrubs. Therefore, the necromass-to-live biomass ratio was also significantly ($P<0.05$) different between the two shrub groups (0.3 and 1.1, respectively).

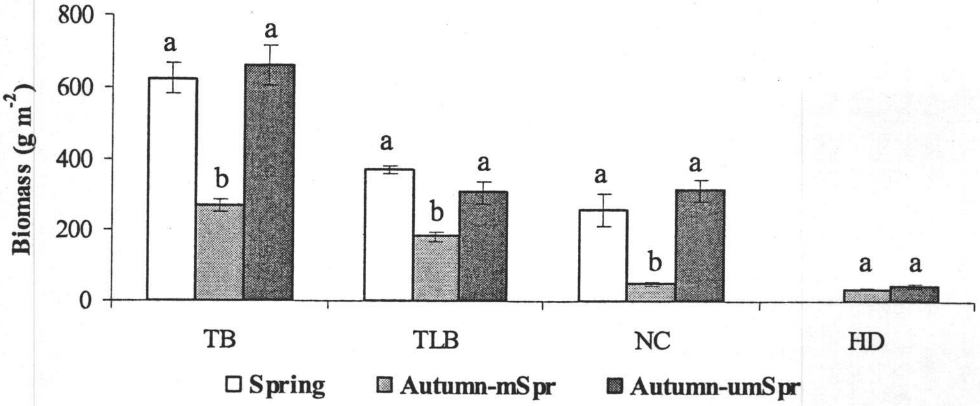

Fig. 4 – Variation (g m^{-2}) of total biomass (TB), vegetative live biomass (TLB), necromass (NC) and reproductive biomass in spring and autumn of *D. viscosa* shrubs (mSpr – shrubs mown in

spring; umSpr – shrubs unmown in spring). Bars represent the standard error of the mean (n=5). Means for the same component with different letters are significantly different ($P<0.05$).

The spring mowing also had a significant effect on the biomass of different vegetative organs (Fig. 5). In autumn, mown shrubs had more green leaf biomass, whereas woody stem biomass was greater in those unmown. The proportion of total vegetative biomass allocated to green leaves was also higher in shrubs mown in spring (39%) than in those unmown (16%), and the allocation to woody stems was lower (7 and 61%, respectively in shrubs mown and unmown in spring). In contrast to green leaves and woody stems, the production of green stems did not differ between mown and unmown shrubs. In accordance with the greater leaf biomass for shrubs mown in spring, by autumn LAI was also higher in mown than in unmown shrubs, although difference was not significant (Table 5).

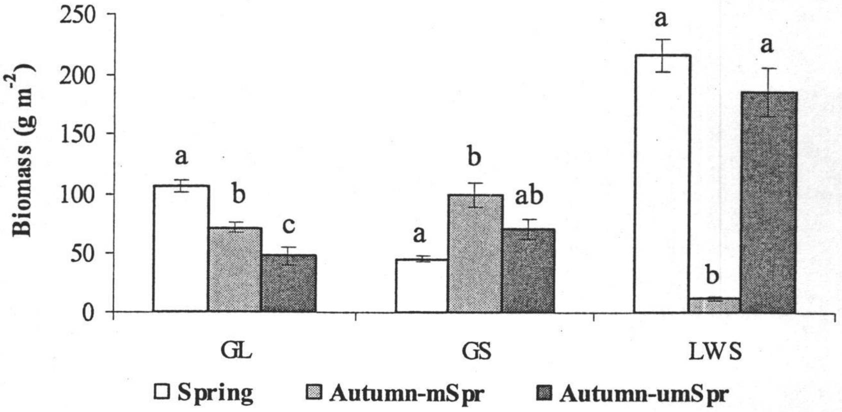

Fig. 5 – Variation (g m^{-2}) of the components of vegetative live biomass (GL – green leaves; GS – green stems; LWS – woody stems) of *D. viscosa* shrubs (mSpr – shrubs mown in spring; umSpr – shrubs unmown in spring). Bars represent the standard error of the mean (n=5). Means for the same component with different letters are significantly different ($P<0.05$).

Seed production per head was similar ($P>0.05$) in shrubs mown (37±5 seeds) and unmown (42±2) in spring. Moreover, significantly differences were not found ($P>0.05$) in seed production per square meter (61,846±11,987 and 85,894±19,100 seeds, respectively), between the two shrub groups.

Seed germination rate ranged between 38 and 77% and average germination rate was 53.98% (±6.76). Although seeds were kept for 27 days in the incubator, half of this percentage value was attained after only 7 days.

Discussion

D. viscosa *distribution along road verges*

D. viscosa showed higher density and cover in verge locations parallel to than in those perpendicular to the roads. Moreover, shrub abundance declined significantly with distance from edge of both roads. This clearly suggests a preferential distribution pattern of the species along roadsides. A similar shrub distribution decline pattern was found for exotic shrubs by Flory and Clay (2006). Several mechanisms have been outlined to explain the spatial distribution of shrubs along roadside. One possible mechanism is that shrub seeds are distributed by birds and other animals in a pattern that parallels the distribution of shrubs (Clifford, 1959; Greenberg et al., 1997). This would mean that the density of dispersed seeds declines with increasing distance to the nearest road but that survival is unaffected by distance to road. Another possible mechanism is that roads may contribute to the spread of some species by channelling the populations along verges because they are a suitable habitat (Christen and Matlack, 2006). Several reasons may contribute to justify this preference like better growth conditions, including increased nutrient or water availability (Watkins et al., 2003). Decreased competition with understory species is also reported for distribution of invasive shrubs roadsides (Watkins et al., 2003; Flory and Clay, 2006). However, *D. viscosa* is a remarkable pioneer able to colonize new habitats and various chemical types of soils such as calcareous as well as acidic or even slightly salty (Soria, 1980; Wacquant and Bouab, 1983). These shrubs are abundantly encountered in fallows as well as in xerophytic and ruderal associations (Bolos, 1975). The species is an aggressively ruderal occupying disturbed areas (Levizou et al., 2004) and attaining a great dominance on extensive areas of abandoned arable land (Soria, 1980). According to the mentioned ecological characteristics of *D. viscosa,* it seems that the better survival and growth of this species at the sites near the road might be also due to better light conditions. The small seeds of *D. viscosa* are strongly light-requiring and light is considered the principal agent of germination induction (Macchia and Caporali, 1984); Doussi and Thanos, 1997). Therefore, we believe that frequent verge disturbances increase exposure to sunlight (Davis et al., 2000; Parendes and Jones, 2000), triggering *D. viscosa* seed germination.

Shrub densities, mean height and canopy area obtained from sectors with *D. viscosa* were similar in the two roads. According to Parendes and Jones (2000), roads with heavier traffic and regular maintenance can show bigger severity of disturbance than roads with less traffic and maintenance. Nevertheless, our study suggests that roads may contribute to the spread of *D. viscosa*, independently of road dimension and traffic level.

Effects of D. viscosa *on composition and structure of verge communities*

Recent studies have shown that *D. viscosa* may have positive effects on a limited range of species, like insects feeding from this species sap (e.g. *Macrolophus melanotoma*, Perdikis et al., 2007). However, according to our study, *D. viscosa* might have strong negative effects on plant communities of road verges regularly disturbed. Our results show that the presence of these shrubs can decrease plant species richness and floristic diversity of verge communities. Additionally, shrub presence can also lower the cover of other plant species. Similar results were obtained for other species, such as *Lupinus polyphyllus* (Muzquiz et al., 2004; Valtonen et al., 2006). Shading, rather than other shrub characteristics, seems to be the most likely cause of the community decline. In fact, *D. viscosa* shrubs present a rapid growth and attain a considerable height (over a metre), thus blocking the light effectively and hindering the growth of other plant species. Leachable allelopathic materials from *D. viscosa* might also interfere with neighbouring plants germination and growth (Karageorgou et al., 2002) contributing to lower plant species richness and floristic diversity. The greater species richness and cover in areas without *D. viscosa* can also be attributed to better growth conditions, due to the combination of higher light and resources availability, as suggested for other shrub species (Flory and Clay, 2006). The spreading of *D. viscosa* along road verges can therefore represent a real threat to plants living on road verge environments, and therefore animal communities of this habitat might also be indirectly affected.

Species that have ecological light requirements similar to *D. viscosa*, like hemicryptophytes or chamaephytes, are more vulnerable to invasion (Pyšek and A Pyšek, 1995). It was therefore not surprising that in *D. viscosa* verges hemicryptophytes and chamaephytes have been out competed due to shading. In contrast to hemicryptophytes or chamaephytes, therophytes seem to be favoured by the presence of *D. viscosa*. In fact, the proportions of therophytes increased in both roads with the presence of *D. viscosa* presumably because shading favours water conservation in such a very sunny environment like road verges, enhancing spring germination. Nevertheless, autumn germinating grass species (e.g. *Avena sterilis*, *Briza minor* and *Vulpia myurus*) are more abundant in non-*Dittrichia* verges. We may suggest that this result is due to the increase of soil water content with the first autumn rains, which favours grass germination (Figueroa and Davy, 1991; Dunnet et al., 1998).

Effects of management on D. viscosa biomass and structure

Spring mowing had significant effects on shrubs, reducing the biomass of vegetative organs observed by autumn. One of the main differences between mown and unmown shrubs was observed in the amount of both life and dead woody stems, which was much higher in unmown shrubs. This result indicates that spring mowing is an important practice to control the frequent fires observed in verges during the summer, especially in what necromass is concerned, because cuttings were removed from the study roads. However, in spite of the lower vegetative biomass in autumn, relative to unmown shrubs, obtained results indicate that *D. viscosa* has a high regeneration capacity in response to spring mowing. Shrubs grew fast and biomass production was high. In fact, the great leaf biomass and the high value of LAI suggest that root development was stimulated by spring mowing. Thus, mown shrubs seem to become more competitive, being able to dominate in short time and to disperse efficiently. Therefore, although mowing in spring seems to be an efficient method to control shrub canopies, as observed in other studies (Jantunen, et al. 2006), it is not enough to reduce shrub colonization, because it did not decrease seed production. This is a particularly important result, since *D. viscosa* is a species with specific characteristics that facilitate survival and dispersal, displaying a high reproductive effort, which is translated into high flowering capacity and high seed production (Soria, 1980; Wacquant, 1990). Thus, we suggest that to control *D. viscosa* dispersal, management of road verge vegetation road verge vegetation should be based on two mowing periods, late-spring to control shrub canopies and late-summer to prevent the production of viable seeds. Moreover, to prevent fire and to enhance colonization by herbaceous species we suggest the removal of cuttings.

Conclusion

Our results showed that *D. viscosa* seems to be invading the study road verges, confirming hence the importance of roads as corridors to *D. viscosa* dispersal. Moreover, the ongoing invasion of study road verges by *D. viscosa* seems to decrease the plant diversity of road sides, with potential effects on animals as well. Based on our results, we suggest that to prevent *D. viscosa* invasion within roadside ecosystems, the control should be based on two mowings, in mid-spring to prevent fires and in late-summer to prevent seed dispersal. Although our study, pioneer in Portugal, clarify some aspects of the composition and functioning of road side vegetation in Portugal, further studies should be made on the characteristics and ecological processes involved in this particular habitat, to improve management choices.

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Considerações Finais

Neste estudo verificou-se que a predominância de *D. viscosa* nas bermas diminui com o aumento da distância à estrada e que o arbusto possui uma distribuição agrupada. O aumento da sua presença nas bermas produz impactos graves sobre as comunidades vegetais, nomeadamente por diminuir a diversidade florística.

O maneio que actualmente é aplicado para controlo da vegetação das bermas e as consequências que ele tem sobre a produção de biomassa foliar e de sementes permitem afirmar que um corte único na primavera é eficaz para controlo da produção de biomassa combustível e melhora a visibilidade das estradas, mas não diminui a quantidade de sementes produzidas, logo não diminui a capacidade de propagação da espécie. Para esse efeito, é necessário que um segundo corte ocorra antes da produção de sementes.

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Appendix A. Supplementary data

List of plant species, and respective family and life form, recorded along the roadside transects on Valverde and Montemor.

Plant Species	Family	Life form
Agrostis castellana	Gramineae	proto-hemicryptophyte
Anagallis monelli	Primulaceae	chamaephyte
Andryala integrifolia	Compositae	hemicryptophyte
Anthylis gerardi	Leguminosae	hemicryptophyte
Anthemis arvensis	Compositae	therophyte
Avena barbata Link	Gramineae	therophyte
Avena sterilis	Gramineae	therophyte
Biserrula pelecinus	Leguminosae	therophyte
Briza maxima	Gramineae	therophyte
Briza minor	Gramineae	therophyte
Bromus diandrus Roth	Gramineae	therophyte
Bromus hordeaceus	Gramineae	therophyte
Bromus madritensis	Gramineae	therophyte
Bromus sterilis	Gramineae	therophyte
Calendula arvensis	Compositae	therophyte
Chamaemelum mixtum	Compositae	therophyte
Conyza bonariensis	Compositae	therophyte
Crepis vesicaria	Compositae	therophyte
Cynodon dactylon	Gramineae	proto-hemicryptophyte
Daucus muricatus	Umbelliferae	therophyte
Dittrichia viscosa	Compositae	chamaephyte
Erodium botrys	Geraniaceae	therophyte
Foeniculum vulgare Miller	Umbelliferae	hemicryptophyte
Galactites tomentosa	Compositae	therophyte
Geranium molle	Geraniaceae	therophyte
Hedypnois cretica	Compositae	therophyte
Hypericum perforatum	Guttiferae	hemicryptophyte
Hypochaeris glabra	Compositae	therophyte
Hypochaeris radicata	Compositae	hemicryptophyte
Jasione montana	Campanulaceae	hemicryptophyte
Lactuca serriola	Compositae	therophyte
Lathyrus angulatus	Leguminosae	therophyte
Leontodon taraxacoides	Compositae	hemicryptophyte
Logfia gallica	Compositae	theropyhte
Lolium perenne	Gramineae	hemicryptophyte
Lotus subbiflorus	Leguminosae	theropyhte
Lupinus angustifolius	Leguminosae	therophyte
Medicago minima	Leguminosae	therophyte
Medicago nigra	Leguminosae	therophyte
Nonea vesicaria	Boraginaceae	therophyte
Ornithopus compressus	Leguminosae	theropyhte

Petrorhagia nanteuilii	Caryophyllaceae	theropyhte
Plantago afra	Plantaginaceae	theropyhte
Plantago coronopus	Plantaginaceae	hemicryptophyte
Plantago lagopus	Plantaginaceae	hemicryptophyte
Psoralea bituminosa	Leguminosae	chamaephyte
Raphanus raphanistrum	Cruciferae	therophyte
Rumex bucephalophorus	Polygonaceae	hemicryptophyte
Sanguisorba minor	Rosaceae	hemicryptophyte
Scabiosa atropurpurea	Dipsacaceae	hemicryptophyte
Senecio jacobaea	Compositae	hemicryptophyte
Senecio vulgaris	Compositae	therophyte
Silene gallica	Caryophyllaceae	therophyte
Sonchus oleraceus	Compositae	therophyte
Trifolium angustifolium	Leguminosae	therophyte
Trifolium arvense	Leguminosae	therophyte
Trifolium stellatum	Leguminosae	therophyte
Trifolium subterraneum	Leguminosae	therophyte
Tuberaria guttata	Cistaceae	therophyte
Urospermum picroides	Compositae	therophyte
Vicia disperma	Leguminosae	therophyte
Vicia lutea	Leguminosae	therophyte
Vicia villosa Roth	Leguminosae	therophyte
Vulpia myuros	Gramineae	therophyte