

Effect of eucalyptus plantations on Collembola communities in Portugal: a review

J.P. SOUSA, M.M. DA GAMA, C. FERREIRA & H. BARROCAS

Instituto do Ambiente e Vida, Dep. Zoologia da Universidade de Coimbra, P3004-517
Coimbra, Portugal (e-mail: jps@zoo.pt).

Abstract

In this paper the authors make a review of the published results on the effects of the plantation of the exotic tree species *Eucalyptus globulus* LABILL. on collembola communities. Data analysis from 12 case studies (= sites), comparing collembola communities from eucalyptus stands with the collembola fauna existing on contiguous forests of autochthonous tree species (*Quercus suber* L., *Quercus ilex* ssp. *ballota* (DESF.) SAMP., *Quercus pyrenaica* WILLD, *Quercus canariensis* WILLD and *Pinus pinaster* AITON), showed that the shift from the autochthonous species to eucalyptus led to a disruption, and in most cases, to an impoverishment of the collembola communities. A decrease in abundance, number of taxa, diversity and species richness was observed in almost all cases. Both diversity indicators and similarity analysis showed that the most affected sites were those where the different oak species were the autochthonous tree present and also those sites where habitat configuration between contiguous stands was most different. Data also showed that those species living on the upper soil layers were the most affected by the reforestation process. The magnitude of the observed differences between collembola communities was mainly due to changes in the structure and quality of the organic horizon, regulated not only by the quality of the litter present, but mainly by the type of management practices adopted to establish and run the eucalyptus plantations. The importance of these two factors in explaining effects at this level and the need for more sustainable management plans to minimise impacts are discussed.

Keywords : Eucalyptus plantation, Collembola diversity, Forest management

Introduction

Due to its edaphic and climatic characteristics, Portugal has, without any doubt, a strong vocation for forestry. Occupying almost 38% of the territory,

forested areas as "centres for biodiversity conservation" and as "resource generators" centralise the attention of many sectors of the public opinion. After forest fires, the plantation of extensive areas with the exotic tree species *Eucalyptus globulus* LABILL. can be considered the most important subject of debate regarding the ecological stability of forest ecosystems, opposing forest industry to environmentalists and ecologists.

This exotic species was introduced in Portugal in the middle of the last century as an ornamental plant, but it was only 100 years later that its potential for cellulose paste production was used. Due to this reason, since the 1940's, the area covered with eucalyptus has been increasing from 30.000 ha. in 1942 (1.2% of the forested area) (SOARES, 1993) to 690.000 ha. (21% of the forested area) in 1997 (DGF, 1999). This increase, strongly pushed by a considerable economical help to private farmers, took place not only by planting trees on non productive agricultural areas, but also at the cost of native forests; *E. globulus* is, at the moment, the third forest species in Portugal regarding to the area covered (Table 1).

Table 1. Area covered by the main forest tree species in Portugal (adapted from DGF, 1999).

Tree species	Area covered	
	1000 ha.	(%)
<i>Pinus pinaster</i> AITON	1026,4	30,9
<i>Pinus pinea</i> L.	78,6	2,4
Other coniferous trees	44,5	1,3
<i>Quercus suber</i> L.	719,4	21,6
<i>Quercus il ex</i> (DESF.) SAMP.	463,8	14,0
Other <i>Quercus</i> spp.	134,1	4,0
<i>Eucalyptus globulus</i> LABILL.	696,3	20,9
<i>Castanea sativa</i> MILLER	40,3	1,2
Other broadleaves trees	120,5	3,6
TOTAL	3323,9	100,0

The actual distribution of this species comprises mainly the western half of the country, with only two incursions into the mainland: one along the Tejo river (in the centre) and another in Alentejo province (in the south). Being an evergreen fast-growing species, eucalyptus may have a strong impact not only on soil, but also on fauna and landscape structure. The magnitude of impacts is dependent on the dimensions of the planted area (higher effects on large and continuous stands), the type of stand (pure or mixed plantations) and the forestry techniques adopted when installing the plantation and subsequent management.

The effects of eucalyptus plantation in Portugal on collembola communities have been assessed recently by some authors (BARROCAS *et al.*, in press; FERREIRA *et al.*, 1994; FIGUEIREDO *et al.*, 1985; GAMA *et al.*, 1989; 1991; 1994a; 1994b; 1995; PINTO *et al.*, 1997; SOUSA & GAMA, 1994; SOUSA *et al.*, 1997;



Fig. 1. Geographic location of the studied sites.

VASCONCELOS *et al.*, 1994), by comparing the fauna from stands of this exotic species with the collembola fauna existing on contiguous forests of autochthonous tree species. At this point in time, a synthesis of the published results is necessary; the cases studied differ in terms of tree species analysed, habitat configuration and management practices, so the search for a trend in effects could help in understanding the principles involved in the disruptions caused by the plantation of this exotic species.

The main objective of this paper is to make that synthesis; the authors aim to analyse the published results for Portugal all together and try to find the driving forces behind the effects observed on collembola communities due to the shift from an autochthonous vegetation cover to eucalyptus.

Materials and Methods

For practical reasons not all the published results were considered for analysis in this paper. The criteria used for the selection of papers were related to (1) the representativity of autochthonous species considered (important tree

Table 2. Brief characterization of selected sites.

Sites selected	Idanha	Fafe	Monchique	Cercal	Almeirim	Sever	Lousã
Correspondent papers	(SOUSA et al., 1994)		(BARROCAS et al., in press)	(GAMA et al., 1991)	(SOUSA et al., 1997)	(GAMA et al., 1995)	(VASCONCELOS et al., 1994)
Autochthonous species							
Tree species	<i>Quercus ilex ballota</i> (±30 years)	<i>Quercus pyrenaica</i> (>30 years)	<i>Quercus suber</i> & <i>Q. canariensis</i>	<i>Quercus suber</i>	<i>Quercus suber</i> (±30 years)	<i>Pinus pinaster</i> (±15 years)	<i>Pinus pinaster</i> (±50 years)
Distribution	Uniform	Uniform	Uniform	-----	Scattered	In grooves forming lines	Uniform
Shrub & herbaceous layers	Dense shrub and herbaceous layers	Dense herbaceous layer	Presence of shrub and herbaceous layers	Presence of shrub layer	Only associated to the presence of trees	Dense shrub layer	Scarce
Soil surface	Homogeneous leaf cover	Abundant homogeneous leaf cover	Dense homogeneous leaf cover	-----	Non regular leaf cover	Covered with pine needles	Covered with pine needles
Eucalyptus plantation							
Tree species	<i>Eucalyptus globulus</i> (±10 years)	<i>Eucalyptus globulus</i> (±20 years)	<i>Eucalyptus globulus</i>	<i>Eucalyptus globulus</i> (±11 years)	<i>Eucalyptus globulus</i> (±20 years)	<i>Eucalyptus globulus</i> (±15 years)	<i>Eucalyptus globulus</i> (±28 years)
Plantation method / tree distribution	In grooves along altitude lines	No specific (uniform tree dist.)	No specific (uniform tree dist.)	No specific	No specific (non regular tree dist.)	In grooves along altitude lines	No specific (uniform tree dist.)
Management practice	Heavily managed with regular cleaning	Only during cutting (every 12 years)	Only during cutting	Only during cutting (every 10 years)	Only during cutting (aprox. every 12 years)	Only during cutting (every 12 years)	Only during cutting (every 14 years)
Shrub & herbaceous layers	Scarce	Poor herbaceous layer (ferns)	Presence of shrub and herbaceous layers	Absent	Dense shrub layer	Dense shrub layer + ferns	Homogeneous shrub layer + ferns
Soil surface	Bare soil; some leaf accumulation on grooves	Non regular leaf cover	Homogeneous cover (leaves, bark and twigs)	-----	Homogeneous cover (leaves, bark and twigs)	Homogeneous cover (leaves, bark and twigs)	Homogeneous cover (leaves, bark and twigs)
Physical-chemical characterization	Marked diff. between sites	Diff. in terms of water & org. matter contents	Marked diff. between sites	-----	No marked diff. between sites	No marked diff. between sites	No marked diff. between sites

NOTE: Measured physical and chemical parameters include thickness of the organic horizon, soil pH and water, organic matter, carbon and nitrogen contents on both horizons.

species at national or regional level), geographical area and type of plantation in terms of management practices and (2) the presentation of raw data. This last point was very important since, in some cases, it was necessary to treat the data in a different way as in the original paper (see point 2) in order to present it in an uniform way.

1. Sampling sites (cases studied)

The selected 7 case studies cover the country along the North-South axis and are located in important areas where the percentage of forest cover occupied by eucalyptus is relevant (Fig. 1). They also represent the most important autochthonous species of Portuguese forests (*Quercus suber* L., *Q. ilex* ssp. *ballota* (DESF.) SAMP., *Q. pyrenaica* WILLD., *Q. canariensis* WILLD. and *Pinus pinaster* AITON) and the management practices adopted for *Eucalyptus globulus* LABILL. plantations. The characterization of the different sites is summarized in Table 2 and includes aspects that could be considered relevant for the interpretation of the results obtained: (1) plantation method and management practices, (2) habitat structure in terms of herbaceous and shrub layers and (3) major outcome of the physical and chemical characterization of sites. In the case of the MONCHIQUE site, the original paper by BARROCAS *et al.* (1998) includes 6 comparisons (2 native species vs. 3 eucalyptus plantations); these comparisons will be considered for analysis, but for the brief characterization on Table II they were pooled. One assumption common to all selected sites is that previously to the instalation of the eucalyptus plantation the area was occupied by the correspondent autochthonous tree species of that specific site.

2. Data treatment

For the analysis of the overall data presented in the selected case studies, and in order to standardise this presentation, two types of parameters were used: (1) biodiversity indicators and (2) similarity analysis. All the comparisons made inside each site (between each pair of stations) were valid since the sampling effort was the same at each station of the same site. At the MONCHIQUE sites, on those cases where an unbalanced sampling occurred, values were corrected whenever necessary.

In the first set of methods, species diversity, evenness and species richness were calculated for each station using Shannon-Weaver, Pielou and Margalef indices respectively (MAGURRAN, 1991). Although authors presented data for organic and mineral horizons and pitfall trap samples, for this analysis data were cumulated for all strata and for all sampling points inside each station.

For the second group of analysis, the SIMAN approach (SOUSA & GAMA, 1994) was used. In this type of analysis, the community composition between the two stations at each site (the autochthonous stand vs. the eucalyptus stand) is compared using similarity measures coupled to normal methods on inferen-

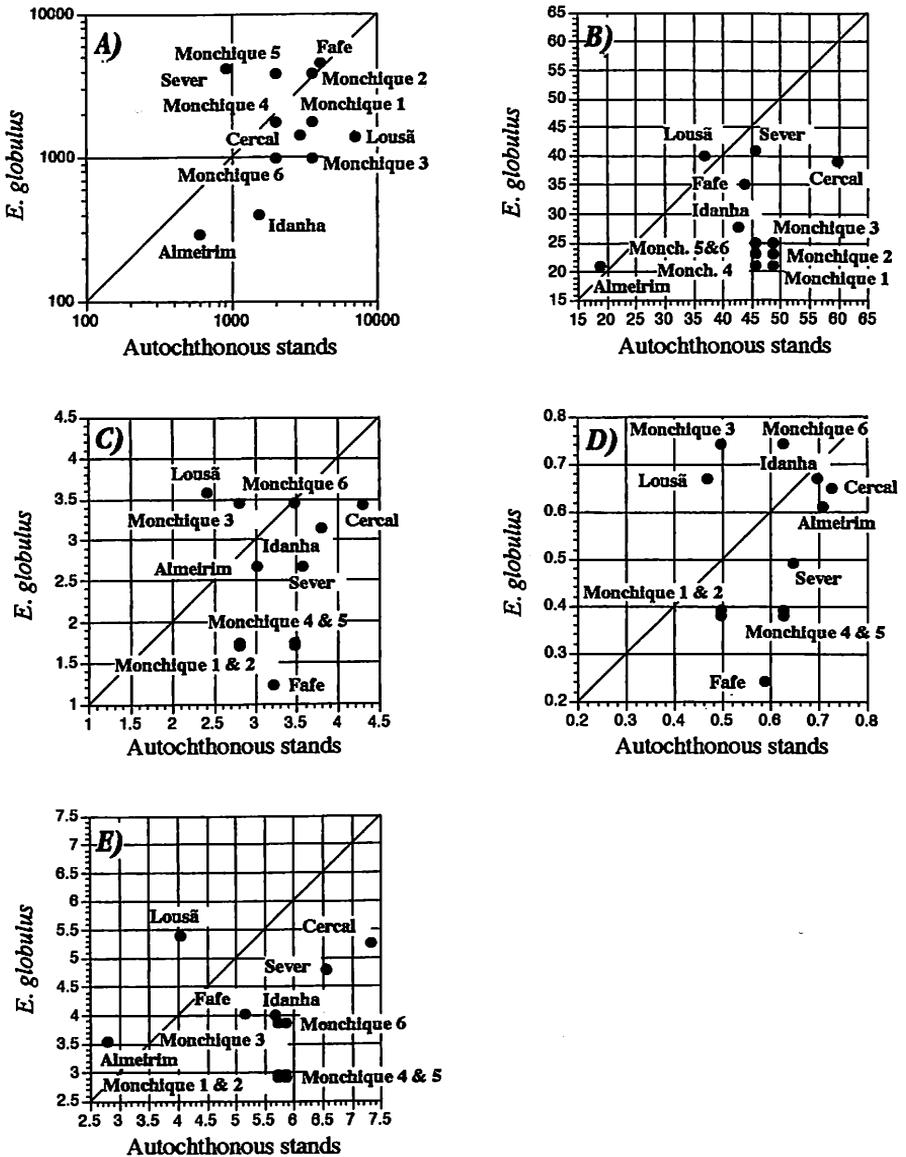


Fig. 2. Characterization of biodiversity indicators for all pairs of studied stations: A) Abundance, B) Number of taxa, C) Diversity, D) Evenness and E) Species richness. Diagonal isolines indicate equivalent values for the autochthonous species and eucalyptus. Lousã - *P. pinaster* vs. *E. globulus*; Sever - *P. pinaster* vs. *E. globulus*; Idanha - *Q. ilex ballota* vs. *E. globulus*; Almeirim - *Q. suber* vs. *E. globulus*; Fafe - *Q. pyrenaica* vs. *E. globulus*; Cercal - *Q. suber* vs. *E. globulus*; Monchique (1-3) - *Q. suber* vs. *E. globulus* (1-3); Monchique (4-6) - *Q. canariensis* vs. *E. globulus* (1-3).

tial statistics; the average control similarity (calculated from the similarity values among the autochthonous samples) is compared with the treatment average similarity (calculated from similarity values between autochthonous vs. eucalyptus samples) using a t-test. The similarity index used in this analysis was the Bray-Curtis coefficient, selected for its robustness in analysing ecological data (FAITH *et al.*, 1987). Before the application of the t-test, similarity values were arcsin-transformed (ZAR, 1984) in order to achieve data normality and homocedasticity.

In order to evaluate which pair of stations were most affected by the plantation of the exotic species, a similar approach was used. In this case, the average distances (=dissimilarities) between autochthonous and eucalyptus samples were calculated for each pair of stations. This type of analysis was not achievable at the CERCAL site due to the absence of individual sample data.

Results

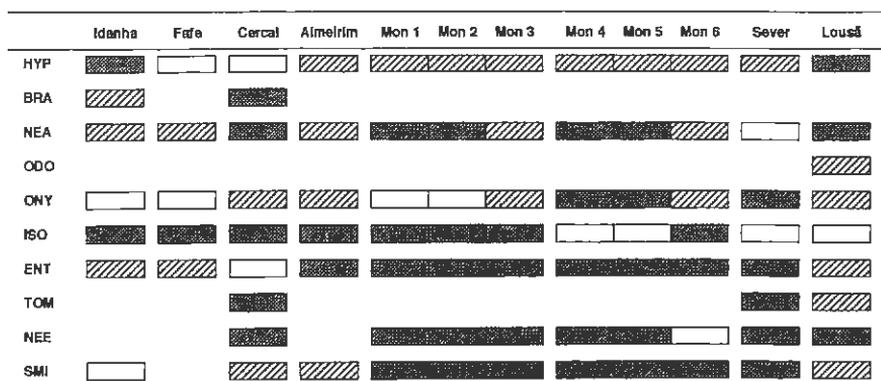
1. Biodiversity indicators

Abundance, estimated as number of individuals, was lower in eucalyptus plantations than in autochthonous forests for all sites but FAFE, SEVER and MONCHIQUE 5 (Fig. 2A). In the first case the great increase in abundance of one Isotomid and two Neanurid species led to an increase in the overall abundance; nevertheless, the other taxa showed a strong decrease in numbers, which was more pronounced at the organic horizon level. At SEVER site, several taxa showed an absolute increase in abundance, especially those belonging to the Hypogastruridae, Neanuridae, Onychiuridae and Entomobryidae families. In the case of MONCHIQUE 5 site, the increase in numbers of two Isotomid and one Hypogastruridae species originated the bias towards the exotic stand.

On the other sites this decrease in abundance was observed in almost all family groups, not only in absolute terms but also in terms of representativity. However, it was more pronounced in the Isotomidae family (especially on those taxa considered as typical forest species) and on those epigeic species (Entomobryidae, Neelidae and Sminthuridae groups) especially at MONCHIQUE sites (Fig. 3A). In the same picture it is also possible to observe an increase in the representativity of Onychiuridae, Entomobryidae and Sminthuridae families, especially on those sites where the differences in terms of habitat configuration between stands was more pronounced (IDANHA, FAFE, CERCAL); the first group includes typical euedaphic species and the other two groups include those species that have great mobility and are able to colonize open spaces (ARDANAZ & JORDANA, 1986; LUCIAÑEZ *et al.*, 1988).

The same general trend was also observed in the number of taxa, with most sites showing a clear tendency towards the autochthonous stand (Fig. 2B). The reduction in the number of taxa, as result from shifting to the eucalyptus, was, in absolute terms, generalized to almost all family groups. In terms of repre-

A - Abundance (%)



B - Number of taxa (%)

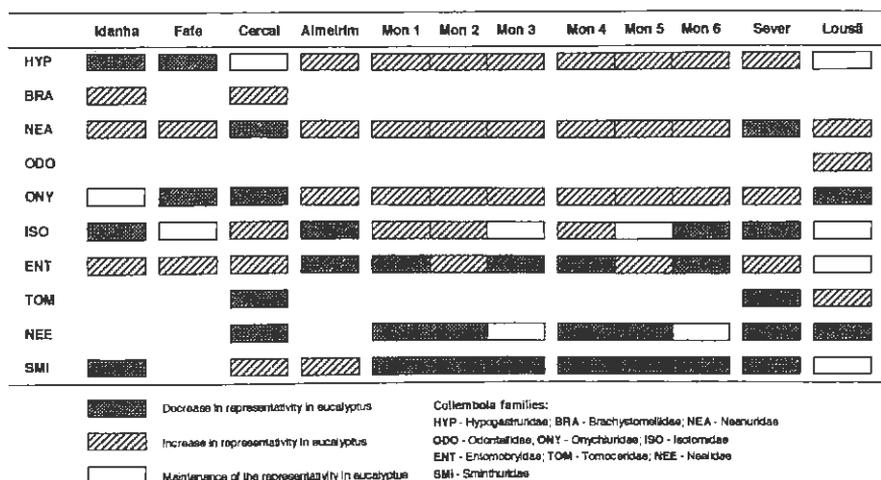


Fig. 3. Schematic representation of changes in representativity (based on percentage values) in abundance (A) and number of taxa (B) of each Collembola family caused by the shift from the autochthonous species to the eucalyptus.

representativity, however, it was possible to observe a different picture (Fig. 3B); the pattern is not so clear as in the case of abundance data, but it was possible to see a decrease in representativity of the epigeic species at the MONCHIQUE sites and an increase of Entomobryidae representativity at those three sites mentioned above (IDANHA, FAFE, CERCAL).

Diversity, evenness and species richness values were also higher in autochthonous stands (Fig. 2C, D, E). In almost all cases, besides the number of taxa, evenness played an important role in regulating diversity values. In fact, the position of the exceptions to this trend (LOUSã and MONCHIQUE 3 sites) and also of those sites plotted near the isoline (e.g. MONCHIQUE 6) may be

explained by a close or even an higher evenness on the eucalyptus stand in comparison to the correspondent native station.

2. SIMAN analysis

The disruption on the collembola communities at the several sites, caused by the plantation of *E. globulus*, was also visible in the SIMAN analysis (Figs 4-6). With the exception of three comparisons made (Figs 4C-Litter, 5F-Soil, 6A-Litter), all the others presented lower and, in most cases, significantly different average similarity values on the treatment groups; this was observed either considering each horizon separately or pooling them together.

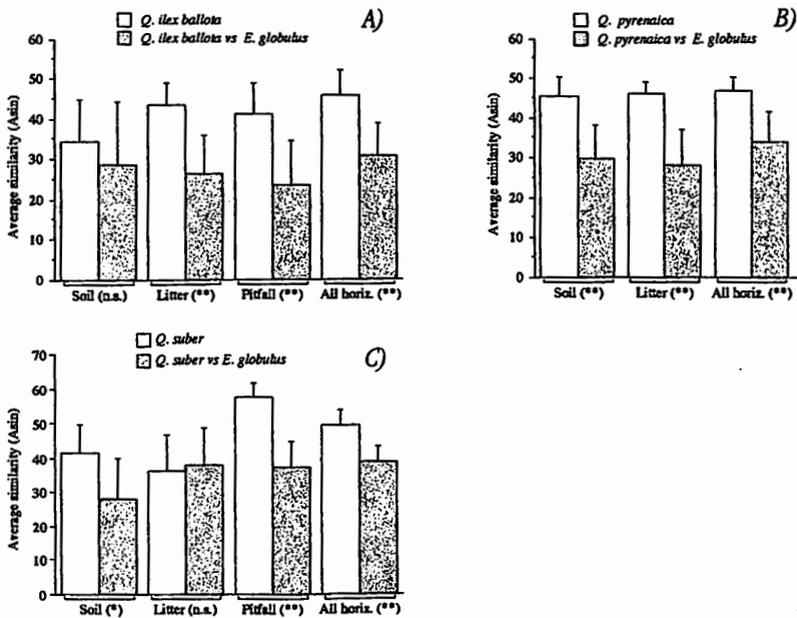


Fig. 4. Average similarities (+SD) on control and treatment groups for Idanha (A), Fafe (B) and Almeirim (C) sites. Asin - arcsin-transformed values. Groups were compared by a t-test: n.s.-non-significant; * $p < 0.05$; ** $p < 0.01$.

When analysing the sampled horizons separately, results show an higher disruption of collembola communities at the organic horizon level and also on the epigeic fauna captured on pitfall trap samples. In opposition to the soil horizon, these two levels showed, in 8 of the 11 comparisons made, highly significant differences between control and treatment similarity values; the exceptions were observed on those sites where habitat configuration between the correspondent stands was similar (Figs 4C, 6A, 6B).

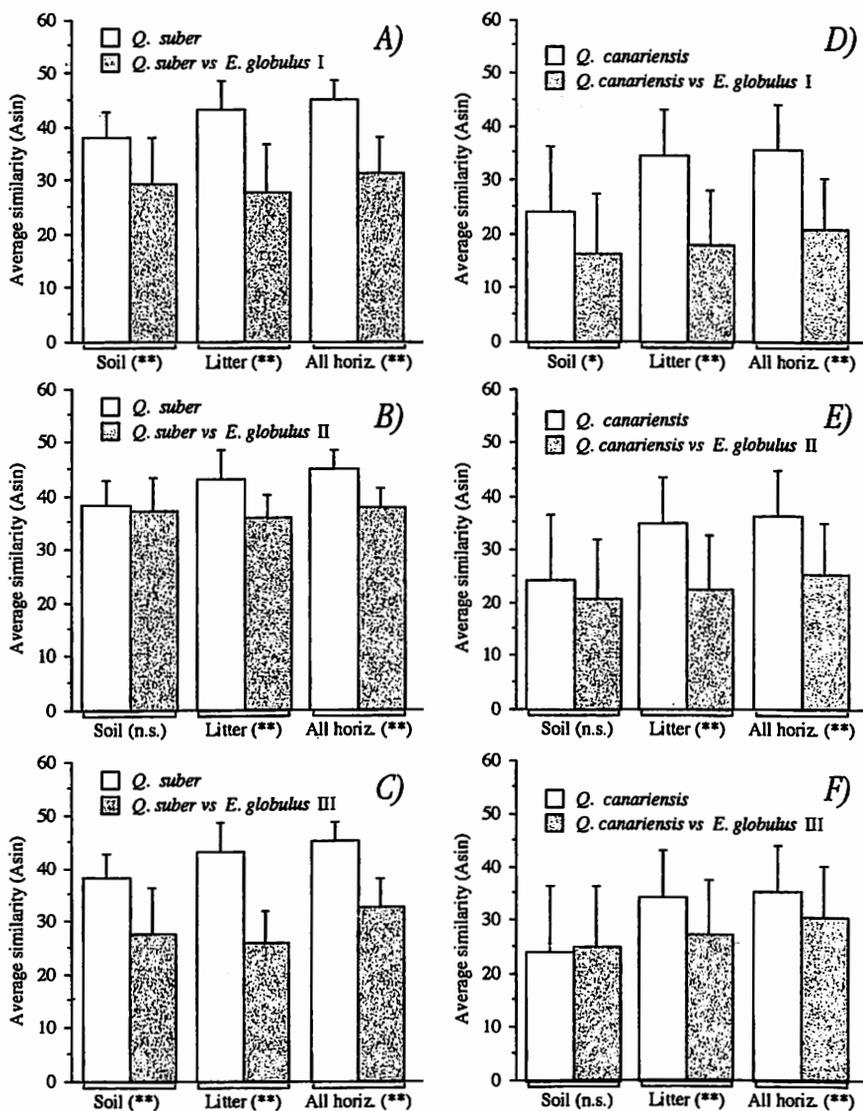


Fig. 5. Average similarities (+SD) on control and treatment groups for Monchique 1-3 (A, B & C) and Monchique 4-6 (D, E & F) sites. Asin - arcsin-transformed values. Groups were compared by a t-test: n.s.-non-significant; * $p < 0.05$; ** $p < 0.01$.

The analysis of the different responses caused by shifting from the autochthonous species to the eucalyptus (Fig. 7), the highest distances were observed on those sites where the habitat configuration and/or the physical and chemical characterization of both stands was most different (indicated by the arrows). The lowest distances were observed on both Pine vs. Eucalyptus sites

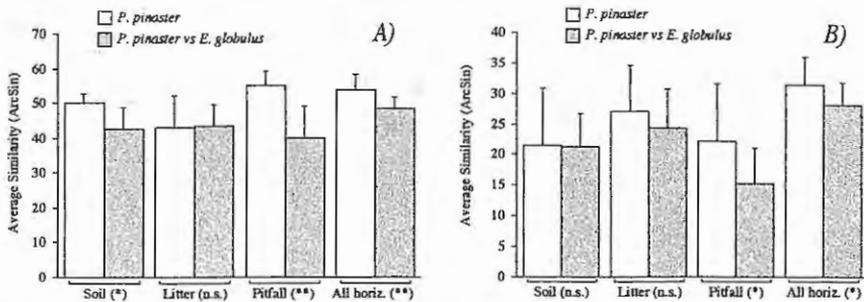


Fig. 6. Average similarities (+SD) on control and treatment groups for Lousã (A) and Sever (B) sites. Asin - arcsin-transformed values. Groups were compared by a t-test: n.s.-non-significant; * $p < 0.05$; ** $p < 0.01$.

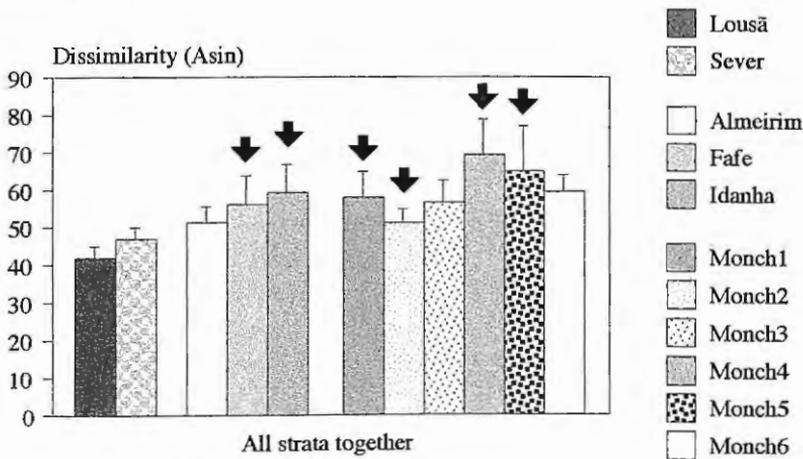


Fig. 7. Average distances (+SD) between autochthonous and eucalyptus samples for each studied site. Values were calculated pooling all strata together for each station. Asin - arcsin-transformed values.

(LOUSÃ and SEVER), mainly characterized by a great resemblance in terms of habitat structure and forest management (SEVER) or by an old pinewood stand with a scarce vegetation cover, not able to support a much richer community in comparison to an eucalyptus stand with a homogeneous shrub cover and a developed litter layer (LOUSÃ). On the *Quercus* spp. sites (MONCHIQUE complex excluded), the highest values were found, as expected, on IDANHA and FAFE sites. At MONCHIQUE, the highest values were found on sites 1, 2, 4 and 5; this agrees with BARROCAS *et al.* (1998) who considers the Eucalyptus site 3 (used in the comparisons for MONCHIQUE 3 and 6) the most similar to the autochthonous stands in terms of collembola community structure.

Discussion

The overall analysis of the selected case studies showed a disruption on Collembola communities associated with *Eucalyptus globulus* stands in comparison to the correspondent autochthonous stands. This shift from native to the exotic tree species also caused, in most cases, an impoverishment of those communities.

Biodiversity indicators and SIMAN analysis showed that effects were more pronounced not only on those sites where the *Quercus* ssp. were the autochthonous tree present, but especially on those sites where the habitat configuration between contiguous stands was most different, with the fauna present on the upper soils layers (organic horizon and pitfall trap samples) being most affected. The two regulating factors behind these findings are the "quality" of the litter present and the management practices adopted to install and run the eucalyptus plantations, both having a strong effect on the structure and quality of the organic horizon.

Considering the first factor, the introduction of the eucalyptus could cause changes on the quality of the substrate, on soil microbial communities and on soil chemistry (e.g., pH and water retention), creating less favourable microhabitat conditions for collembola. On the other hand, when comparing oak and pinewood sites, the structure and quality of the organic horizon was more favourable to the existence of well structured collembola communities on the first sites, therefore being submitted to more pronounced impacts when the shift occurred. The low quality of eucalyptus litter, acting as a less suitable substrate for soil arthropods, was also found in other studies either comparing faunal communities from *E. globulus* stands and from several native forests (CABRAL & MARTINS, 1985; PINTO *et al.*, 1997), or analysing litter decomposition and litterbag colonization (SERRALHEIRO & MADEIRA, 1991; PEREIRA *et al.*, 1998) and even in bioenergetic studies with soil detritivores (SOUSA *et al.*, 1998).

In terms of management, the tillage practices necessary to prepare the soil for the plantation, the periodical vegetation cleaning and the removal of standing stock biomass after each cut, could lead to a great disruption of the vegetation cover affecting the integrity of the organic horizon. The importance of habitat configuration for collembola, as a result of management practices, was also observed by other authors when analysing the effects of different forest interventions, ranging from pure deforestations (BONNET *et al.*, 1976; 1977; 1979) to reafforestations with other exotic tree species (DEHARVENG, 1996; ARBEA & JORDANA, 1985; JORDANA *et al.*, 1987; LUCIAÑEZ & SIMON, 1988); their results show that on more managed sites there was a strong impoverishment of the collembola communities, with a decrease in diversity values and in the representativity of species living on the upper soil layers.

In relation to the influence of this last factor, the same question could be posed when dealing with a reafforestation with a native species. Of course any

action of this nature can cause a disturbance on the equilibrium of soil biological communities. The magnitude of this disruption, however, is expected to be greater if an exotic species is used. This makes very difficult to attribute a degree of importance to each of the two factors considered. They can act synergistically, therefore generalizations about impacts of reafforestation actions at this level should be done carefully.

The future of eucalyptus plantations in Portugal, more than on the increase of the planted area, depends mainly on the existence of appropriate management plans. Since the area covered by this exotic species has an impact on soil functioning and landscape structure at local and regional levels, these plans should be ruled by a sustainable use of the plantations and must include active measures to improve the site specific biodiversity. These measures may include, for instance, the diversification of the plantations (age structure and tree species), the increase of rotation length (increasing growth and cut cycles) and the incorporation of forest residues into the soil (leading to an enrichment on organic matter, nutrients and diminishing the problem of water retention and soil erosion). Together with these measures, a monitoring programme, with well defined indicators, should be implemented to check the outcome of those measures and the quality of the plantations. These should include not only parameters used in forestry, but also several types of biological structural and functional parameters.

Bibliography

- ARBEA J.I. & JORDANA R., 1985. - Efecto de una repoblación con coníferas en un robleal de Navarra sobre los colembolos edáficos. *Boletim da Sociedade Portuguesa de Entomologia*, 2: 277-286.
- ARDANAZ A. & JORDANA R., 1986. - Estudio ecológico sobre la fauna colembológica de las Peñas de Echauri, Navarra. (Insecta, Collembola). III. - Prado-Matorral. *Actas de las VIII Jornadas de A y E.*, 253-260.
- BARROCAS H.M., GAMA M.M. DA., SOUSA J.P. & FERREIRA C.S., (1998). - Impact of reafforestation with *Eucalyptus globulus* Labill. on the edaphic collembolan fauna from Serra de Monchique (Algarve). *Miscellanea Zoologica*, 21 (2) : 9-23.
- BONNET L., CASSAGNAU P. & DEHARVENG L., 1976. - Un exemple de rupture de l'équilibre biocénotique par déboisement: Les peuplements de Collemboles édaphiques du Piau d'Engaly (Hautes-Pyrénées). *Revue d'Écologie et Biologie du Sol*, 13: 337-351.
- BONNET L., CASSAGNAU P. & DEHARVENG L., 1977. - Influence du déboisement et du reboisement sur les biocénoses de Collemboles dans quelques sols Pyrénéens. *Bulletin d'Écologie*, 8 : 321-332.
- BONNET L., CASSAGNAU P. & DEHARVENG L., 1979. - Recherche d'une méthodologie dans l'analyse de la rupture des équilibres biocénotiques: applications aux Collemboles édaphiques des Pyrénées. *Revue d'Écologie et Biologie du Sol*, 16: 373-401.
- CABRAL M.T. & MARTINS S.C., 1985. - Estudo comparativo da fauna do solo de povoamentos de *Eucalyptus globulus* LABILL. de várias idades e de *Pinus pinaster* AIT.. *Boletim da Sociedade Portuguesa de Entomologia*, 3: 75-86.

- DEHARVENG L., 1996. - Soil collembola diversity, endemism and reforestation: a case study in Pyrenees (France). *Conservation Biology*, 10 : 74-84.
- DEVY-VARETA N., 1993.- A Questão da Florestação em Portugal: um Processo de Longa Duração. *Sociedade e Território. Revista de Estudos Urbanos e Regionais*, 19: 49-70.
- DEVY-VARETA N., 1994. - Dos carvalhos aos eucaliptais: evolução espacial da árvore e da floresta em Portugal. *Actas do III Encontro Pedagógico sobre Risco de Incêndio Florestal*, 39-54.
- DGF, 1999. - Inventário Florestal Nacional. Direcção Geral das Florestas. Ministério da Agricultura do Desenvolvimento Rural e das Pescas. Lisboa.
- FAITH D.P., MINCHIN P.R. & BELBIN L., 1987. - Compositional dissimilarity as a robust measure of ecological distance. *Vegetatio*, 69: 57-68.
- FERREIRA C.S., GAMA M.M. DA., SOUSA J.P. & VASCONCELOS T.M., 1994. - Comparative study of the collembola populations from a *Pinus pinaster* Aiton forest and a *Eucalyptus globulus* Labill. plantation. *Ciência Biológica Ecology & Systematics*, 14: 19-34.
- FIGUEIREDO M.C., CABRAL M.T., MARTINS S.C. & GAMA M.M. DA, 1985. - Nota prévia sobre um estudo comparativo das populações de Colêmbolos de eucaliptais (*Eucalyptus globulus* Labill.) de várias idades e de pinhal (*Pinus pinaster* Ait.). *Boletim da Sociedade Portuguesa de Entomologia*, 2: 221-234.
- GAMA M.M. DA, SANTOS A.F.A.M. DOS & NOGUEIRA A., 1989. - Comparaison de la composition de populations de Collemboles de peuplements d' *Eucalyptus* (*Eucalyptus globulus*) et de Chêne-liège (*Quercus suber*). *Proceedings of the 3rd International Seminar on Apterygota*, 339-345.
- GAMA M.M. DA, NOGUEIRA A. & SANTOS A.F.A.M. dos, 1991. - Effets du reboisement par *Eucalyptus globulus* sur les Collemboles édaphiques. *Revue d'Écologie et de Biologie du Sol*, 28: 9-18.
- GAMA M.M. DA, SOUSA J.P. & VASCONCELOS T.M., 1994a. - Comparison of Collembolan Populations from Portuguese Forests of *Quercus rotundifolia* Lam. and *Eucalyptus globulus* Labill. *Professor Germano da Fonseca Sacarrão. Arquivos do Museu Bocage*. Lisboa, 201-214.
- GAMA M.M. DA, VASCONCELOS T.M. & SOUSA, J.P., 1994b. - Collembola diversity in Portuguese autochthonous and allochthonous forests. *Acta Zoologica Fennica*, 195: 44-46.
- GAMA M.M. DA, SOUSA J.P. & VASCONCELOS T.M., 1995. - Comparison of Collembolan populations structure from Portuguese forests of *Pinus pinaster* Aiton and *Eucalyptus globulus* Labill. *Bulletin Entomologique de Pologne*, 64: 77-89.
- JORDANA R., ARBEA J.I., MORAZA L., MONTENEGRO E., MATEO M.D., HERNANDEZ M.A. & HERRERA L., 1987. - Effect of reafforestation by conifers in natural biotops of middle and South Navarra (Northern Spain). *Revue Suisse de Zoologie*, 94 : 491-502.
- LUCIAÑEZ M.J., PASCUAL M.M. & BENTO M.J.S., 1988. - Estudio colemológico de los robledales del Macizo Central de la Sierra de Gredos (Sistema Central). *Actas II Jornadas sobre la Sierra de Gredos*.
- LUCIAÑEZ M.J. & SIMÓN, J.C., 1988. - Estudio colemológico de un robledal y un pinar en la vertiente sur de la sierra de Gredos. *Eos*, 64: 57-87.

- MAGURRAN A.E., 1991. - Ecological diversity and its measurement. Chapman and Hall, London, 179 pp.
- MONTEIRO ALVES A.A., 1994. - Um quadro para o debate da problemática do Eucalipto in "Eucalipto: economia e território". SPER. Edições Cosmos, Lisboa, 71-78.
- PINTO C., SOUSA J.P., GRAÇA M.A.S. & GAMA, M.M. DA, 1997. - Forest Soil Collembola. Do tree introductions make a difference? *Pedobiologia*, 41: 131-138.
- PEREIRA P., GRAÇA M.A.S. & MOLLES M., 1998. - Leaf litter decomposition in relation to litter physico-chemical properties, fungal biomass, arthropod colonization, and geographical origin of plant species. *Pedobiologia*, 42: 316-327.
- SERRALHEIRO F. & MADEIRA M., 1991. - Acari colonization of *Quercus suber* and *Eucalyptus globulus* litter. in "Modern Acarology", F. DUSBÁBEK & V. BUKVA (Eds.), Academia and SPB Academic Publishing, Prague The Hague, Vol. 1: 353-358.
- SOARES J., 1993. - Balanço da Florestação em Portugal nas Últimas Cinco Décadas. *Sociedade e Território. Rvista de Estudos Urbanos e Regionais*, 19: 29-32.
- SOUSA J.P. & GAMA M.M. DA, 1994. - Rupture in a Collembola community structure from a *Quercus rotundifolia* Lam. forest due to the reafforestation with *Eucalyptus globulus* Labill. *European Journal of Soil Biology*, 30: 71-78.
- SOUSA J.P., VINGADA J.V., BARROCAS H. & GAMA, M.M. DA, 1997. - Effects of introduced exotic tree species on Collembola communities: the importance of management techniques. *Pedobiologia*, 41: 145-153.
- SOUSA J.P., VINGADA J.V., LOUREIRO S., GAMA M.M. DA. & SOARES A.M.V.M., 1998. - Effects of introduced exotic tree species on growth, consumption and assimilation rates of the soil detritivore *Porcellio dilatatus* (Crustacea: Isopoda). *Applied Soil Ecology*, 9: 399-403.
- VASCONCELOS T.M., GAMA M.M. DA & SOUSA J.P., 1994. - Estudo Comparativo da Biodiversidade Colembológica em Povoamentos de Pinheiro bravo e de Eucalipto. *Silva Lusitana*, 2: 179-191.
- ZAR J.H., 1984. - Biostatistical Analysis. Prentice-Hall, London, 718 pp.