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Absence of effects on nutrient budgets after insect defoliation in a small *E. globulus* watershed in Galicia (NW Spain)

C. Fernandez*, J. A. Vega, S. Bara, M. Alonso and T. Fonturbel

Centro de Investigación Forestal-Lourizán. Consellería do Medio Rural. Xunta de Galicia. P.O. Box 127. 36080 Pontevedra. Spain

Abstract

Nutrient export via streamflow after the defoliation by *Gonipterus scutellatus* Gill. in a *Eucalyptus globulus* Labill. watershed in Galicia (NW Spain) was monitored from 1999 to 2006. The effects of such defoliation on nutrients balance had not been previously evaluated.

Insect defoliation caused no significant changes in streamflow nutrient concentrations during the period of study compared with the pre-perturbation period and nutrient exports in streamflow were compensated via precipitation in all cases.

The results presented here show that in spite of the reduction in E.globulus growth caused by the defoliation, nutrient balances were positive, suggesting a minor impact in the soil-plant system nutrient budget.

Key words: eucalypts; nutrient balance; defoliation; *Gonipterus scutellatus*.

Resumen

Ausencia de efectos en los balances de nutrientes después de defoliación por insectos en una cuenca experimental de *E. globulus* en Galicia (NW de España)

Se ha desarrollado un estudio entre 1999 y 2006 para evaluar el efecto de la defoliación por *Gonypterus scutellatus* Gill. sobre la pérdida de nutrientes por escorrentía en una cuenca experimental de *Eucalyptus globulus* Labill. en Galicia (NW España). Esos efectos no habían sido evaluados hasta ahora.

La defoliación no causó variaciones significativas en las concentraciones de nutrientes durante el período de estudio en relación con el período pre-perturbación y las entradas de nutrientes por precipitación compensaron las salidas de nutrientes por escorrentía en todos los casos.

Los resultados que se presentan en este trabajo muestran que a pesar de la reducción en el crecimiento de *E.globulus* causado por la defoliación, los balances de nutrientes fueron positivos, sugiriendo un impacto menor en el balance de nutrientes del sistema suelo-planta.

Palabras clave: eucaliptos; balance de nutrientes; defoliación; *Gonipterus scutellatus.*

Introduction

Eucalyptus globulus Labill. covers about 175,000 ha in mono specific and 160,000 ha (Ministerio de Medio Ambiente, 2001) in mixed stands in Galicia (NW Spain), the area with the largest eucalypt plantations in Europe (Ruiz *et al.,* 2008). These eucalypt stands, characterized by their high growth rate (Ruiz *et al.*, 2008), are managed in short rotations (10-15 years) with mechanized skidding and intensive logging slash manipulation after clearcutting.

The Eucalyptus snout beetle, *Gonipterus scutellatus* Gill., is a generalist herbivore of *Eucalyptus* spp, both the snout beetle adults and larvae eat the leaves, buds and shoots of the eucalypt trees. It was found in NW Spain in 1991 (Mansilla, 1992) and now it has spread and become in a serious problem affecting the Galician eucalypt plantations (Mansilla *et al.*, 1995, 1996; Cordero *et al.*, 1999; Cordero and Santolamazza, 2000; Santolamazza *et al.*, 2006). Snout beetle can develop up to three generations each year (Santolamazza *et al.*, 2006), thus increasing its eucalypt defoliating capability.

Little is known about the effects of insect attacks on nutrient cycling in forested watersheds. Most studies of the effects of insect defoliation on watersheds nutrient

* Corresponding author: cristinaffilgueira@hotmail.com
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Table 1. Main characteristics of Castrove soils

Depth (cm)	Texture			pH	C (%)	C/N	Exchangeable cations [cmol (+) kg^{-1}]				Available P	Exchangeable cation capacity [cmol (+) kg^{-1}]
	Sand (%)	Lime (%)	Silt (%)				Ca	Mg	Na	K		
0-20	73	19	8	4.5	10.8	17.4	0.01	0.03	0.14	0.07	0.06	3.7
20-50	70	20	10	4.9	5.4	18.1	< 0.01	0.02	0.04	0.02	0.03	2.7
50-100	72	18	10	4.8	3.1	19.4	< 0.01	< 0.01	0.03	< 0.01	0.01	1.6

fluxes have been carried out in native forests of North America (*e.g.* Swank *et al.*, 1981; Webb *et al.*, 1995; Eshelman *et al.*, 1998; Lewis and Likens, 2007) and as authors know, being inexistent in eucalypt plantations.

Insect defoliation effects in the ecosystem include the disturbances directly associated to the action of the pest, which cause tree defoliation, loss of vigor or death and other indirect consequences such as temporary reduction in productivity and evapotranspiration, increased leaching of nutrients, stimulation of decomposition, and changes in microclimatic conditions in the forest (Webb *et al.*, 1995; Lovett *et al.*, 2002). Foliar herbivory may also affect soil faunal population structure and N acquisition (Bradford *et al.*, 2008).

The effect of forest cover reduction on water yield after insect infestation has been analysed in Galicia (Fernández *et al.*, 2006, 2007). However, the consequences of such defoliation on nutrients export in streamflow has not been investigated until now. These plantations are growing in very poor soils and subjected to an intensive management which endanger their sustainability (Dambrine *et al.*, 2000) and additional nutrient losses by insect defoliation could contribute to hamper their sustainability.

The aim of the present study was to determine if an insect defoliation causes changes in dissolved nutrient export in a representative *E. globulus* watershed in the coastal area of NW Spain.

Material and methods

Study area

The experimental area is located close to the Atlantic Ocean inlet of Pontevedra in the Castrove hillslopes (42° 26’ 40”-42° 27’ 00” N and 8° 43’ 30”-8° 43’ 55” W). Catchment area is 9.9 ha and it was completely covered by an *E. globulus* plantation. Tree density was 1,250 trees ha^{-1}. Soils are Alumiumbric Regosols and Alumiumbric Leptosols (Calvo and Macías, 2001), sandy and sandy-loam textured and developed on granitic and granodiorite parent material. The main soil characteristics are listed in Table 1. More detailed information can be found in Dambrine *et al.* (2000).

The climate in the area is oceanic, temperate and rainy. Mean annual temperature is 14°C. Mean temperature in the coldest month is 9°C and 20.5 °C in the hottest month. Average annual precipitation is 1,880 mm y^{-1} and 41% of this falls in the period October-December. There is a dry period in summer (July-September) when 12% of annual precipitation falls. The understory stratum is primary occupied by *Acacia melanoxylon* R. Br. and *Ulex europaeus* L. *Pteridium aquilinum* and some Ericaceae plants are also present.

In the spring of 2000 an attack by *G. scutellatus* Gill. started, causing a moderate tree defoliation in most of the catchment area. To evaluate the degree of tree defoliation 15 plots (radius 10 m) were installed in summer 2000. Mean tree density in these plots was 1,200 trees ha^{-1}. Mean variation of tree height and diameter during the period of study is compiled in Table 2. Tree crown defoliation volume was visually estimated with the aid of binocular in each tree inside the plot. A mean value of the percentage of eucalypt defoliation was used to

Table 2. Mean dendrometric *E. globulus* characteristic in the defoliation evaluation plots during the period of study in the Castrove experimental watershed. In brackets, standard error. Water year: October-September

Water year	Mean height (m)	Mean diameter at breast height (cm)
1999-2000	11.0 (0.7)	8.5 (1.3)
2000-2001	12.3 (0.8)	9.5 (1.0)
2001-2002	13.5 (0.7)	10.6 (0.6)
2002-2003	14.8 (0.9)	11.5 (1.5)
2003-2004	15.6 (1.1)	12.4 (1.3)
2004-2005	16.0 (0.7)	13.1 (1.0)
2005-2006	16.5 (1.0)	13.5 (0.8)

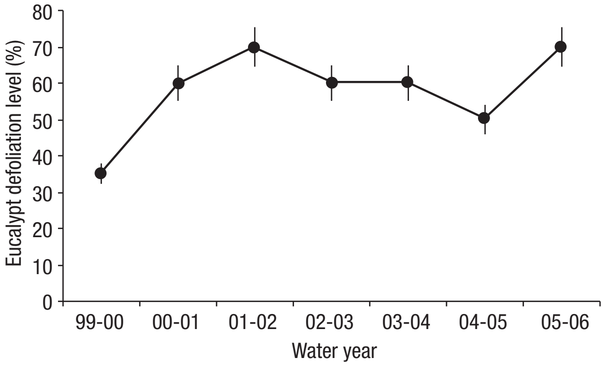

Figure 1. Mean variation of the percentage of eucalypt crown volume defoliation in the Castrove experimental watershed during the period of study. Vertical bars, standard error. Water year: October-September.

determine the level of tree defoliation in the whole catchment. The evolution of the mean percentage of defoliation during the study period is shown in Figure 1. During the first years, part of the trees showed basal sprouts and in some of them leaves from epicormic buds also emerged. The intensity of the insect attack peaked in 2002 (Fig. 1), reducing the capacity of eucalypt trees to regrowth. From *G. scutellatus* attack onwards, *Acacia melanoxylon* was progressively sharing dominance with *E. globulus*. The understory of *Ulex europaeus* L. also increased its cover. Estimated cover of *A. melanoxylon* was around 50% of catchment area at the end of the study (Fig. 2).

The watershed under study began to be monitored in October 1987. This watershed had suffered a sequence of perturbations and management activities from 1989 to 1995 (wildfire, harvesting and coppice sprout selection thinning) that affected the water and nutrient balances (Fernández *et al.*, 2006; Fernández *et al.*, in

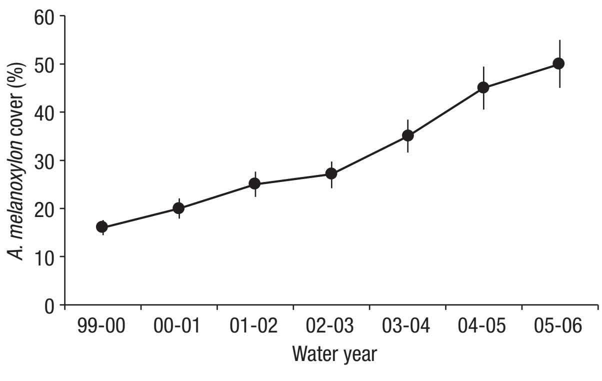

Figure 2. Mean variation of the percentage of *Acacia melanoxylon* cover in the Castrove experimental watershed during the period of study. Vertical bars, standard error. Water year: October-September.

press). Coppice sprout selection thinning caused minor changes in nutrient concentrations (Fernández *et al.,* in press), and this period (1995-1996/1998-1999) was used as a control for insect defoliation changes in nutrient concentrations evaluation.

Although lack of replication may affect the results (Bennet and Adams, 2004), further replication was not possible because of logistical (lack of catchments covered by *E. globulus* with a sufficient degree of similarity and no perturbation) and financial constraints. Moreover, in an experimental design based on the selection of several paired eucalypt catchments, it would not have been possible to replicate unforeseen perturbations such as wildfire or insect infestation.

Data collection

Streamflow was continuously measured at the outlet of the catchment using 90°V-notch weirs with standard ink scripture limnigraphs (OTT Kempten). Charts were digitised, and runoff calculated according to the shape of the weir and the corresponding data added at weekly intervals. Mean precipitation was obtained from a network of carefully located rainfall gauges in the watershed.

Automatic samplers were used to collect streamflow samples at weekly intervals in both watersheds. Grab samples of precipitation were collected manually at weekly intervals.

The water samples were filtered (0,45 µm), then Ca and Mg were analysed by spectrophotometry in the presence of lanthane, K and Na by emission, and NO_3^-, PO_4^{3-}, SO_4^{2-}, Cl^-, Al^{3+} and Fe^{3+} by ion chromatography. Determinations of SO_4^{2-} Al^{3+} and Fe^{3+} were only available for the post-perturbation period. Nutrient fluxes were determined by multiplying the measured concentration of dissolved chemicals in the samples by the respective amounts of precipitation or stream water for each sampling interval, respectively.

Statistical analysis

The differences in the mean annual values of nutrient concentrations between each water year after insect defoliation and the previous period (1995-1998) were evaluated by a Mann-Whitney test. Mean monthly values of nutrient concentrations were used to obtain annual means. Previously, we verified that the requirements of non-autocorrelation were met.

The SPSS (2004) statistical package was used to carry out the analyses.

Results

No differences in the annual values of Ca, Mg, K, PO_4^{3-} and NO_3^- concentrations in the streamflow were observed during the insect defoliation period nor with the previous period. Mean Ca concentration for the insect defoliation period was 0.3 mg kg^{-1} *vs* 0.2 during the previous period, these figures were 0.4 and 0.4 for Mg, 0.2 and 0.2 for K, 7.0 and 6.0 for Na, 0.03 and 0.02 for P and 0.05 and 0.05 for nitrate, respectively. Also, no significant changes in sulphate, aluminium and iron concentrations were observed during the period of study which mean values were 1.6, 0.03 and 0.02 mg kg^{-1}, respectively.

Precipitation inputs compensated streamflow cation losses in all cases, excepting for Na in some of the water years (Table 3). Nitrate exports remained low during the period of study and were always lesser than the inputs via precipitation. The same happened in the case of sulfate which budgets were always positive.

Discussion

The absence of significant increments in the mean annual values of nutrient concentrations after insect defoliation, observed in this study, are somehow different to the results obtained in earlier studies that reported an increase in cation concentrations after insect defoliation (Webb *et al.*, 1995; Eshelman *et al.*, 1998; Tokuchi *et al.*, 2004; Lewis and Likens, 2007) as a consequence of increased nitrification. In our case, the comparison with a post-thinning period could affect the results, particularly for K, but the modifications in nutrient concentrations observed after thinning were small and restricted to the first post-thinning year (Fernández *et al.*, in press). Moreover, if we compare nutrient concentrations after insect defoliation with the pre-perturbation period (1987-1989) no changes in concentrations were detected.

Generally, the impact on nutrient concentrations and exports varies with the degree of disturbance, but site-specific factors associated with soil and vegetation characteristics are also important. In this study, nor modification in nitrate or sulfate concentrations in the

Table 3. Atmospheric input and hydrologic loss of nutrients after *G. scutellatus* infestation (kg ha^{-1}) in the Castrove experimental watershed

Water		Ca	Mg	K	Na	P	Al	Fe	NO_3^-	Cl	SO_4^{2-}
99-00	Precipitation Input (I)	5.1	6.2	3.8	70.9	0.6	0.4	0.2	0.4	101.8	24.9
	Stream water output (O)	1.6	4.5	1.5	69.5	0.4	0.4	0.1	0.3	101.8	20.5
	I-O	3.5	1.7	2.3	1.4	0.2	0.0	0.1	0.1	0.0	4.4
00-01	Precipitation Input (I)	6.6	10.6	6.0	110.5	0.7	0.6	0.3	0.8	172.2	41.4
	Stream water output (O)	2.7	4.8	3.5	124.9	0.6	0.6	0.2	0.6	172.2	37.7
	I-O	3.9	5.8	2.5	–14.4	0.1	0.0	0.1	0.2	0.0	3.7
01-02	Precipitation Input (I)	4.0	5.2	3.4	47.8	0.6	0.3	0.1	0.5	71.2	17.6
	Stream water output (O)	1.1	2.2	0.9	31.7	0.2	0.3	0.1	0.2	71.2	10.2
	I-O	2.9	3.0	2.5	–16.1	0.4	0.0	0.0	0.3	0.0	7.4
02-03	Precipitation Input (I)	5.7	8.4	5.0	93.7	0.6	0.5	0.2	0.7	134.4	32.2
	Stream water output (O)	2.2	3.9	2.2	101.2	0.5	0.5	0.2	0.6	134.4	27.9
	I-O	3.5	4.5	2.8	–7.5	0.1	0.0	0.0	0.1	0.0	4.3
03-04	Precipitation Input (I)	4.8	6.6	4.1	58.0	0.4	0.3	0.2	0.6	84.6	23.3
	Stream water output (O)	1.5	2.4	1.2	56.8	0.3	0.3	0.1	0.2	84.6	16.7
	I-O	3.3	4.2	2.9	1.2	0.1	0.0	0.1	0.4	0.0	6.6
04-05	Precipitation Input (I)	3.4	4.3	2.7	35.5	0.3	0.2	0.1	0.5	51.2	14.7
	Stream water output (O)	1.0	1.6	0.9	35.5	0.1	0.1	0.0	0.2	51.2	5.2
	I-O	2.4	2.7	1.8	0	0.2	0.1	0.1	0.3	0.0	9.5
05-06	Precipitation Input (I)	4.1	4.0	3.3	47.2	0.4	0.3	0.1	0.5	71.0	17.7
	Stream water output (O)	1.5	3.0	1.2	55.0	0.2	0.3	0.1	0.4	71.0	16.3
	I-O	2.6	1.0	2.1	–7.8	0.2	0.0	0.0	0.1	0.0	1.4

Water year: October-September.

drainage water were found during the insect defoliation period. An increase of nitrate concentration associated to the presence of N-fixing plants (Van Miegroet and Cole, 1984; Compton *et al.*, 2003) like *A. melanoxylon* did not occur. In our site, apparently, no increase in nitrate production or aluminium and iron mobilization seemed to have occurred, and the low sulfate concentrations in streamwater reflect the high sulfate adsorption capacity of these desaturated soils with high organic matter content (Dambrine *et al.*, 2000). Absence of response in nutrient concentration after insect defoliations was also reported by Bormann and Likens (1979) and Christenson *et al.* (2002) in watersheds covered by other tree species different from *E. globulus*.

The insect defoliation may cause an increase of nitrogen and labile carbon to the forest floor (Rinker *et al.*, 2001; Lovett *et al.*, 2002; Frost and Hunter, 2008). The nitrogen pulse comes from the insect feces, dead caterpillars, unconsumed green foliage and increased leaching of nitrogen from dame foliage. Most of this N is immobilized by soil microorganisms (Lovett *et al.*, 2002, 2006) or incorporated into soil organic matter (Christenson *et al.*, 2002; Lovett *et al.*, 2002). Although increases in nitrate leaching have been frequently reported after insect defoliation (Swank *et al.*, 1981; Webb *et al.*, 1995; Eshelman *et al.*, 1998; Reynolds *et al.*, 2000; Tokuchi *et al.*, 2004; Hubber, 2005; Lewis and Likens, 2007) this did not happen in our case, probably because it was rapidly taken up by regrowing plants (Christenson *et al.*, 2002; Frost and Hunter, 2004) which expanded very fast at the same time that eucalypts decline. On the other hand, it is possible that if the trees do not die from the defoliation and their roots to be capable of taking up available N in the soil even though their foliage has largely been removed (Lovett *et al.*, 2002). In the case of labile C, it increases can increase foliar C, maintain C rhizodeposition and N assimilation and shift N resources to storage (Frost and Hunter, 2008). Eyles *et al.* (2009) found, after defoliation in *E. globulus,* a reduction in biomass allocation to coarse roots, mobilization of carbohydrate reserves, robust internal N dynamics and increased ratio of foliage to wood dry mass.

In the watershed under study, apparently *Acacia melanoxylon* took advantage of eucalypt decline and its expansion was very noticeable possibly due to its capacity for rapid growth, associated to high respiration rates (Jiménez *et al.*, 2010), its fast response to positive changes in available resources and lack of competition (Jennings *et al.*, 2003). In fact, increases in water production in these watershed during insect defoliation were moderate (23% as average, Fernández *et al.*, 2006, 2007), suggesting that the *A. melanoxylon* took advantage of the reduction in water consumption by defoliated eucalypt trees. That rapid increase of the area occupied by *A. melanoxylon* could also partially explain the absence of nutrient losses after perturbation.

In our case, the magnitude of nutrient export appeared to be more influenced by increased discharge resulting from reduced evapotranspiration (Fernández *et al.*, 2006, 2007) than by the minor changes in nutrient concentration. However, atmospheric deposition exceeded the increased losses during the period of study, suggesting a limited impact of insect defoliation on the sustainability of these stands since nutrient release by weathering and nutrient dry deposition could also positively contribute to nutrient budget. This behaviour is attributed to the desaturated soils, the very low concentrations of NO_3 and SO_4 of drainage water in an area with very low level of atmospheric pollution, and to the strong mineral uptake of fast growing stands (Dambrine *et al.*, 2000). However, these plantations in these acidic soils may be very sensitive to perturbations due to its dependence on to its ability to recycle nutrients provided by surface horizons and rainfall inputs (Dambrine *et al.*, 1997).

Conclusions

This study provided information on the nutrient export response to insect defoliation in a representative *E. globulus* catchment in Galicia which consequences on watershed nutrient balances had not been evaluated until now.

No changes in the mean annual nutrient concentrations induced by insect defoliation in *E. globulus* were detected. Nutrient export after perturbation were balanced by nutrient inputs via precipitation in all cases, suggesting a moderately high buffer capacity of the system. Given the economic relevance of these eucalypt plantations in the area, the intensive management used and the threat of more severe insect attacks, more research on these aspects is needed.

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