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Six years of study on fast growing forest plantations catchments in the Northwest of Spain

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ABSTRACT

Data on water balance in three fast growing forest plantations experimental catchments in the northwest of Spain are presented. Two watersheds are covered by Eucalyptus globulus and other is covered by Pinus pinaster.

During the six years of study several perturbations occurred. In 1989 two consecutives wildfires affected to one E. globulus watershed. The second fire also burned the other eucalyptus watershed. All eucalyptus were felled since 1991 to 1992. Also 25% of the watershed area in the pine catchment was cutted in 1991. Quick changes in the hydrologycal regimen took place after these perturbations.

The very fast recovering capacity after fire and cutting of Eucalyptus globulus facilitated the return to pre-fire hydrologic parameter values within only a few years.

Before perturbations occurred, nutrient balances were very conservative, and were similar among the cathments. This indicates a good performance on the part of both tree plantations. Water comsumption for pine and eucalyptus stands was very similar.

INTRODUCTION

The eucalyptus plantations in Galicia were initiated in the forties, expanding very quickly, due to the excellent yield of this fast growing species, especially in the coastal area. Another factor in this expansion has been the occurrence of forest fires which, from the seventies until now, have dramatically affected Galician forests. The pyrophytic character of *Eucalyptus globulus* has given rise to an explosive expansion of this tree into an area initially covered by shrubs and *Pinus pinaster* stands. Consequently, at this time -with only 40,000 ha. of pure *Eucalyptus globulus* plantations- the total area that has been invaded by this myrtacea species is nearly 200,000 ha., in which the *E. globulus* has mixed mainly with *P. pinaster*. This significant expansion from its original planted area has caused an increase in concern about the assumed detrimental ecological effects of this species, especially with regard to the excessive water consumption in plantations of these species.

Some factors that are important to consider are the enormous variability that the mountainous terrain in Galician forests has, and the very short rotation that is applied to the *E. globulus* plantations in the northwest of the Iberian Peninsula (usually, 10 to 15 years). Both of these factors complicate the evaluation of the ecological effects of these species,and at the same time support the choice of watershed experimentation that allows integration of most of variability previously mentioned.
When this approach was initiated, information existed on the effects of eucalyptus forest plantations on soil in Galicia (Diaz Fierros, et al.(1982); Rodriguez Fernandez (1984); and Bará et al.(1985). However, very little knowledge existed on the hydrological effects of eucalyptus. Poore and Fries (1985), Florence (1986), Lima (1987), and Adlard (1987) had compiled most of the hydrological information at a world-wide level. The ex-

periments of Van Lill et al. (1980) on *E. grandis* plantations in South Africa, Soares David, et al. (1986) on *E. globulus* plantations in Portugal, and the work of the C.S.W.C.R.I. of Udhagamodalam (1987) on plantations of this same species in India constituted the data available to us at the time on eucalyptus plantations in experimental watersheds. Only a few studies on some aspects of water relations of *E. globulus* had been carried out on experimental plots in Galicia (Calvo et al., 1979; Paz Gonzalez, 1982).

Consequently, in the mid-1980s, the C.I.F. de Lourizan made the decision to establish a series of experimental catchment basins in eucalyptus forest plantations to study water balance and water consumption. It was deemed necessary to compare the data from the eucalyptus experiments with information obtained for other species; similar installations were put in place for *Pinus pinaster*. *Pinus pinaster* was chosen as the most traditional and most important commercial forest tree, with a habitat similar to that of *E. globulus*. Both species are currently the principle source of raw material for forest industries in Galicia.

These fast growing tree plantations have a very short rotation period, and are subject to frequent fires. They induce some rapid changes in the hydrological regime, and watersheds covered with these species provide good examples of temporal hydrological variability; in contrast to catchments for other, more slow-growing species that have a steadier hydrologic regime. This paper discusses the installation of three experimental watersheds covered with *E. globulus* and *P. pinaster*. It will emphasize the annual variability of several hydrologic parameters affected by a wild fire, partial cutting, and a clearcut, in a short period of six years.

Methodology and description of the experimental watersheds

The method employed in this work is the experimental watershed water balance method (Toebes and Ourivaev, 1970). This well known method has been in use for many years (Bormann and Likens, 1967, 1970, 1979; Likens and Bormann, 1972; Bosch and Hewlett, 1982),etc. and more recently in Spain (Escarré, Gracia, Rodá and Terradas, 1984).

Three experimental watersheds were installed:

In 1987, the Castrove Eucalyptus globulus watershed

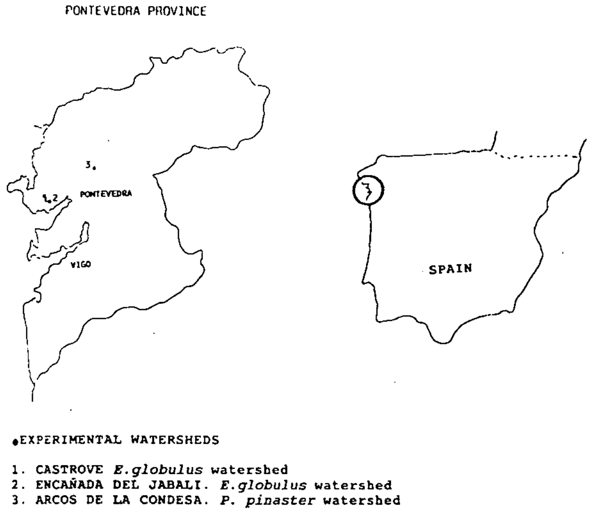


Figure 1. Experimental watersheds in the Pontevedra province: 1) castrove E. Globulus watersheds, 2) Encañada del jabalí. E. Globulus watershed, 3) Arcos de la condesa, P. Pinaster watershed

was located on the south slope of the Castrove mountain ridge, near the shore of the Ria of Pontevedra.(fig. 1)

The catchment is totally occupied by a *Eucalyptus globulus* plantation that was 15 years old in 1987 (this age is the most common for the final cut for this species in Galicia). Under the eucalyptus plantation *Acacia melanoxylon* grows (mainly in the most humid parts of the catchment), as does *Ulex europaeus* and *Pteridium aquilinum.*

We have measured a strong pluviometric gradient with altitude in this area, comparating it with the nearest pluviometric stations; for a long period of years, mean annual precipitation in the watershed probably was more than 2100 mm.Other data are in tables 1 and 2.

In the same year,1987, the Arcos de la Condesa Pinus pinaster watershed was installed.This basin is a small valley on the east face of Monte Axeiros (fig.1). All the catchment is covered by a *Pinus pinaster* plantation that was 30 years old at the beginning of the experiment. Also present are young plants of *Quercus robur* (very frequent in the part of the catchment where soils are deep and fresh), *Pteridium aquilinum* (very thicket and high in spring and summer), *Ulex europaeus* and *Rubus sp.* in the understory. Grass (*Agrostis curtisii* and *Arrenatherum sp.*) abounds in the watershed.

Complementary data are summarized in tables 1 and 2.

In 1989,other experimental watershed,Encañada del Jabalí Eucalyptus globulus watershed was established in

Table 1. Catchments location and main physiographic characteristics.

Name	Situation Lat N	Lon W	Altitude (m)	Mean Slope(%)	Exposition	Area (ha)
CASTROVE	42º26'40" - 27'00"	8º43'30" - 55"	348- 445	22	S-SE	9.9
ARCOS	42º34'28" - 48"	8º36'57' - 37'8"	210 -251	10	S-SE	6.74
ENCAÑADA	42º25'49" - 27'9"	8º43'4" - 44'4"	150- 475	13	S	194

Table 2. Catchments climatic,edaphic,and vegetation characteristics

Name	Parent Material	Soil Texture	Ta (ºC)	Tc (ºC)	Th (ºC)	Climate	Annual Mean P (mm)
CASTROVE	granitic	sandy	14.1	8.8	20.2	maritime warm-humid	1940
ARCOS	granitic	loam	14.2	9.1	20.6	"	1540
ENCAÑADA	granitic	sandy	14.1	8.8	20.2	"	1940

Ta.- annual mean temperature. Tc.- mean temperature in the coldest month Th.- mean temperature in the hottest month. P .- precipitation.

the big Eucalyptus plantation area of Monte Castrove ridge.(fig.1)

Almost all the catchment area was covered by 15-30 year old *Eucalyptus globulus* plantations. This watershed contained in its interior the smaller Castrove watershed already described.
Other characteristics are in tables 1 and 2.

Equipment in the watersheds

The three catchments have stream gauging stations with standard ink scripture limnigraphs (OTT Kempten). In Castrove and Arcos de la Condesa watersheds, v-notch weirs are installed, and Encañada del Jabalí has a rectangular weir. There are automatic water sampler pumps in the three stream gauging stations (HCV Struers). In Encañada del Jabalí there is also a proportional water sampler (Aquapropor PRT 41 Struers).

Two meteorological stations were installed, one in the interior of the Encañada del Jabalí *Eucalyptus globulus* watershed, and the other in the *Pinus pinaster* watershed. In both there are pluviometers, a pluviograph, a windmeter, a hygrothermograph, maximum and minimum thermometers, and a Piché evaporimeter. Devices for taking rain water samples are installed in the eucalyptus and pine watersheds. Three plots per catchment were used to make water content determinations (gravimetric method). Data are taken weekly.

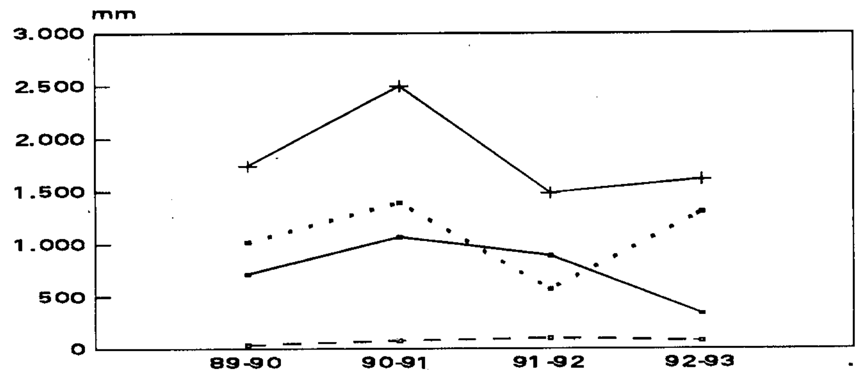
Standart pluviometers under trees (twelve per catchment) and stemflow rings (ten per catchment) were instaled to measure rain interception in Castrove watershed and in Arcos de la Condesa watershed. Data were taken weekly or more frecuently in some periods of very heavy rain.

Changes in the watersheds during the study period

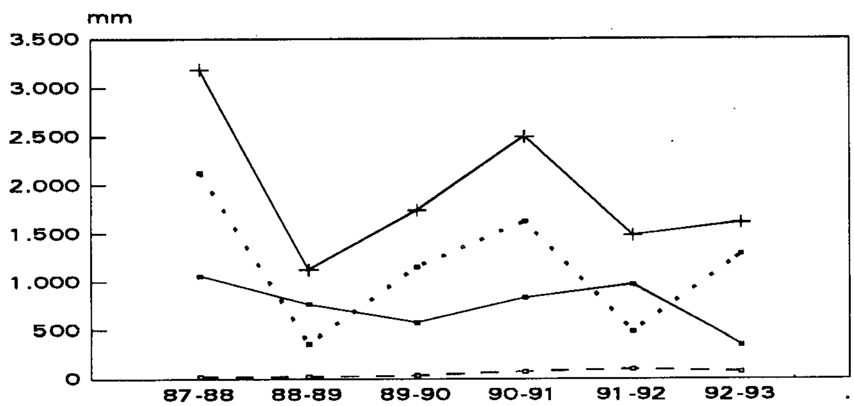
During the first hydrological year studied (87-88) no perturbation or change occurred in the two first installed watersheds. Both forest plantations were growing in a natural way, without human intervention or perturbation.

During the very dry 88-89 hydrological year, the Castrove eucalyptus catchment was affected by two consecutive forest fires. The first one happened at the beginning of spring, with a very high soil moisture level. It

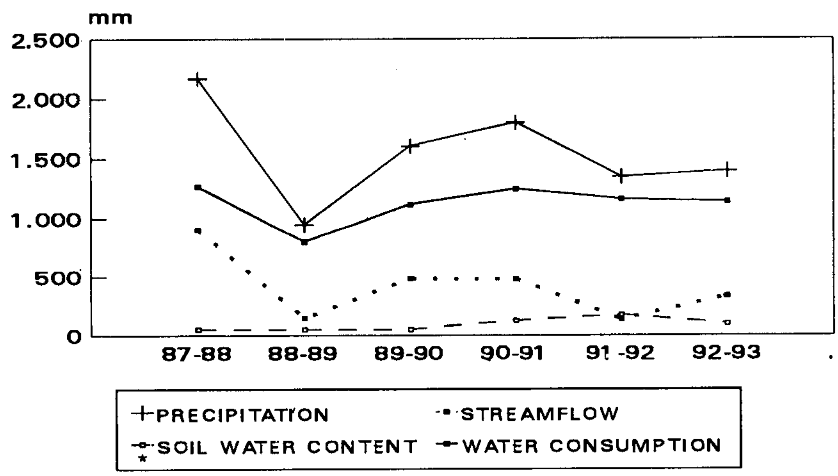
ENCAÑADA EUCALYPTUS WATERSHED WATER BALANCE



CASTROVE EUCALYPTUS WATERSHED WATER BALANCE



ARCOS P. PINASTER WATERSHED WATER BALANCE



* at the end of the summer.

Figure 2

Table 3. Nutrient balance in Castrove eucalyptus watershed during a non alteration period: Hydrologic year 87-88. (Values in Kg. per ha. and year)

	Ca	Mg	K	Na	PO4-3	NO-3
INPUT	9,6	12,7	6,4	132,5	0,22	0,0
OUTPUT	1,5	8,2	1,0	124,7	0,20	0,0
BALANCE	+8,1	+4,5	+5,4	+7,8	+0,02	0,0

Table 4. Mean nutrient concentrations in Castrove eucalyptus catchment water streamflow during hydrologic year 87-88. (Values in parts per million.)

	Ca	Mg	K	Na	PO4-3	NO-3
p.p.m	0,07	0,39	0,05	5,9	0,009	0,0

Table 5. Nutrient balance in Arcos de la Condesa Pinus pinaster watershed during a non alteration period: hydrologic year 87-88. (Values in Kg per ha. and year)

	Ca	Mg	K	Na	PO4-3	NO-3
INPUT	5,4	10,2	4,3	90,1	0,15	0,0
OUTPUT	4,0	4,7	1,2	69,5	0,05	0,0
BALANCE	+1,4	+5,5	+3,1	+20,6	+0,10	0,0

Table 6. Mean nutrient concentrations in Arcos de la Condesa Pinus pinaster watershed during a non alteration period: hydrologic year 87-88.

	Ca	Mg	K	Na	PO4-3	NO-3
p.p.m	0,44	0,52	0,13	7,7	0,005	0,0

Table 7. Maximum nutrient concentrations in stream water flow Castrove eucalyptus watershed after summer 1989 forest fire. (Values in parts per million)

	Ca	Mg	K	Na	PO4-3	NO-3
p.p.m	1,5	1,3	2,3	15,0	0,04	1,28

was a very low-intensity fire and only a small part of the litter was consumed; 20% of the total area of the catchment was burned. Understorey recovery was very fast.

At the end of July, after a long, dry and windy period with high temperatures, a tremendous forest fire took place on the south face of the Castrove range. All, of the Castrove watershed was affected and an important part of the Encañada del Jabalí watershed was also affected by the fire. Most of the litter and shrubs were consumed. Eucalyptus trees were injured in different ways, depending on their position in the catchments.

Extensive eucalyptus defoliation occurred. Some eucalyptus were badly damaged, and died in a short time, but the majority of trees resisted fire and began to regrow very early, slowly recovering the foliar surface destroyed by fire during the next few years. All of the eucalyptus trees in the Encañada del Jabalí watershed affected by fire were felled during the hydrological year 91-92, and the same occurred at the end of summer 1992 in the Castrove watershed. Trees on 25% of the total area in Arcos de la Condesa *Pinus pinaster* watershed were also felled at the end of Summer 1991.

In the eucalyptus watersheds, slash burning was applied after clearcutting.

Chemical water analysis

Rainfall and water streamflow have been sampled and analysed periodically (weekly, when possible) for nutrient content. Cations analysed are: Calcium, Magnesium, Potasium and Sodium; and the anions: PO_4^{-3} and NO_3-.

RESULTS

Water balances in experimental watersheds

These data appear in the fig.2. Looking at the results of the two eucalyptus catchments, we can point out the following aspects:The hydrologic year 87-88 was tremendously wet in this region, and no water deficit occurred throughout all the year. So, the obtained water consumption (1061 mm) is probably very close to the potential evapotranspiration for a representative eucalyptus plantation in the coastal area of Pontevedra. The next hydrologic year (88-89) was very dry, and so the water consumption was very low (766 mm), and far from the potential consumption.

After the fire in the summer of 1989, a strong reduction in water consumption occurred because an important transpirant foliar surface had been destroyed (Langford, 1976). But the incredible recovery capacity of eucalyptus makes it possible for water consumption to increase in the following years (Langford and O'Shaughnessy, 1977). So, in the hydrologic year 91-92, water consumption in Castrove watershed reached 972 mm, which is a considerable value, indicating a strong recuperation of the eucalyptus trees.

The Encañada del Jabalí eucalyptus catchment was less affected by fire than the Castrove watershed over the majority of its area and so in the first year after the fire (89-90), water consumption in Encañada was 715 mm; 139 mm more than in Castrove watershed (576 mm). But on other hand, on some steep slopes in Encañada, severely affected by fire, soil erosion after the first rains was considerable.

Finally, what is remarkable in both catchments is the large reduction in evapotranspiration after tree felling. So, in the first hydrologic year after cutting, 92-93 a moderately rainy year, water consumption for Castrove and Encañada were only 352 mm and 334 mm, respectively. The almost identical consumption for a very similar reduction of vegetation indicates the equality of hydrological behaviour between both watersheds.

In the Arcos de la Condesa *Pinus pinaster* watershed, the high water retention capacity of soils makes possible a high level of consumption. The canopy interception that was measured gave the values of 15% and 25% of rainfall for *E. globulus* and *P. pinaster* respectivelly. So for a moderate precipitation year (1750 mm aproximately), the *P. pinaster* plantation intercepted 175 mm more than the *E. globulus* plantation.

Both soil, and interception, contributed in an important way to the resulting total water consumption in the Arcos de la Condesa Watershed.

Nutrient balances and nutrient concentrations in water streamflow

During a period without any alteration, nor human intervention, in the *P. pinaster* and *E. globulus* catchments (hydrologic year 87-88), nutrient balances were very conservative, and were similar between the catchments. Mean nutrient concentrations in water streamflow during this period were low, and extremely low for PO_4^{-3} and NO_3-. All of this indicates a good performance on the part of both tree plantations.

In the opposite direction, after the 1989 forest fire in the eucalyptus catchments, significant changes in nutrient concentration in water streamflow occurred.

In tables 3, 4, 5 and 6, appear values on nutrient balances and mean nutrient concentrations in Castrove and Arcos de la Condesa watersheds. In table 7 appear values of maximun nutrient concentrations in stream water flow in Castrove eucalyptus watershed after summer 1989 forest fire.

CONCLUSIONS

Quick changes in the hydrological regimen take place just after an intense forest fire and a clearcut in eucalyptus plantations.

An important reduction in water consumption in the first post fire year occurred as a consequence of the drastic reduction of foliar surface in the eucalyptus stand.

The extraordinary recovering capacity of *Eucalyptus globulus* after fire facilitates the return to hydrologic parameter values that are very close to the ones of the prefire situation within only a few years.

Water potential consumption in a representative and undisturbed galician *Eucalyptus globulus* plantation was around 1000-1100 mm per year. This figure was similar to that of *Pinus pinaster* in another experimental watershed from the same area.

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