INFLAMMABILITIES OF MEDITERRANEAN SPECIES

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SUMMARY

Flammability parameters of the main forest species of the French Mediterranean ecosystem have been measured during more than a decade.

The flammability measurement method is described and the main flammability parameters are defined.

Ignition delay decreases quickly at the beginning of summer and then varies according to dryness index, both flammability parameters are related to the amount of rain and the number of days between rainfall and flammability measurement.

The variations of the flammability parameters of herbs, shrubs and trees are compared.

Shrubs like Erica arborea or Thymus vulgaris present a high or fairly high increment of their flammability marks from spring to fall, some others like Cytisus triflorus remain at a low level even if the season is dry.

Quercus ilex and Pinus halepensis flammability marks are not significantly different.

Two or three years old pine needles (Pinus pinaster) are more inflammable than one year old needles.

Flammability marks of deciduous trees like Castanea sativa or Quercus pubescens always increase in fall and winter.

Abies cephalonica or Cedrus atiantica needles are less inflammable than Quercus sp. leaves although these species are conifers. Exponential model describes the relation between ignition delay and dryness index, specific equations have been established.

Flammability parameters can be used as wildfire occurrences alarms, during 1989 and 1990 summers, Erica arborea flammability parameters give better predictions than normalised vegetation index collected by N.O.A.A. satellite.

1 INTRODUCTION

This course has three aims:

- to describe the method developed to study flammability of Mediterranean species,
- to classify these species, principally shrubs, following their flammability and the risks of wildfire ignition and propagation they present,
- to follow monthly evolutions of their flammability all over the year and their weekly evolutions during summer when wildfire hazard is at its highest.

In the frame of Mediterranean forest management policies, foresters have to know the species they have to destroy or to control and those that they can leave on fuel-breaks without increasing wildfire hazard.

That is the reason why Forest Wildfire Prevention research unit has collected, during more than a decade, flammability data of the main Mediterranean species.

Most of the data have been measured by Claude MORO, I.N.R.A.'s technician, in the laboratory the unit owns in the Domaine Expérimental du Ruscas, Borrnes les Mimosas, Var, France.

The laboratory is particularly devoted to flammability studies and more generally to fuel characteristics analyses.

2 WHAT MEANS INFLAMMABILITY

Flammability is the ability of a fuel to ignite after having been submitted to caloric energy.

Ail the vegetal material are decayed by heat:

- in a first period, water and some oils are released in vapour and gases, this period is an energy consuming period, an endothermic one,
- in a second period, dry organic matter will be decayed in gases by heat, this second period is also endothermic,
- inflammable gases produced by the decay of organic matter constitute with oxygen an explosive mixture; this mixture can flash by alone (auto-ignition) or if a naked flame is present (piloted ignition), this third period is largely exothermic, light and heat are produced,
- during the fourth period, temperature of the remaining ashes will decrease quickly, back to the ambient one.

The amount of energy needed to reach the third step characterizes fuel flammability.

3 WHAT ARE THE AIMS OF FLAMMABILITY MEASUREMENTS

Flammability is studied and analysed to reach the following goals:

- to know the reaction to heat of given species or of given parts like twigs, leaves, buds, bark, ...), -
- to follow seasonal variations of flammability according to physiological variations like cellulose or lignin content, colour, water status, dryness,
- to classify, in a given community, ecosystem or on a given area, the Mediterranean species, particularly shrubs, in term of wildfire danger,
- to elaborate structural and conjunctural maps of wildfire danger,
- to indicate to forest managers the species they have to suppress and those they have to promote or even to introduce so that wildfire hazards will be reduced,
- to elaborate particular recommendations for prescribed burning according to flammability differences.

4 HOW IS INFLAMMABILITY MEASURED

4.1 FUEL SAMPLING AND PREPARATION

To characterise correctly flammability, to reduce values dispersion and to compare data collected during numerous tests and to analyse their averages, fuel must be as homogeneous as possible.

For pine trees, according to their chemical composition, needles must be sorted by age so that needles which appear at different growing seasons will not be mixed.

Large deciduous leaves must be removed from the twigs, tips of twigs have to measure the same length, juvenile leaves must not be mixed with audits ones.

As soon as material is collected, it is introduced in plastic bags. These bags are blown out and put in an ice-box.

Back to the laboratory, the material is mixed to avoid local differences and fifty samples of one-gram fresh weight (in fact between 0.9 and 1.1 g) are prepared.

Larger samples (about 5 g) will be weighted during the experiment to follow fuel moisture content variations.

4.2 FLAMMABILITY MEASUREMENT DEVICE

The electric radiator whose radiant disk has a diameter of 1 0 cm radiates 7 W/cm² when alternating current is stabilized at 220 V and at 50 hertz.

At this steady level, radiant disk temperature is about 600'C.

A pilot flame is located 4 cm above the centre of the disk.

Electric radiator and pilot flame are under a hood to prevent any air current to disturb inflammation process.

4.3 A FLAMMABILITY EXPERIMENT

Fifty tests constitute a flammability experiment.

The hand timer is released when the sample is laid on the radiant disk.
In a first period, water is vaporized, twirls of white smokes are observed.
Then, organic matter is decayed, twirls of blue or black smokes are observed.

When flash occurs, ignition time is noted. Combustion index is evaluated according to flame size and combustion intensity.
When flame dies down, combustion duration is noted.

After each test, remaining ashes are removed from the disk and ail the data concerning the test are introduced in the microcomputer.

4.4 FLAMMABILITY PARAMETERS

The great number of tests (50) allows statistical analysis of the data:

- for an experiment and a given parameter, to analyse their dispersion,
- for a given parameter, to compare the means of different experiments.

Ignition Frequency IF is the number of tests during which inflammation has occurred divided by the total number of tests (50).

Ignition Time ID is the arithmetical mean of the noted ignition times, in 0.1 second.

Combustion Duration CD is the arithmetical mean of the noted combustion durations, in 0.1 second.

Combustion Index CI is the combustion intensity of each test, it is evaluated according to f lame size :

- **CI1**: very low combustion intensity, the flame is very small, less than 1 cm and does not covered the disk
- **CI2**: low combustion intensity, the flame is small, between 1 and 3 cm and does no reach the pilot flame but covered the disk
- **CI3**: medium combustion intensity, the flame whose length is between 4 to 7 cm includes the pilot flame
- **CI4**: high combustion intensity, the flame is between 8 to 12 cm long
- **CI5**: very high combustion intensity, the flame length is more than 12 cm and very often blows up the pilot flame.

Flammability Mark IM is attributed according to ignition frequency and ignition time (see table 1 below):

- **IM0**: weakly flammable
- **IM1**: not very flammable
- **IM2**: moderately flammable
- **IM3**: flammable
- **IM4**: highly flammable
- **IM5**: extremely inflammable

Dryness Index DI is calculated according to fresh weight FW and oven-dry weight DW (24 hours at 60'C)

Di = 200 * (DW 1 FW) - 100

This index is the arithmetical mean of four measurements realized during each experiment.

Relation between dryness index and fuel moisture content is given by the following equation:

DI=100*(100-FMC)/(100+FMC)

Dryness index varies from -60 (new leaves, needles or twigs) to 100 (dead material during the hottest hours of the driest summer days.
It is equal to 100 when fuel moisture content is equal to 0 and to 0 when fuel moisture content is equal to 100.

5 THE MAIN RESULTS

5.1 SEASONAL EVOLUTION OF FLAMMABILITY PARAMETERS

Summer variations of Erica arborea flammability parameters are represented on figure 1 as an example.
From June to mid July, ignition time decreases from 25 s to 17s and then it varies between 15 s and 11 s.
Dryness index generally increases from -8 to 25.
Figure 1 illustrates the very tight relation between these two parameters; their correlation coefficient is equal to -0.875.
Figure 1 illustrates also the relation between ignition time and combustion duration; their correlation coefficient is equal to -0.757 and figure 6 indicates that the three sudden variations of dryness index and ignition time are partially related to the amount of rain and to the number of days between rainfall and flammability measurement.

5.2 COMPARISON BETWEEN HERBS, SHRUBS AND TREES

Table 2 summarizes flammability marks variations of herbs, shrubs and trees, from May to November.
This table describes mean trends; severe summer drought will induce specific responses.

The flammability times of herbs are always closely related to dryness index.
The growing conditions of Brachypodium pinnaturn, which are less severe than those of Brachypodium ramosum, explain the lower flammability marks.

Some shrubs (Erica sp., Thymus vulgaris, Phyllirea latifolia and also Calluna vulgaris) present a high increment of their flammability marks, some (Cistus monspelliensis, Rosmarinus officinalis) stay at a medium level and some others (Cistus salvaefolius and Cytisus triflorus) remain at a low level.
Even if Ulex parviflorus living twigs do not present high flammability marks, wildfire risk induced by this species is always high because its dead and dry twigs remain during several years at the bottom of the plant and, thus, constitute a very dangerous fuel.

Flammability marks of deciduous trees (Castanea sativa, Quercus pubescens) always increase in fall and winter, this can explain some of winter wildfires.
Quercus ilex and Pinus halepensis flammability marks are not significantly different.

Two year old pine tree needles are always more flammable than one year old needles.

Cupressus arizonica twigs are always less flammable than Cupressus sempervirens (VALETTE and MORO, 1991).

Abies cephalonica or Cedrus atlantica needles are less flammable than Quercus sp. leaves although these species are conifers.

Juvenile leaves of Eucalyptus sp. are more flammable than adult leaves but both are extremely flammable.

5.3 RELATIONS BETWEEN FLAMMABILITY PARAMETERS AND DRYNESS INDEX

The relation between flammability parameters and dryness index was established according to dryness index variations from normal summer values (living samples) to oven- dry weight (dead samples).

Figure 2 presents the results for three major species.

According to the distribution of the points, an exponential model has been chosen.

General expression of this model is

$$ID = A * \exp (B * DI)$$

The correlation coefficient R between DI and ID, the determination coefficient R^2 of the model and A and B values are indicated in table 3.

For summer dryness index values, figure 2 indicates clearly that Quercus pubescens leaves are significantly more flammable than those of Quercus suber or Arbutus unedo.

Near to oven-dry weight, specific differences are no more significant.

According to exponential equation, B is the ignition time increment Io inflammation delay ratio.

Quercus pubescens ratio is significantly lower than the two others.

Specific ratios are to be related to specific leaf mass-to-surface ratios and to the amount of energy shuttled out by the leaves.

Figures 3 and 4 describe relations between dryness index and in ignition time for some living shrubs and trees.

During summer period, shrub dryness index increase with drought (figure 2).

Cistus rnonspelliensis ignition time decreases quicker than that of Érica arborea.

During the same period, Quercus ilex and Quercus pubescens dryness index and ignition times vary without any temporal trend, whereas Pinus halepensis dryness index increases regularly.

Relations between the two parameters have been searched according to the values of the correlation coefficients R between DI and ID.

When R was significant, regression equations have been established by least-square fitting, according to the model described just above.

The correlation coefficient R between DI and ID, the determination coefficient R^2 of the model and A and B values are indicated in table 3.

5.4 FLAMMABILITY PARAMETERS AS WILDFIRE OCCURRENCES ALARMS

In 1989 and 1990 Erica arborea flammability parameters have been measured and compared to satellite information concerning the same location and to wildfires which occurred in the neighbourhood of this laboratory.

Flammability parameters give better predictions than normalized vegetation index or surface temperature collected by N.O.A.A. satellite (VALETTE, 1991).

Figures 5 and 6 indicate that the two main catastrophic wildfires occurred each time in 1989 (end of July and end of August) and in 1990 (middle of August and end of September) a couple of days after a sudden inflammation delay decrease.

6 CONCLUSION

Flammability parameters describe specifc fuel behaviour and reactions to heat according to fuel characteristics like dryness index.

That the reason why they can be used to improve fire risk index.

They do not describe fire behaviour.

Specific studies are to be conducted in different types of communities in taking in account the biomass and the biovolume of these fuels and not only their flammability parameters.

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8 TABLES

ID						
	0	0	0	1	1	2
32.5						
	0	0	1	1	2	2
27.5						
	0	0	1	2	2	3
22.5						
	0	1	2	2	3	3
17.5						
	1	1	2	3	3	4
12.5						
	1	2	3	3	4	5
IF	<25	25-38	39-41	42-44	45-47	48-50

Table 1 : Inflammation mark related to inflammation delay **ID** and inflammation frequency **IF**

	R	R^2	A	B
Dried leaves and twigs				
Arbutus unedo	-0.964	0.989	22.888	-0.0215
Quercus suber	-0.957	0.971	16.320	-0.0195
Quercus pubescens	-0.965	0.974	8.431	-0.0149
Shrubs (living twigs)				
Quercus coccifera	-0.673	0.429	33.119	-0.0197
Cistus monspelliensis	-0.890	0.825	28.289	-0.0181
Arbutus unedo	-0.873	0.745	25.007	-0.0168
Erica arborea	-0.875	0.800	18.099	-0.0167
Trees (living needles or leaves)				
Pinus halepensis	-0.756	0.572	17.374	-0.0270
Quercus ilex	-0.371	-	-	-
Quercus pubescens	-0.244	-	-	-

Table 3 : Specific correlation coefficients between dryness index and inflammability delay, and specific model parameters

	May	Jun	Jul	Aug	Sep	Oct	Nov
Herbs							
Brachypodium pinnatum	0	1	1	3	2	5	5
Brachypodium ramosum	0	2	4	5	5	4	5
Shrubs							
Arbutus unedo	0	0	1	3	2	3	3
Buxus sempervirens	0	1	1	2	2	2	2
Calluna vulgaris	0	2	3	4	3	4	4
Calycotoma spinosa	0	0	1	2	2	1	2
Cistus albidus	0	0	1	2	3	3	3
Cistus monspelliensis	0	1	2	3	3	2	2
Cistus salvaefolius	0	0	1	1	2	1	2
Cytisus triflorus	0	0	1	1	2	1	2
Erica arborea	0	1	3	5	4	4	5
Erica scoparia	0	2	4	5	4	5	5
Phyllirea latifolia	0	2	4	5	4	5	5
Quercus coccifera	0	1	3	4	3	3	4
Rosmarinus officinalis	0	1	3	3	3	2	3
Thymus vulgaris	0	2	3	5	4	4	5
Ulex parviflorus	0	1	2	3	4	3	5
Trees							
Abies cephalonica	0	0	1	2	1	0	1
Acacia dealbata	0	1	3	4	4	4	5
Acacia melanoxylon	0	2	4	4	3	4	5
Alnus subcordata	0	2	4	5	5	5	5
Castanea sativa	0	3	5	5	5	5	5
Cedrus atlantica	0	0	1	1	2	2	2
Cupressus arizonica	0	0	1	1	1	0	2
Cupressus sempervirens	0	0	1	2	2	2	3
Eucalyptus dalrympleana	5	5	5	5	5	5	5
Eucalyptus Macarthuri	5	5	5	5	5	5	5
Pinus halepensis	0	1	3	4	4	3	5
Pinus pinaster (new needles)	0	1	2	3	3	2	3
Pinus pinaster (old needles)	3	3	3	4	4	4	4
Quercus ilex	0	3	5	5	5	5	5
Quercus pubescens	0	2	5	5	5	5	5
Quercus suber	0	2	4	4	3	4	4

Table 2 : Specific inflammability marks variations from May to November

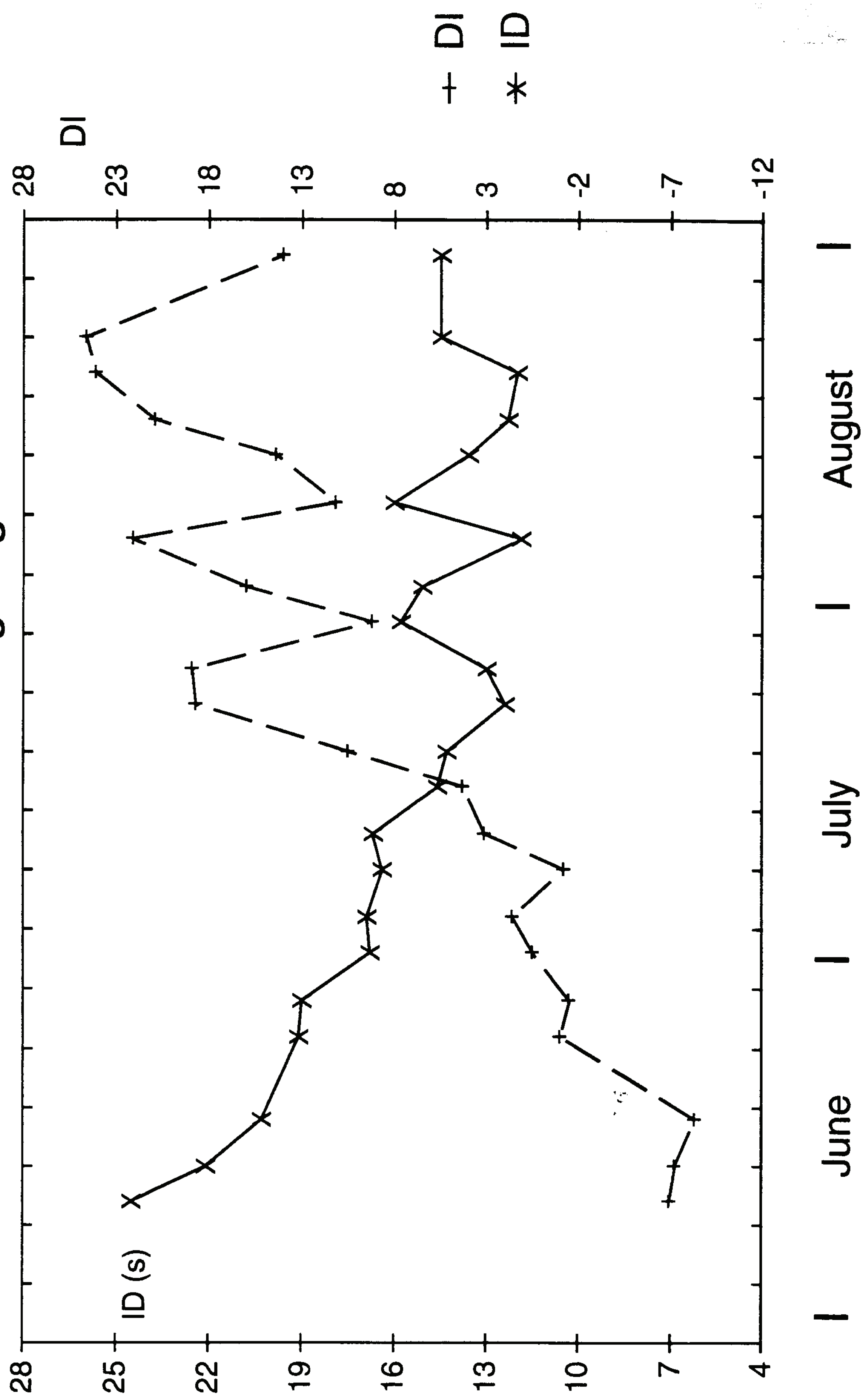


Figure 1 : Inflammation Delay and Dryness Index of Erica arborea living twigs

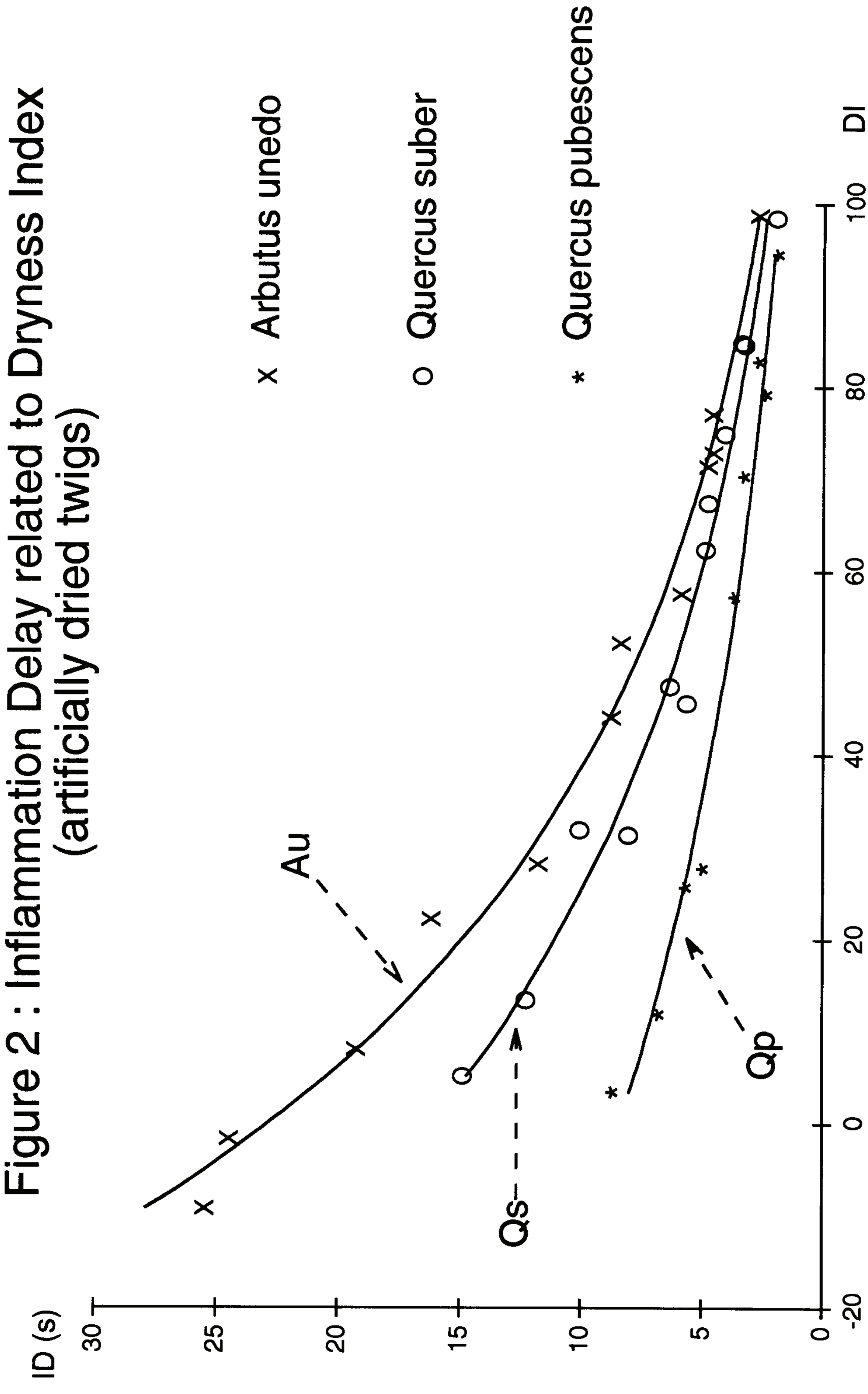
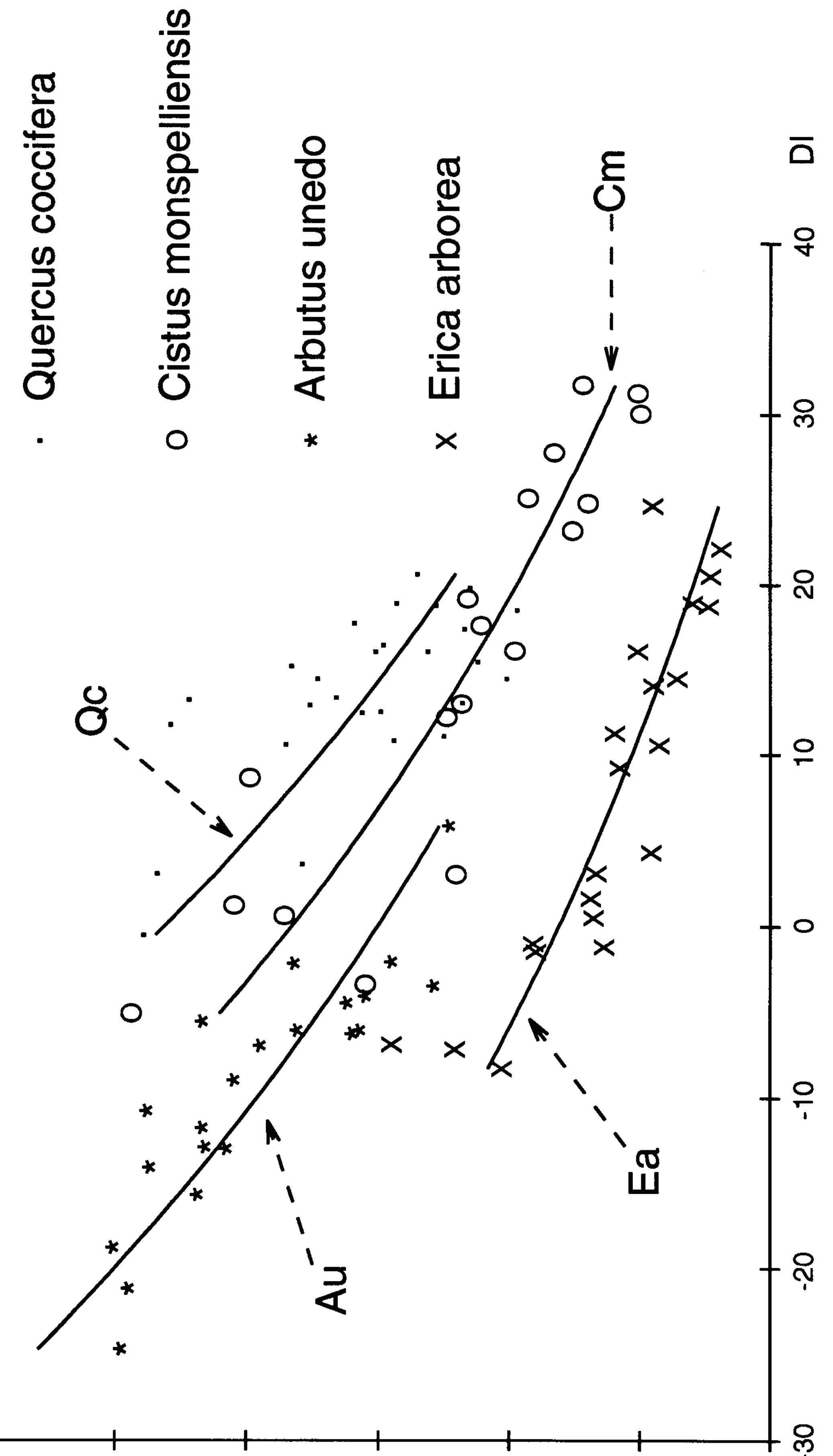


Figure 2 : Inflammation Delay related to Dryness Index (artificially dried twigs)

Figure 3 : Inflammation Delay related to Dryness Index (shrubs living twigs)



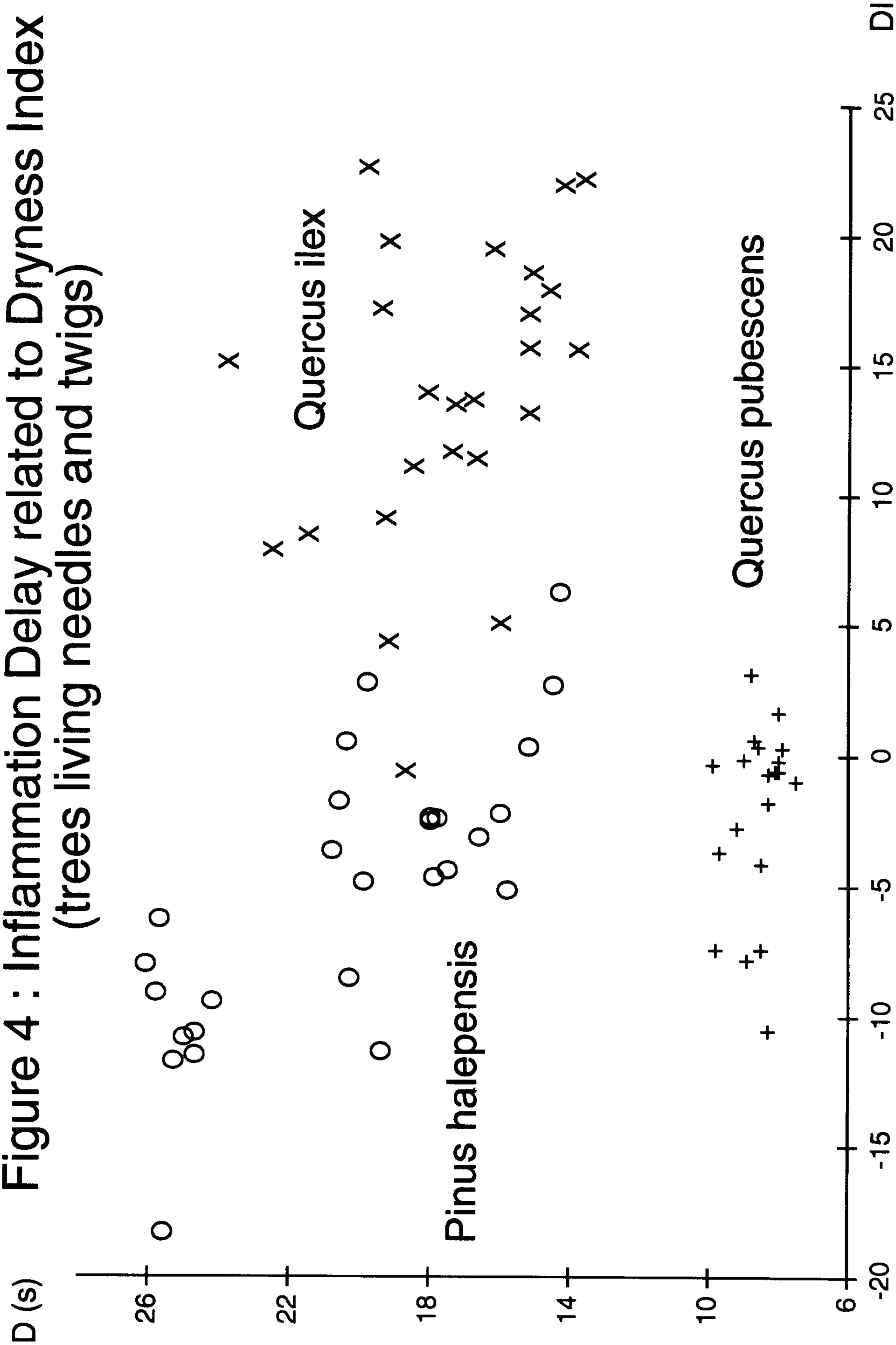
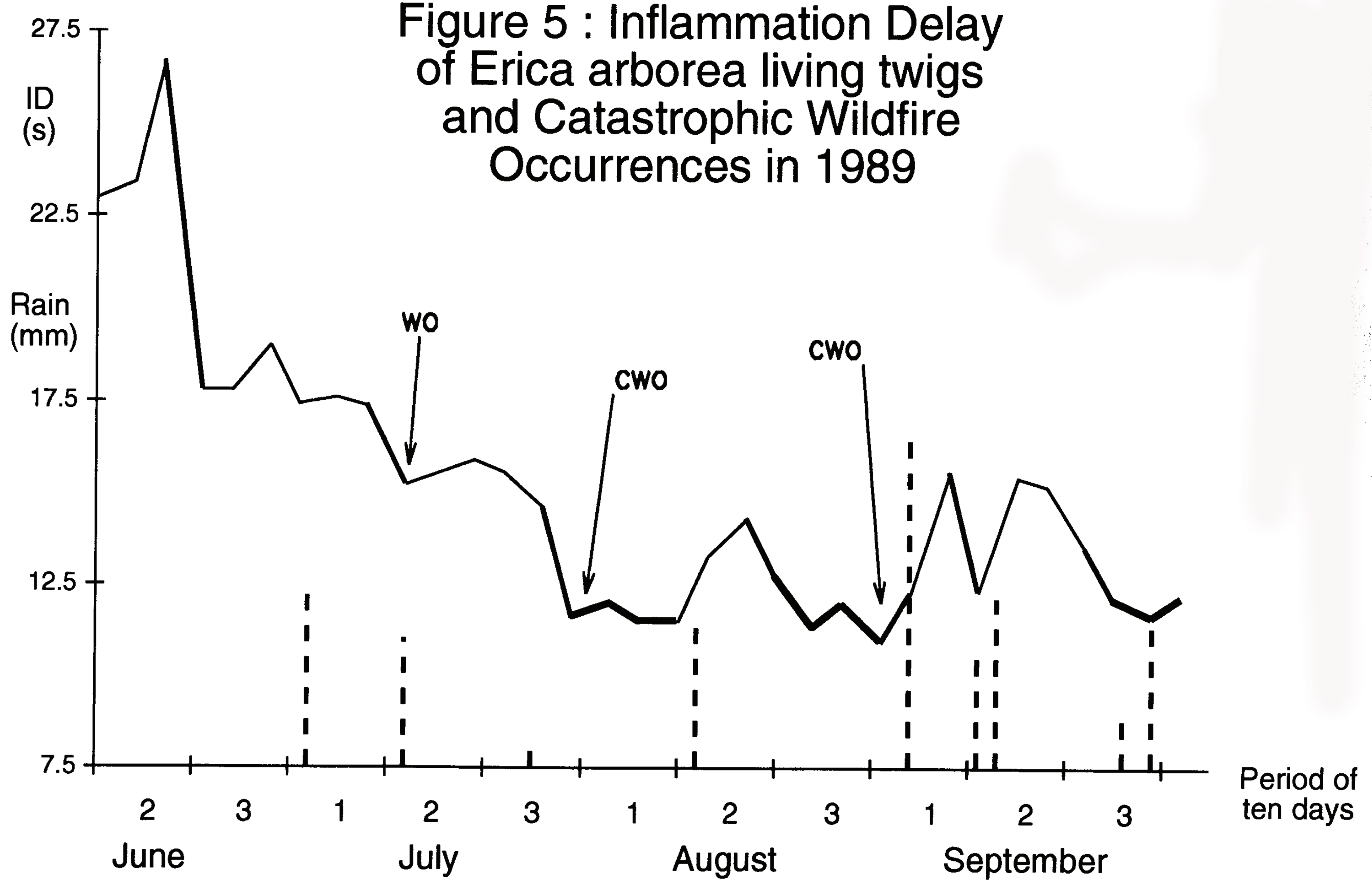


Figure 4 : Inflammation Delay related to Dryness Index
(trees living needles and twigs)

Figure 5 : Inflammation Delay of Erica arborea living twigs and Catastrophic Wildfire Occurrences in 1989



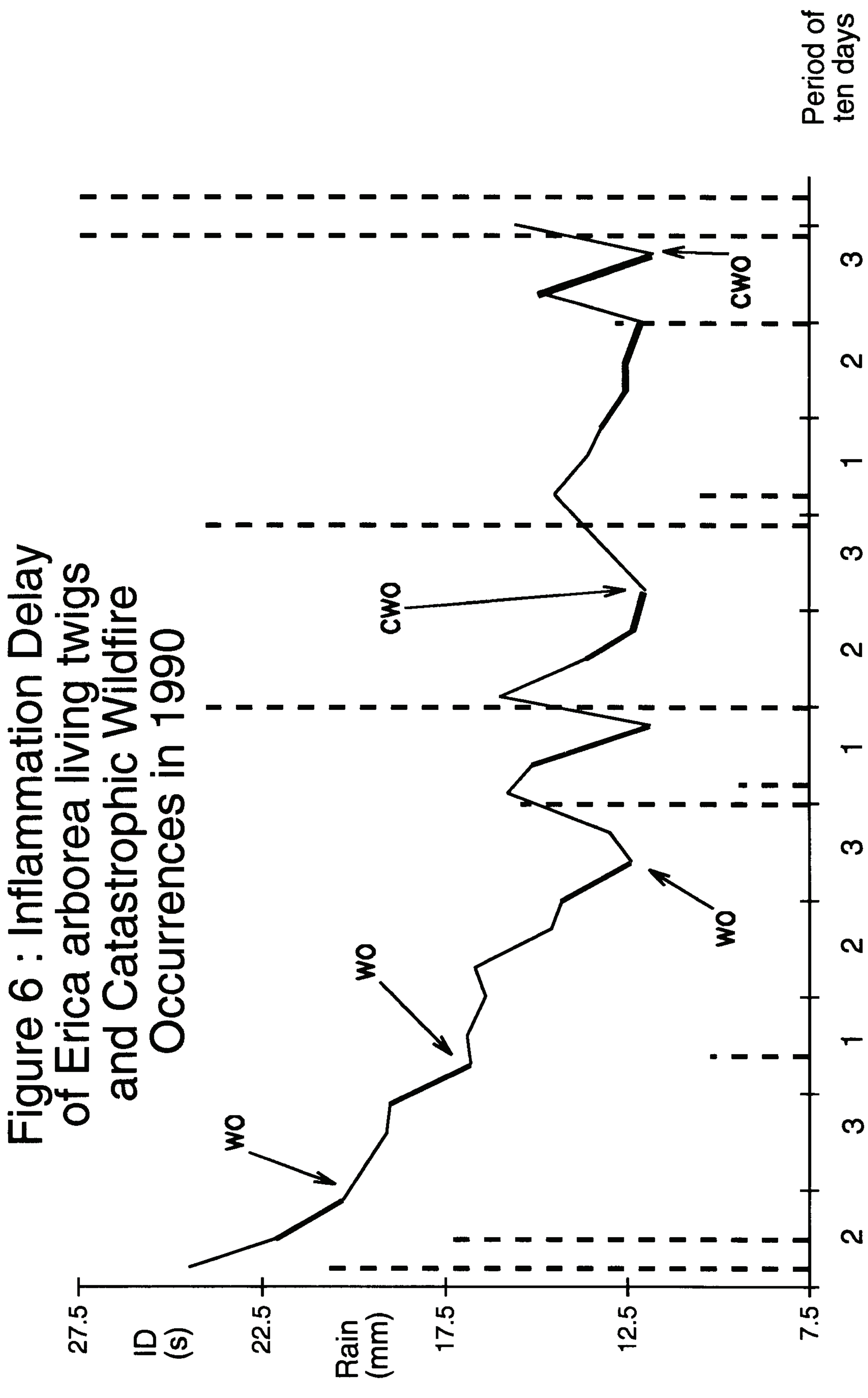


Figure 6 : Inflammation Delay of Erica arborea living twigs and Catastrophic Wildfire Occurrences in 1990