

**AMENDMENTS compared to V1:****Rephrasing mainly in 1<sup>st</sup> paragraph**

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**Field protocol on continuous measures of forest growth**

## Action Group D1: Tree vitality and adaptation

In addition to the five-year periodic growth measurements - which will be continued - within demonstration action D1 a continuous measurement of diameter on a sub-sample of trees is expected. Continuous measurements may be realized by either of two methods: (1) by electronic dendrometers **and/or** (2) permanent girth bands, to be read manually. Both allow not just the recording of **annual** increment values but also the **distribution of increment** and **swelling** and **shrinking** of the bark and wood during the year with different resolution in time and different need for technical infrastructure. They serve, therefore, to identify stem **growth** and tree **physiological** reactions to seasonal climatic conditions, in particular **water availability**. Stem growth is one indicator of tree condition and tree vitality (Dobbertin 2005) and thus an essential measurement in D1. Where electronic girth bands are installed it is strongly recommended that they should be complemented with manually read girth bands.

While five-year tree growth should be measured on all trees in the (sub)plot (for details see the ICP Forests Manual on Forest Growth, which will be revised until 2010), trees for growth bands are selected according to different criteria. To be representative of the stand however, trees should be selected according to the observed diameter distribution across the plot, and should allow the estimates of both the relative growth of the stand and the uptake of carbon to be calculated. Selection of trees should allow comparison with periodic measures of increment (five year intervals measured on all trees in the plot).

**Permanent measurements with manually read girth bands****Tree selection procedures**

It is recommended to select at least **fifteen** trees of the main tree species of the plot for measurement. If it is a mixed stand then the species may be selected in proportion of their percentage in the canopy. Trees can be selected randomly or stratified randomly using the diameter distribution of all trees in the plot, or using the social class (i.e. selecting dominant or co-dominant) or both of the latter two. For example, trees could be ordered by stem basal area and total basal area cumulated. Trees will then be randomly selected from within certain even sizes proportion of this cumulative proportion (for example 3 trees from the lowest 20% of the basal area distribution, 3 trees from the next 20% etc.). Bear in mind that to end the sampling interval with data from for example ten trees it may be prudent to install more than ten bands as in a given year some may be lost or damaged due to e.g. animal or other disturbance.

The stems of the selected trees should not have any visible damage or injuries at the measuring height, should have no branches or knots at the measuring height and no visible resin flow from above. Their cross section should be as circular as possible with little irregularities. Avoid extreme thick bark if possible.

### **Installation of the girth bands**

For trees with naturally thick bark or bark that peels off in chunks, the outer bark has to be carefully removed. This should be reported as comment in the submission forms. This can happen with a knife or sickle for the larger parts and with a steel brush to remove loose dead bark. Mosses and lichens should also be removed around the stem where the circumference band will be placed. Care should be taken not to remove or disturb the live bark.

The measurement instrument (girth band) consists of a band (metal or plastic), a spring and a scale (preferable a Nonius scale - also called vernier scale - which allows accuracies to 0.1 mm). Short springs are favourable and spring tension at installation is important. The band may need to be moved on the tree until it fits tightly and well. The girth band should be selected with an appropriate length and the spring positioned to allow measuring for several years without having to readjust the spring or replace the band. The spring should be placed in a way that only the end of the spring facing the Nonius scale need to be replaced and can be hooked into the next hole. By this way the band remains tight around the stem.

The position on the stem should be permanently marked on the stem and should be slightly above breast height to not interfere with the periodic measurements. To see if the girth band had been moved along the stem, it is useful to mark the position of the band at two to three points along the stem with a color spray. When spraying, cover the girth band, otherwise you won't be able to read the scale anymore and don't spray too close to the Nonius scale. If necessary you can repeat the spraying during the annual reading. Control the tightness and the position of the spring each time you perform a reading. Make sure that the spring is not touching the Nonius scale. In stands with high UV radiation, plastic bands may most likely weaken sooner and should be checked more frequently (bleaching of the color is an obvious sign of such weakening of the material).

### **Timing of Installation and Reading**

Installation should ideally take place in winter which would allow trees with shrinking and swelling during and following frost events to 'adjust' into the girth bands. When readings are made several times during winter a stable reading may be obtained. If the band is not tightly fixed to the stem, the first-year reading will underestimate growth. When bands are installed in late winter or early spring some tree species may show bark shrinkage and first-year growth may be overestimated. For annual readings it seems that in central and northern Europe mid to late fall is the best date to compare readings (less influence due to drought shrinkage and frost shrinkage). In southern Europe other dates may be better suited.

### **Sampling Intervals**

Sampling intervals may vary from annual to weekly recordings. It may be useful to carry out readings at four-weekly (monthly or even two weekly) intervals when collections of deposition samples at the plot are being carried out. Sampling frequency may be increased during the growing season. It is strongly recommended to conduct measurements at least monthly during the growing season. For annual increment calculations the values of approximately the same date in the autumn of every year should be selected. Air temperature at the time of reading should be recorded.

### **Continuous recording of stem changes with electronic dendrometers**

Dendrometer can be separated into point dendrometer (the radius change at one point of the stem is measured) and band dendrometers (a wire or metal tape is placed around the stem to measure its changes). For detailed review we refer to the attached publication by Drew and Downes in press). Automatic dendrometers are typically connected via cable to a data logger, which collects the reading. The number of trees that can be measured is restricted by the capacity of data logger. Readings may be collected, for example hourly (or even every 15 minutes!) and either stored directly or first averaged and stored. One at the moment frequently used dendrometer band (UMS München) uses a Teflon mesh, which is placed between the bark and the invar steel cable.

### **Sample tree selection**

As dendrometers are expensive, require a central data logger and their distribution is therefore restricted by cable length, only few trees per stand and fewer sites will be selected. Therefore sampling can not be representative for the stand growth as in the case for periodic measurement or girth bands. Instead, trees should be selected to be dominant or codominant, because small or understorey trees grow slow and often have higher seasonal fluctuations of stem diameter due to swelling or shrinking of the bark than annual growth.

### **Installation of band dendrometers**

Installation of band dendrometers follows essentially the same procedures than that for the manual girth bands (see above).

A Teflon mesh can also be used around the tree to reduce the friction of the cable and to protect it from icing, resin or callousing. Expansion and contractions of the tree stem is recorded here via a strain-gage clip-censor as the change of measured voltage (or amperage if a measuring amplifier is used) of the strain gage as a function of the change of the clip. This change is stored in the data logger and therefore the voltage must be known to calculate voltage change to increment values. The UMS D6 band has the advantage that it can be easily fixed to the trunk without any damage to the bark or disturbance of growth. Most other dendrometers have to be screwed to the tree stem. Disadvantages of dendrometer bands are that they are somehow more sensitive to temperature changes due to the long cable or bands and also to disturbance by animals, snow or ice.

Point dendrometers have the disadvantage that they require screws to fix them permanently to the stem. This can in the long-run alter the recorded growth due to increased callus cells. Therefore, point

dendrometers should not be installed close to where the periodic measurements are conducted. The advantage of point dendrometers is that the bark needs to be removed at only one position around the stem. They may also be less sensitive to temperature changes and can be more easily protected against biotic or abiotic damages. Continuous electronic dendrometers may be used with measuring amplifiers or without. These amplifiers are recommended as they allow cables of more than 10m to be used.

### **Sources of error**

It is important to remember that there are sources of error associated with continuous dendrometers, such as frost expansion, animal disturbance, electrical errors and general damage. Therefore, one band should be installed to a fixed material to test the effect of the instrument on temperature changes (i.e. a rock or a plastic tube of deposition sampling). All electronic dendrometers need cables and these may be damaged by animals. Remotely, automatical uploading of data at certain intervals will help to detect malfunctioning of the dendrometers.

### **Note:**

It is strongly recommended that manually read girth bands are also installed along with electrical dendrometers in the event of damage or failure of equipment or power supply in order to adjust the relative stem changes to actual stem changes. The dendrometer should be installed above the manually read girth band to avoid disturbance.

### **Accuracies**

Manually read girth bands should allow an accuracy of reading of 0.1 mm

Electronic dendrometer should reach a recording accuracy of 0.02 mm (Accuracy of UMS Clip sensor is 5  $\mu\text{m}$ ).