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**PROTOCOL**

# Estimating growth characteristics of agroforestry trees

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# 1 Introduction

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To determine the carbon sequestration potential of afforestation, reforestation, or agroforestry projects it is necessary to determine the carbon accumulated in the main carbon pools. Aboveground biomass is likely to be the carbon pool impacted most by project activities, and it is therefore important that the estimates of carbon accumulation in this pool are reliable. For many commercially important species, there are well defined yield tables that describe growth characteristics under a variety of conditions. For less well-known species, including many of the local species used in agroforestry projects, little or no information concerning growth characteristics is available. To use models such as CO2FIX it is therefore necessary to determine how trees of each species planted are likely to grow under the conditions at the project site. This protocol describes a methodology for estimating the annual increment of agroforestry trees from field measurements of trees of known age.

## 2 Measuring trees in the field

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Once the species that will be planted have been determined, a literature search should be carried out to identify any existing information for that species, such as yield tables, or annual increments. Local universities and forestry departments should also be contacted to determine what information is available. If yield tables or annual increment information for the species under conditions comparable to those at the project site are not available it will be necessary to derive these from measurements of trees of known age.

### 2.1 Tree selection

Trees of different ages and sizes throughout the range of interest (e.g. 5-50 cm dbh, or 1-60 years old) should be selected from the locality of the project area. For each tree selected it must be possible to determine when the tree was planted. This is usually achieved through conversation with the farmer. A minimum of around 100 trees per species should be measured with a minimum of 10 trees in each 5 cm size class (i.e. 5-10cm, 10-15cm, 15-20cm, etc.). If there is a lot of variation among individual trees, larger sample sizes may be necessary.

### 2.2 Measurements

For each farm visited record:

- district;
- sector;
- elevation in m.a.s.l.;
- rainfall in mm/yr; and
- soil type.

For each tree measured record:

- latitude and longitude, using GPS and/or a map;
- the species;
- the diameter of the stem 1.3 m above ground level (a stick marked at 1.3 m can be useful for determining the correct height to make the measurements). Be aware of the correct way to

- measure trees with non-standard stems (see Figure 1). Record the value in cm to one decimal place (i.e. 10.2 cm);
- the height of the tree, measured directly for smaller trees, or with the technique described in Figure 2 for larger trees. Record the value in m to one decimal place (i.e. 3.4 m);
  - crown position (1-5; see Figure 3);
  - crown form (1-5; see Figure 4);
  - whether the tree is planted or grew naturally;
  - age of the tree; and
  - any signs or details of management (e.g. coppicing or pruning).

An example datasheet for recording these measurements is provided in Appendix A.

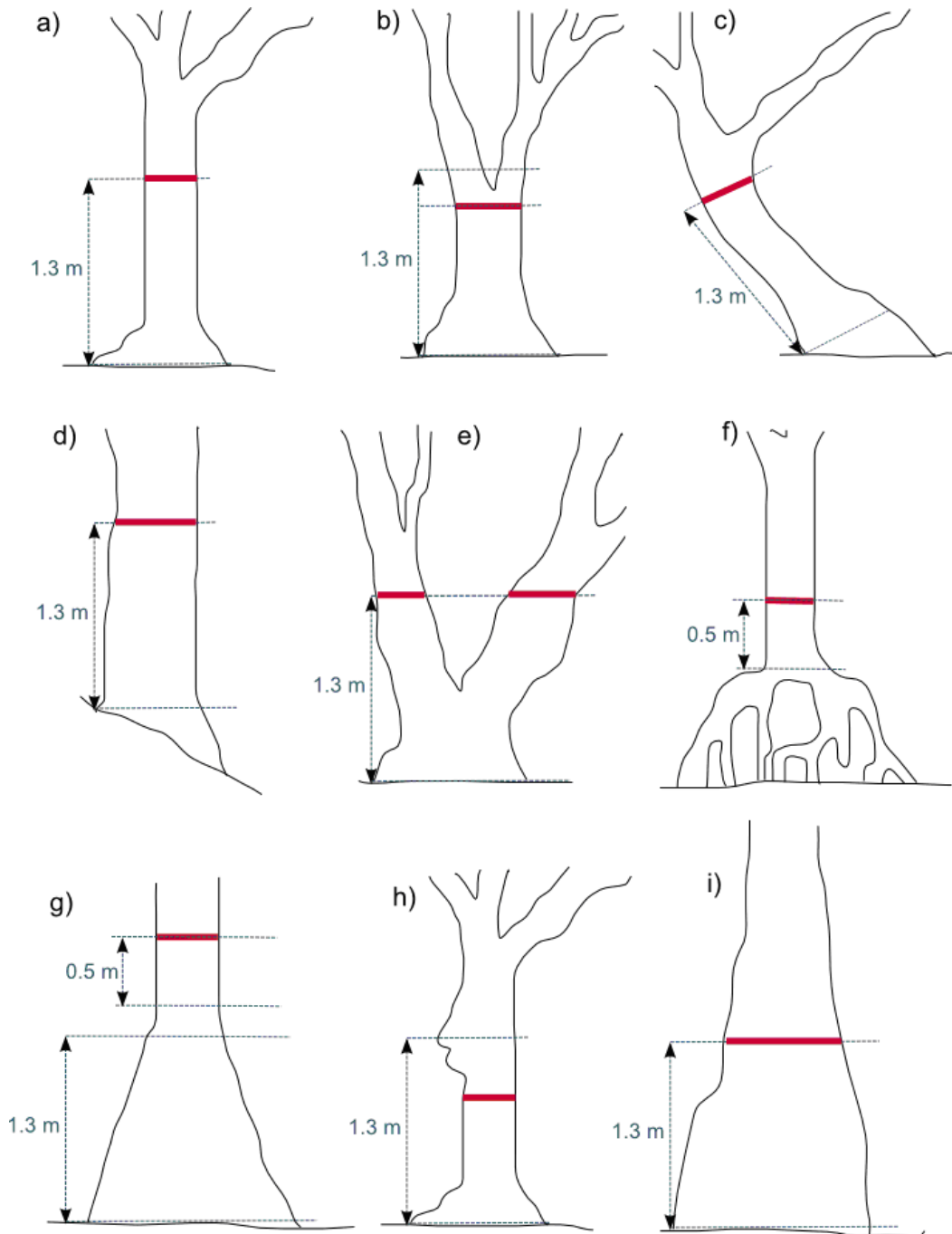


Figure 1. To determine the point of measurement for trees: a) Whenever possible record dbh at 1.3 m height b) if the tree is forked at or below 1.3 m, measure just below the fork point; c) if the tree is leaning, make sure the tape measure is wrapped around the tree according to the tree's natural angle (instead of parallel to the ground); d) if the tree is on a slope measure record measure 1.3 m on the uphill side; e) if it is not possible to measure below the fork point, measure as two trees; f) if the tree has stilt roots, measure 50 cm above the highest stilt root; g) if the tree is buttressed at 1.3 m, measure 50 cm above the top of the buttress; h) if the tree is deformed at 1.3 m, measure 2 cm below the deformity; i) if the tree is fluted for its entire height, measure at 1.3 m If the tree has fallen but is still alive (if there are green leaves present) measure the dbh as if it was standing). Pass the tape under any vines or roots on the stem.

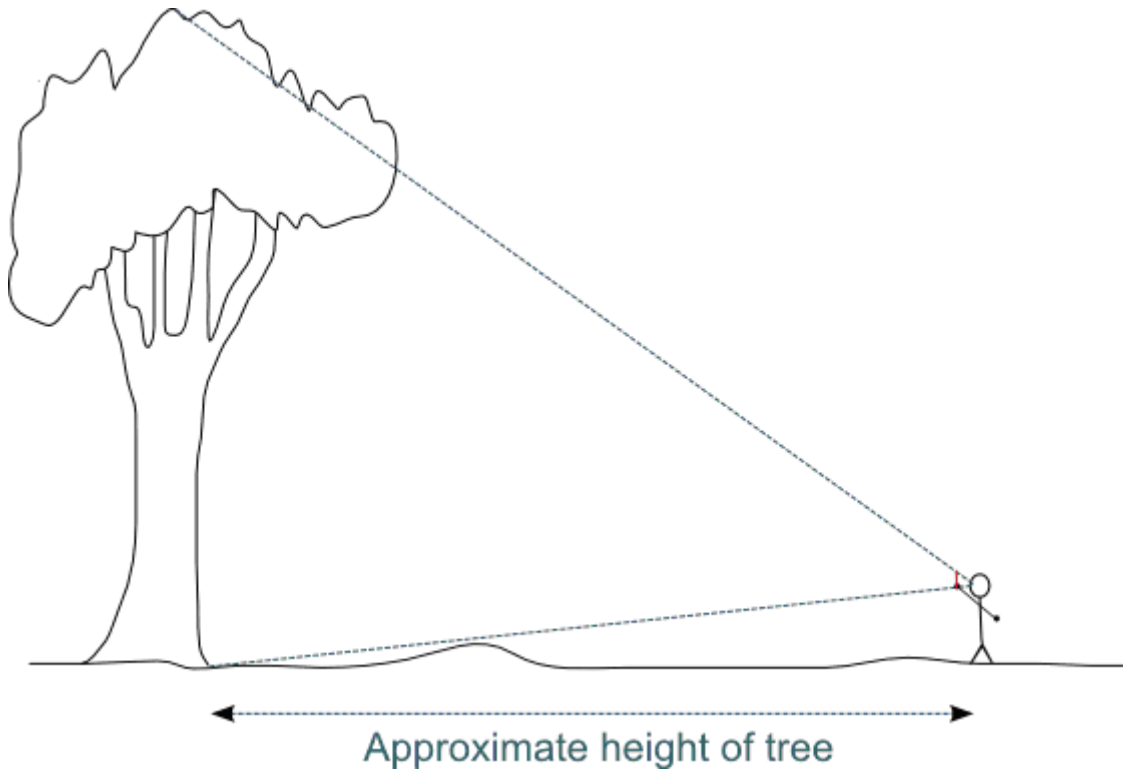


Figure 2. For a rough estimate of tree height, cut a straight stick to exactly the same length as your arm. Walk away from the tree to a point where, when holding the stick vertically at arm's length, the entire tree's vertical centre-line is hidden behind the stick. The distance to the base of the tree is approximately the same as the tree's height (as long as the ground is not sloping).

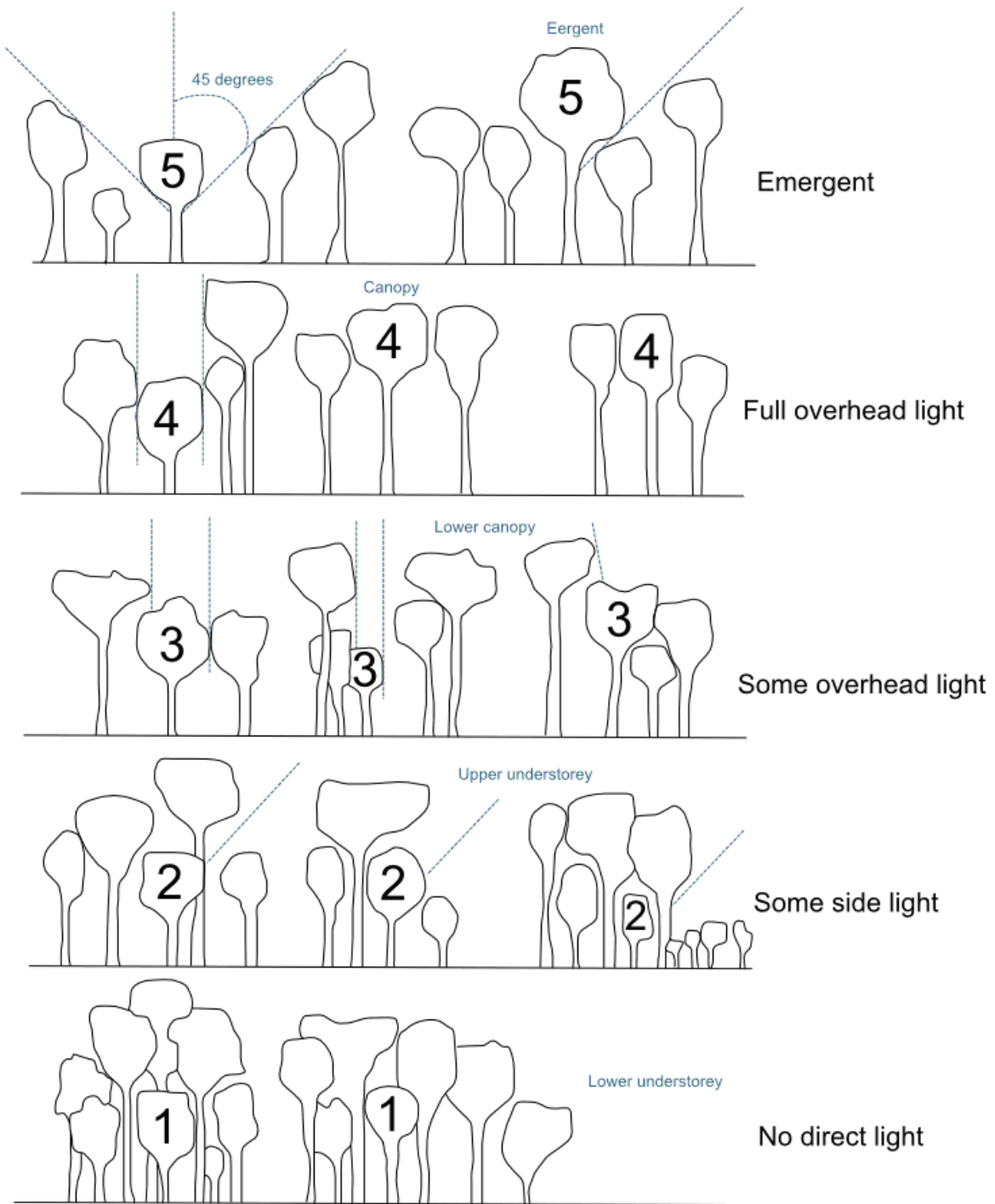


Figure 3. Crown position index (CPI; reproduced from Alder and Synnott 1992). Trees are classified on a scale from 1 to 5 depending on light received by the crown of the tree.

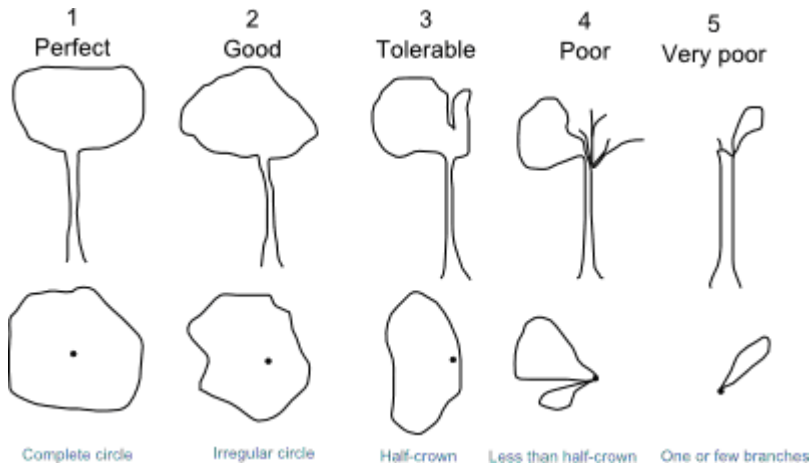


Figure 4. Crown form index (CFI; reproduced from Alder and Synnott 1992). Trees are classified on a scale from 1 to 5 depending on the condition of the crown.

### 3 Deriving annual increment from tree measurements

The following method allows the determination of annual volume increment of a species from measurements of trees of known age. Tree measurements included should be from trees in environmental conditions similar to those at the project site, and with crowns with a CFI  $\geq 3$ , and a CPI that represents conditions in the planting plans. The method is highlighted with an example and R-code for calculations. The example dataset it provided in Appendix B.

#### 3.1 Estimate dbh:height relationship

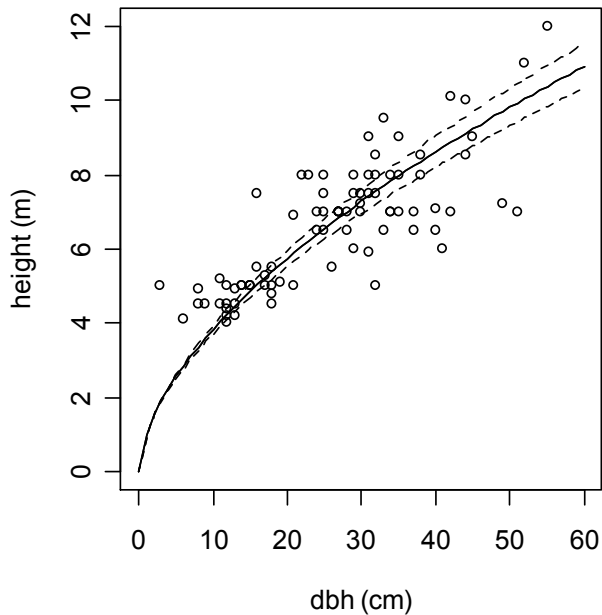
Tree height ( $h$ ) is often related to dbh ( $d$ ) by a relationship with takes the form:

$$\log_{10} h_i = \alpha (\log_{10} d_i)$$

So to determine the relationship across a range of sizes it is necessary to determine the value of  $\alpha$ :

```
data<-read.csv("C:\\data.csv",header=T)
dbh_height<-lm(log10(height)~log10(dbh)+0, data=data)
summary(dbh_height)
```

Species	intercept	$\alpha$	Lower 95%CI for slope	Upper 95%CI for slope	$r^2$
<i>Mangifera indica</i>	0	0.584	0.577	0.590	0.989



### 3.2 Estimate dbh:age relationship

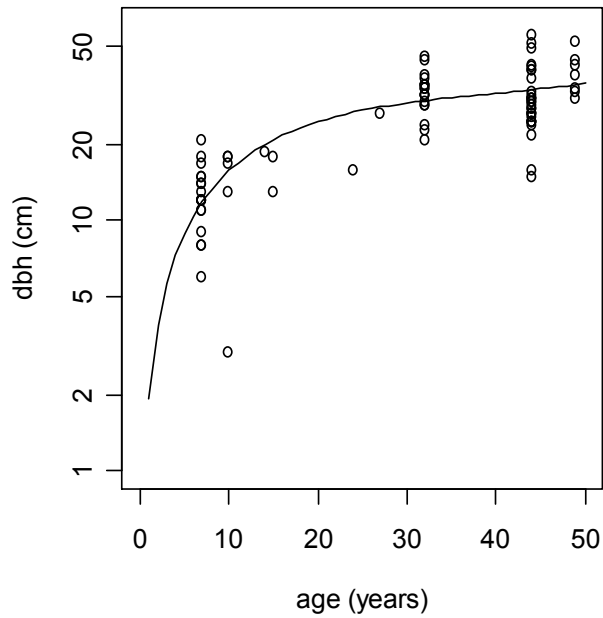
Tree diameter ( $d$ ) is often related to age ( $a$ ) by a relationship which takes the form:

$$d_i = \alpha_1 a_i + \alpha_2 a_i^2 + \alpha_3 a_i^3$$

So it is necessary to determine the parameters  $\alpha_1$ ,  $\alpha_2$ , and  $\alpha_3$ :

```
age_dbh<-lm(dbh~age+I(age^2)+I(age^3)+0, data=data)
summary(age_dbh)
```

Species	intercept	$\alpha_1$	$\alpha_2$	$\alpha_3$	$r^2$
<i>Mangifera indica</i>	0	$2.004 \times 10^{-0}$	$4.625 \times 10^{-2}$	$4.066 \times 10^{-4}$	0.932



### 3.3 Estimate height:age relationship

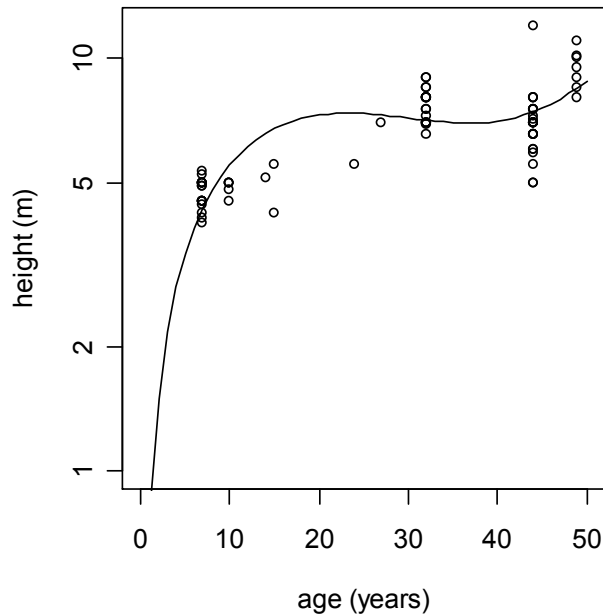
Tree height ( $h$ ) is often related to age ( $a$ ) by a relationship which takes the form:

$$h_i = \beta_1 a_i + \beta_2 a_i^2 + \beta_3 a_i^3$$

So it is necessary to determine  $\beta_1$ ,  $\beta_2$ , and  $\beta_3$ :

```
age_height<-lm(height~age+I(age^2)+I(age^3)+0, data=data)
summary(age_height)
```

Species	intercept	$\beta_1$	$\beta_2$	$\beta_3$	$r^2$
<i>Mangifera indica</i>	0	$8.042 \times 10^{-1}$	$-2.828 \times 10^{-2}$	$3.142 \times 10^{-4}$	0.973



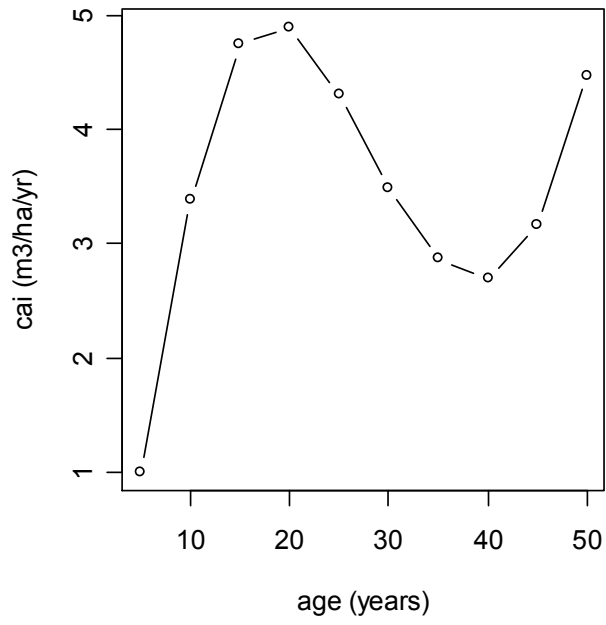
### 3.4 Calculate annual increment

The current annual increment in tree volume can be calculated by dividing the volume of the tree by its age. The general relationships defined above can be used to determine the typical height and dbh of trees of a given age. Simple volume relationships, or more complicated allometric equations can be used to determine tree volume from dbh and/or height. For example, tree volume ( $v$ ) is approximately equal to:

$$v_i = \frac{\pi \left( \frac{d_i}{200} \right)^2 h_i}{\rho}$$

Where  $\rho$  = form factor.

A plot of current annual increment (CAI) across a range of age classes can be useful to determine whether the data conform to the type of relationship that was expected. For example in the graph below an increase in CAI of trees older than 40 is unlikely (based on existing knowledge of this species). The predicted CAI for older trees is therefore likely to be an overestimate, and an appropriate adjustment should be considered to avoid overestimating carbon accumulation.



## 4 Equipment

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Equipment required by each survey team includes:

- 30 m measuring tape for recording tree height
- 5 m measuring tape for recording tree diameter
- a stick for determining tree height
- hand trowel for checking soil characteristics
- maps of local area
- pencils
- record sheets

Survey teams would also benefit from the use of:

- GPS
- a clinometer
- an altimeter
- a digital camera

