# *INPA'S APPROACH TO ESTIMATE CHANGES IN CARBON STOCKS AND RELATED UNCERTAINTIES*

## *by*

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# FRA 2005 BIOMASS CATEGORIES

**Above-ground biomass:** All living biomass above the soil including stem, stump, branches, bark, seeds, and foliage.

**Below-ground biomass:** All living biomass of live roots. Fine roots of less than 2mm diameter are excluded because these often cannot be distinguished empirically from soil organic matter or litter.

**Dead wood biomass:** All non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country.

# *Uncertainty*

*Standard deviation of the mean $s_{\bar{x}} = s / \sqrt{n}$*

*CI 95% => limits are approximately 2 $s_{\bar{x}}$ = normal distribution*
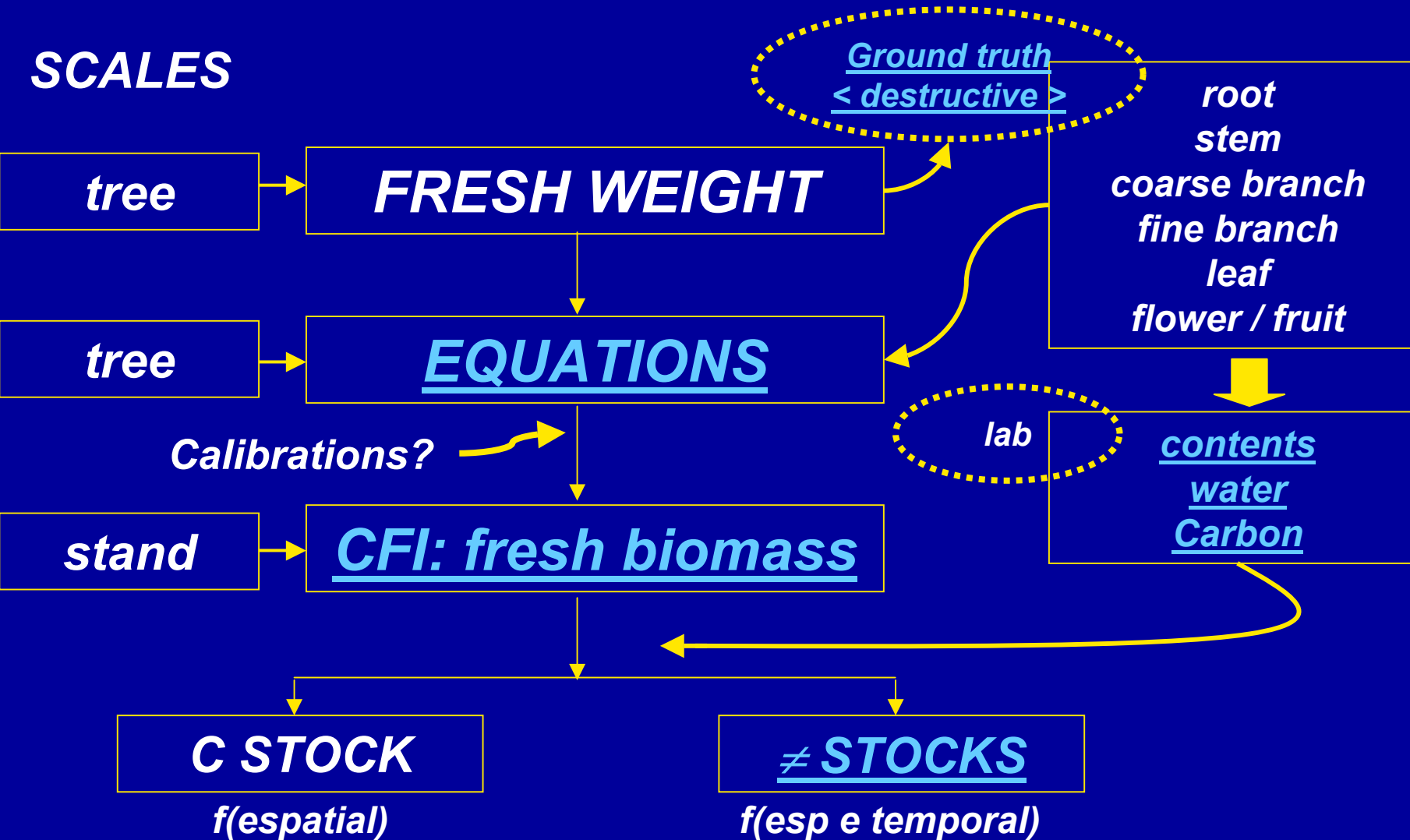
*CI (95%) = $\bar{x} \pm 2\, s_{\bar{x}}$*

*In summary => CI is the uncertainty in the estimate of the standard deviation.*

*Uncertainty in percentage = ( 2 $s_{\bar{x}}$ / $\bar{x}$ ) * 100*

# CHANGES IN CARBON STOCKS
## < primary, managed, and secondary forests >

**SCALES**

**Ground truth < destructive >**

root
stem
coarse branch
fine branch
leaf
flower / fruit

| tree | → | **FRESH WEIGHT** |

| tree | → | **EQUATIONS** |

**Calibrations?**

*lab*

**contents water Carbon**

| stand | → | **CFI: fresh biomass** |

**C STOCK**

*f(espatial)*

**≠ STOCKS**

*f(esp e temporal)*

# THANK YOU !

# STEM BIOMASS



*Sample for water and C contents, and nutrients and age*

# COARSE AND FINE BRANCHES AND LEAVES
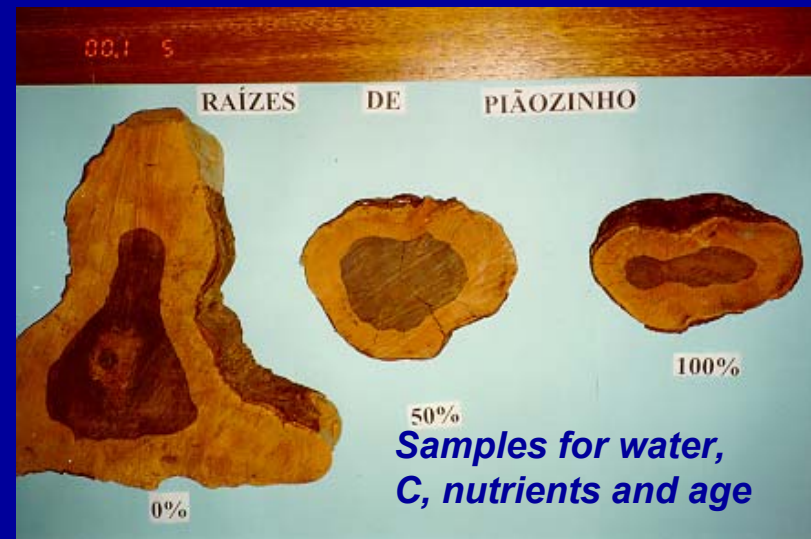


Coarse branch
Diam > 10 cm

Fine branch
Diam < 10 cm

Coarse branch scaling

Leaves

# COARSE ROOT (diam>2mm) BIOMASS



RAÍZES DE PIÃOZINHO

Samples for water, C, nutrients and age

# PRIMARY FOREST
## DESCRIPTIVE STATISTICS

### a) ABOVEGROUND BIOMASS

|  | dbh (cm) | total height (m) | fresh weight (kg) |
|---|---|---|---|
| N of cases | 494 | 494 | 494 |
| Minimum | 4.5 | 5.6 | 8.3 |
| Maximum | 120 | 41.4 | 25,634 |

**Dominant height of this site = 30 m (4.2% uncertainty)**

### b) BELOWGROUND BIOMASS

|  | dbh (cm) | total height (m) | fresh weight (kg) |
|---|---|---|---|
| N of cases | 131 | 131 | 131 |
| Minimum | 5 | 5.9 | 1.26 |
| Maximum | 85 | 34.5 | 2,709.49 |

# SECONDARY FOREST
## DESCRIPTIVE STATISTICS

### a) ABOVEGROUND BIOMASS

|  | dbh (cm) | total height (m) | fresh weight (kg) |
|---|---|---|---|
| N of cases | 593 | 593 | 593 |
| Minimum | 5 | 3.9 | 5.4 |
| Maximum | 37.2 | 27.0 | 1,690.2 |

### b) BELOWGROUND BIOMASS

|  | dbh (cm) | total height (m) | fresh weight (kg) |
|---|---|---|---|
| N of cases | 65 | 65 | 65 |
| Minimum | 5.2 | 7.4 | .52 |
| Maximum | 27.5 | 22.1 | 78.8 |

# PRIMARY FOREST



**PRIMARY FOREST
ABOVE : BELOW GROUND**

84%

16%
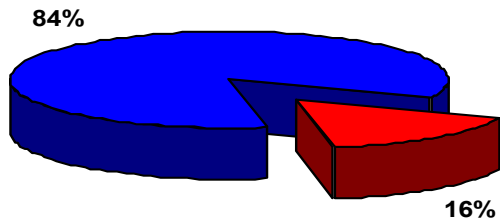
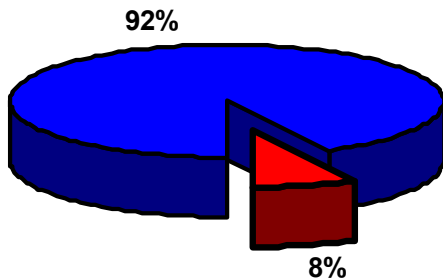aboveground    belowground

**CONTRIBUTION OF EACH TREE
COMPONENT**

68%

14%

0%3%    15%
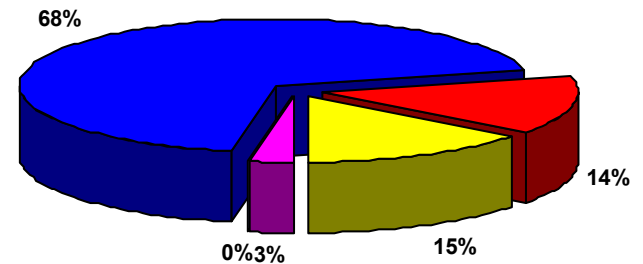
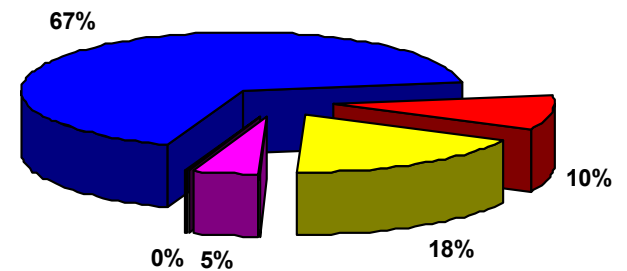trunk    coarse branch    fine branch    leaves    flower/fruit

# *SECONDARY FOREST*



SECONDARY FOREST
ABOVE : BELOW GROUND

92%

8%

■ aboveground    ■ belowground



SECONDARY FOREST
CONTRIBUTION OF EACH TREE COMPONENT

67%

10%

0%  5%    18%

■ trunk   ■ coarse branch   □ fine branch   ■ leaves   ■ flower/fruit

# PRIMARY FOREST – ABOVEGROUND BIOMASS

## $Ln\ FW = a + b\ ln\ DBH$

**FW = fresh weight in kg; DBH = diameter at breast height in cm**

Dep Var: LNFW   **N: 494**   Multiple R: 0.9863   Squared multiple R: 0.9728
**Adjusted squared multiple R: 0.9727**
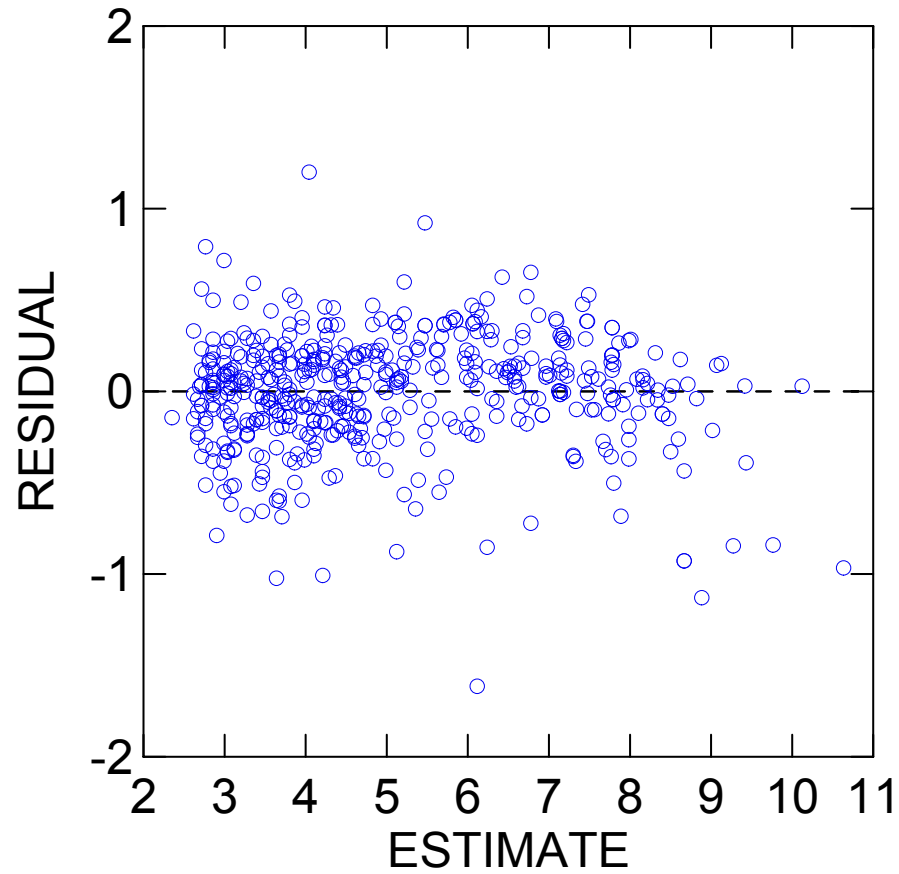**Standard error of estimate: 0.3021**
**Mean ln FW = 5,0385**
**Uncertainty (%) = 0.55**

| Effect | Coefficient | Std Error | Std Coef | Tolerance | t | P(2 Tail) |
|--------|-------------|-----------|----------|-----------|---|-----------|
| CONSTANT | -1.4452 | 0.0507 | 0.0000 | . | -28.4846 | 0.0000 |
| LND | 2.5252 | 0.0190 | 0.9863 | 1.0000 | 132.6450 | 0.0000 |

## Analysis of Variance

| Source | Sum-of-Squares | df | Mean-Square | F-ratio | P |
|--------|----------------|----|-------------|---------|---|
| Regression | 1606.0037 | 1 | 1606.0037 | 17594.7088 | 0.0000 |
| Residual | 44.9086 | 492 | 0.0913 | | |

Plot of Residuals against Predicted Values

# PRIMARY FOREST – ABOVEGROUND BIOMASS

## Ln FW = a + b ln DBH + ln HT

### FW = fresh weight in kg; DBH in cm; HT = total height in m

Dep Var: LNFW  **N: 494**  Multiple R: 0.9906  Squared multiple R: 0.9813

**Adjusted squared multiple R: 0.9812**
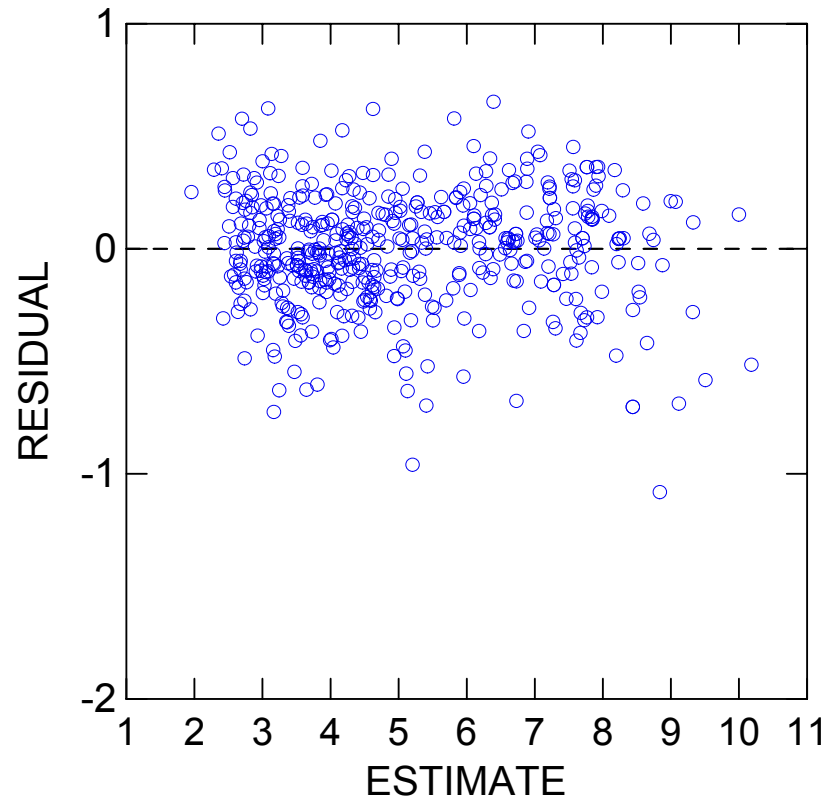**Standard error of estimate: 0.2506**
**Mean ln FW = 5,0385**
**Uncertainty (%) = 0.45**

| Effect | Coefficient | Std Error | Std Coef | Tolerance | t | P(2 Tail) |
|--------|-------------|-----------|----------|-----------|-----|-----------|
| CONSTANT | -2.6262 | 0.0894 | 0.0000 | . | -29.3759 | 0.0000 |
| LND | 2.0587 | 0.0349 | 0.8041 | 0.2044 | 58.9467 | 0.0000 |
| LNHT | 0.8584 | 0.0573 | 0.2043 | 0.2044 | 14.9731 | 0.0000 |

## Analysis of Variance

| Source | Sum-of-Squares | df | Mean-Square | F-ratio | P |
|--------|----------------|-----|-------------|---------|-----|
| Regression | 1620.0812 | 2 | 810.0406 | 12900.3167 | 0.0000 |
| Residual | 30.8310 | 491 | 0.0628 | | |

Plot of Residuals against Predicted Values

# PRIMARY FOREST – BELOWGROUND BIOMASS

## $Ln\ FW_{root} = a + b\ ln\ DBH$

*FW = fresh weight in kg; DBH = diameter at breast height in cm*

Dep Var: LNFW   **N: 131**   Multiple R: 0.9718   Squared multiple R: 0.9443
**Adjusted squared multiple R: 0.9439**
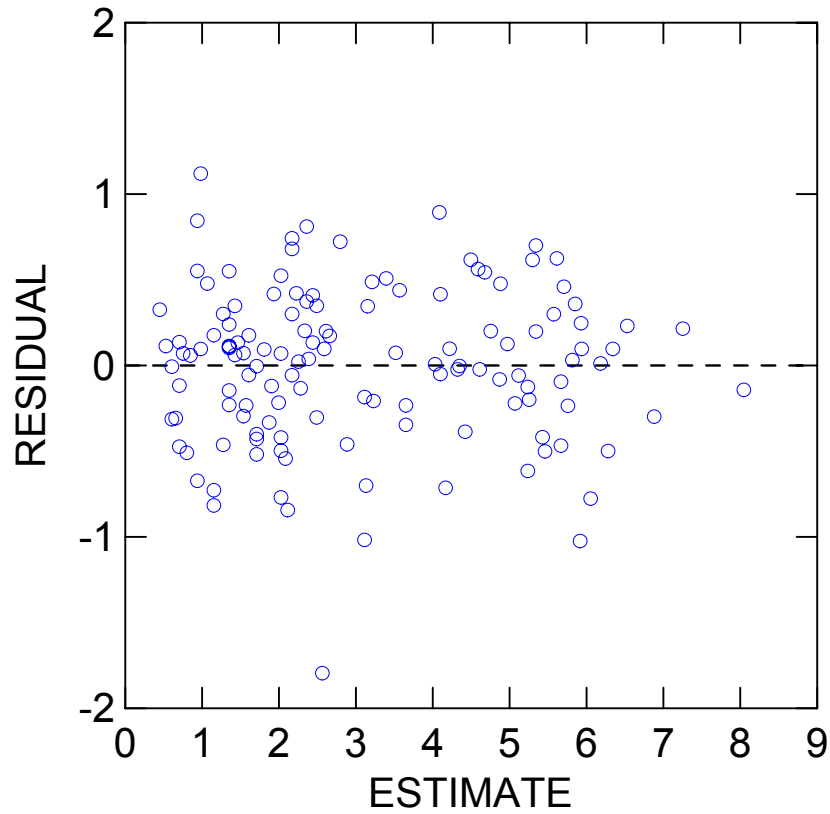**Standard error of estimate: 0.4541**
**Mean ln FW = 3,0887**
**Uncertainty (%) = 2.57**

| Effect | Coefficient | Std Error | Std Coef | Tolerance | t | P(2 Tail) |
|--------|-------------|-----------|----------|-----------|------|-----------|
| CONSTANT | -3.8660 | 0.1539 | 0.0000 | . | -25.1204 | 0.0000 |
| LND | 2.6816 | 0.0573 | 0.9718 | 1.0000 | 46.7707 | 0.0000 |

## Analysis of Variance

| Source | Sum-of-Squares | df | Mean-Square | F-ratio | P |
|--------|----------------|-----|-------------|---------|---|
| Regression | 451.0887 | 1 | 451.0887 | 2187.4953 | 0.0000 |
| Residual | 26.6014 | 129 | 0.2062 | | |

Plot of Residuals against Predicted Values

# PRIMARY FOREST – BELOWGROUND BIOMASS

## Ln FW = a + b ln DBH + ln HT

**FW = fresh weight in kg; DBH in cm; HT = total height in m**

Dep Var: LNFW   **N: 131**   Multiple R: 0.9722   Squared multiple R: 0.9452
**Adjusted squared multiple R: 0.9444**
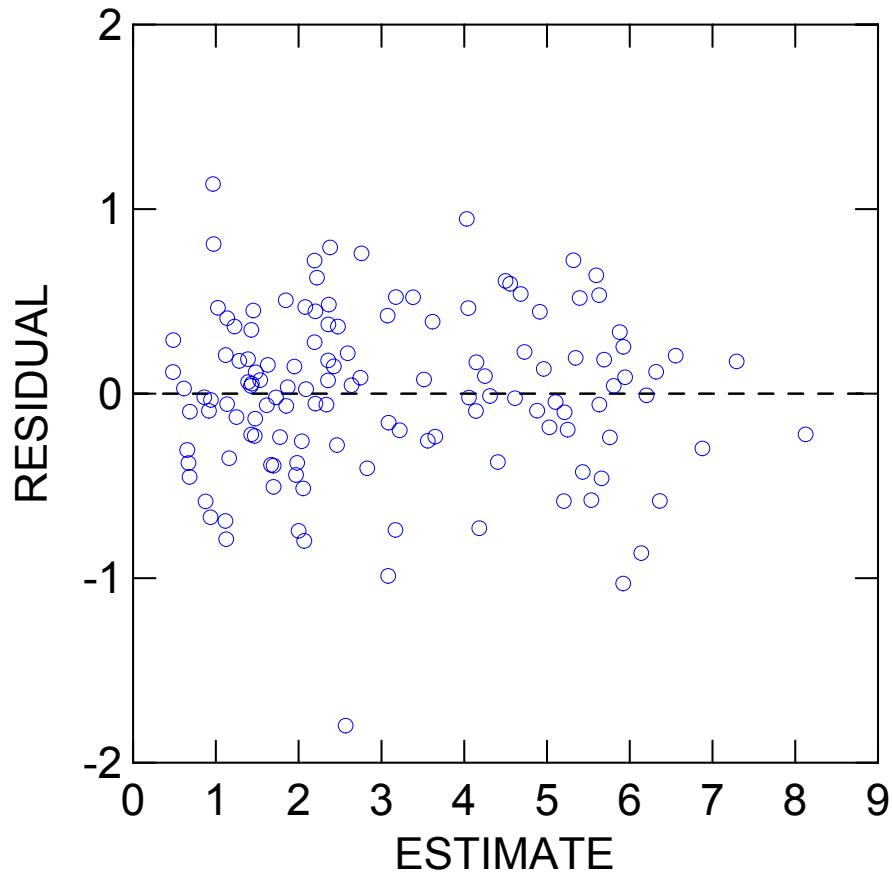**Standard error of estimate: 0.4522**
**Mean ln FW = 3,0887**
**Uncertainty (%) = 2.56**

| Effect | Coefficient | Std Error | Std Coef | Tolerance | t | P(2 Tail) |
|---|---|---|---|---|---|---|
| CONSTANT | -3.4408 | 0.3302 | 0.0000 | . | -10.4205 | 0.0000 |
| LND | 2.8420 | 0.1242 | 1.0299 | 0.2113 | 22.8844 | 0.0000 |
| LNHT | -0.3031 | 0.2084 | -0.0654 | 0.2113 | -1.4541 | 0.1484 |

## Analysis of Variance

| Source | Sum-of-Squares | df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|
| Regression | 451.5210 | 2 | 225.7605 | 1104.2534 | 0.0000 |
| Residual | 26.1691 | 128 | 0.2044 | | |

Plot of Residuals against Predicted Values

# SECONDARY FOREST – ABOVEGROUND BIOMASS

## ln FW = a + b ln D

### FW = fresh weight in kg; D = dbh in cm

*Dep Var: LNPF* **N: 593** *Multiple R: 0.9420 Squared multiple R: 0.8873*
**Adjusted squared multiple R: 0.8872**
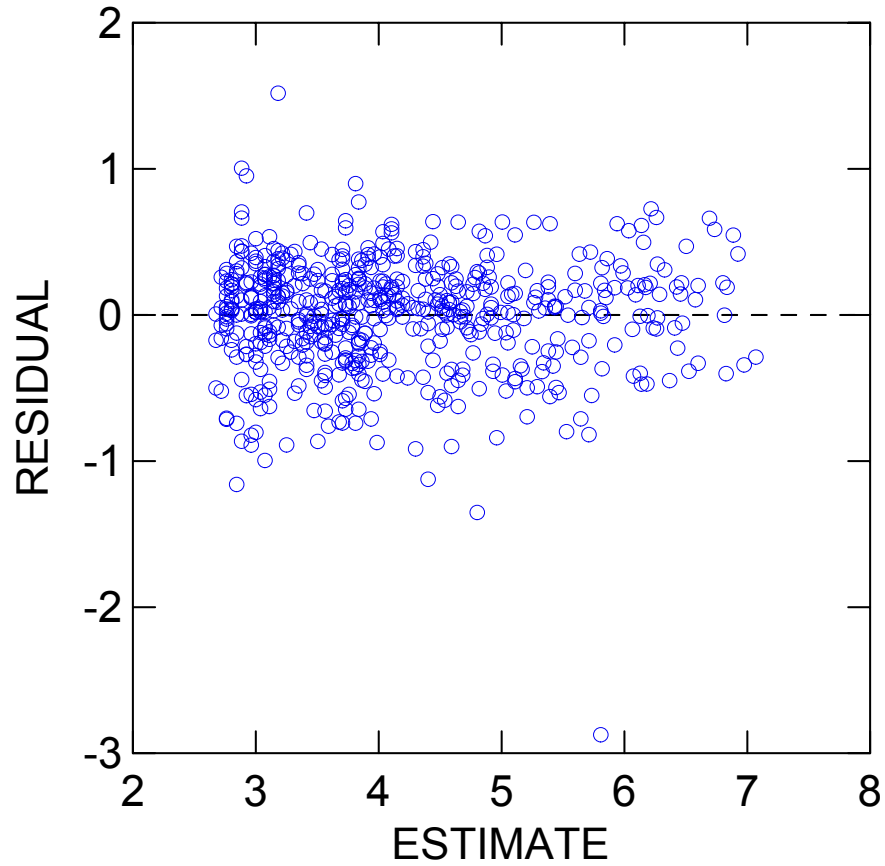**Standard error of estimate: 0.3770**
**Mean ln FW = 4.1196**
**Uncertainty (%) = 0.75**

| Effect | Coefficient | Std Error | Std Coef | Tolerance | t | P(2 Tail) |
|---|---|---|---|---|---|---|
| CONSTANT | -0.8481 | 0.0744 | 0.0000 | . | -11.3927 | 0.0000 |
| LND | 2.1898 | 0.0321 | 0.9420 | 1.0000 | 68.2269 | 0.0000 |

## Analysis of Variance

| Source | Sum-of-Squares | df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|
| Regression | 661.7202 | 1 | 661.7202 | 4654.9120 | 0.0000 |
| Residual | 84.0138 | 591 | 0.1422 | | |

Plot of Residuals against Predicted Values

# SECONDARY FOREST –ABOVEGROUND BIOMASS

## ln FW = a + b ln D + c ln HT

### FW = fresh weight in kg; D = dbh in cm; HT = total height in m

Dep Var: LNPF   **N: 593**   Multiple R: 0.9522   Squared multiple R: 0.9066
**Adjusted squared multiple R: 0.9063**
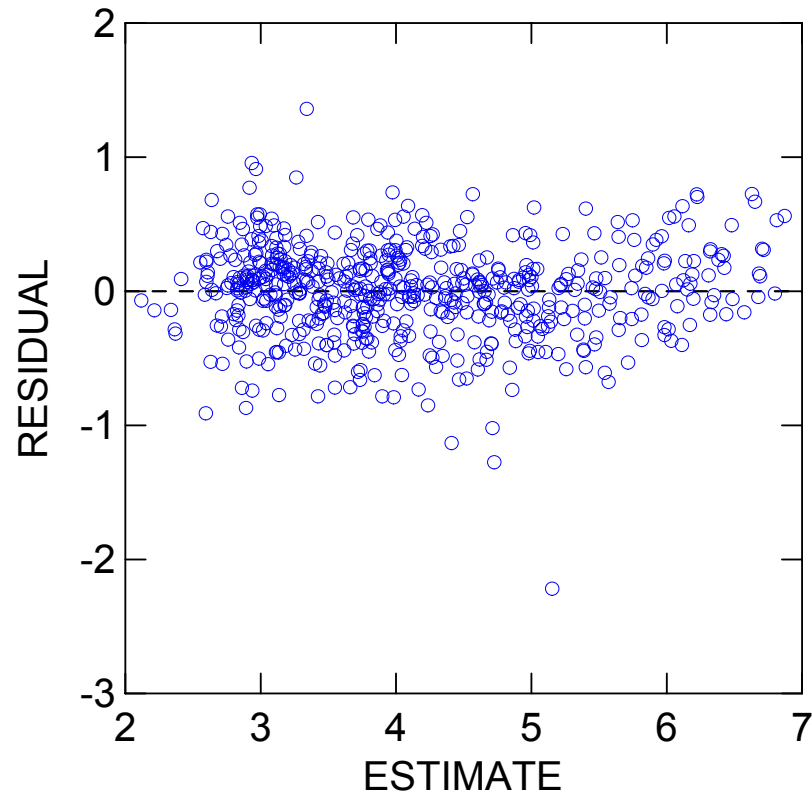**Standard error of estimate: 0.3436**
**Mean ln FW = 4.1196**
**Uncertainty (%) = 0.69**

| Effect | Coefficient | Std Error | Std Coef | Tolerance | t | P(2 Tail) |
|---|---|---|---|---|---|---|
| CONSTANT | -1.9222 | 0.1187 | 0.0000 | . | -16.1927 | 0.0000 |
| LND | 1.7278 | 0.0511 | 0.7433 | 0.3277 | 33.8159 | 0.0000 |
| LNHT | 0.8299 | 0.0753 | 0.2424 | 0.3277 | 11.0266 | 0.0000 |

## Analysis of Variance

| Source | Sum-of-Squares | df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|
| Regression | 676.0754 | 2 | 338.0377 | 2863.1400 | 0.0000 |
| Residual | 69.6586 | 590 | 0.1181 | | |

Plot of Residuals against Predicted Values

# SECONDARY FOREST – BELOWGROUND BIOMASS

## ln FW = a + b ln D

## FW = fresh weight in kg; D = dbh in cm

Dep Var: LNFW   **N: 65**   Multiple R: 0.8421   Squared multiple R: 0.7091
**Adjusted squared multiple R: 0.7045**
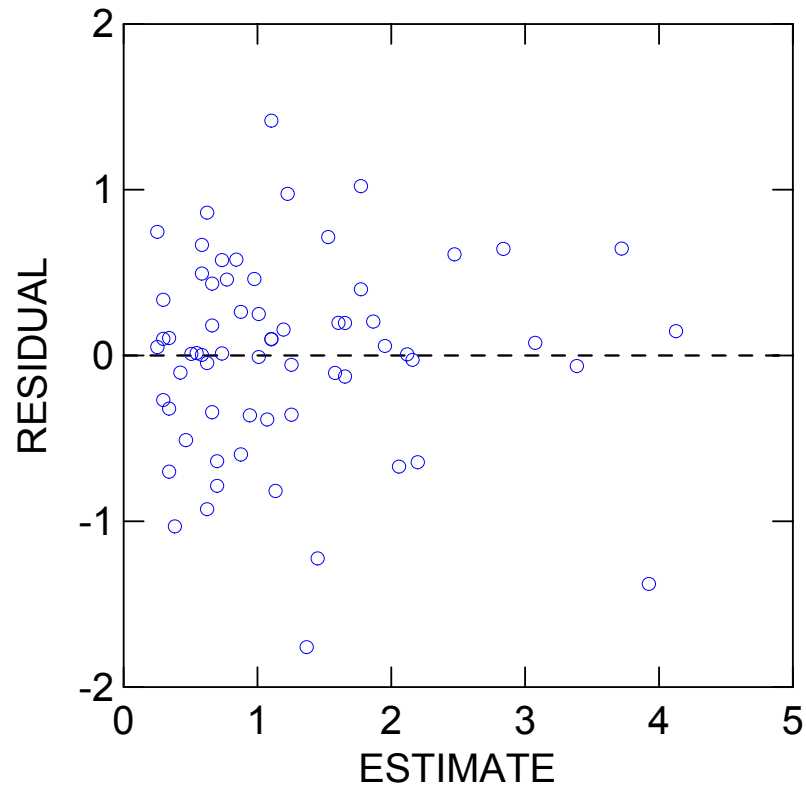**Standard error of estimate: 0.5971**
**Mean ln FW = 1.2502**
**Uncertainty (%) = 11.8**

| Effect | Coefficient | Std Error | Std Coef | Tolerance | t | P(2 Tail) |
|--------|-------------|-----------|----------|-----------|-----|-----------|
| CONSTANT | -3.5838 | 0.3970 | 0.0000 | . | -9.0262 | 0.0000 |
| LND | 2.3268 | 0.1878 | 0.8421 | 1.0000 | 12.3925 | 0.0000 |

## Analysis of Variance

| Source | Sum-of-Squares | df | Mean-Square | F-ratio | P |
|--------|----------------|-----|-------------|---------|-----|
| Regression | 54.7518 | 1 | 54.7518 | 153.5738 | 0.0000 |
| Residual | 22.4606 | 63 | 0.3565 | | |

Plot of Residuals against Predicted Values

# SECONDARY FOREST – BELOWGROUND BIOMASS

## $\ln FW = a + b \ln D + c \ln HT$

**FW = fresh weight in kg; D = dbh in cm; HT = total height in m**

Dep Var: LNFW   **N: 65**   Multiple R: 0.8424   Squared multiple R: 0.7096
**Adjusted squared multiple R: 0.7002**
**Standard error of estimate: 0.6014**
**Mean ln FW = 1.2502**
**Uncertainty (%) = 11.9**

| Effect | Coefficient | Std Error | Std Coef | Tolerance | t | P(2 Tail) |
|---|---|---|---|---|---|---|
| CONSTANT | -3.3807 | 0.7356 | 0.0000 | . | -4.5958 | 0.0000 |
| LND | 2.4147 | 0.3275 | 0.8739 | 0.3334 | 7.3731 | 0.0000 |
| LNHT | -0.1550 | 0.4711 | -0.0390 | 0.3334 | -0.3289 | 0.7433 |

## Analysis of Variance

| Source | Sum-of-Squares | df | Mean-Square | F-ratio | P |
|---|---|---|---|---|---|
| Regression | 54.7909 | 2 | 27.3955 | 75.7540 | 0.0000 |
| Residual | 22.4215 | 62 | 0.3616 | | |

Plot of Residuals against Predicted Values
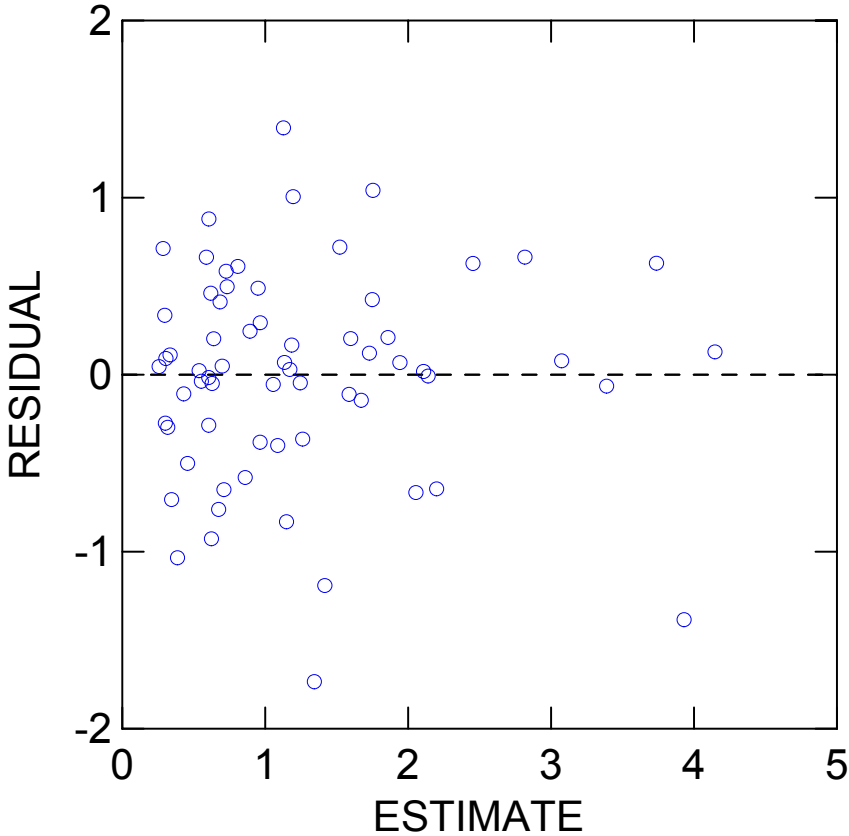
# PRIMARY FOREST
## *Water content in different tree components*

| | ABOVEGROUND | | BELOWGROUND | |
|---|---|---|---|---|
| | STEM n = 132 | CROWN n = 132 | COARSE n = 76 | FINE n = 75 |
| *mean* | 37.6 | 44.1 | 48.1 | 43.9 |
| *sd* | 8.3 | 7.1 | 9.7 | 8.8 |
| *Uncertainty %* | 3.7 | 2.7 | 4.6 | 4.6 |

*ABOVEGROUND: stem (65%) and crown (35%)*
*CROWN: coarse branches (55%); fine branches (39%) and leaves (6%)*

*Water content:*
*Aboveground => 40% => 37.6 * 0.65 + 44.1 * 0.35 = 39.8%*
*Belowground => 48%*

# PRIMARY FOREST
## Carbon content in different tree components

| | STEM | | ROOT | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | n = 44 | | WOODY TISSUE n = 106 | | | BARK n = 103 | | | FINE n = 92 |
| | 0% | 100% | 0% | 50% | 100% | 0% | 50% | 100% | bulk |
| mean | 48.7 | 48.3 | 47.3 | 47.0 | 46.9 | 42.6 | 42.7 | 42.7 | 45.7 |
| sd | 1.5 | 1.0 | 2.9 | 2.7 | 2.6 | 4.7 | 4.3 | 4.2 | 2.6 |
| Unc. | 1.0 | 0.6 | 1.3 | 1.1 | 1.1 | 2.1 | 1.9 | 1.9 | 1.1 |

*Unc. = uncertainty in %*

Carbon contents:
aboveground => 48.5%
belowground => 47%

# SECONDARY FORESTS

## Water content in different tree components

| Component  Uncertainty = 4.4% | S-8 site – 14 yr old  n = 31 | | | ZF-2 site – 23 yr old  n = 30 | | |
|---|---|---|---|---|---|---|
| | ( 1 ) | ( 2 ) | ( 3 ) | ( 1 ) | ( 2 ) | ( 3 ) |
| Stem | 47.1 | 0.6761 | 31.8 | 47.1 | 0.6704 | 31.6 |
| Coarse Branch | 47.0 | 0.0806 | 3.8 | 47.0 | 0.1111 | 5.2 |
| Fine Branch | 51.7 | 0.1867 | 9.7 | 51.7 | 0.1715 | 8.9 |
| Leaf | 65.2 | 0.0535 | 3.5 | 65.2 | 0.0467 | 3.0 |
| Flower | 57.8 | 0.0030 | 0.2 | 57.8 | 0.0003 | 0.0 |
| | | | 49.0 | | | 48.7 |

(1) = water content; (2) = contribution to the total aboveground biomass and (3) = weighted water content

aboveground = 49%

belowground => 47.3% (uncertainty = 7.4%)

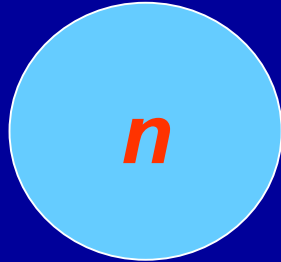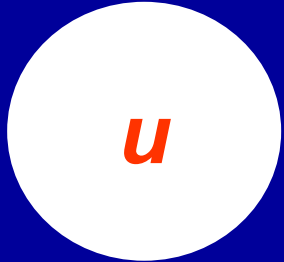# SECONDARY FORESTS

## Carbon content in different tree components

| component | C (%) | uncertainty (%) |
|---|---|---|
| stem | 44,82 | 0,86 |
| coarse branch | 44,79 | 2,04 |
| root | 44.82 | 0,01 |

**CARBON CONTENT IN SECONDARY FOREST => 44.5%**

v

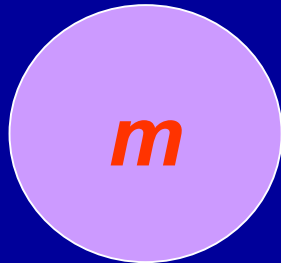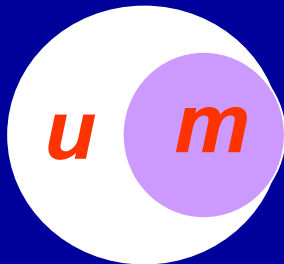# CFI - CONTINUOUS FOREST INVENTORY

**1st occasion**          **2nd occasion** . . . . . . . . . . **n occasions**

u          n          → **Temporary plot in each occasion**
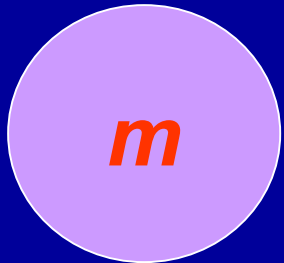
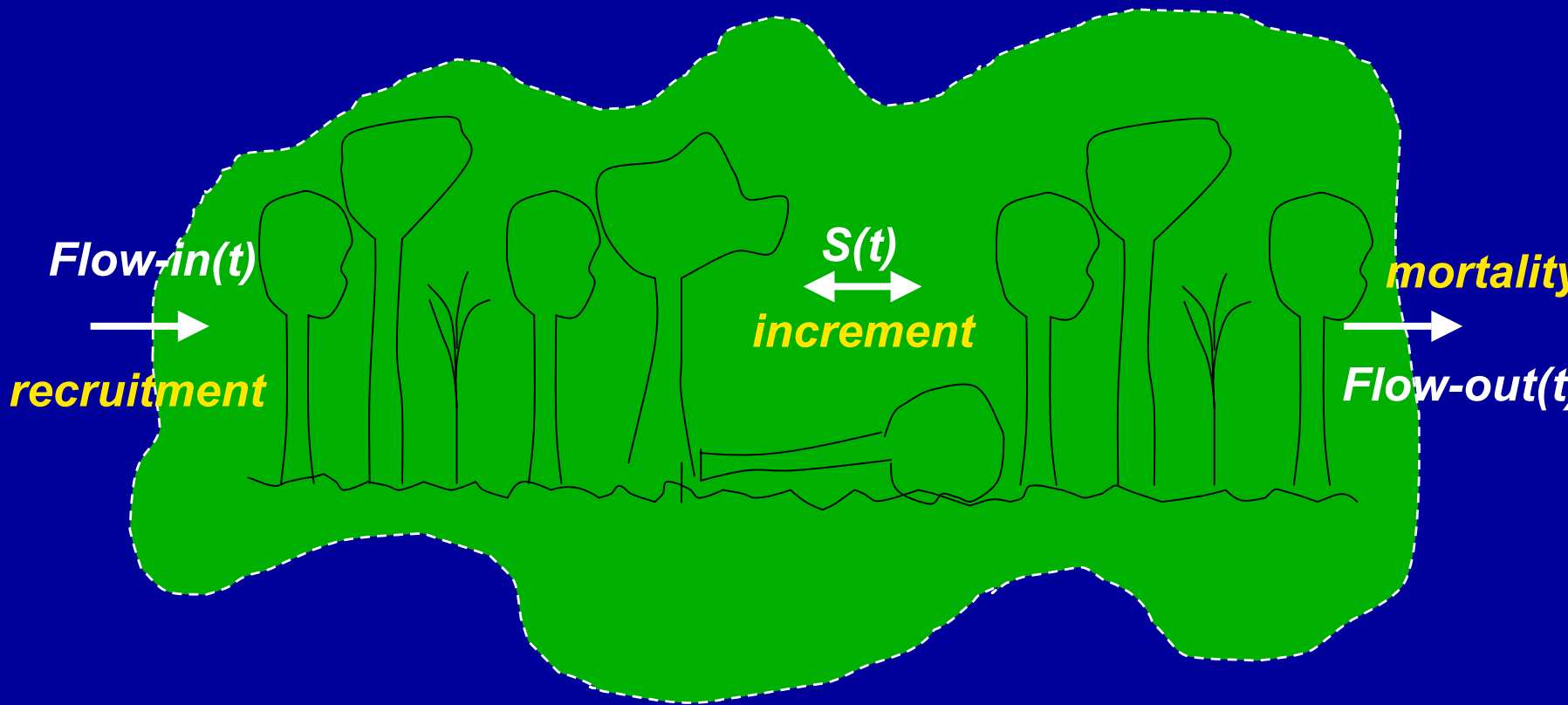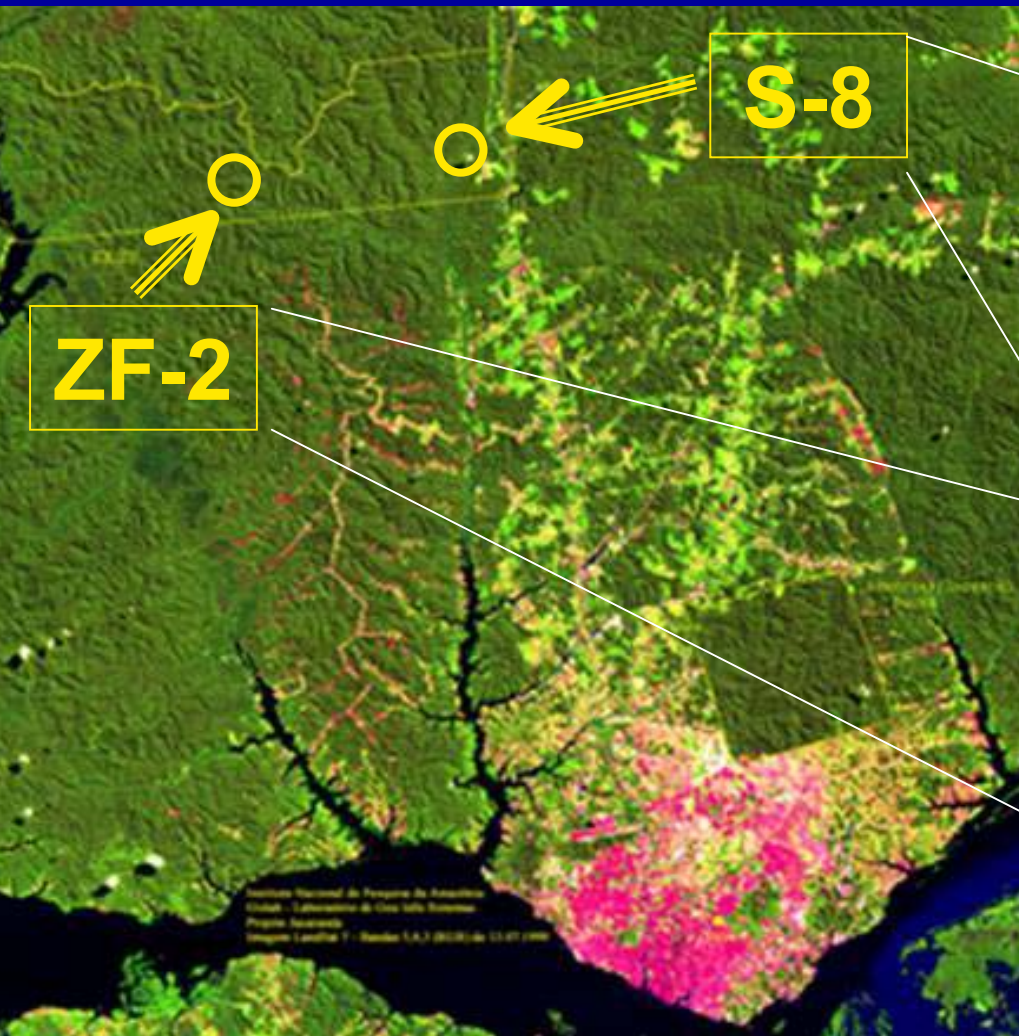m          m          → **Permanent plots on succeeding occasions**
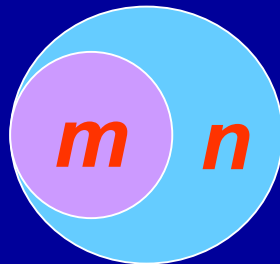
u m          m n          → **Successive sampling with partial replacement**

V

# CHANGES IN CARBON STOCKS

$$S(t) = S(t_0) + \int_0^t [ F_{in}(t) - F_{out}(t) ] \, dt$$

Flow-in(t)

recruitment

S(t)

increment

mortality

Flow-out(t)

V

# "CAPOEIRA" (SECONDARY FOREST) SITES



**S-8**

**ZF-2**

1991 => One-hectare plot clear cut and burned. and abandoned

2005 => 14 years later => 5 quadrates of 20 x 20 m each were clear cut => n = 252

1982 => Five-hectare plot clear cut. reforested. and abandoned

2005 => 23 years later => 5 quadrates of 20 x 20 m each were clear cut => n = 349

# Fresh aboveground biomass stock and mean annual increment (MAI) of capoeiras in metric tones

| Quadrate | S-8 per ha | ZF-2 per ha | MAI S-8 | MAI ZF-2 |
|---|---|---|---|---|
| 1 | 216.93 | 223.15 | 15.49 | 9.70 |
| 2 | 175.51 | 230.94 | 12.54 | 10.04 |
| 3 | 148.03 | 260.19 | 10.57 | 11.31 |
| 4 | 126.66 | 259.22 | 9.05 | 11.27 |
| 5 | 86.40 | 242.32 | 6.17 | 10.54 |
| mean | 150.71 | 243.17 | 10.76 | 10.57 |
| st deviation | 49.30 | 16.57 | 3.52 | 0.72 |
| CI (95%) | 43.21 | 14.53 | 3.09 | 0.63 |
| uncertainty (%) | 29 | 6 | 29 | 6 |

*In South Pará, FABs for capoeiras of 5, 10 and 20 years old are, respectively, 26, 88 e 162 t.ha$^{-1}$.*

# ALLOMETRIC EQUATIONS FOR CAPOEIRAS – SINGLE- AND DOUBLE ENTRY

| data set | model | n | a | b | c | $r^2$ | $S_{y.x}$ |
|---|---|---|---|---|---|---|---|
| S-8 | ( 1 ) | 252 | -0.9178 | 2.1848 | | 0.88 | 0.4046 |
| S-8 | ( 2 ) | 252 | -1.8338 | 1.7335 | 0.7662 | 0.89 | 0.3803 |
| ZF-2 | ( 1 ) | 349 | -0.7480 | 2.1659 | | 0.89 | 0.3647 |
| ZF-2 | ( 2 ) | 341 | -1.9338 | 1.7540 | 0.8285 | 0.92 | 0.3074 |
| S8 + ZF2 | ( 1 ) | 601 | -0.8222 | 2.1751 | | 0.88 | 0.3864 |
| S8 + ZF2 | ( 2 ) | 587 | -1.9255 | 1.7239 | 0.8349 | 0.91 | 0.3427 |

Model (1) => ln FAB = a + b ln D;

Model (2) => ln FAB = a + b ln D + c ln HT

Where:

FAB = fresh aboveground biomass in kg; D = dbh in cm; HT = total height in m; *a*, *b* and *c* = regression coefficients; $r^2$ = determination coefficient and $s_{y.x}$ = standard error of estimate

# Use of single-entry model of 5 different sources to estimate FAB – difference in %

| S-8 | Nelson (%) | Higuchi (%) | S-8 (%) | ZF-2 (%) | all (%) |
|---|---|---|---|---|---|
| 1 | -22 | 48 | -15 | -5 | -0.09 |
| 2 | -22 | 53 | -17 | -7 | -0.11 |
| 3 | -25 | 46 | -20 | -10 | -0.14 |
| 4 | -11 | 57 | 3 | 16 | 0.10 |
| 5 | -10 | 63 | 3 | 16 | 0.10 |
| Diff | -18 | 54 | -9 | 2 | -3 |
| ZF-2 | Nelson (%) | Higuchi (%) | S-8 (%) | ZF-2 (%) | all (%) |
| 1 | -23 | 43 | -14 | -4 | -8 |
| 2 | -29 | 38 | -24 | -15 | -19 |
| 3 | -33 | 35 | -31 | -23 | -27 |
| 4 | -15 | 64 | -9 | 2 | -3 |
| 5 | -26 | 45 | -20 | -10 | -15 |
| diff | -25 | 45 | -20 | -10 | -14 |