Predict Mature Forest Biomass from Environmental Predictors

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Table of contents

Optim

```
data <- read.csv("data/mature_biomass_climate_categ.csv")
# the data comes with yearly columns of seasonality and precipitation. Since for the
# mature forest prediction we only want yearly values, we will calculate the mean of each cli
patterns <- c("si_", "prec_")
means <- sapply(patterns, function(pat) rowMeans(data[, grep(pat, names(data))], na.rm = TRU
colnames(means) <- c("mean_si", "mean_prec")
data <- cbind(data, means)

# remove unnecessary columns
data <- data[, -grep("prec_|si_|biome|geo|system.index", names(data))]

# turn categorical variables into dummy variables
categorical <- c("ecoreg", "soil")
data[categorical] <- lapply(data[categorical], as.factor)
data <- createDummyFeatures(data, cols = categorical)
data <- data %>%
    rename(agbd = b1, cwd = b1_1)
```

```r
# Normalize numeric columns (0-1)
# Store max and min values to transform back the predctions
min_agbd <- min(data$agbd, na.rm = TRUE)
max_agbd <- max(data$agbd, na.rm = TRUE)
# transform all numeric columns
numeric_cols <- c("mean_si", "mean_prec", "cwd", "agbd")
data[numeric_cols] <- lapply(data[numeric_cols], function(x) {
    (x - min(x, na.rm = TRUE)) / (max(x, na.rm = TRUE) - min(x, na.rm = TRUE))
})
```

```r
pars_chosen <- c("cwd", "protec", "mean_si", "mean_prec", "indig")
pars <- setNames(rep(0.1, length(pars_chosen)), pars_chosen)

mat_biomass_function <- function(pars, data, pars_chosen) {
    pred_agbd <- data[[1]] * 0
    for (i in seq_along(pars_chosen)) {
        pred_agbd <- pred_agbd + pars[[pars_chosen[i]]] * data[[pars_chosen[i]]]
    }
    return(pred_agbd)
}

likelihood <- function(pars, data, pars_chosen) {
    return(sum((mat_biomass_function(pars, data, pars_chosen) - data$agbd)^2))
}

o <- optim(pars,
    likelihood,
    data = data,
    pars_chosen = pars_chosen
)
o$value
```

```
[1] 1035.765
```

```r
o$par
```

```
      cwd    protec   mean_si mean_prec     indig
0.4724562 0.1190372 0.1376150 0.3019738 0.1052000
```

```r
# Calculate R-squared
calc_r_squared <- function(observed, predicted) {
    mean_observed <- mean(observed, na.rm = TRUE)
    TSS <- sum((observed - mean_observed)^2, na.rm = TRUE)
    RSS <- sum((observed - predicted)^2, na.rm = TRUE)
    R_squared <- 1 - (RSS / TSS)
    return(R_squared)
}

calc_r_squared(data$agbd, mat_biomass_function(o$par, data, pars_chosen))
```

```
[1] 0.3006736
```

If, however, we run it with all parameters, we get a worse fit:

```r
pars_chosen <- names(data)[!names(data) %in% "agbd"]
pars <- setNames(rep(0.1, length(pars_chosen)), pars_chosen)

o <- optim(pars,
    likelihood,
    data = data,
    pars_chosen = pars_chosen
)
o$value
```

```
[1] 2879.161
```

```r
o$par
```

```
       cwd      indig     protec    mean_si  mean_prec ecoreg.439 ecoreg.440
      0.11       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.441 ecoreg.442 ecoreg.443 ecoreg.444 ecoreg.445 ecoreg.446 ecoreg.447
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.448 ecoreg.449 ecoreg.450 ecoreg.451 ecoreg.453 ecoreg.454 ecoreg.455
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.456 ecoreg.457 ecoreg.458 ecoreg.459 ecoreg.460 ecoreg.461 ecoreg.462
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.463 ecoreg.464 ecoreg.465 ecoreg.466 ecoreg.467 ecoreg.468 ecoreg.469
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.470 ecoreg.471 ecoreg.472 ecoreg.473 ecoreg.474 ecoreg.475 ecoreg.476
```

```
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.477 ecoreg.478 ecoreg.479 ecoreg.480 ecoreg.481 ecoreg.482 ecoreg.483
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.484 ecoreg.485 ecoreg.486 ecoreg.487 ecoreg.488 ecoreg.489 ecoreg.490
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.491 ecoreg.492 ecoreg.493 ecoreg.494 ecoreg.495 ecoreg.496 ecoreg.497
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.498 ecoreg.499 ecoreg.500 ecoreg.501 ecoreg.502 ecoreg.503 ecoreg.504
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.505 ecoreg.506 ecoreg.507 ecoreg.508 ecoreg.509 ecoreg.510 ecoreg.511
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.512 ecoreg.513 ecoreg.514 ecoreg.515 ecoreg.516 ecoreg.517 ecoreg.518
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.519 ecoreg.520 ecoreg.521 ecoreg.522 ecoreg.523 ecoreg.524 ecoreg.525
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.526 ecoreg.527 ecoreg.528 ecoreg.529 ecoreg.530 ecoreg.531 ecoreg.532
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.533 ecoreg.534 ecoreg.535 ecoreg.536 ecoreg.537 ecoreg.538 ecoreg.539
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.540 ecoreg.541 ecoreg.542 ecoreg.543 ecoreg.544 ecoreg.545 ecoreg.546
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.547 ecoreg.548 ecoreg.549 ecoreg.550 ecoreg.551 ecoreg.552 ecoreg.553
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.554 ecoreg.555 ecoreg.556 ecoreg.557 ecoreg.558 ecoreg.559 ecoreg.560
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.561 ecoreg.562 ecoreg.563 ecoreg.564 ecoreg.565 ecoreg.566 ecoreg.567
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.568 ecoreg.569 ecoreg.570 ecoreg.571 ecoreg.572 ecoreg.574 ecoreg.575
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.577 ecoreg.578 ecoreg.579 ecoreg.580 ecoreg.581 ecoreg.582 ecoreg.583
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.584 ecoreg.585 ecoreg.587 ecoreg.588 ecoreg.589 ecoreg.591 ecoreg.593
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.597 ecoreg.600 ecoreg.602 ecoreg.605 ecoreg.606 ecoreg.608 ecoreg.609
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
ecoreg.610 ecoreg.611 ecoreg.616     soil.2     soil.3     soil.4     soil.5
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
    soil.6     soil.7     soil.8     soil.9    soil.10    soil.11    soil.12
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
   soil.13    soil.14    soil.15    soil.16    soil.17    soil.18    soil.19
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
   soil.20    soil.21    soil.22    soil.23    soil.24    soil.25    soil.26
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
```

```
   soil.27    soil.28    soil.29    soil.30    soil.31    soil.32    soil.33
      0.10       0.10       0.10       0.10       0.10       0.10       0.10
   soil.34
      0.10
```

GAM

```r
pars_categ <- names(data)[!names(data) %in% numeric_cols]

# Fit a GAM model
# Construct the formula dynamically
formula <- as.formula(paste("agbd ~ s(cwd) + s(mean_si) + s(mean_prec) +", paste(pars_categ,

# Fit the GAM model with the dynamically created formula
gam_model <- gam(formula, data = data)
summary(gam_model)
```

```
Family: gaussian
Link function: identity

Formula:
agbd ~ s(cwd) + s(mean_si) + s(mean_prec) + indig + protec +
    ecoreg.439 + ecoreg.440 + ecoreg.441 + ecoreg.442 + ecoreg.443 +
    ecoreg.444 + ecoreg.445 + ecoreg.446 + ecoreg.447 + ecoreg.448 +
    ecoreg.449 + ecoreg.450 + ecoreg.451 + ecoreg.453 + ecoreg.454 +
    ecoreg.455 + ecoreg.456 + ecoreg.457 + ecoreg.458 + ecoreg.459 +
    ecoreg.460 + ecoreg.461 + ecoreg.462 + ecoreg.463 + ecoreg.464 +
    ecoreg.465 + ecoreg.466 + ecoreg.467 + ecoreg.468 + ecoreg.469 +
    ecoreg.470 + ecoreg.471 + ecoreg.472 + ecoreg.473 + ecoreg.474 +
    ecoreg.475 + ecoreg.476 + ecoreg.477 + ecoreg.478 + ecoreg.479 +
    ecoreg.480 + ecoreg.481 + ecoreg.482 + ecoreg.483 + ecoreg.484 +
    ecoreg.485 + ecoreg.486 + ecoreg.487 + ecoreg.488 + ecoreg.489 +
    ecoreg.490 + ecoreg.491 + ecoreg.492 + ecoreg.493 + ecoreg.494 +
    ecoreg.495 + ecoreg.496 + ecoreg.497 + ecoreg.498 + ecoreg.499 +
    ecoreg.500 + ecoreg.501 + ecoreg.502 + ecoreg.503 + ecoreg.504 +
    ecoreg.505 + ecoreg.506 + ecoreg.507 + ecoreg.508 + ecoreg.509 +
    ecoreg.510 + ecoreg.511 + ecoreg.512 + ecoreg.513 + ecoreg.514 +
    ecoreg.515 + ecoreg.516 + ecoreg.517 + ecoreg.518 + ecoreg.519 +
    ecoreg.520 + ecoreg.521 + ecoreg.522 + ecoreg.523 + ecoreg.524 +
```

```
    ecoreg.525 + ecoreg.526 + ecoreg.527 + ecoreg.528 + ecoreg.529 +
    ecoreg.530 + ecoreg.531 + ecoreg.532 + ecoreg.533 + ecoreg.534 +
    ecoreg.535 + ecoreg.536 + ecoreg.537 + ecoreg.538 + ecoreg.539 +
    ecoreg.540 + ecoreg.541 + ecoreg.542 + ecoreg.543 + ecoreg.544 +
    ecoreg.545 + ecoreg.546 + ecoreg.547 + ecoreg.548 + ecoreg.549 +
    ecoreg.550 + ecoreg.551 + ecoreg.552 + ecoreg.553 + ecoreg.554 +
    ecoreg.555 + ecoreg.556 + ecoreg.557 + ecoreg.558 + ecoreg.559 +
    ecoreg.560 + ecoreg.561 + ecoreg.562 + ecoreg.563 + ecoreg.564 +
    ecoreg.565 + ecoreg.566 + ecoreg.567 + ecoreg.568 + ecoreg.569 +
    ecoreg.570 + ecoreg.571 + ecoreg.572 + ecoreg.574 + ecoreg.575 +
    ecoreg.577 + ecoreg.578 + ecoreg.579 + ecoreg.580 + ecoreg.581 +
    ecoreg.582 + ecoreg.583 + ecoreg.584 + ecoreg.585 + ecoreg.587 +
    ecoreg.588 + ecoreg.589 + ecoreg.591 + ecoreg.593 + ecoreg.597 +
    ecoreg.600 + ecoreg.602 + ecoreg.605 + ecoreg.606 + ecoreg.608 +
    ecoreg.609 + ecoreg.610 + ecoreg.611 + ecoreg.616 + soil.2 +
    soil.3 + soil.4 + soil.5 + soil.6 + soil.7 + soil.8 + soil.9 +
    soil.10 + soil.11 + soil.12 + soil.13 + soil.14 + soil.15 +
    soil.16 + soil.17 + soil.18 + soil.19 + soil.20 + soil.21 +
    soil.22 + soil.23 + soil.24 + soil.25 + soil.26 + soil.27 +
    soil.28 + soil.29 + soil.30 + soil.31 + soil.32 + soil.33 +
    soil.34

Parametric coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.4307997  0.0063254  68.106  < 2e-16 ***
indig        0.0777038  0.0016692  46.552  < 2e-16 ***
protec       0.0634781  0.0017043  37.247  < 2e-16 ***
ecoreg.439  -0.0742534  0.0118441  -6.269 3.67e-10 ***
ecoreg.440  -0.0665299  0.0089177  -7.460 8.82e-14 ***
ecoreg.441   0.0335574  0.0353750   0.949 0.342822
ecoreg.442  -0.0060503  0.0100755  -0.600 0.548177
ecoreg.443  -0.0120278  0.0118465  -1.015 0.309967
ecoreg.444  -0.0177077  0.0891683  -0.199 0.842587
ecoreg.445  -0.0780848  0.0404046  -1.933 0.053297 .
ecoreg.446   0.1397366  0.0135887  10.283  < 2e-16 ***
ecoreg.447   0.0665990  0.0383025   1.739 0.082085 .
ecoreg.448  -0.0736584  0.0891111  -0.827 0.408475
ecoreg.449   0.1644319  0.0516851   3.181 0.001467 **
ecoreg.450  -0.0420301  0.0564334  -0.745 0.456414
ecoreg.451   0.0567971  0.0565842   1.004 0.315500
ecoreg.453  -0.0190900  0.0630847  -0.303 0.762190
ecoreg.454   0.0961750  0.0565284   1.701 0.088885 .
ecoreg.455  -0.0070661  0.0516361  -0.137 0.891155
```

```
ecoreg.456   0.0402188  0.0630755   0.638 0.523719
ecoreg.457   0.0434391  0.0728165   0.597 0.550809
ecoreg.458   0.0089493  0.0728619   0.123 0.902245
ecoreg.459  -0.2539921  0.0890128  -2.853 0.004328 **
ecoreg.460  -0.0022460  0.0448580  -0.050 0.960068
ecoreg.461   0.0606512  0.0565167   1.073 0.283209
ecoreg.462   0.0905673  0.0565496   1.602 0.109263
ecoreg.463   0.0619137  0.0631422   0.981 0.326825
ecoreg.464   0.1561339  0.0105144  14.850  < 2e-16 ***
ecoreg.465   0.2204134  0.0070029  31.474  < 2e-16 ***
ecoreg.466   0.1020306  0.0068044  14.995  < 2e-16 ***
ecoreg.467   0.0800077  0.0251343   3.183 0.001458 **
ecoreg.468   0.1284864  0.0318191   4.038 5.40e-05 ***
ecoreg.469   0.1464230  0.0124861  11.727  < 2e-16 ***
ecoreg.470   0.1198888  0.0209426   5.725 1.05e-08 ***
ecoreg.471   0.1307861  0.0238346   5.487 4.11e-08 ***
ecoreg.472   0.1533022  0.0285154   5.376 7.66e-08 ***
ecoreg.473   0.0951876  0.0060754  15.668  < 2e-16 ***
ecoreg.474   0.2137846  0.0058376  36.622  < 2e-16 ***
ecoreg.475   0.1684999  0.0144482  11.662  < 2e-16 ***
ecoreg.476   0.1571182  0.0052048  30.187  < 2e-16 ***
ecoreg.477   0.0937981  0.0112265   8.355  < 2e-16 ***
ecoreg.478   0.0721093  0.0123084   5.859 4.71e-09 ***
ecoreg.479   0.1178488  0.0128203   9.192  < 2e-16 ***
ecoreg.480   0.0161841  0.0081351   1.989 0.046664 *
ecoreg.481   0.0530817  0.0057474   9.236  < 2e-16 ***
ecoreg.482   0.0748011  0.0089274   8.379  < 2e-16 ***
ecoreg.483   0.0612014  0.0138348   4.424 9.73e-06 ***
ecoreg.484   0.0626258  0.0081804   7.656 1.97e-14 ***
ecoreg.485   0.0680732  0.0137465   4.952 7.38e-07 ***
ecoreg.486   0.1050224  0.0149565   7.022 2.23e-12 ***
ecoreg.487   0.0761704  0.0158723   4.799 1.60e-06 ***
ecoreg.488   0.0489554  0.0160988   3.041 0.002360 **
ecoreg.489   0.1111797  0.0155622   7.144 9.23e-13 ***
ecoreg.490   0.1040590  0.0129525   8.034 9.74e-16 ***
ecoreg.491   0.0736794  0.0155788   4.729 2.26e-06 ***
ecoreg.492   0.0847267  0.0146681   5.776 7.70e-09 ***
ecoreg.493   0.1093376  0.0152914   7.150 8.83e-13 ***
ecoreg.494   0.0870196  0.0149415   5.824 5.79e-09 ***
ecoreg.495   0.1173265  0.0153133   7.662 1.88e-14 ***
ecoreg.496   0.1294392  0.0068941  18.775  < 2e-16 ***
ecoreg.497   0.1154154  0.0059640  19.352  < 2e-16 ***
ecoreg.498   0.0388436  0.0086592   4.486 7.29e-06 ***
```

```
ecoreg.499   0.1267296  0.0154781   8.188 2.75e-16 ***
ecoreg.500  -0.0043770  0.0081843  -0.535 0.592786
ecoreg.501   0.1205419  0.0166705   7.231 4.90e-13 ***
ecoreg.502   0.1315553  0.0145519   9.040  < 2e-16 ***
ecoreg.503   0.1876272  0.0090745  20.676  < 2e-16 ***
ecoreg.504   0.1453671  0.0163164   8.909  < 2e-16 ***
ecoreg.505   0.2619506  0.0055350  47.326  < 2e-16 ***
ecoreg.506   0.0783523  0.0242180   3.235 0.001216 **
ecoreg.507   0.1695657  0.0055409  30.603  < 2e-16 ***
ecoreg.508   0.0197813  0.0072234   2.738 0.006175 **
ecoreg.509   0.0136373  0.0223935   0.609 0.542537
ecoreg.510   0.0423928  0.0193171   2.195 0.028201 *
ecoreg.511   0.1686353  0.0054435  30.979  < 2e-16 ***
ecoreg.512   0.0254269  0.0272346   0.934 0.350503
ecoreg.513   0.0502136  0.0339329   1.480 0.138939
ecoreg.514   0.0148075  0.0299966   0.494 0.621564
ecoreg.515  -0.0141300  0.0352255  -0.401 0.688327
ecoreg.516   0.0146273  0.0285082   0.513 0.607891
ecoreg.517  -0.0028529  0.0251248  -0.114 0.909597
ecoreg.518   0.1492285  0.0063361  23.552  < 2e-16 ***
ecoreg.519   0.0674992  0.0515404   1.310 0.190327
ecoreg.520  -0.1188407  0.0515587  -2.305 0.021175 *
ecoreg.521   0.0488701  0.0734704   0.665 0.505948
ecoreg.522   0.0018267  0.0480759   0.038 0.969692
ecoreg.523   0.0972232  0.0563909   1.724 0.084700 .
ecoreg.524   0.0027131  0.0227712   0.119 0.905161
ecoreg.525  -0.0095078  0.0178329  -0.533 0.593925
ecoreg.526   0.0943004  0.0480201   1.964 0.049565 *
ecoreg.527   0.0548492  0.0630336   0.870 0.384220
ecoreg.528  -0.0186671  0.0515514  -0.362 0.717274
ecoreg.529  -0.0354355  0.0116181  -3.050 0.002290 **
ecoreg.530   0.0555296  0.0480348   1.156 0.247677
ecoreg.531  -0.0931387  0.0891263  -1.045 0.296021
ecoreg.532   0.0087250  0.0515721   0.169 0.865655
ecoreg.533   0.0257686  0.0401060   0.643 0.520545
ecoreg.534  -0.1004629  0.0630938  -1.592 0.111331
ecoreg.535   0.0795471  0.0564604   1.409 0.158873
ecoreg.536   0.0143299  0.0422354   0.339 0.734395
ecoreg.537   0.1248870  0.0515502   2.423 0.015414 *
ecoreg.538  -0.1300764  0.0515509  -2.523 0.011632 *
ecoreg.539  -0.0184970  0.0401982  -0.460 0.645415
ecoreg.540   0.0262030  0.0111400   2.352 0.018670 *
ecoreg.541  -0.2192766  0.0726704  -3.017 0.002551 **
```

```
ecoreg.542  -0.0096409  0.0447294  -0.216 0.829349
ecoreg.543  -0.0261211  0.0477363  -0.547 0.584248
ecoreg.544   0.0193718  0.0565382   0.343 0.731877
ecoreg.545  -0.0892522  0.0630125  -1.416 0.156662
ecoreg.546  -0.1949202  0.0515272  -3.783 0.000155 ***
ecoreg.547  -0.1471373  0.0629834  -2.336 0.019490 *
ecoreg.548  -0.0406402  0.0732489  -0.555 0.579020
ecoreg.549  -0.0469167  0.0421834  -1.112 0.266056
ecoreg.550   0.1041851  0.0727180   1.433 0.151945
ecoreg.551  -0.0382511  0.0515590  -0.742 0.458159
ecoreg.552   0.0382207  0.0447048   0.855 0.392580
ecoreg.553   0.0161438  0.0516099   0.313 0.754432
ecoreg.554   0.0426617  0.0477321   0.894 0.371449
ecoreg.555  -0.0292415  0.0421652  -0.693 0.488002
ecoreg.556  -0.1081452  0.0515082  -2.100 0.035774 *
ecoreg.557  -0.1427208  0.0446881  -3.194 0.001406 **
ecoreg.558  -0.0437645  0.0516219  -0.848 0.396562
ecoreg.559  -0.1457752  0.0516140  -2.824 0.004741 **
ecoreg.560   0.0225915  0.0447505   0.505 0.613680
ecoreg.561  -0.0620270  0.0564184  -1.099 0.271596
ecoreg.562  -0.2593282  0.0728415  -3.560 0.000371 ***
ecoreg.563  -0.1023181  0.0564236  -1.813 0.069780 .
ecoreg.564  -0.0295571  0.0447526  -0.660 0.508966
ecoreg.565  -0.0546933  0.0400779  -1.365 0.172364
ecoreg.566  -0.0543414  0.0300938  -1.806 0.070969 .
ecoreg.567  -0.0453490  0.0071733  -6.322 2.61e-10 ***
ecoreg.568  -0.0300690  0.0477951  -0.629 0.529272
ecoreg.569  -0.0896340  0.0727165  -1.233 0.217715
ecoreg.570  -0.0094037  0.0114981  -0.818 0.413453
ecoreg.571  -0.1424411  0.0597711  -2.383 0.017172 *
ecoreg.572  -0.0205766  0.1260854  -0.163 0.870365
ecoreg.574  -0.1252577  0.0303167  -4.132 3.61e-05 ***
ecoreg.575  -0.0776654  0.0733224  -1.059 0.289501
ecoreg.577  -0.1869087  0.1256886  -1.487 0.137003
ecoreg.578  -0.1865966  0.0729277  -2.559 0.010512 *
ecoreg.579  -0.2259895  0.0631630  -3.578 0.000347 ***
ecoreg.580  -0.2176242  0.1260839  -1.726 0.084351 .
ecoreg.581  -0.0727554  0.0729057  -0.998 0.318316
ecoreg.582  -0.2465381  0.0893163  -2.760 0.005778 **
ecoreg.583  -0.1328021  0.0728147  -1.824 0.068185 .
ecoreg.584  -0.1116494  0.0182958  -6.102 1.06e-09 ***
ecoreg.585   0.0649584  0.1259325   0.516 0.605984
ecoreg.587   0.0189281  0.1261473   0.150 0.880728
```

```
ecoreg.588  -0.0970350  0.1261976  -0.769 0.441950
ecoreg.589  -0.1644150  0.0630084  -2.609 0.009074 **
ecoreg.591  -0.2332488  0.1257239  -1.855 0.063570 .
ecoreg.593  -0.2862042  0.1261224  -2.269 0.023259 *
ecoreg.597  -0.0881532  0.0727399  -1.212 0.225560
ecoreg.600  -0.0383061  0.1264821  -0.303 0.762000
ecoreg.602  -0.0804968  0.0728561  -1.105 0.269222
ecoreg.605  -0.0659336  0.1263082  -0.522 0.601670
ecoreg.606  -0.1053543  0.1263577  -0.834 0.404412
ecoreg.608  -0.1131677  0.1262052  -0.897 0.369887
ecoreg.609  -0.0928699  0.1264940  -0.734 0.462841
ecoreg.610  -0.0609596  0.1262358  -0.483 0.629168
ecoreg.611  -0.1272270  0.0358582  -3.548 0.000389 ***
ecoreg.616  -0.3575479  0.0727743  -4.913 9.00e-07 ***
soil.2       0.0398724  0.0335072   1.190 0.234068
soil.3       0.0228070  0.0111450   2.046 0.040725 *
soil.4       0.0347386  0.0270824   1.283 0.199607
soil.5       0.0023037  0.0239902   0.096 0.923500
soil.6       0.0282675  0.0294320   0.960 0.336843
soil.7      -0.0081140  0.0059773  -1.357 0.174637
soil.8       0.0005319  0.0071855   0.074 0.940994
soil.9       0.0612607  0.0049341  12.416  < 2e-16 ***
soil.10     -0.0229421  0.0058113  -3.948 7.90e-05 ***
soil.11     -0.0397036  0.0082400  -4.818 1.45e-06 ***
soil.12     -0.0464289  0.0086815  -5.348 8.95e-08 ***
soil.13     -0.0381901  0.0093415  -4.088 4.36e-05 ***
soil.14      0.0719378  0.0060794  11.833  < 2e-16 ***
soil.15     -0.0070193  0.0109447  -0.641 0.521306
soil.16     -0.0017451  0.0117173  -0.149 0.881606
soil.17      0.0522283  0.0118363   4.413 1.02e-05 ***
soil.18      0.0325326  0.0087058   3.737 0.000187 ***
soil.19      0.0223433  0.0111731   2.000 0.045535 *
soil.20      0.0533981  0.0120316   4.438 9.10e-06 ***
soil.21      0.0369457  0.0124186   2.975 0.002932 **
soil.22      0.0263679  0.0123091   2.142 0.032189 *
soil.23      0.0297592  0.0115380   2.579 0.009906 **
soil.24      0.0505442  0.0095710   5.281 1.29e-07 ***
soil.25      0.0846911  0.0049655  17.056  < 2e-16 ***
soil.26      0.0363679  0.0078025   4.661 3.16e-06 ***
soil.27      0.0333454  0.0104879   3.179 0.001477 **
soil.28      0.0216095  0.0083169   2.598 0.009374 **
soil.29      0.0307940  0.0087434   3.522 0.000429 ***
soil.30      0.0298338  0.0094316   3.163 0.001562 **
```

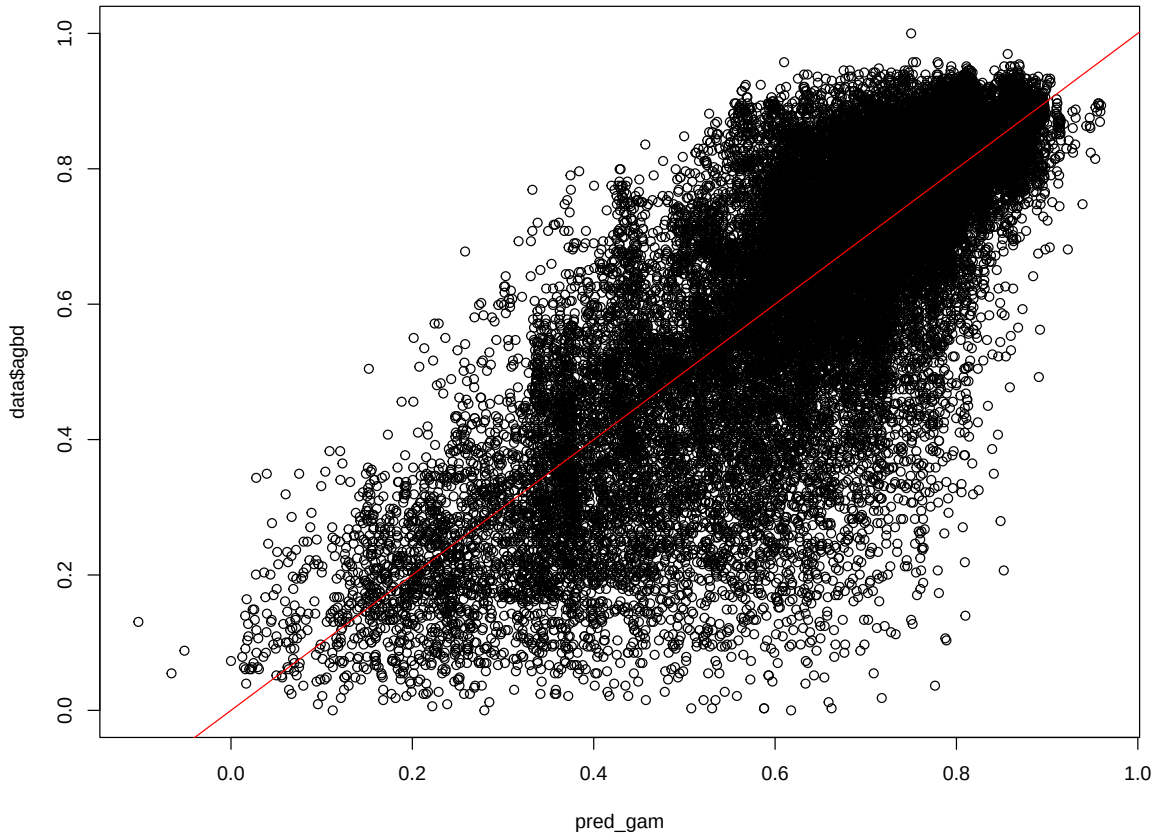
```
soil.31      0.0277788  0.0054332   5.113 3.19e-07 ***
soil.32      0.0641746  0.0062191  10.319  < 2e-16 ***
soil.33     -0.1461932  0.0928157  -1.575 0.115244
soil.34     -0.1532979  0.0912967  -1.679 0.093138 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
               edf Ref.df     F p-value
s(cwd)       8.201  8.838 18.57  <2e-16 ***
s(mean_si)   8.948  8.998 96.28  <2e-16 ***
s(mean_prec) 8.698  8.975 54.34  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Rank: 220/222
R-sq.(adj) =   0.62   Deviance explained = 62.3%
GCV = 0.016055  Scale est. = 0.015955  n = 35243
```

```r
# Predict using the GAM model
pred_gam <- predict(gam_model, newdata = data)

# Plot predictions vs observed
plot(pred_gam, data$agbd)
abline(0, 1, col = "red")
```




```
calc_r_squared(data$agbd, pred_gam)
```

```
[1] 0.6226956
```