**Supplementary Material 1 – R Code for Lichenometry Growth Curve**

\* Please note – The R language code in this supplementary material is built under R version 4.0.3 and implemented in RStudio version 2023.03.1-446. The code is prepared for use as a markdown file (.rmd)

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.

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The first several lines of code describe the title and author of the file, followed by statistical summaries for the lichenometry curve function (including the upper and lower limits of confidence envelopes at 95.4 and 68.3 critical intervals), and then individual date predictions for stone wall features organized by site name and feature name. Date predictions are based on intercepts with the curve as well as upper and lower limits of confidence envelopes.

# refers to a code line description

\*\*Copy and paste the code lines below into a blank document (.rmd) in RStudio and the program will create an output of the Colorado Front Range Growth Curve for *Rhizocarpon* sp. using the curve control points, a logarithmic polynomial curve function, and wall feature date estimates plotted on the curve.

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title: "Colorado Front Range Rhizocarpon Age-Growth Curve"

author: "Kelton Meyer"

date: "May 17, 2023"

output: html\_document

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```{r setup, include=FALSE}

knitr::opts\_chunk$set(echo = TRUE)

```

## CFR\_Rhizo\_Curve

```{r CFR\_Rhizo\_Curve}

# Curve - Control Point Regression Slope Values - X axis

x <- c(-0.1836 ,-0.0638 , -0.0615 , -0.0542 , -0.0240 , -0.0185)

# Curve - Control Point Dates in cal BP IntCAL20 - Y axis

y <- c(42, 870, 1030, 1070, 3570, 4710)

# Curve - Upper 68.3% of cal BP Dates - Y axis

yUpper1sig <- c(44, 960, 1180, 1180, 3680, 4840)

# Curve - Lower 68.3% of cal BP Dates - Y axis

yLower1sig <- c(40, 740, 920, 960, 3480, 4610)

# Curve - Upper 95.4% of cal BP Dates - Y axis

yUpper2sig <- c(44, 1070, 1270, 1280, 3820, 4860)

# Curve - Lower 95.4% of cal BP Dates - Y axis

yLower2sig <- c(40, 680, 790, 920, 3400, 4520)

plot(c(-0.2, 0), c(0, 5000),

 type = "n",

 xlab = "Slope of Regression Line",

 ylab = "Age cal BP")

x\_grid <- seq(from = -0.2, to = 0, length.out=1000)

New <- data.frame(x = x\_grid)

# Curve Polynomial Function

fit1 <- lm(log(log(y)) ~ poly(x, 2))

# Curve Polynomial Function - Upper-edge Confidence Envelope - 68.3%

fit2 <- lm(log(log(yUpper1sig)) ~ poly(x, 2))

# Curve Polynomial Function - Lower-edge Confidence Envelope - 68.3%

fit3 <- lm(log(log(yLower1sig)) ~ poly(x, 2))

# Statistical Summary of Growth Curve

summary(fit1)

#Statistical summary of polynomial regression fit to Upper-edge Confidence Envelope

summary(fit2)

#Statistical summary of polynomial regression fit to Lower-edge Confidence Envelope

summary(fit3)

# Curve Polynomial Function - Upper-edge Confidence Envelope - 95.4%

fit4 <- lm(log(log(yUpper2sig)) ~ poly(x, 2))

# Curve Polynomial Function - Lower-edge Confidence Envelope - 95.4%

fit5 <- lm(log(log(yLower2sig)) ~ poly(x, 2))

#Statistical summary of polynomial regression fit to Upper-edge Confidence Envelope

summary(fit4)

#Statistical summary of polynomial regression fit to Lower-edge Confidence Envelope

summary(fit5)

# Predict function for the curve

pfit1 <- predict(fit1, newdata = New)

# Predict function for the Upper-Edge Confidence Envelope - 68.3%

pfit2 <- predict(fit2, newdata = New)

# Predict function for the Lower-edge Confidence Envelope - 68.3%

pfit3 <- predict(fit3, newdata = New)

# Plot of the curve

lines(x\_grid, exp(exp((pfit1))), col = "black", lwd = 2)

# Plot of the Upper-edge Confidence Envelope - 68.3%

lines(x\_grid, exp(exp((pfit2))), col = "gray", lty = 3, lwd = 1)

# Plot of the Lower-edge Confidence Envelope - 68.3%

lines(x\_grid, exp(exp((pfit3))), col = "gray", lty = 3, lwd = 1)

# Plot of the original curve control points

points(x, y, pch = 16, col = "black")

# Predict function for the Upper-edge Confidence Envelope - 95.4%

pfit4 <- predict(fit4, newdata = New)

# Predict function for the Lower-edge Confidence Envelope - 95.4%

pfit5 <- predict(fit5, newdata = New)

# Plot of the Upper-edge Confidence Envelope - 95.4%

lines(x\_grid, exp(exp((pfit4))), col = "gray", lwd = 1)

# Plot of the Lower-edge Confidence Envelope - 95.4%

lines(x\_grid, exp(exp((pfit5))), col = "gray", lwd = 1)

# High Grade site wall feature data - Walls A through D

HighGrade\_Slopes <- c(-0.126, -0.118, -0.123, -0.0843)

HighGrade\_Dates <- c(146, 179, 157, 455)

# Predict function for High Grade site wall data

Predict\_HighGrade1 <- data.frame(x = HighGrade\_Slopes)

rbind(round(exp(exp(predict(fit1, newdata = Predict\_HighGrade1))), 0),

 HighGrade\_Dates)

# Plot of High Grade stone wall regression values

points (HighGrade\_Slopes, HighGrade\_Dates, pch = 3, col = "blue")

# Predict function for High Grade site wall data on Upper-edge 68.3 Confidence

Predict\_HighGrade2 <- data.frame(x = HighGrade\_Slopes)

rbind(round(exp(exp(predict(fit2, newdata = Predict\_HighGrade2))), 0),

 HighGrade\_Dates)

# Predict function for High Grade site wall data on Lower-edge 68.3 Confidence

Predict\_HighGrade3 <- data.frame(x = HighGrade\_Slopes)

rbind(round(exp(exp(predict(fit3, newdata = Predict\_HighGrade3))), 0),

 HighGrade\_Dates)

# Predict function for High Grade site wall data on Upper-edge 95.4 Confidence

Predict\_HighGrade4 <- data.frame(x = HighGrade\_Slopes)

rbind(round(exp(exp(predict(fit4, newdata = Predict\_HighGrade4))), 0),

 HighGrade\_Dates)

# Predict function for High Grade site wall data on Lower-edge 95.4 Confidence

Predict\_HighGrade5 <- data.frame(x = HighGrade\_Slopes)

rbind(round(exp(exp(predict(fit5, newdata = Predict\_HighGrade5))), 0),

 HighGrade\_Dates)

# Olson site wall feature data - Walls 1 through 2

Olson\_Slopes <- c(-0.0518, -0.0656)

Olson\_Dates <- c(1301, 817)

# Predict function for Olson site wall data

Predict\_Olson1 <- data.frame(x = Olson\_Slopes)

rbind(round(exp(exp(predict(fit1, newdata = Predict\_Olson1))), 0),

 Olson\_Dates)

# Plot of Olson stone wall regression values

points (Olson\_Slopes, Olson\_Dates, pch = 3, col = "blue", add = TRUE)

# Predict function for Olson site wall data on Upper-edge 68.3 Confidence

Predict\_Olson2 <- data.frame(x = Olson\_Slopes)

rbind(round(exp(exp(predict(fit2, newdata = Predict\_Olson2))), 0),

 Olson\_Dates)

# Predict function for Olson site wall data on Lower-edge 68.3 Confidence

Predict\_Olson3 <- data.frame(x = Olson\_Slopes)

rbind(round(exp(exp(predict(fit3, newdata = Predict\_Olson3))), 0),

 Olson\_Dates)

# Predict function for Olson site wall data on Upper-edge 95.4 Confidence

Predict\_Olson4 <- data.frame(x = Olson\_Slopes)

rbind(round(exp(exp(predict(fit4, newdata = Predict\_Olson4))), 0),

 Olson\_Dates)

# Predict function for Olson site wall data on Lower-edge 95.4 Confidence

Predict\_Olson5 <- data.frame(x = Olson\_Slopes)

rbind(round(exp(exp(predict(fit5, newdata = Predict\_Olson5))), 0),

 Olson\_Dates)

# Flattop Mtn site wall feature data - Wall D

Flattop\_Slopes <- c(-0.0676)

Flattop\_Dates <- c(766)

# Predict function for Flattop wall data

Predict\_Flattop1 <- data.frame(x = Flattop\_Slopes)

rbind(round(exp(exp(predict(fit1, newdata = Predict\_Flattop1))), 0),

 Flattop\_Dates)

# Plot of Flattop stone wall regression values

points (Flattop\_Slopes, Flattop\_Dates, pch = 3, col = "blue", add = TRUE)

# Predict function for Flattop wall data on Upper-edge 68.3 Confidence

Predict\_Flattop2 <- data.frame(x = Flattop\_Slopes)

rbind(round(exp(exp(predict(fit2, newdata = Predict\_Flattop2))), 0),

 Flattop\_Dates)

# Predict function for Flattop wall data on Lower-edge 68.3 Confidence

Predict\_Flattop3 <- data.frame(x = Flattop\_Slopes)

rbind(round(exp(exp(predict(fit3, newdata = Predict\_Flattop3))), 0),

 Flattop\_Dates)

# Predict function for Flattop wall data on Upper-edge 95.4 Confidence

Predict\_Flattop4 <- data.frame(x = Flattop\_Slopes)

rbind(round(exp(exp(predict(fit4, newdata = Predict\_Flattop4))), 0),

 Flattop\_Dates)

# Predict function for Flattop wall data on Lower-edge 95.4 Confidence

Predict\_Flattop5 <- data.frame(x = Flattop\_Slopes)

rbind(round(exp(exp(predict(fit5, newdata = Predict\_Flattop5))), 0),

 Flattop\_Dates)

# Waterdog Divide site wall feature data - Wall 1

Waterdog\_Slopes <- c(-0.0968)

Waterdog\_Dates <- c(316)

# Predict function for Waterdog wall data

Predict\_Waterdog1 <- data.frame(x = Waterdog\_Slopes)

rbind(round(exp(exp(predict(fit1, newdata = Predict\_Waterdog1))), 0),

 Waterdog\_Dates)

# Plot of Waterdog wall regression values

points (Waterdog\_Slopes, Waterdog\_Dates, pch = 3, col = "blue", add = TRUE)

# Predict function for Waterdog wall data on Upper-edge 68.3 Confidence

Predict\_Waterdog2 <- data.frame(x = Waterdog\_Slopes)

rbind(round(exp(exp(predict(fit2, newdata = Predict\_Waterdog2))), 0),

 Waterdog\_Dates)

# Predict function for Waterdog wall data on Lower-edge 68.3 Confidence

Predict\_Waterdog3 <- data.frame(x = Waterdog\_Slopes)

rbind(round(exp(exp(predict(fit3, newdata = Predict\_Waterdog3))), 0),

 Waterdog\_Dates)

# Predict function for Waterdog wall data on Upper-edge 95.4 Confidence

Predict\_Waterdog4 <- data.frame(x = Waterdog\_Slopes)

rbind(round(exp(exp(predict(fit4, newdata = Predict\_Waterdog4))), 0),

 Waterdog\_Dates)

# Predict function for Waterdog wall data on Lower-edge 95.4 Confidence

Predict\_Waterdog5 <- data.frame(x = Waterdog\_Slopes)

rbind(round(exp(exp(predict(fit5, newdata = Predict\_Waterdog5))), 0),

 Waterdog\_Dates)

# Devil's Thumb Pass site wall feature data - Wall 1

DTPass\_Slopes <- c(-0.0717)

DTPass\_Dates <- c(672)

# Predict function for DTPass wall data

Predict\_DTPass1 <- data.frame(x = DTPass\_Slopes)

rbind(round(exp(exp(predict(fit1, newdata = Predict\_DTPass1))), 0),

 DTPass\_Dates)

# Plot of DTPass wall regression values

points (DTPass\_Slopes, DTPass\_Dates, pch = 3, col = "blue", add = TRUE)

# Predict function for DTPass wall data on Upper-edge 68.3 Confidence

Predict\_DTPass2 <- data.frame(x = DTPass\_Slopes)

rbind(round(exp(exp(predict(fit2, newdata = Predict\_DTPass2))), 0),

 DTPass\_Dates)

# Predict function for DTPass wall data on Lower-edge 68.3 Confidence

Predict\_DTPass3 <- data.frame(x = DTPass\_Slopes)

rbind(round(exp(exp(predict(fit3, newdata = Predict\_DTPass3))), 0),

 DTPass\_Dates)

# Predict function for DTPass wall data on Upper-edge 95.4 Confidence

Predict\_DTPass4 <- data.frame(x = DTPass\_Slopes)

rbind(round(exp(exp(predict(fit4, newdata = Predict\_DTPass4))), 0),

 DTPass\_Dates)

# Predict function for DTPass wall data on Lower-edge 95.4 Confidence

Predict\_DTPass5 <- data.frame(x = DTPass\_Slopes)

rbind(round(exp(exp(predict(fit5, newdata = Predict\_DTPass5))), 0),

 DTPass\_Dates)

# Bob Lake site wall feature data - Wall B

Bob\_Slopes <- c(-0.0450)

Bob\_Dates <- c(1654)

# Predict function for Bob Lake wall data

Predict\_Bob1 <- data.frame(x = Bob\_Slopes)

rbind(round(exp(exp(predict(fit1, newdata = Predict\_Bob1))), 0),

 Bob\_Dates)

# Plot of Bob Lake wall regression values

points (Bob\_Slopes, Bob\_Dates, pch = 3, col = "blue", add = TRUE)

# Predict function for Bob Lake wall data on Upper-edge 68.3 Confidence

Predict\_Bob2 <- data.frame(x = Bob\_Slopes)

rbind(round(exp(exp(predict(fit2, newdata = Predict\_Bob2))), 0),

 Bob\_Dates)

# Predict function for Bob Lake wall data on Lower-edge 68.3 Confidence

Predict\_Bob3 <- data.frame(x = Bob\_Slopes)

rbind(round(exp(exp(predict(fit3, newdata = Predict\_Bob3))), 0),

 Bob\_Dates)

# Predict function for Bob Lake wall data on Upper-edge 95.4 Confidence

Predict\_Bob4 <- data.frame(x = Bob\_Slopes)

rbind(round(exp(exp(predict(fit4, newdata = Predict\_Bob4))), 0),

 Bob\_Dates)

# Predict function for Bob Lake wall data on Lower-edge 95.4 Confidence

Predict\_Bob5 <- data.frame(x = Bob\_Slopes)

rbind(round(exp(exp(predict(fit5, newdata = Predict\_Bob5))), 0),

 Bob\_Dates)

# Arapaho Pass site wall feature data - Wall D, Blind 1, Wall I, Wall E, Wall G, Wall H

APass\_Slopes <- c(-0.0610, -0.0622, -0.0734, -0.0738, -0.0768, -0.0780)

APass\_Dates <- c(951, 914, 636, 628, 572, 551)

# Predict function for APass wall data

Predict\_APass1 <- data.frame(x = APass\_Slopes)

rbind(round(exp(exp(predict(fit1, newdata = Predict\_APass1))), 0),

 APass\_Dates)

# Plot of APass wall regression values

points (APass\_Slopes, APass\_Dates, pch = 3, col = "blue", add = TRUE)

# Predict function for APass wall data on Upper-edge 68.3 Confidence

Predict\_APass2 <- data.frame(x = APass\_Slopes)

rbind(round(exp(exp(predict(fit2, newdata = Predict\_APass2))), 0),

 APass\_Dates)

# Predict function for APass wall data on Lower-edge 68.3 Confidence

Predict\_APass3 <- data.frame(x = APass\_Slopes)

rbind(round(exp(exp(predict(fit3, newdata = Predict\_APass3))), 0),

 APass\_Dates)

# Predict function for APass wall data on Upper-edge 95.4 Confidence

Predict\_APass4 <- data.frame(x = APass\_Slopes)

rbind(round(exp(exp(predict(fit4, newdata = Predict\_APass4))), 0),

 APass\_Dates)

# Predict function for APass wall data on Lower-edge 95.4 Confidence

Predict\_APass5 <- data.frame(x = APass\_Slopes)

rbind(round(exp(exp(predict(fit5, newdata = Predict\_APass5))), 0),

 APass\_Dates)

# Sawtooth site wall feature data - Wall 1, Wall 2, Wall 3, Wall 3A, Wall 3B, Wall 4, Wall 5, Wall 6, Wall 8, Wall 10, Wall 10B, Wall 10C

Sawtooth\_Slopes <- c(-0.0438, -0.0407, -0.0526, -0.0414, -0.0517, -0.0568, -0.0585, -0.0533, -0.0682, -0.0485, -0.0458, -0.0533)

Sawtooth\_Dates <- c(1727, 1933, 1265, 1884, 1306, 1096, 1034, 1235, 751, 1461, 1608, 1235)

# Predict function for Sawtooth wall data

Predict\_Sawtooth1 <- data.frame(x = Sawtooth\_Slopes)

rbind(round(exp(exp(predict(fit1, newdata = Predict\_Sawtooth1))), 0),

 Sawtooth\_Dates)

# Plot of Sawtooth wall regression values

points (Sawtooth\_Slopes, Sawtooth\_Dates, pch = 3, col = "blue", add = TRUE)

# Predict function for Sawtooth wall data on Upper-edge 68.3 Confidence

Predict\_Sawtooth2 <- data.frame(x = Sawtooth\_Slopes)

rbind(round(exp(exp(predict(fit2, newdata = Predict\_Sawtooth2))), 0),

 Sawtooth\_Dates)

# Predict function for Sawtooth wall data on Lower-edge 68.3 Confidence

Predict\_Sawtooth3 <- data.frame(x = Sawtooth\_Slopes)

rbind(round(exp(exp(predict(fit3, newdata = Predict\_Sawtooth3))), 0),

 Sawtooth\_Dates)

# Predict function for Sawtooth wall data on Upper-edge 95.4 Confidence

Predict\_Sawtooth4 <- data.frame(x = Sawtooth\_Slopes)

rbind(round(exp(exp(predict(fit4, newdata = Predict\_Sawtooth4))), 0),

 Sawtooth\_Dates)

# Predict function for Sawtooth wall data on Lower-edge 95.4 Confidence

Predict\_Sawtooth5 <- data.frame(x = Sawtooth\_Slopes)

rbind(round(exp(exp(predict(fit5, newdata = Predict\_Sawtooth5))), 0),

 Sawtooth\_Dates)

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