Identifying Metrics of Ecosystem Recovery on Reclaimed Min Sites in Eastern Hardwood Forests

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June 3rd, 5:00pm
Knoxville Convention Center, Room 301A

Figure 1 ZebTop Site, TN

Outline

- Introduction
- Method
- Results
- Conclusions/Discussion

Figure 2 Cool Mushrooms, TN

Figure 3 Cool Mushroom pt. 2, TN

Introduction

Background

- Reclamation of Surface Mined Sites in Southeastern Appalachian region
  - Surface Mining Control and Reclamation Act of 1977 (SMCRA)
    - Pre-SMCRA reclamation
    - Post-SMCRA requirements and shortcomings
    - Forestry Reclamation Approach[5, 9, 20, 21]
- Ecosystem Services as metrics for recovery
  - Advantages: Communication, Policy Development, Land Management
  - Cross-disciplinary benefits

Figure 4 Horseshoe Mountain, October 2015 (Google Earth Pro)

Introduction

Background

- Ecosystem Services[1]

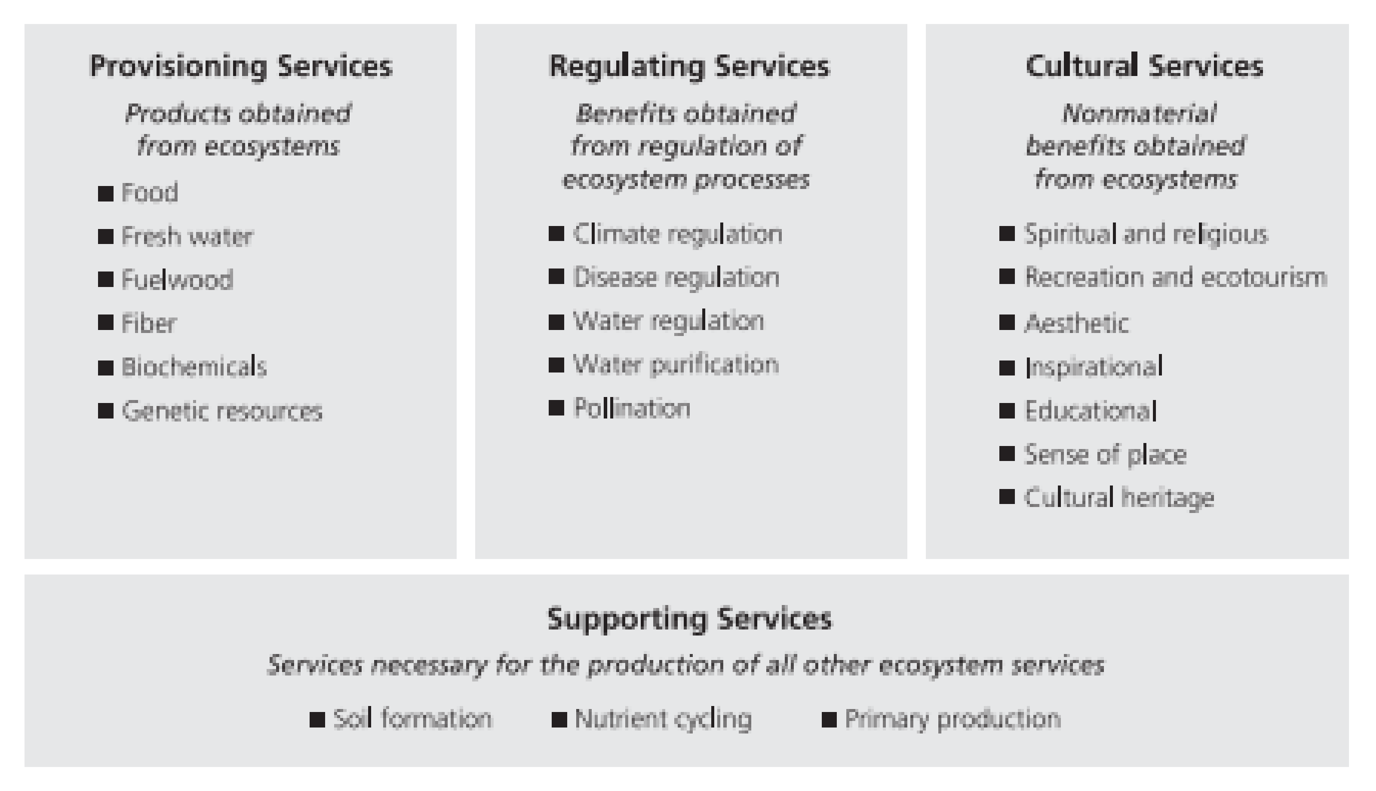


Figure 5 Ecosystem Services,
Figure 2.1 in Assessment (2005)

Introduction

Where to start?

Figure 6 Windrock, TN

- Examining changes over time
  - Same type of disturbance, different points in time
  - Assume sites are similar enough to make meaningful comparisons
- Disturbance Types
  - Surface-mining
  - Clearcut Harvest
    - Also a major disturbance
  - Severe vs. moderate disturbance comparison
    - Room for analysis and range of results
- The Goal
  - Examine a number of ecosystem services to determine the suitability of any one or more as a metric for site recovery

Introduction

Hypotheses

- 1) One or more of the examined ecosystem services will show a significant and consistent change as age class increases.
  - Most important
- 2)Ecosystem services in question will not vary significantly from one another across disturbance (site) types.
  - Metrics should be useful and applicable to a variety of circumstances
- 3)Potential ecosystem service metrics will not show significant variation between control sites and the final age class.
  - Stop-gap to check final age class as an informative stopping point

Introduction

Tested Ecosystem Services:

- Diameter at Breast Height (DBH) and Species ID (Provisioning/Supporting/Cultural)
  - Tree diversity is known to be significant to forest ecosystems [8]
    - Species diversity and composition is important for stand resistance to disturbance
  - Aboveground carbon may be indicative of site recovery [3]
  - Basal Area was also assessed as a potential indicator
- Canopy Cover (Regulating/Supporting)
  - Closed canopy creates a microclimate beneath it [4]
    - More stable, and less prone to disturbance by weather, temperature, etc.
    - Is there a relationship between percent canopy cover and recovery?

Introduction

Tested Ecosystem Services:

- Water Infiltration and Soil Density (Supporting/Regulating)
  - Water must be able to move through an ecosystem, soil must allow for it
    - Overly compacted soil limits root growth and water infiltration
      - Both very common to selected disturbances
- Insect Biomass (Regulating/Supporting)
  - Insects are crucial to many ecosystem functions(7)
    - May be a useful indicator, both biomass and diversity
- Decomposition Rate (Regulating/Supporting)
  - Rate of Decomposition affects carbon cycling
    - Can be affected by soil density, moisture, mineral composition, pH, etc.

Methods

Design and Implementation

- Structure
  - 5 age classes + 1 control category
    - Time since last disturbance
      - 0-5, 6-10, 11-15, 16-29, 30+
      - Control = undisturbed within 50+ years
  - Three plots per age class + two control plots = 32 plots (+1 accidental extra)
- Plots
  - 1/10th acre, 37.2ft. Radius, 3 subplots 120° apart
  - Subplots Labeled A, B, C, clockwise from A, A almost always uphill or south
- Additional Challenges:
  - Minimizing Expense and Complexity
  - Covariates – Slope, Elevation
  - North Aspected Sites
- All data recorded and charts created using Excel(12)

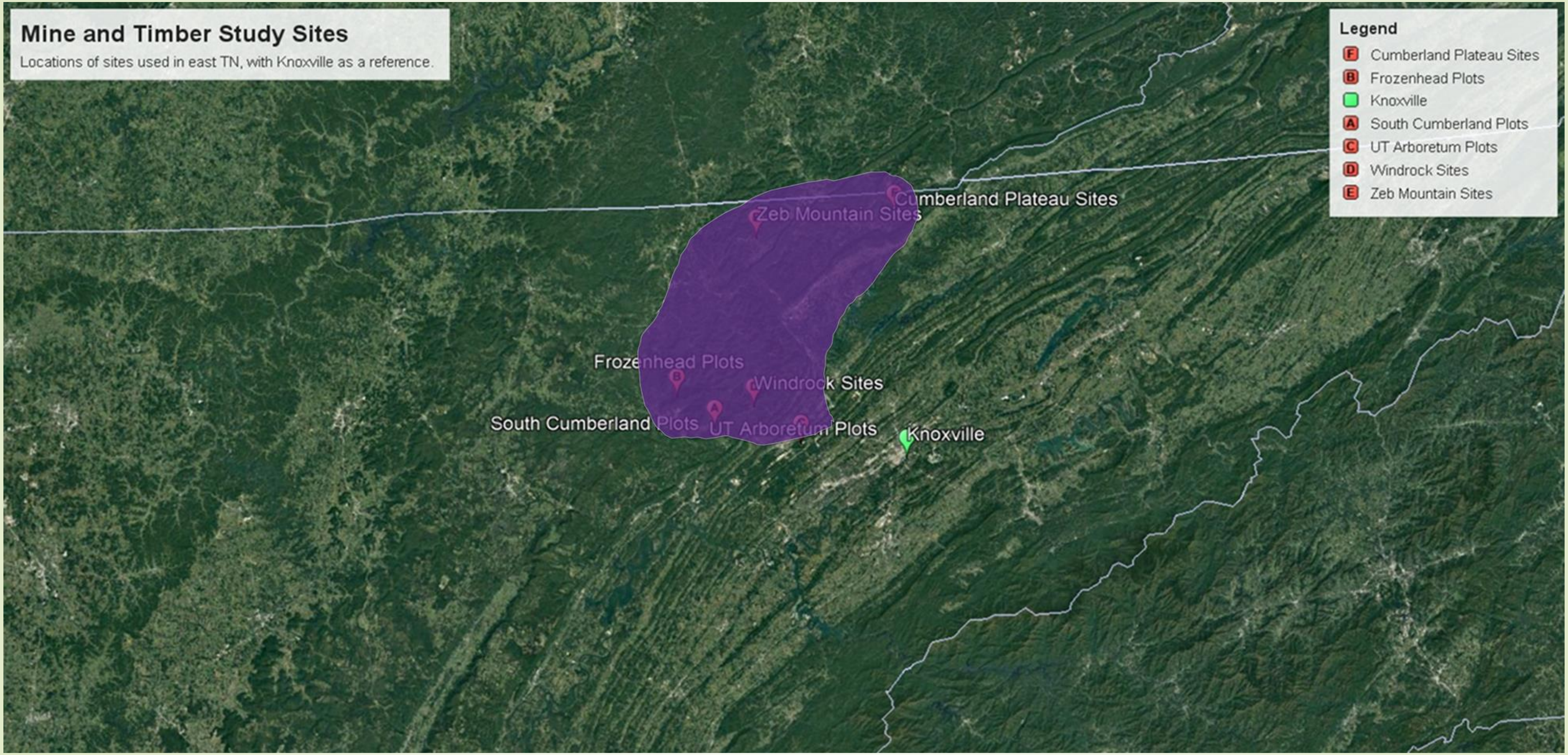


Figure 7 Map depicting general geographic locations and clusters of sites, with Knoxville as a reference

Methods

DBH and Tree Species

- Method of collection
  - Standard FIA practices – DBH tapes
  - Every tree ≥ 1.1” in diameter
- Species Count
  - Analyzed with Kruskal-Wallis test
- Basal Area
  - Calculated with formula: Basal Area = $DBH^2 * 0.005454$
- Aboveground biomass
  - Analyzed using equations from Chojnacky et al. 2014
    - Nearest taxonomical relative used for species not explicitly listed

Methods

Canopy Cover

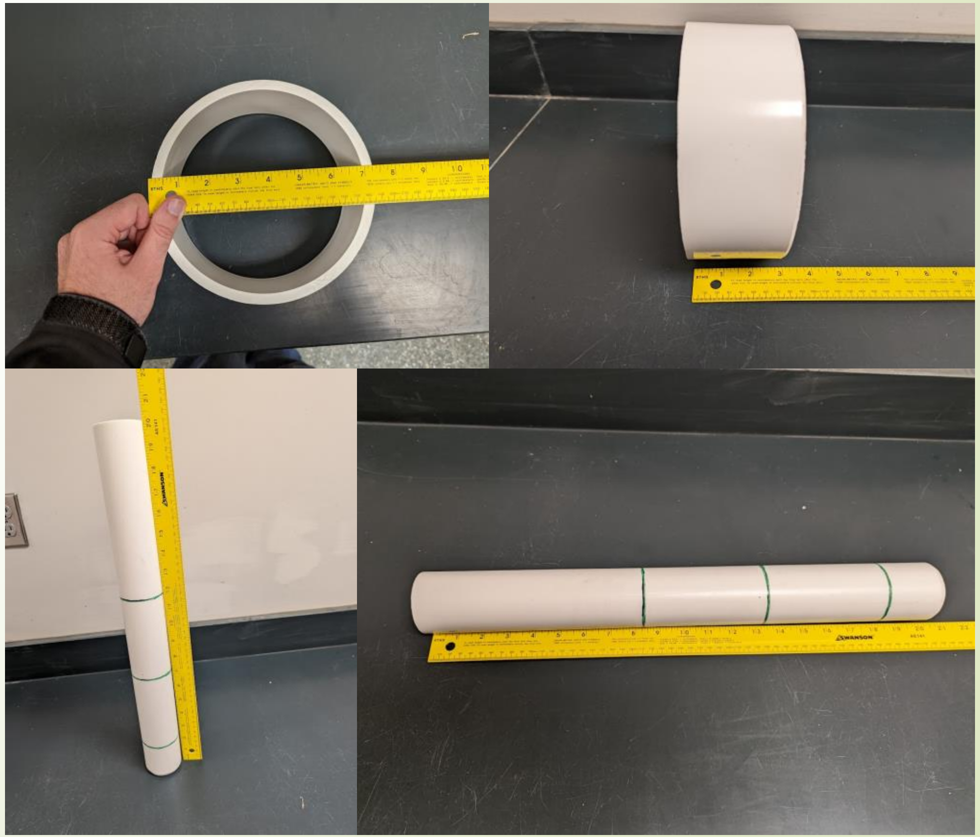
- Method of collection
  - App called CanopyCapture
  - Recommended and tested against standard methods
- Collection
  - Tested three times per subplot, on each subplot
- Analyzed with Kruskal-Wallis test by subplot

Methods

Water Infiltration Rate and Soil Density

- Method of collection
  - Two Parts
    - 1) Water Infiltration
      - Single Ring Method[12]
    - 2) Soil Density
      - Collected using PVC tube; volume known
- Process
  - Two infiltration tests/subplot, one dry, one wet
  - Density sample collected after wet infiltration
    - Two samples per subplot (5.9cm and 17.9cm)

Figure 8 Single Ring and Density Tube, PBB



Methods

Water Infiltration Rate and Soil Density cont.

- Processing Soil Samples
  - Roots were pulled from each soil sample and dried
    - Dried samples were massed
    - This is to examine root mass as another variable, and a function of belowground biomass (Supporting).
  - Each soil sample was oven dried after removing and recording volume of rocks
    - Dry sample was massed
- Infiltration Times
  - Recorded in seconds, and rate calculated to millimeters per second (mm/s)

Methods

Figure 9 Bug Sample Storage, PBB

Insect Biomass

- Method of Collection
  - Simple pitfall trap[2]
    - 8oz. Cup, ~4 oz. propylene glycol, leave for 28 days
    - 1 trap per subplot
- Collection and Storage
  - Storage in 95% ethanol solution for measurement
- Processing
  - Samples were drained via sieve[18]
  - Sorted by flying insect vs. non-flying insect vs. non-insect and then massed
    - Non-insect was omitted from analysis as method focused solely on insects

Figure 10 Miller, Summer 2022

Methods

Decomposition Rate

- Method of Collection
  - Tea Bag Index (TBI) test[11]
  - Pairs of green and rooibos tea bags, 2g of tea each
    - 1 pair per subplot, leave for 90 days
- Processing
  - Dried, roots removed, then massed
- Analyzed using equations from Keuskamp et al. 2013

Figure 11 Retrieved Tea Bags, PBB

Results

General

- All data tested for normal distribution using Shapiro-Wilk
  - Non-normal data transformed to meet assumptions of normality where possible
    - Square root transformation for Basal Area, transformTukey[14] function for all else
- Data modeled using two-way ANOVA against Site Type and Age Class
  - Elevation was included for all models as a covariate
- One way ANOVA models used for variables with interaction between factors
  - Usually by Age Class unless it was not significant
- Variables with significant variation were analyzed with a Duncan post hoc test (not shown here, still being consolidated)
- All data analysis conducted using SAS[17] & R Programming[6, 10, 14, 15, 16, 19]

19

Results

Infiltration Rate

- Not normally distributed ($W= 0.4501$, $p= 2.2e-16$)
  - Transformed according to transformTukey function; raised to λ
    - $\lambda= 0.05$, $W=0.9707$, $p=0.0396$; almost normal
    - Q-Q and Density Plots appeared good, so ANOVA proceeded
- Significant interactions between Site Type and Age Class ($p=0.0461$); split out by Site Type
  - Age Class significant on Mine Sites ($p= 6.82e-4$), not significant on Clearcut ($p= 0.310$)
- General upwards trend, differs significantly by 4th age class, but only 1st age class different from controls

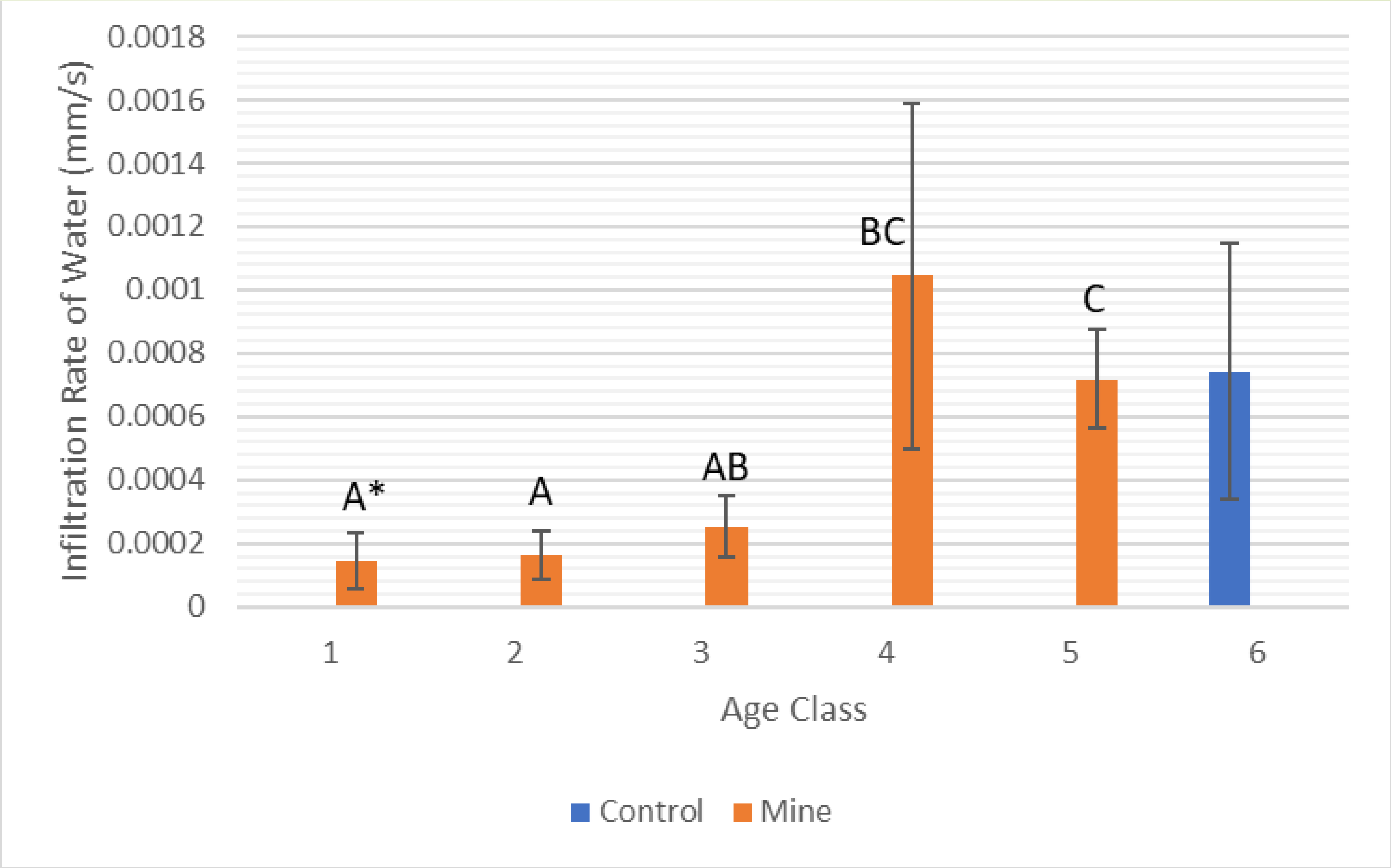


Figure 12 Average infiltration rate for each age class on mine and control sites. Bars denote standard error. Different letters indicate statistical differences between disturbance types at P < 0.05. Asterisk indicates significant difference from control at P < 0.05.

Results

Soil Density

- Density 1st Layer
  - Not normally distributed (W=0.0846, p=2.2e-16)
    - Outlier removed, and data transformed (λ= 0.4, W= 0.9794, p= 0.0681)
  - Significant Interaction between Site Type and Age Class (p= 0.0103); split out
    - Age Class significant on Mine sites (p=0.0348); not significant on Clearcut (p=0.314)
  - General downwards trend on mine sites, only significant between 1st and 4th age classes
- Density 2nd Layer
  - Removed outlier, data normally distributed (W=0.9794, p=0.1917)
  - Not significant to Age Class or Site Type (p=0.5447 and p=0.3197, respectively)

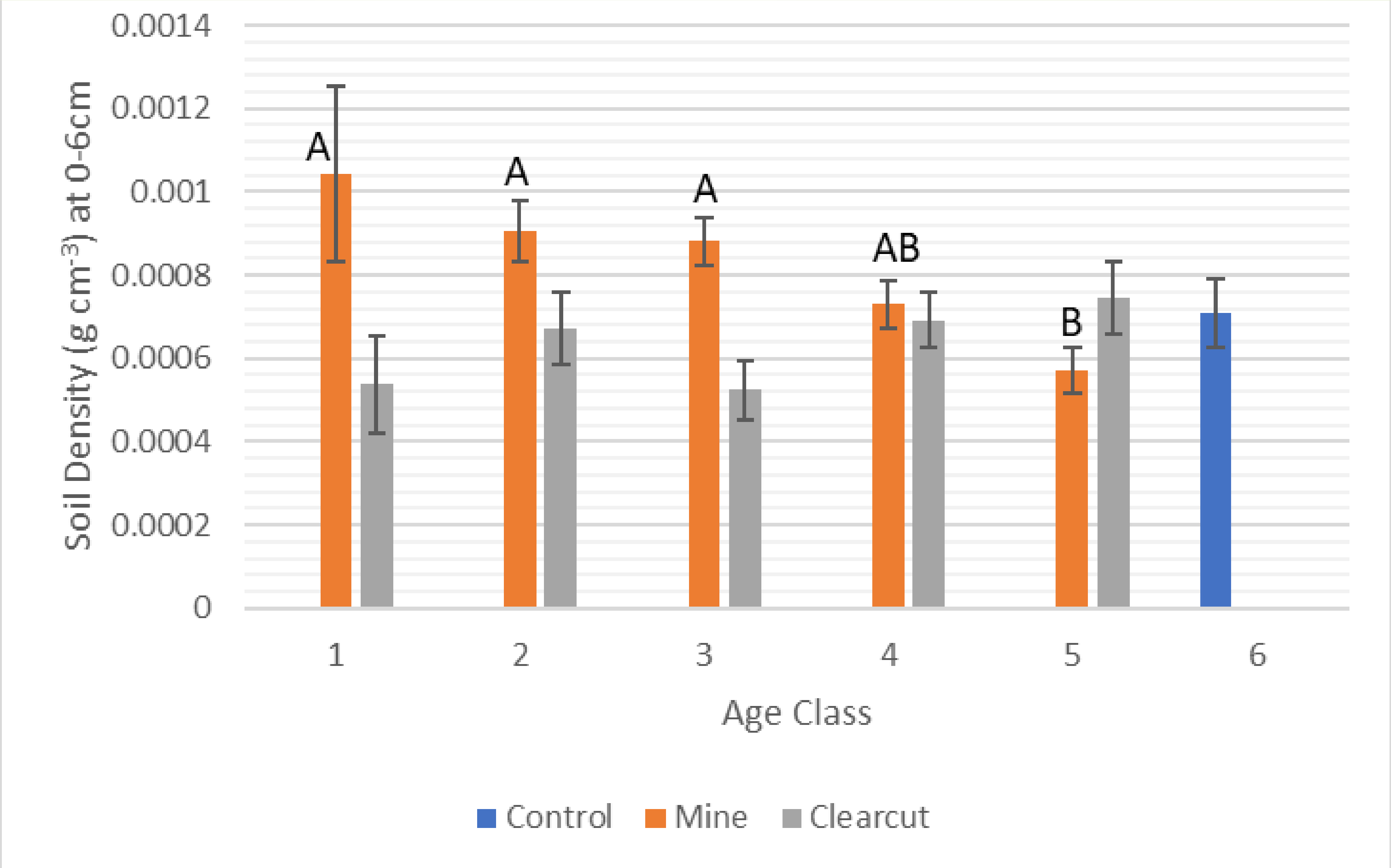


Figure 13 Average first layer soil density for each age class on mine, clearcut, and control sites. Bars denote standard error. Different letters indicate statistical differences between disturbance types at $P < 0.05$. Asterisk indicates significant difference from control at $P < 0.05$.

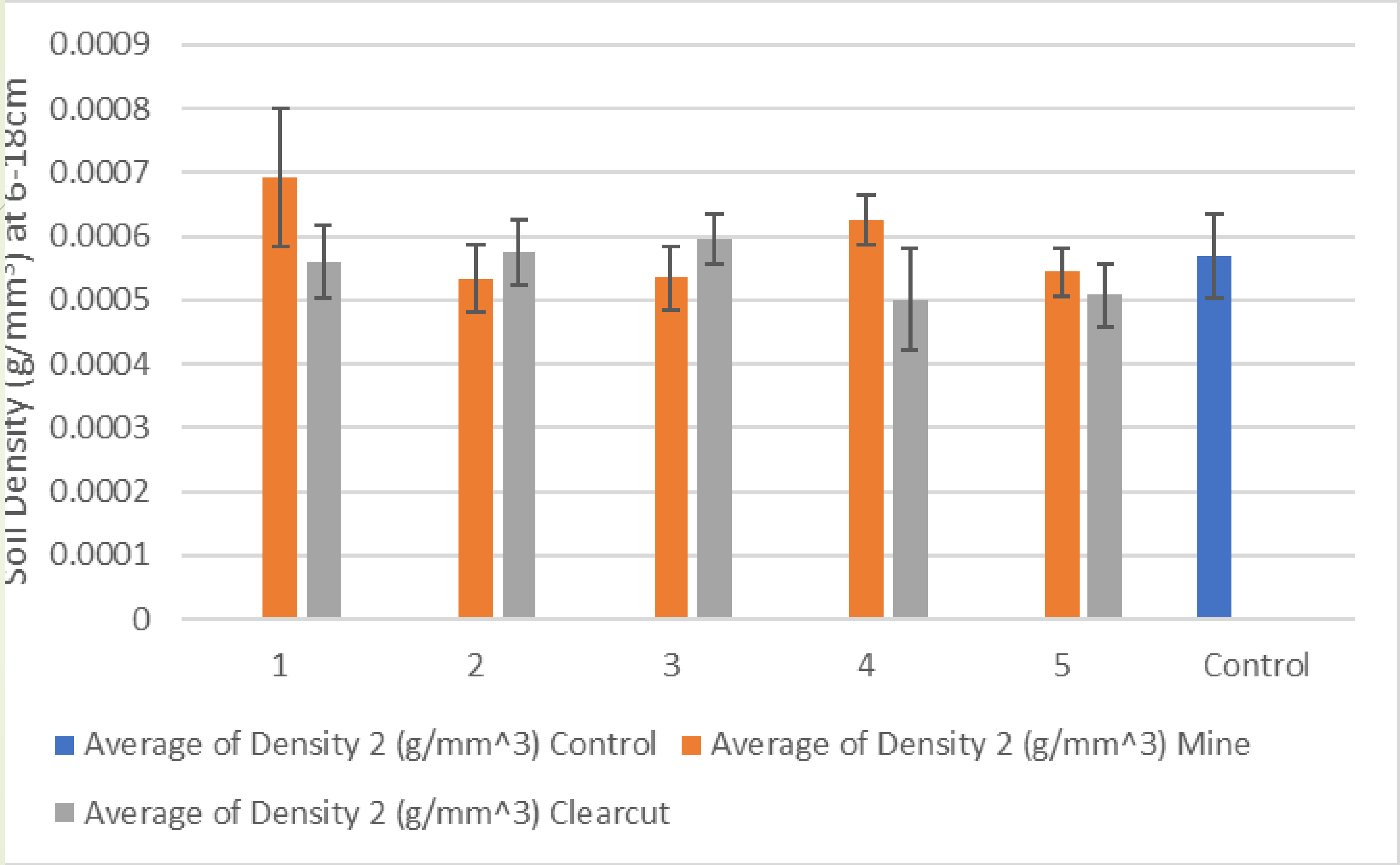


Figure 14 Average second layer soil density for each age class on mine, clearcut, and control sites. Bars denote standard error. Different letters indicate statistical differences between disturbance types at $P < 0.05$. Asterisk indicates significant difference from control at $P < 0.05$.

Results

Root Mass

- Root Mass 1st Layer
  - Not normally distributed ($W=0.7485$, $p=2.16e\text{-}11$)
    - Data transformed ($\lambda= 0.2$, $W= 0.9903$, $p= 0.7291$)
  - No significant interaction between Site Type and Age Class; no need to split
    - Charts appear odd, split anyway; Age class on Mine sites significant ($p=0.00102$)
    - Not significant on Clearcut ($p=0.5556$)
  - Gradual upwards trend on mine sites, significant around the 3rd age class
- Root Mass 2nd Layer
  - Not normally distributed ($W=0.7693$, $p=7.72e\text{-}11$)
    - Data transformed ($\lambda= 0.225$, $W= 0.9829$, $p= 0.2565$)
  - Significant Interaction between Site Type and Age Class ($p= 0.0228$); split out
    - Age Class significant on Mine sites ($p=3.26e\text{-}7$); not significant on Clearcut ($p=0.735$)
  - Very gradual but noticeable upwards trend on mine sites, sudden spike in final age class

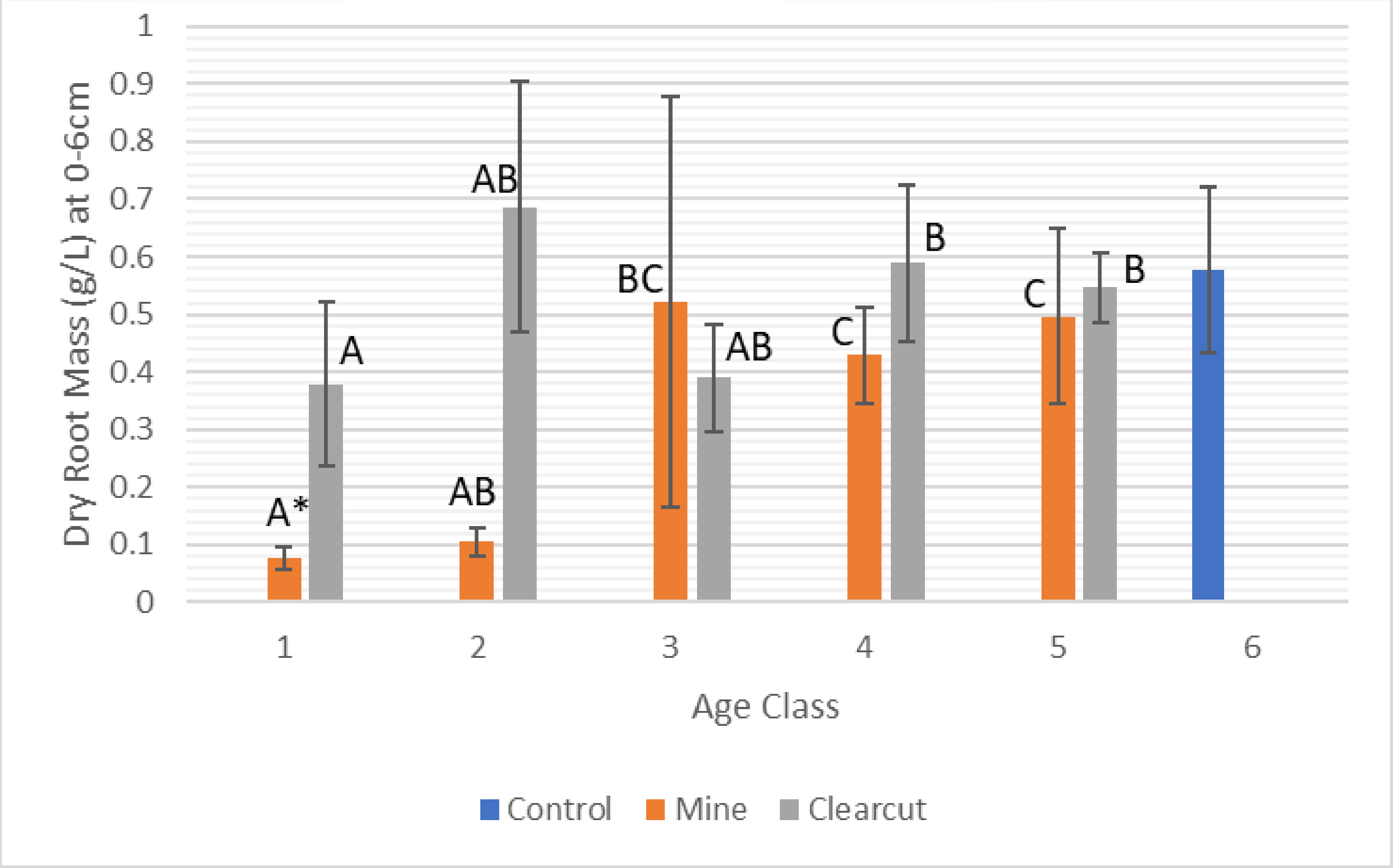


Figure 15 Average first layer root mass for each age class on mine, clearcut, and control sites. Bars denote standard error. Different letters indicate statistical differences between disturbance types at $P < 0.05$. Asterisk indicates significant difference from control at $P < 0.05$.

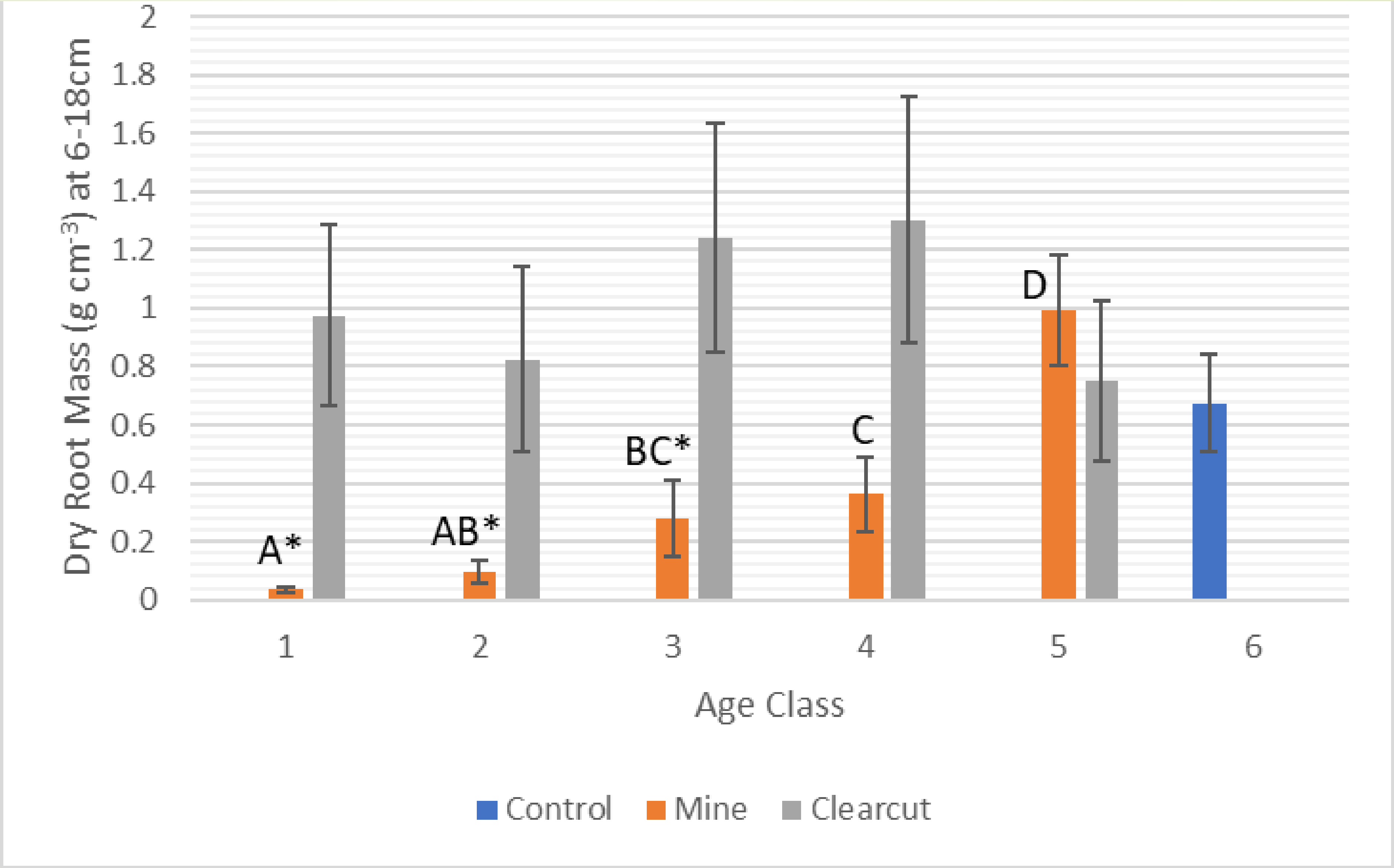


Figure 16 Average second layer root mass for each age class on mine, clearcut, and control sites. Bars denote standard error. Different letters indicate statistical differences between disturbance types at $P < 0.05$. Asterisk indicates significant difference from control at $P < 0.05$.

Results

Insect Mass

- (Non-flying)Insect Mass
  - Not normally distributed ($W=0.7573$, $p=1.71e-9$)
    - Data transformed ($\lambda= 0.275$, $W= 0.9925$, $p= 0.9503$)
  - No significant interaction between Site Type and Age Class; no need to split
    - Site Type individually significant ($p=7.2e-4$), Age Class not significant ($p=0.2137$)
      - Post hoc test examines Site Type
- Total Insect Mass (includes ground and flying insects)
  - Not normally distributed ($W=0.8231$, $p=8.88e-8$)
    - Data transformed ($\lambda= 0.325$, $W= 0.9872$, $p= 0.6874$)
  - Significant Interaction between Site Type and Age Class ($p= 0.0199$); split out
    - Age Class not significant on Mine sites ($p=0.0584$); not significant on Clearcut ($p=0.116$)
      - Post hoc examines differences in Site Type overall
- Clearcut sites have significantly more insect mass than surface mined sites overall

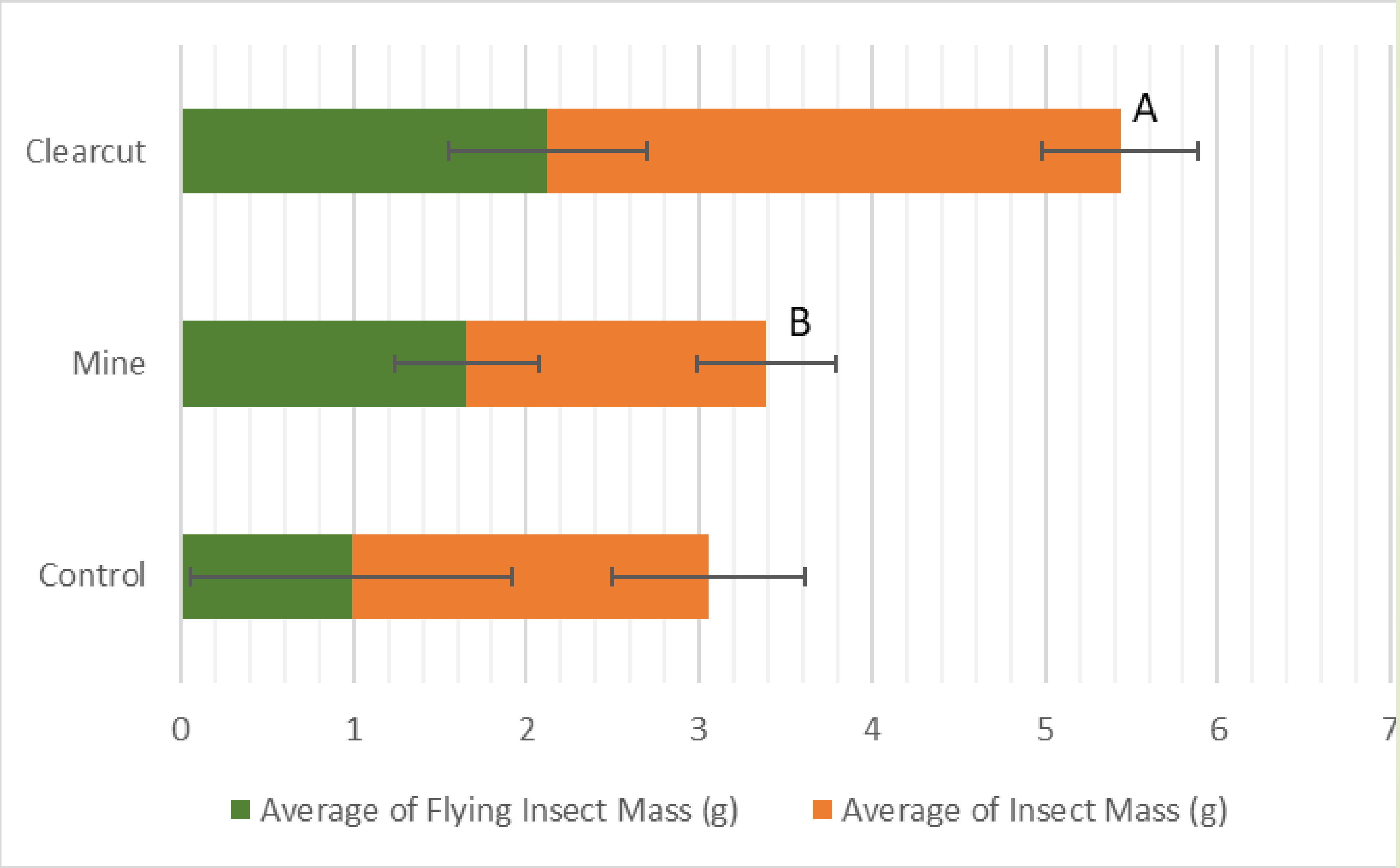


Figure 17 Average of flying and non-flying insect mass by site type. Bars indicate standard error. Different letters indicate statistical differences between disturbance types at $P < 0.05$.

Results

Decomposition

- Only significant by site type ($p=0.0131$)
- Clearcut and Mine sites only significant difference ($p=0.0064$)
- Of note: Decomposition Rate on mine sites greater overall than on clearcut

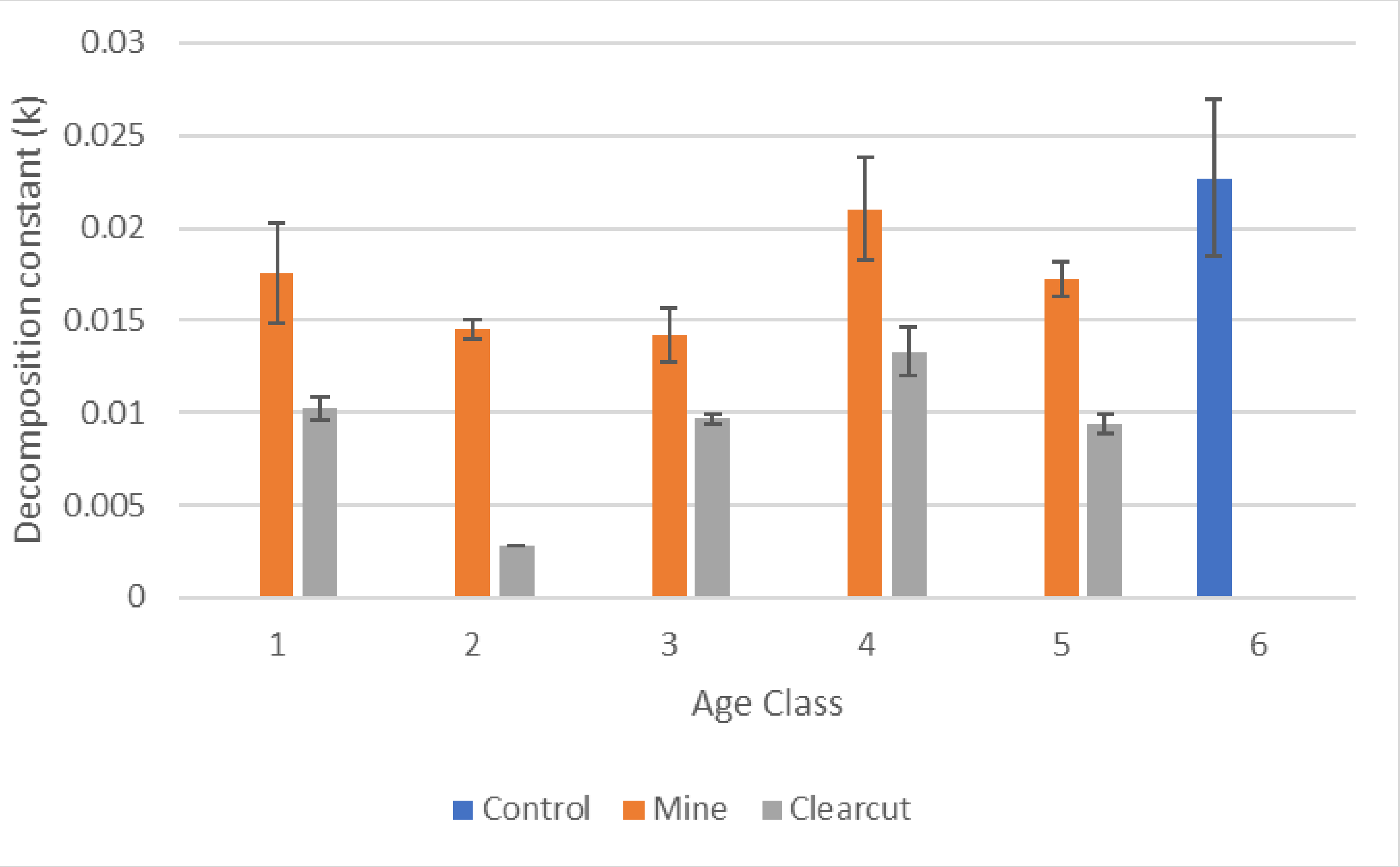


Figure 18 Average decomposition rate on mine, clearcut, and control sites. Bars denote standard error.

Results

Canopy Cover

- Split out by Site Type to analyze change in Age Class; two Kruskal Wallis Tests
- Mine sites were significant by age class (χ^2=107.68, p<2.2e-16)
  - Changes over time significant until 10-15 years post-disturbance
- Clearcut sites were also significant by age class (χ^2=19.818, p=0.001352)
  - Canopy closes much sooner, within 5-10 years post-disturbance

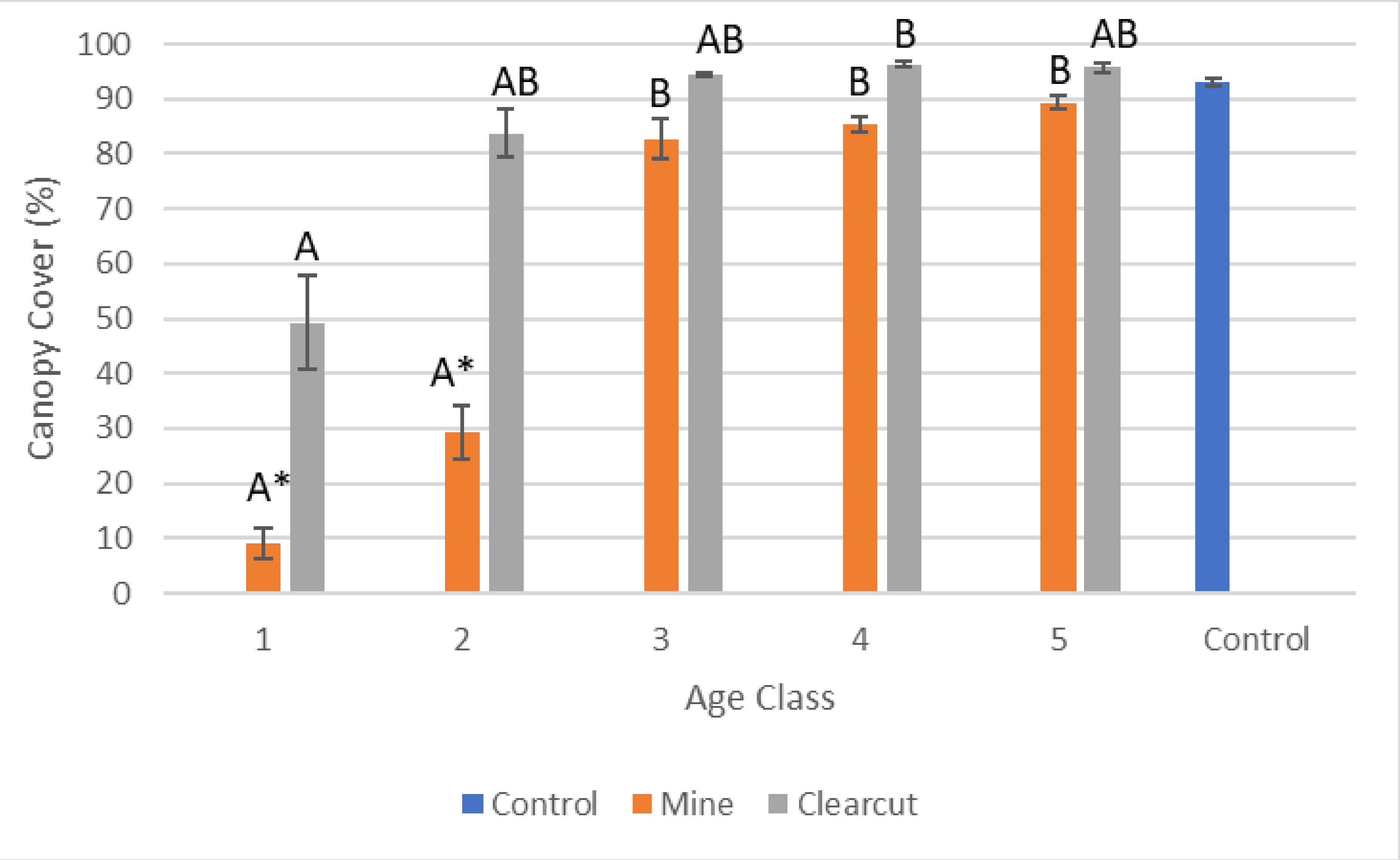
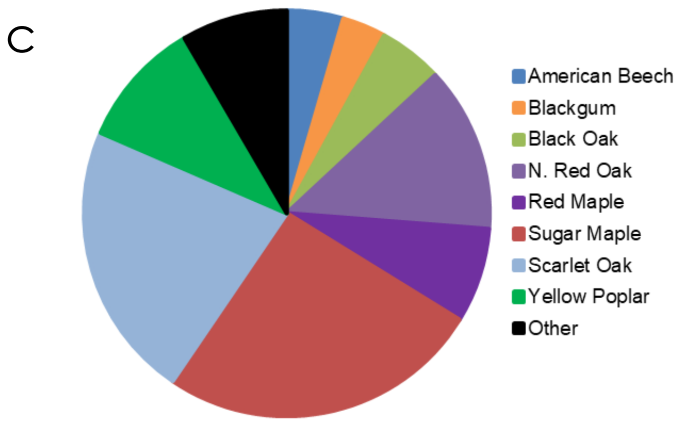


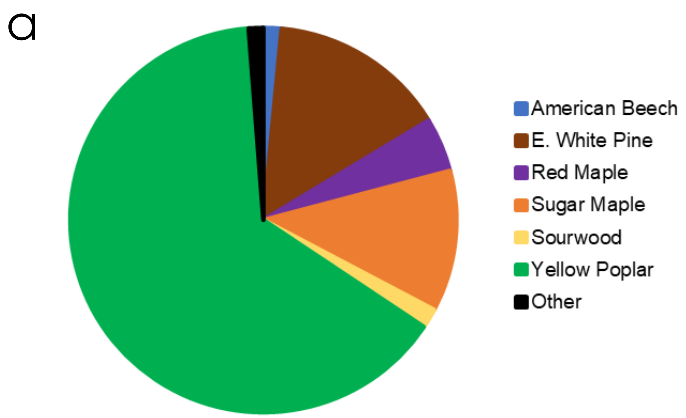
Figure 19 Average canopy cover for each age class on mine, clearcut, and control sites. Bars denote standard error. Different letters indicate statistical differences between disturbance types at $P < 0.05$. Asterisk indicates significant difference from control at $P < 0.05$.

Results

Basal Area, Species Composition, Species Count, Trees Per Acre

- Trees Per Acre proved non-significant.
- Species count showed significant differences between disturbance types ($\chi 2$ = 5.99, H = 6.23), but not between age classes ($\chi 2$ = 11.07, H = 9.06).
- Species Composition results were varied.
  - Yellow-poplar (*Liriodendron tulipifera*) dominated on clearcut sites until final age class, then red maple (*Acer rubrum*)
  - Black locust (*Robinia pseudoacacia*) most common on surface mined sites, along with yellow-poplar.
  - Maple and beech (*Fagus grandifolia*) most common on control sites, along with oak.
- Basal Area was significant in the interaction between site type and age class ($p<0.0001$), therefore split out by site type.
  - Significant on mine sites ($p<0.0001$), and on clearcut sites ($p=0.0003$)





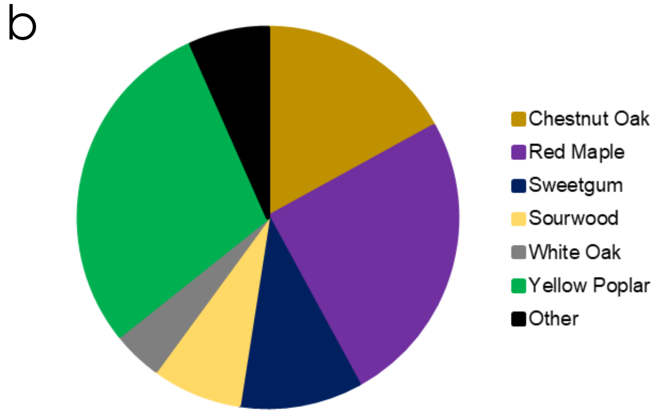


Figure 20 Species composition by basal area on (a) ≥30-year-old surface-mined sites, (b) ≥30-year-old clearcut sites, (c) control sites. Predominant species were American beech (Fagus grandifolia), black oak (Quercus velutina), blackgum (Nyssa sylvatica), chestnut oak (Quercus montana), eastern white pine (Pinus strobus), northern red oak (Quercus rubra), red maple (Acer rubrum), scarlet oak (Quercus coccinea), sourwood (Oxydendrum arboretum), sugar maple (Acer saccharum), sweetgum (Liquidambar styraciflua), white oak (Quercus alba), and yellow-poplar (Liriodendron tulipifera).

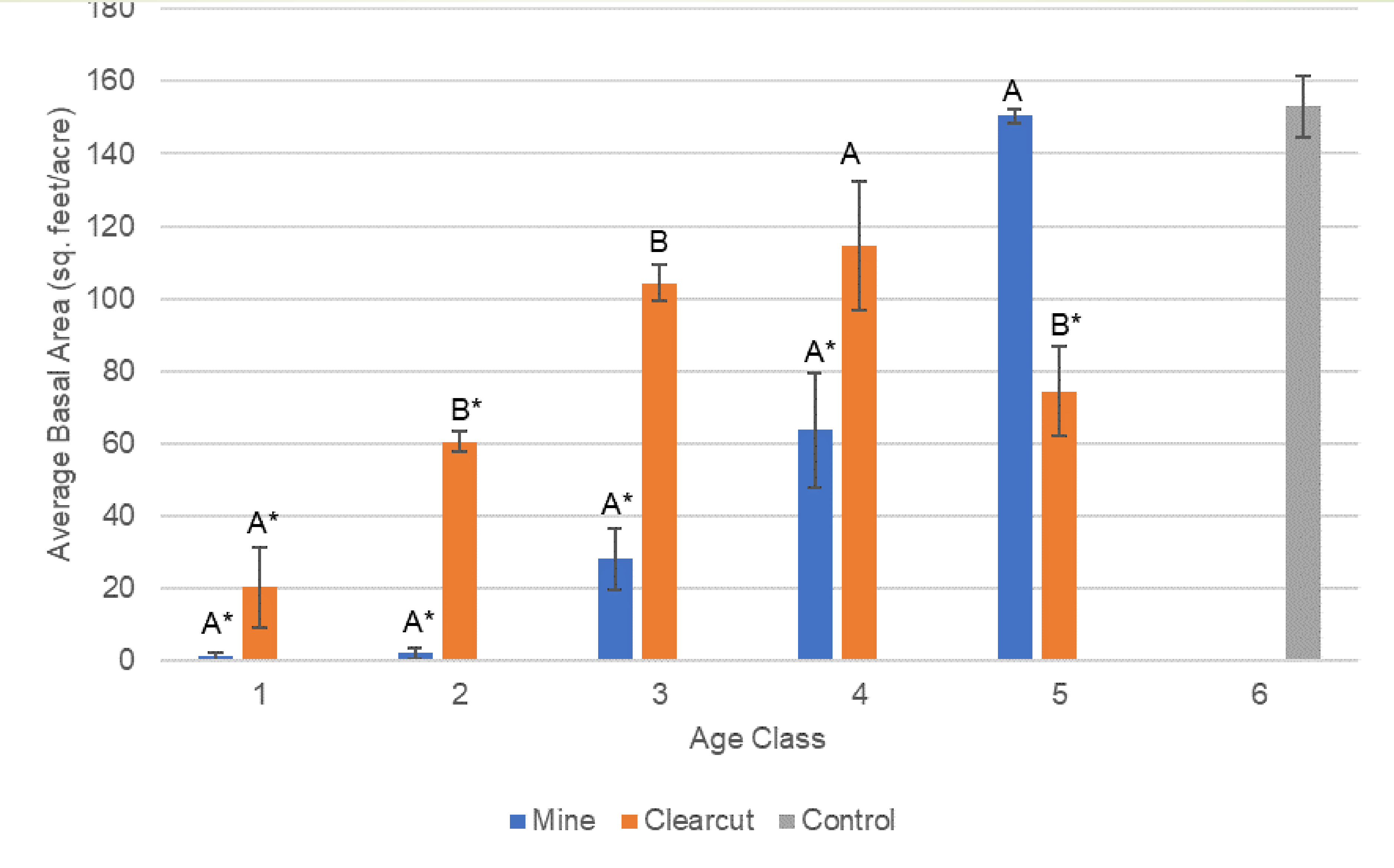


Figure 21 Average basal area by age class and disturbance type. Bars indicate standard error. Different letters indicate statistical differences between disturbance types at P < 0.05. Asterisk indicates significant difference from control at P < 0.05.

Results

Aboveground tree Biomass

- Significant by Age Class ($p<2e-16$) and Site Type ($p=4.06e-14$)
  - Also significant by interaction between Site type and Age Class ($p=0.000495$)
- Significant change in Age Class on Mine sites ($p=5.53e-14$)
  - Positive changes with a steadily upwards trend, no significant difference between controls and final age class ($p=0.58703$)
- Significant change in Age Class on Clearcut sites as well ($p<2e-16$)
  - Everything age class significantly different from one another except 2nd and 3rd ($p=0.6228$) and 4th and 5th ($p=0.7020$); plateaus at these age classes, but other wise positive growth
  - Final age class is different from controls ($p=0.0344$), implying room for more growth?

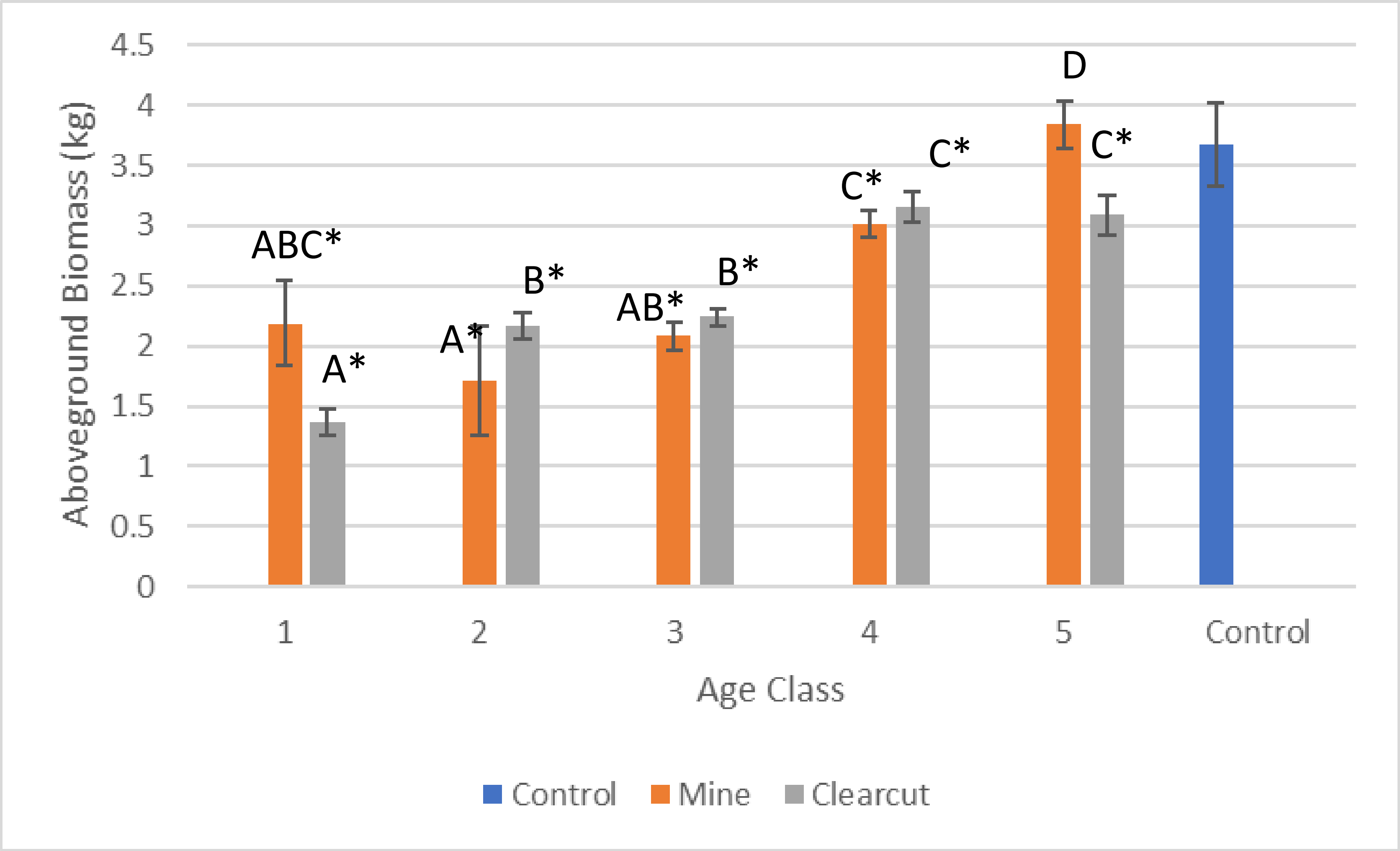


Figure 22 Average canopy cover for each age class on mine, clearcut, and control sites. Bars denote standard error. Different letters indicate statistical differences between disturbance types at $P < 0.05$. Asterisk indicates significant difference from control at $P < 0.05$.

Conclusions

Hypotheses

- 1) One or more of the examined ecosystem services will show a significant and consistent change according as age class increases.
  - Fail to Reject: Infiltration Rate, Density 1st Layer, Root Mass 1st & 2nd Layer, Canopy Cover, Aboveground tree Biomass*, Average Basal Area*, Species Composition+
  - Reject: Insect Mass & Total Insect Mass**, Decomposition Rate**, Trees Per Acre, Species Count
- 2)Ecosystem services in question will not vary significantly from one another across disturbance (site) types.
  - This hypothesis is rejected across all variables
- 3)Potential ecosystem service metrics will not show significant variation between control sites and the final age class.
  - This hypothesis was not rejected by any relevant variable save Aboveground tree Biomass and Average Basal Area on Clearcut sites

Discussion

Breakdowns, Exceptions, and Qualifiers

- *Surface Mining Control and Reclamation Act of 1977
  - At least one surface mined site in the final age class reclaimed pre-SMCRA
  - FRA Practices[5, 9]
    - Two surface mined sites in the third age class
- **Uncontrollable complications
  - Sample Loss, Site Availability, Site Accessibility
- Future studies, repeat studies, and follow ups
  - Soil Sampling/Testing, Later study

Acknowledgements*

Figure 23 Franklin (2022)

- Dr. Jennifer Franklin
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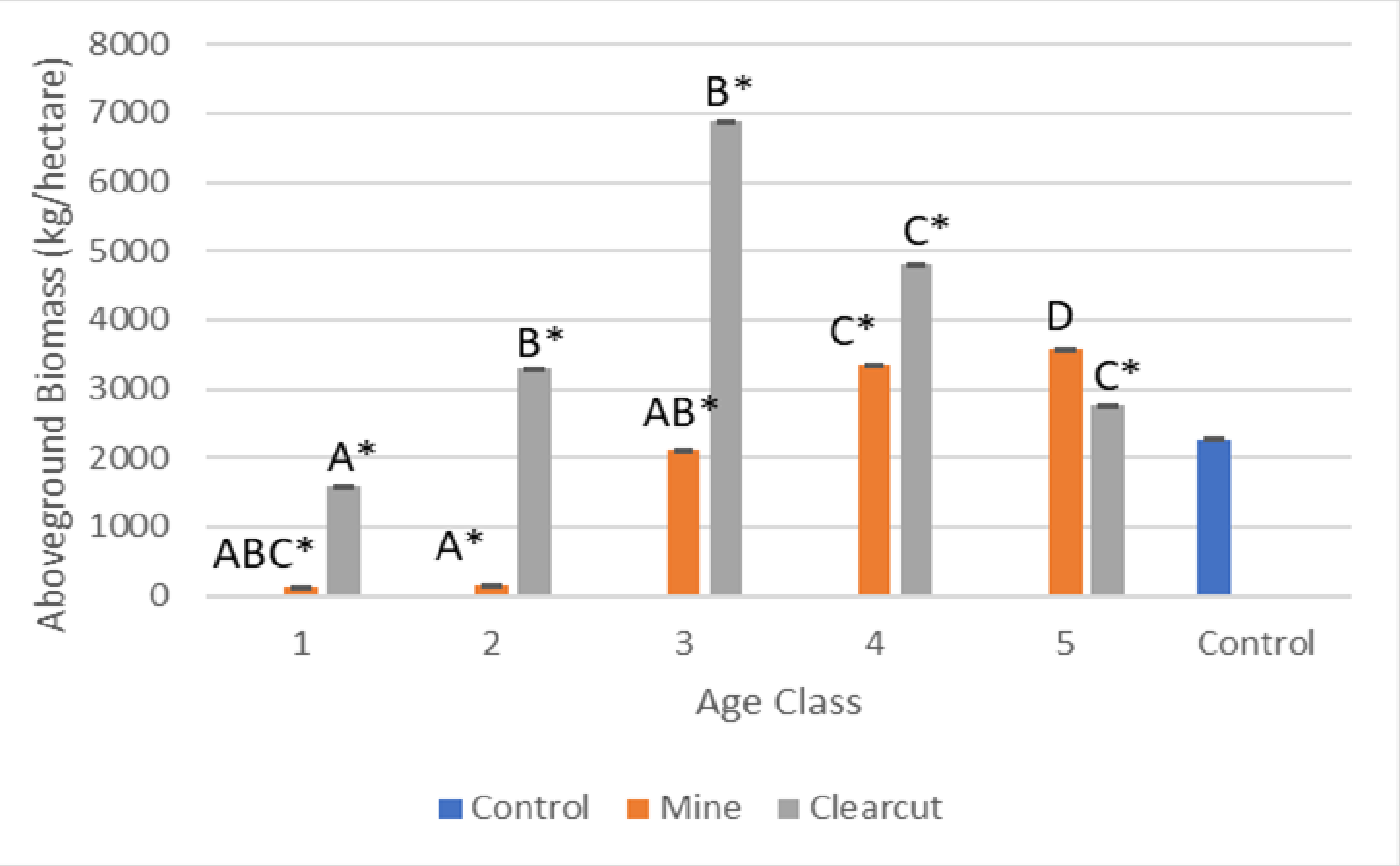
References

1. Assessment, M. E. (2005). Ecosystems and human well-being (Vol. 5, p. 563). Island Press, Washington, DC.
2. Boetzl, F. A., Ries, E., Schneider, G., & Krauss, J. (2018). It's a matter of design-how pitfall trap design affects trap samples and possible predictions. *PeerJ*, *6*, e5078. https://doi.org/10.7717/peerj.5078
3. Calderón-Loor, M., Cuesta, F., Pinto, E., & Gosling, W. D. (2020). Carbon sequestration rates indicate ecosystem recovery following human disturbance in the equatorial Andes. *PloS one*, *15*(3), e0230612.
4. De Frenne, P., et al. (2021). "Forest microclimates and climate change: Importance, drivers and future research agenda." Global Change Biology **27**(11): 2279-2279
5. Franklin, J. A., Zipper, C. E., Burger, J. A., Skousen, J. G., & Jacobs, D. F. (2012). Influence of herbaceous ground cover on forest restoration of eastern US coal surface mines. *New forests*, *43*, 905-924.
6. Fox J, Weisberg S (2019). _An R Companion to Applied Regression_, Third edition. Sage, Thousand Oaks CA. <https://socialsciences.mcmaster.ca/jfox/Books/Companion/>.
7. Hamaekers, W. (2021). Insect Biodiversity and Biomass in a Forested Region in Belgium: A case study in Bosland, Limburg.
8. Jactel, H., et al. (2017). "Tree diversity drives forest stand resistance to natural disturbances." Current Forestry Reports **3**(3): 223-243
9. J. Skousen, P. Ziemkiewicz & C. Venable (2006) Tree recruitment and growth on 20-year-old, unreclaimed surface mined lands in West Virginia, International Journal of Mining, Reclamation and Environment, 20:2, 142-154, DOI: 10.1080/17480930600589833
10. Kassambara A (2023). _ggpubr: 'ggplot2' Based Publication Ready Plots_. R package version 0.6.0, <https://CRAN.R-project.org/package=ggpubr>.
11. Keuskamp, J. A., et al. (2013). "Tea Bag Index: a novel approach to collect uniform decomposition data across ecosystems." Methods in Ecology and Evolution **4**(11): 1070-1075.
12. Lili, M., et al. (2008). "Methods for measuring soil infiltration: State of the art." International Journal of Agricultural and Biological Engineering **1**(1): 22-30.
13. Microsoft Corporation. (2021) Microsoft Excel (2209) [Computer software]. Microsoft 365 MSO.
14. Mangiafico, Salvatore S. (2023). rcompanion: Functions to Support Extension Education Program Evaluation. version 2.4.34. Rutgers Cooperative Extension. New Brunswick, New Jersey. https://CRAN.R-project.org/package=rcompanion
15. Posit team (2022). RStudio: Integrated Development Environment for R. Posit Software, PBC, Boston, MA. URL http://www.posit.co/.
16. R Core Team (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.
17. SAS (2013) Statistical Analysis Software. User's Guide Statistics Version 9.4. SAS Institute Inc., Cary.
18. Schwan, H., Sorg, M., & Stenmans, W. (1993). Naturkundliche Untersuchungen zum Naturschutzgebiet Die Spey (Stadt Krefeld, Kreis Neuss)—I. Untersuchungsstandorte und Methoden. *Natur am Niederrhein (NF)*, *8*(1), 1-13.
19. Signorell A (2023). _DescTools: Tools for Descriptive Statistics_. R package version 0.99.50, <https://CRAN.R-project.org/package=DescTools>.
20. Skousen, J., Zipper, C.E. Post-mining policies and practices in the Eastern USA coal region. *Int J Coal Sci Technol* **1**, 135–151 (2014). https://doi.org/10.1007/s40789-014-0021-6
21. Zipper, C.E., Burger, J.A., Skousen, J.G. *et al.* Restoring Forests and Associated Ecosystem Services on Appalachian Coal Surface Mines. *Environmental Management* **47**, 751–765 (2011). https://doi.org/10.1007/s00267-011-9670-z

Photo Credits

- Google Earth Pro v7.3.6.9345 (2022) Horseshoe Mountain, 36°32'09"N 83°52'02"W, 3819ft, [Online] https://earth.google.com/web/@36.53593035,-83.87157564,1163.90406271a,0d,35y,91.13h,54.3809t,0.0008r/data=CggqBggBEgAYADoDCgEw, [Accessed 12/7/2023]
- Miller A. (2022) *Big Rock Mine Site subplot C* [Digital Image].
- Franklin J. (2022) *Big Rock Group Photo* [Digital Image].

Figure 24 GRSMNP, TN


Aboveground Biomass (kg/hectare)
8000
7000
6000
5000
4000
3000
2000
1000
0
ABC*
A*
A*
B*
AB*
B*
C*
C*
D
C*
1
2
3
4
5
Control
Age Class
Control
Mine
Clearcut