Optimizing plant size:biomass allometric relationships at the Sevilleta LTER

Alesia Hallmark[1], Jenn Rudgers[1], Scott Collins[1], Doug Moore[1], Lauren Baur[1], Stephanie Baker[2]

[1]Department of Biology, University of New Mexico and [2]Sevilleta Field Station, University of New Mexico

Background: Accurately estimating primary production is a core research theme of all Long-Term Ecological Research (LTER) sites. Non-destructive methods of measuring productivity are preferable in arid regions where plants recover slowly from disturbance. Allometric equations allow researchers to relate non-destructive measurements such as plant height or cover to plant biomass. Here, we present the updated workflow used to generate allometric equations for plant species at the Sevilleta LTER in central New Mexico.

LTER Data: Over the past 20 years, Sevilleta researchers have revisited thousands of sampling points to record well over a million observations of plant identity, abundance and size during the peak of each spring and fall/monsoon growing season. These locations span desert grasslands, shrublands, savannahs, and piñon-juniper woodlands. We use allometric equations to convert these non-destructive observations of plant size into a common unit of biomass.

In order to create species-specific allometries, we used a destructive harvest dataset of >22,000 individual plants representing nearly 200 species. Specimens growing in a range of biomes and climatic conditions are measured, cut at ground level, dried, and weighed.

All observations and harvested samples are paired with weather data from a nearby meteorological tower.

In order to make Sevilleta LTER data as understandable and transparent as possible, all data manipulation and analyses were conducted in a free, open-source software, R, and all code was committed to GitHub.

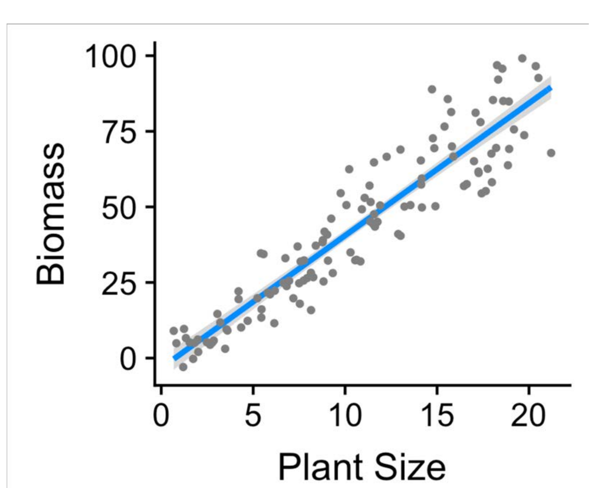


Fig. 1: A simple linear relationship between plant size and mass

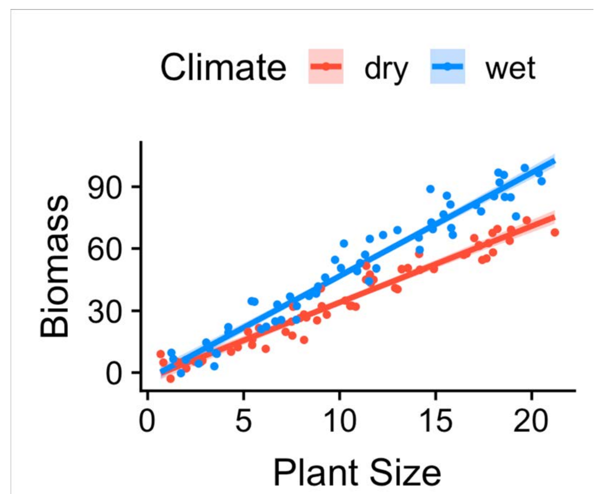


Fig. 2: A linear relationship between plant size and mass that varies with climate

Allometric Models: For each species we first considered the simple linear relationship between plant size (either ground cover or plant volume) and biomass.

We also tested whether the size:mass relationship varied between years, biomes, or in response to climate. Climate variables considered include seasonal precipitation, growing degree days (GDD, a measure of accumulated temperature), or 6-month $SPEI_{comp}$, (a measure of how hot and dry the preceding 6 months were at a given site, compared to all other 6-month periods from all sites.

1) Data is collected in the field

- Plant Observations
- Destructive Harvest
- Meteorology

2) Allometric relationships are assessed

- Each species and season assessed separately
- Compare the summary statistics of Harvested individuals versus Observed individuals
- If time since fire affects allometry, exclude samples from recently burned years
- Exclude years with poor quality or incomplete data
- If 30 Harvested individuals remain, create allometric models with remaining sample
- If not, collect more samples

Basic model structures:

$$\text{biomass} \sim \left\{ \begin{matrix} \text{cover or} \\ \text{volume} \end{matrix} \right\}$$

$$\text{biomass} \sim \left\{ \begin{matrix} \text{cover or} \\ \text{volume} \end{matrix} \right\} * \left\{ \begin{matrix} \text{precipitation,} \\ \text{GDD, or SPEI} \end{matrix} \right\}$$

3) Best models are selected

Model selection process relies on automation *and* human evaluation

Winning model fits were recalculated using all high quality data

Best Model
- simple
- lowest AIC
- little influence of outliers
- representative data

Best Invariant Model
- only models that do *not* include an interacting climate term

Best Cover Model
- only models that use Cover to predict biomass

4) Biomass is estimated

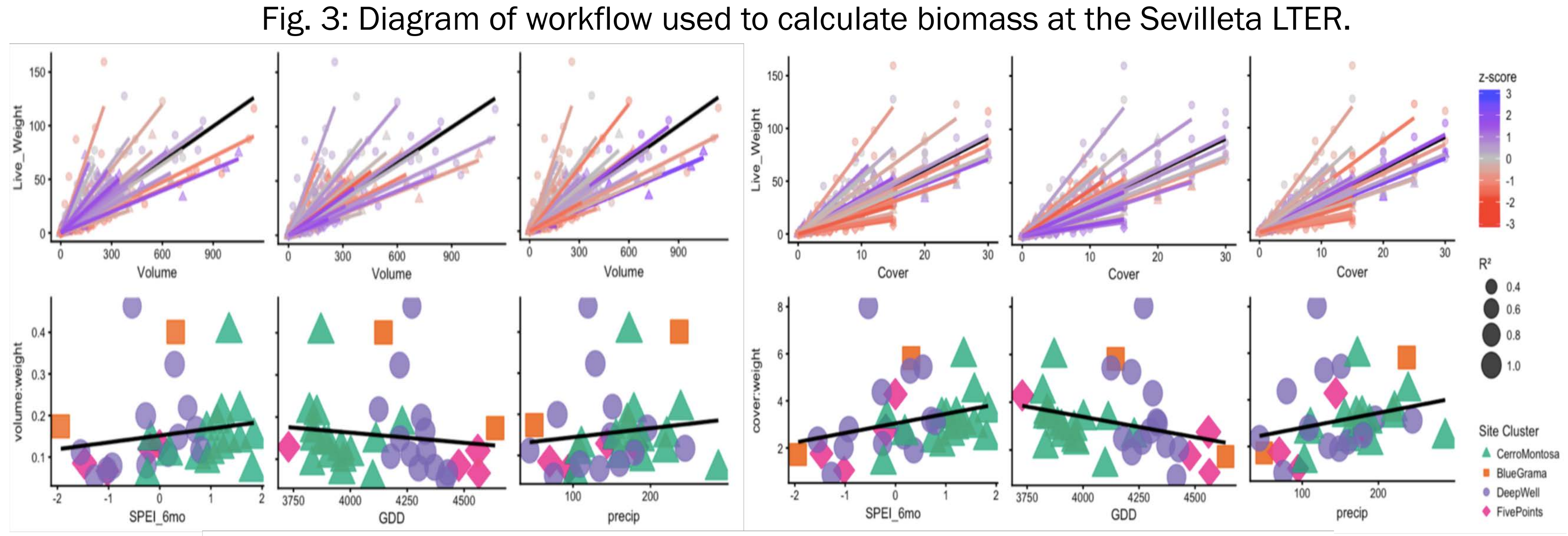
All observations converted to common units of biomass (g/m²).
Data from all sites and experiments compiled for larger-scale analyses.

5) All data and code made publicly available

Code
Raw data
Final data

- All data on SEV LTER website and EDI
- Easy-to-read R Markdown files on GitHub

Fig. 3: Diagram of workflow used to calculate biomass at the Sevilleta LTER.



kartez	model.name	model.samp	clim.years	main.eff	main.p	mainclim.eff	mainclim.p	inter.eff	inter.p	AIC	dAIC
BOER4	Volume+SiteYear	731	35	0.391	0	NA	NA	NA	0.000	5030.01	NA
BOER4	Cover+SiteYear	731	35	5.848	0	NA	NA	NA	0.000	5030.01	NA
BOER4	Volume	731	35	0.110	0	NA	NA	NA	NA	5780.38	274.31
BOER4	Cover	731	35	3.039	0	NA	NA	NA	NA	5515.19	9.12
BOER4	Volume+Site	731	35	0.101	0	NA	NA	NA	0.000	5737.23	231.16
BOER4	Cover+Site	731	35	3.022	0	NA	NA	NA	0.875	5514.57	8.50
BOER4	Volume*zSPEI	731	35	0.111	0	0.846	0.115	0.005	0.088	5783.95	277.88
BOER4	Cover*zSPEI	731	35	3.047	0	1.082	0.025	0.108	0.129	5506.16	0.09
BOER4	Volume*zGDD	731	35	0.111	0	-0.734	0.195	-0.004	0.325	5788.04	281.97
BOER4	Cover*zGDD	731	35	3.061	0	-1.262	0.012	-0.086	0.281	5506.07	0.00
BOER4	Volume*zprecip	731	35	0.112	0	0.564	0.286	-0.006	0.015	5788.36	282.29
BOER4	Cover*zprecip	731	35	3.050	0	0.984	0.038	-0.086	0.153	5518.63	12.56

Fig. 4: Diagnostic plots and model summaries used to select Best Model for black grama (*Bouteloua eriopoda*)

"Winning" Models: We were able to create strong species- or genus-specific allometric models for 174 species-seasons, representing over 90% of all Sevilleta core site observations. Aggregated plant functional type allometric equations were used for rarer species.

Cover predicted biomass better than volume in 67% of cases.

Climate-invariant models performed best in 77% of cases.

Of those models that did show strong climate interactions, 47.5% varied more with seasonal precipitation, 37.5% with temperature (GDD), and 15% with aridity (SPEI).

Select time series:

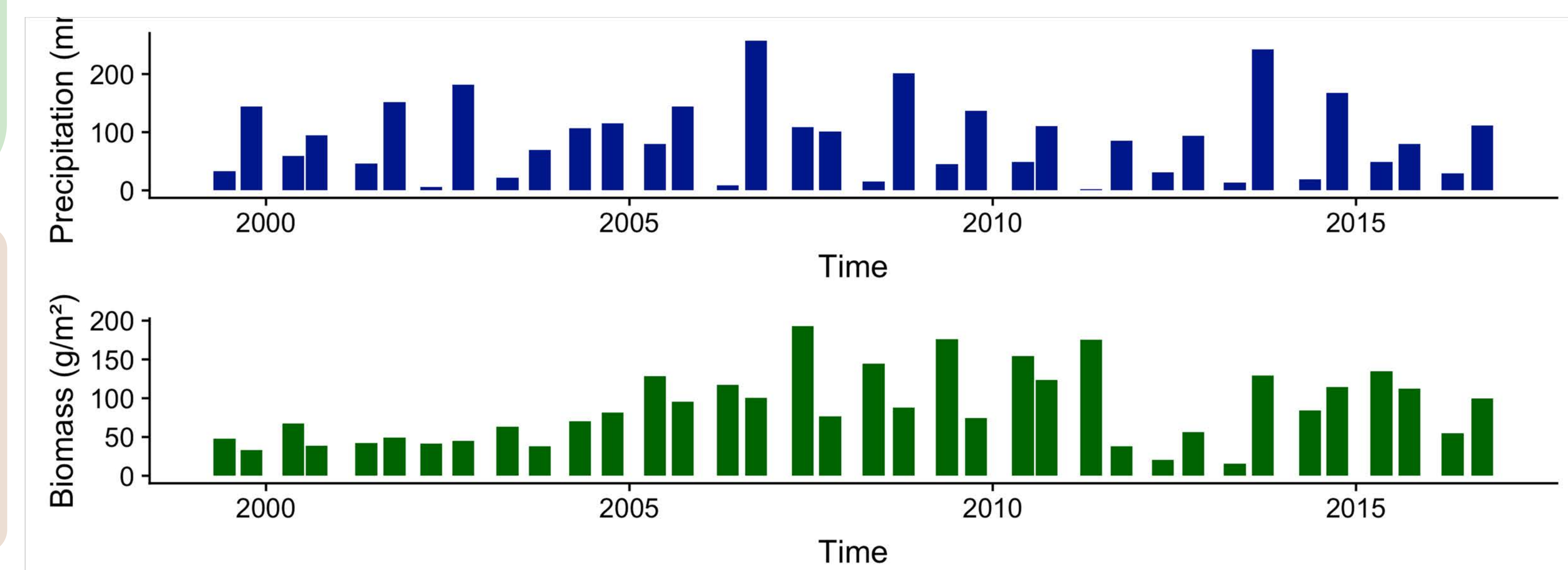


Fig. 5: Seasonal precipitation and biomass of C4 grasses at Black Grama Core site

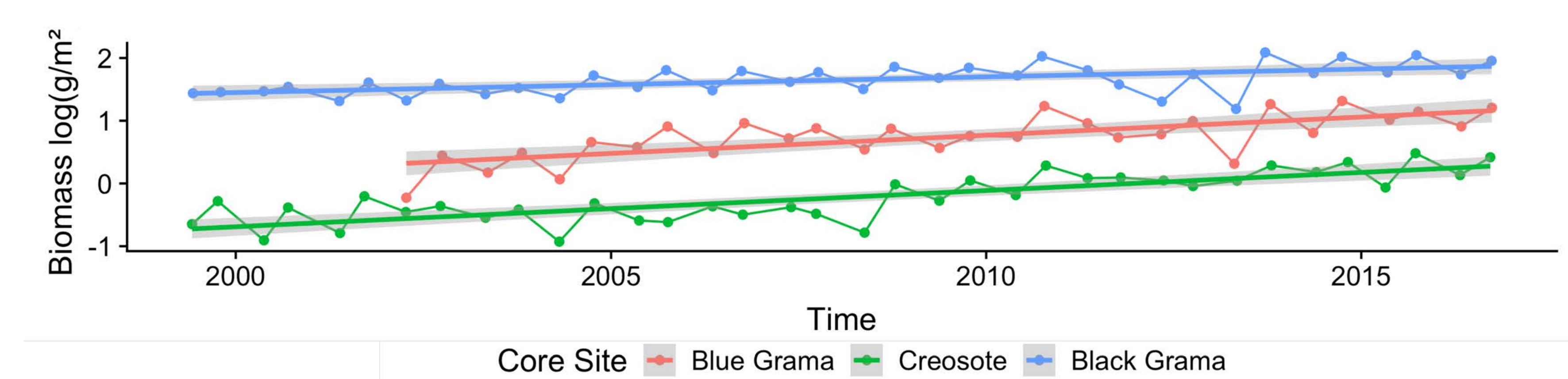


Fig. 6: Biomass of black grama (*Bouteloua eriopoda*) at core sites increases over time.

Outcomes: We were able to find robust allometric relationships for most species (percent of observations) at the Sevilleta LTER. The majority of models were climate-invariant and many only required measurements of cover to predict biomass. This supports the use of these models in novel biomes and climate scenarios. It may also reduce field efforts and aid biomass estimation using aerial drone photography in the future. However, it should be noted that invariant models were selected in multiple cases due to their simplicity and to exclude confounding outliers.

Future work includes the inclusion of more species in our destructive harvest dataset, analysis of the phylogenetic basis of allometric relationships, and exploration of fruiting allometries.

THE UNIVERSITY of NEW MEXICO
LTER NETWORK

Many thanks to Esteban Muldavin and Doug Moore for curating this dataset for so many years, all of the field crew members that collected data, and Jenn Rudgers for encouraging and funding this work!