Eco-hydrologic modeling of rangelands: Evaluating a new carbon allocation approach and simulating ecosystem response to changing climate and management conditions

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1 | Introduction

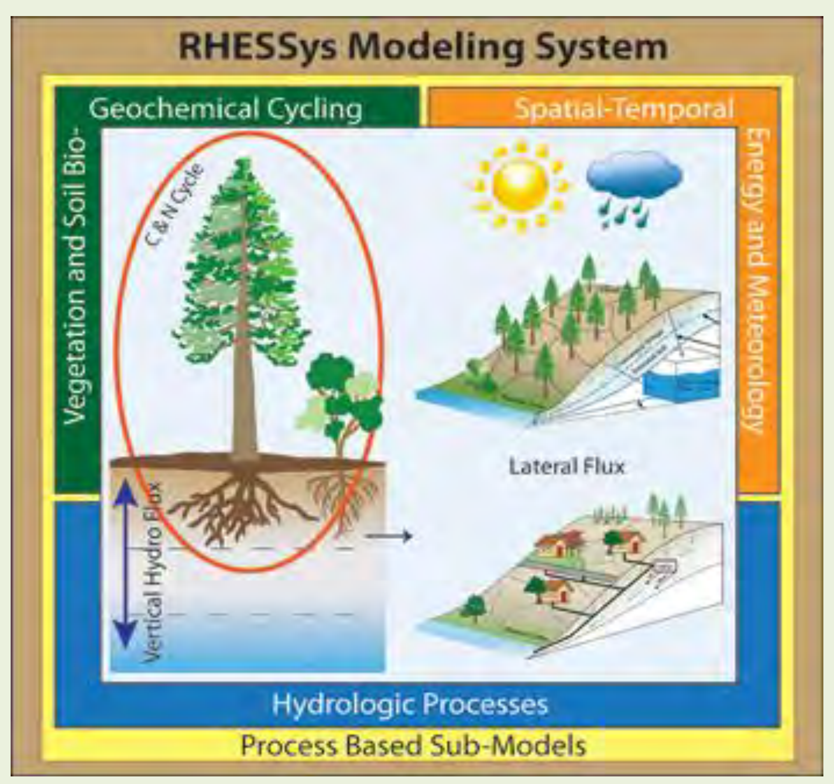
Rangelands cover more than one-third of the United States and support both forage production and livestock grazing. These areas also provide important ecosystem services, such as soil carbon (C) storage (White et al., 2000; Reeves and Mitchell, 2012). Typically, rangelands are located in areas of highly variable climatic regimes, e.g., experiencing large pulses of rainfall and drought conditions (Reeves et al., 2014) . Capturing the interactions among water, C, and nitrogen (N) cycles within the context of regional-scale patterns of climate and management is important to understand feedbacks between human and natural systems (NRC, 2011).

The ultimate goal of this study is to provide information on the interactions between management activities, climate and ecosystem processes to inform sustainable rangeland management. The *specific objectives* of this paper are to (1) evaluate a new carbon allocation strategy for grasses and (2) test the sensitivity of this improved strategy to changes in climate and grazing strategies.

2 | Methodology

[a] Model Description

Regional Hydro-Ecologic Simulation System



RHESSys is a process-based model that simulates hydrology and biogeochemical cycling at the watershed scale (Tague and Band, 2004).

- A spatially distributed hydrology model is fully coupled with dynamic soil and vegetation models with C and N cycling.

- A unique feature of RHESSys is its hierarchical landscape representation. Climate, soil, vegetation, and management can each be represented as distinct spatial patterns at different levels.

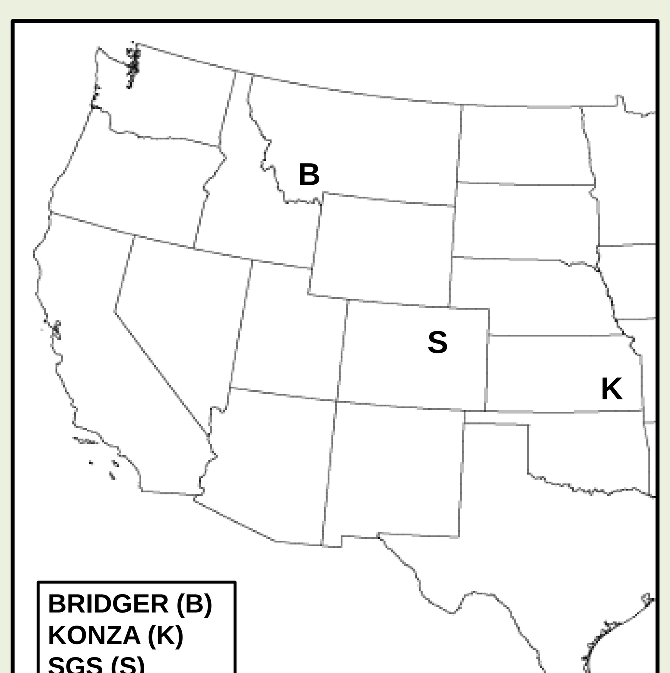
- Spatial heterogeneity is represented by inter-linked "patches" and there is lateral transport of water and nutrients among them.

[b] Site Description

Table 1. Geographical and vegetation characteristics of modeled sites.

	Bridger (Montana)	Konza (Kansas)	SGS LTER (Colorado)
Elevation	2340 m	400m	1660m
MAT (C)	2.67	15.2	8.3
MAP (mm)	930	859	332
Rangeland type	Mountain grassland	Tallgrass prairie	Shortgrass steppe (SGS)
Dominant vegetation	*Festuca idahoensis*	*Andropogen gerardii*	*Bouteloua gracilis*

MAT: Mean annual temperature; MAP: Mean annual precipitation



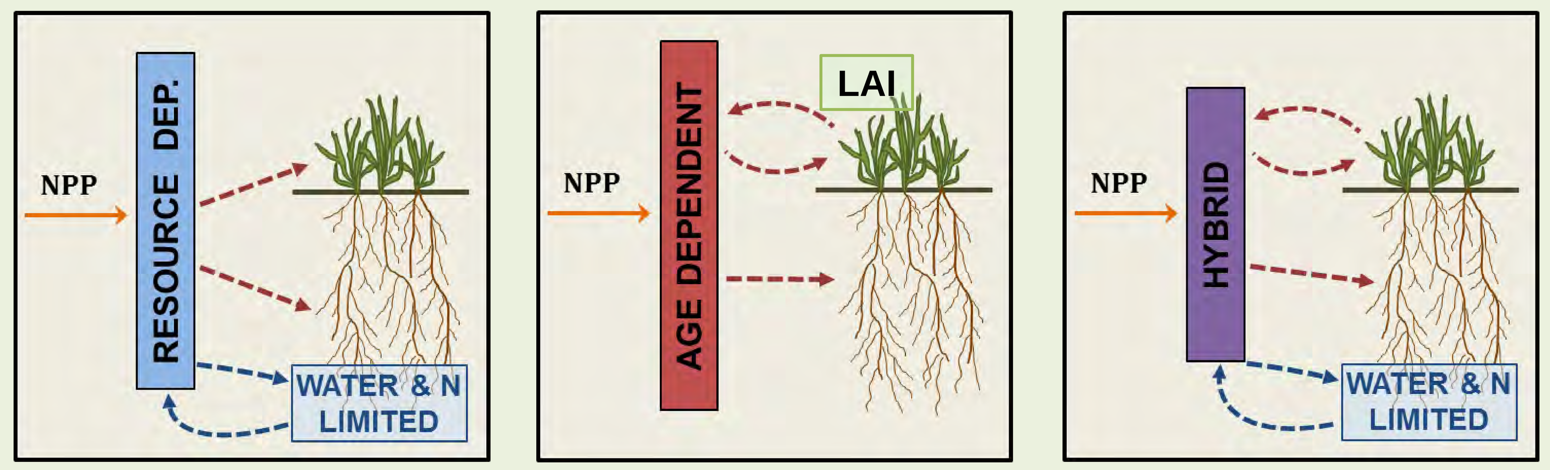
References

Bestelmeyer, B. & Briske, D. 2012. *Rangeland Ecolology Management.*
Dickenson et al. 1998. *Journal of Climate*.
Landsberg, J & Waring, R. 1997. *Forest Ecology Management.*
National Research Council (U.S.). 1996. *Nutrient requirements of beef cattle.*
National Research Council (U.S.). 2001. *Grand challenges in environmental sciences.*
Reeves, M. & Mitchell J. 2012. Synoptic review of U.S. rangelands. USDA-FS.
Reeves et al. 2014. *Climatic Change*.
Tague , C.L. & Band, L.E. 2004. *Earth Interactions*.
White et al. 2000. *Pilot analysis of global ecosystems: Grassland ecosystems.* World Resources Institute.

3 | Model Development

[a] Carbon allocation

Allocation of net primary production (NPP) to above and belowground biomass compartments in RHESSys is primarily determined using three strategies: (1) ***resource-dependent*** (Waring and Running, 1998), (2) ***age-dependent (i.e., growth)*** (Dickenson et al., 1998), or (3) ***hybrid***.

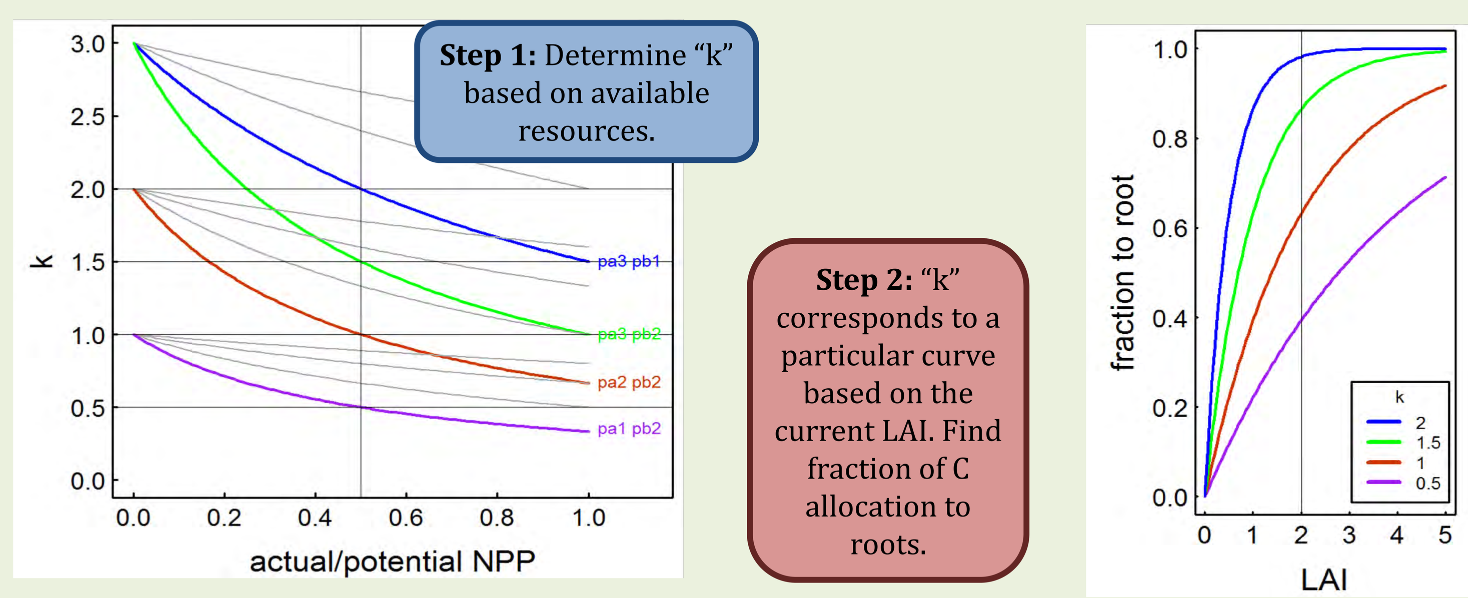


For grasses, we developed a ***hybrid*** allocation approach: taking into account both *resource limitation* (i.e. reduced soil moisture, inadequate nutrient availability) and *growth* (using leaf area index, LAI).

The ***hybrid*** allocation strategy uses the resource-dependent relationship to determine the "k" constant of the age-dependent relationship.

Fraction to root = $[1 - exp(-1 \cdot k \cdot LAI)]$

$$k = \frac{pa}{1 + pb * \frac{actual\ NPP}{potential\ NPP}}$$



Model parameter	Description
pa, pb	Allocation equation parameters
FNSC	Fraction of NPP allocated to storage (available reserves) in current year
FAD	Fraction of NPP allocated during growing season; Remained is stored for next year's spring leaf/root growth
ndays_expand; ndays_litfall	Number of days for leaf expansion and leaf litterfall.

Table 2. Model parameters related to carbon allocation and phenology. Allocation parameters describe the partitioning of NPP between aboveground and belowground plant compartments. Number of days for expansion and litterfall control time for growth and death.

[b] Grazing: Biomass removal and recovery

Information on forage quality and livestock are incorporated into an empirical relationship to determine the dry matter intake of cattle, or biomass removed from the landscape.

Forage quality
- ADF (acid detergent fiber) (cellulose, lignin)
- CP (crude protein)

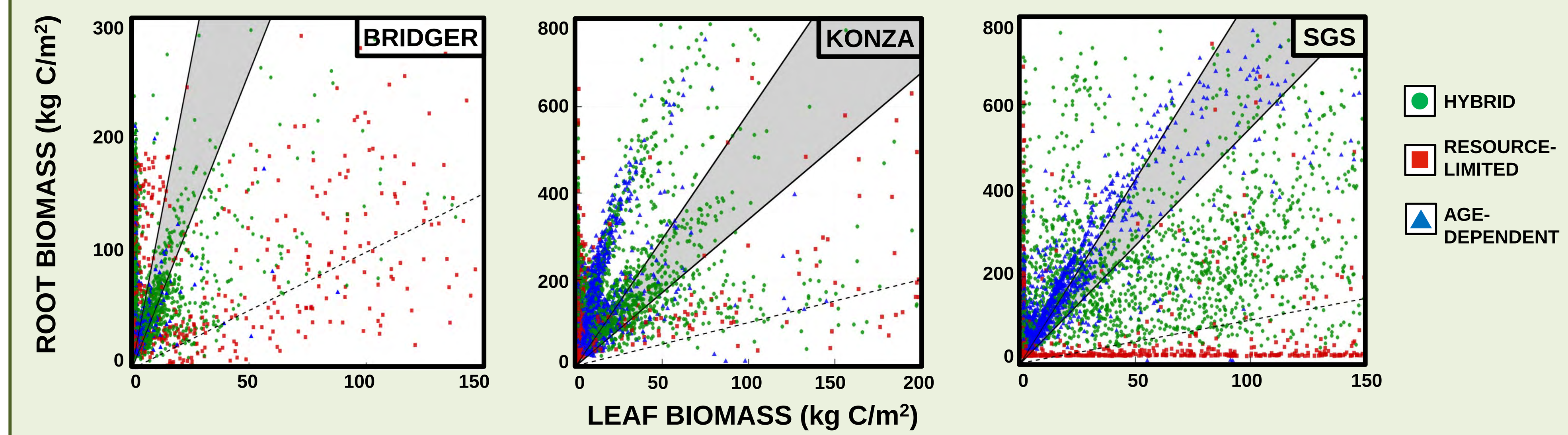
Livestock characteristics
- Grazing intensity [ha/animal unit month (AUM)]
- Body weight

Dry matter intake (kg/cow/day) : all-forage diet equation (NRC, 1996)
Total biomass lost due to grazing

4 | Results

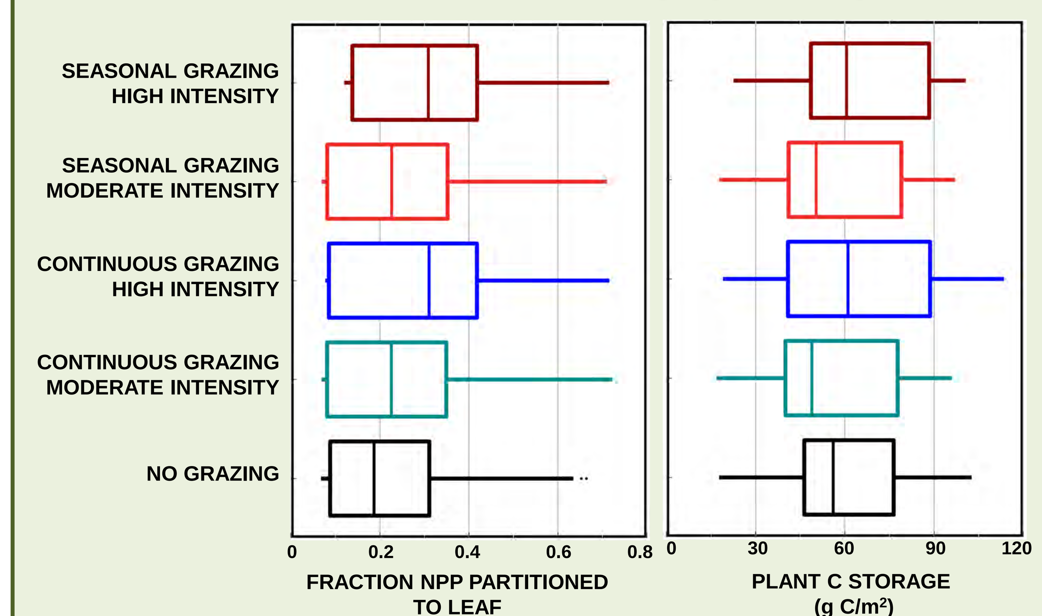
[a] Carbon allocation

Scatter plots show simulated values of leaf and root biomass using different allocation strategies across randomly generated parameters (see Table 2). Gray-shaded regions represent ranges of observed leaf (i.e. shoot) and root biomass, which are bounded by observed minimum and maximum root:shoot ratios.



The hybrid strategy produces root:shoot ratios closest to the observed range at the wetter sites (Bridger and Konza). At all three sites, the resource-limited strategy either over- or underestimates the root:shoot ratio.

[b] Biomass response during grazing



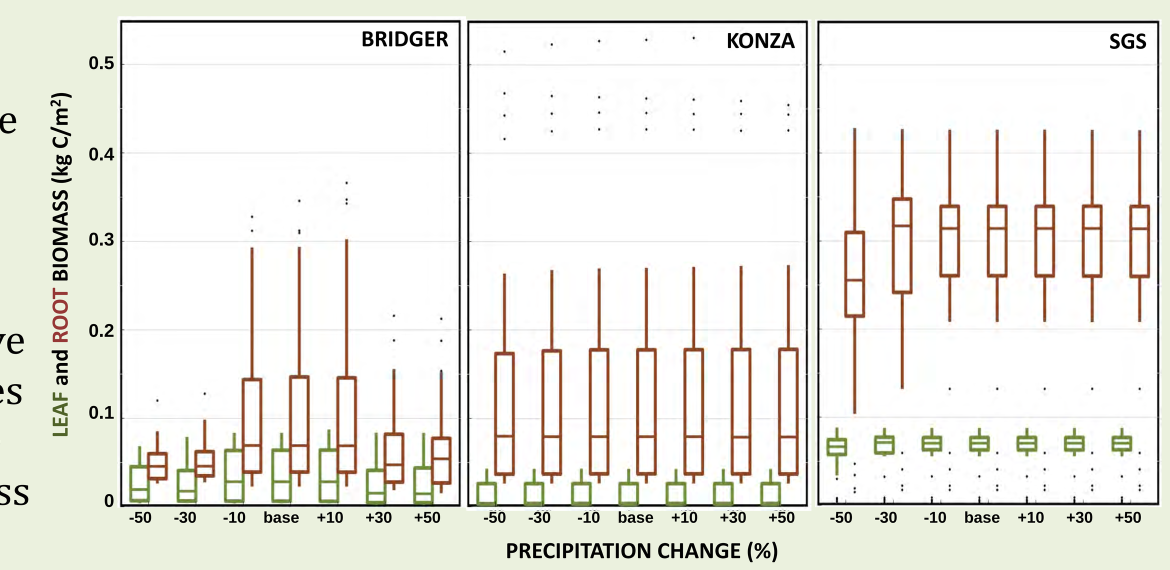
Using the hybrid allocation strategy, we simulated both seasonal and continuous (i.e. year round) grazing at two intensity levels at SGS. Box plots show how C is partitioned during grazing.

In all grazing scenarios, NPP partitioned to leaves increased. During moderate intensity grazing (seasonal and continuous), plant C storage is drawn down as reserves are used to sustain plant growth. The reverse is observed for high intensity grazing where plant C storage increases. Biomass slightly decreases at higher grazing intensity (not shown), indicating that additional plant C storage may be used as reserves during high intense defoliation events.

[c] Climate sensitivity exercise

Boxplots show site differences in biomass response to percent changes in precipitation. The hybrid strategy was used in these climate simulations.

At the cold-wet site (Bridger), large changes in precipitation (both increases and decreases) have adverse effects on belowground biomass. In cases of decreased root biomass, limited resources are shifted away from growing belowground biomass as soil moisture decreases.



The humid and temperate climate at Konza may explain the relatively insensitive response of biomass to changes in rainfall.

5 | Conclusions

- ❖ At colder and wetter sites, the hybrid allocation strategy simulates aboveground and belowground biomass within observed ranges. At the temperate-dry site, both age-dependent and hybrid allocation strategies may be appropriate in these rangeland ecosystems.
- ❖ Higher intensity grazing regardless of temporal constraints (i.e. seasonal vs year-long) supports greater C allocated to leaves. Since biomass slightly decreases at high intensity grazing, additional C is allocated into "reserves" or plant C storage, which is accessed during defoliation events (i.e. grazing).
- ❖ Using the hybrid approach, reduced precipitation decreased productivity at both temperate and cold sites. Colder and wetter sites may be more sensitive to variable regimes of precipitation.
- ❖ As a next step, altered timing of precipitation and frequency of storms will be tested across rangeland sites.
- ❖ This work contributes to the grand challenge of "resilience-based management" in rangelands. Through integrated environmental modeling of ecologic and hydrologic systems, a better understanding of climate and management impacts on rangelands can be achieved (Bestelmeyer and Briske, 2012) .

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