中国科学院 西北生态环境资源研究院
Northwest Institute of Eco-Environment and Resources,CAS

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How do biotic and abiotic factors affect stemflow production and funneling efficiency of shrubs?

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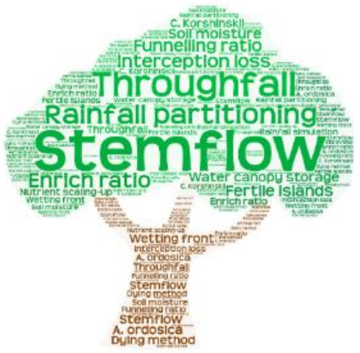

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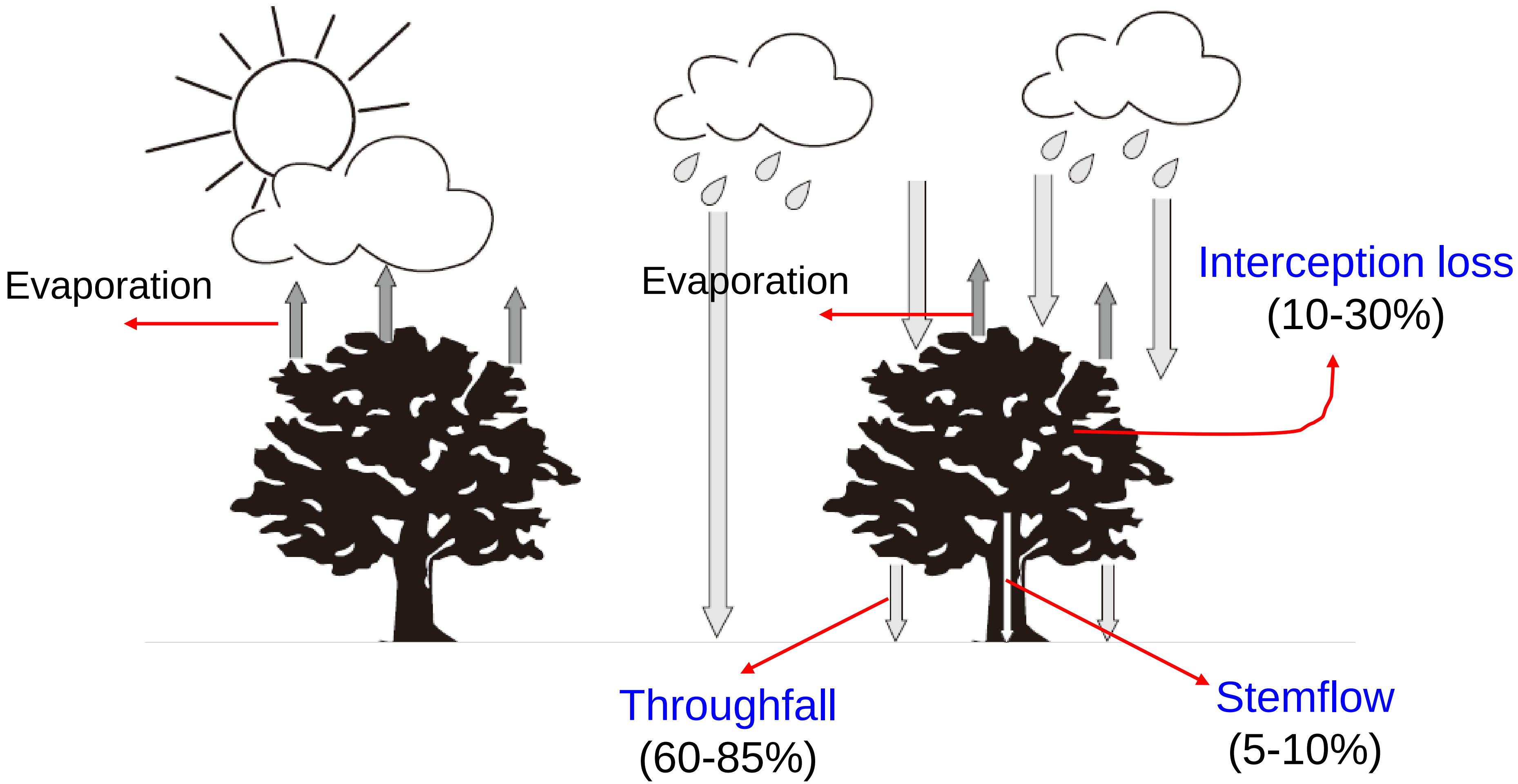
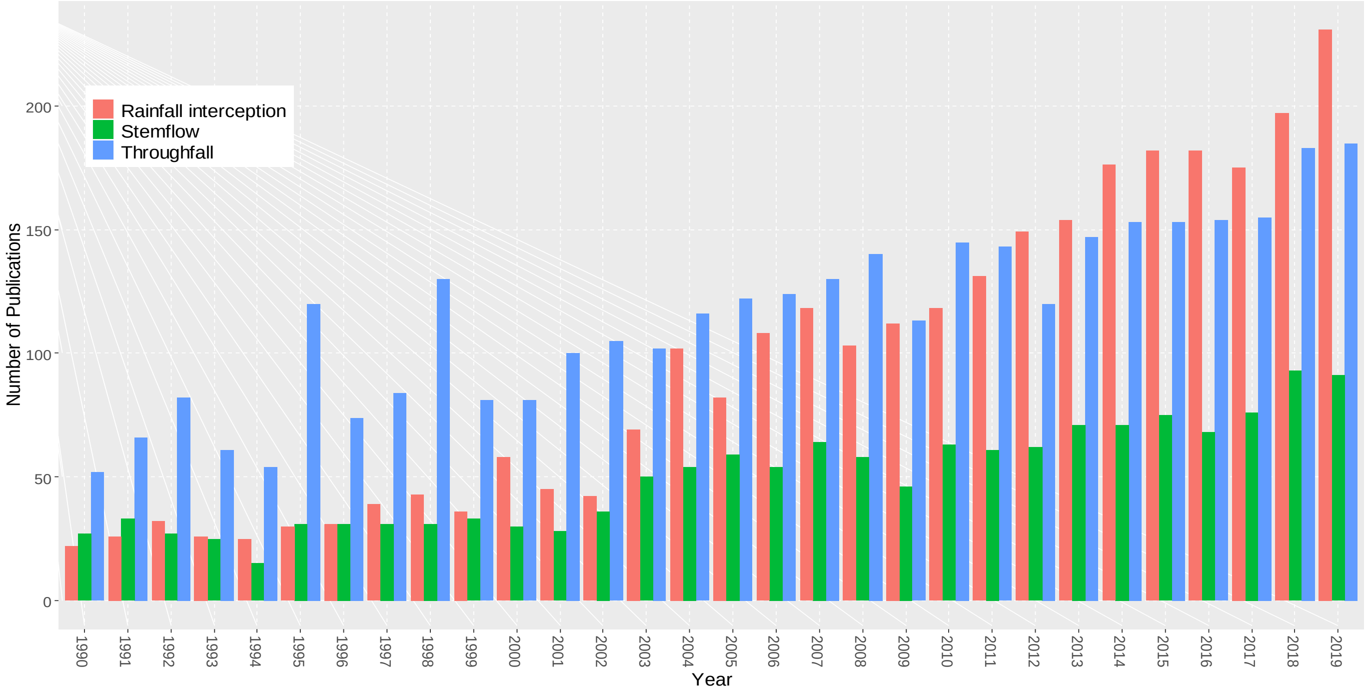
Rainfall partitioning

Gross rainfall = Interception loss + Throughfall + Stemflow

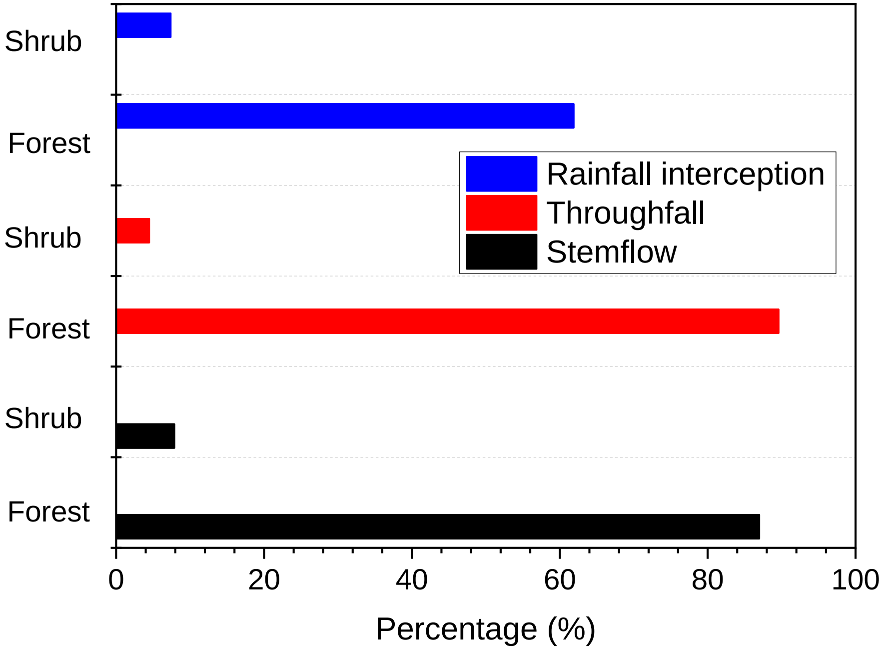


- Rainfall partitioning implies the redistribution of rainfall by vegetation as water passes through the canopy.

Rainfall partitioning

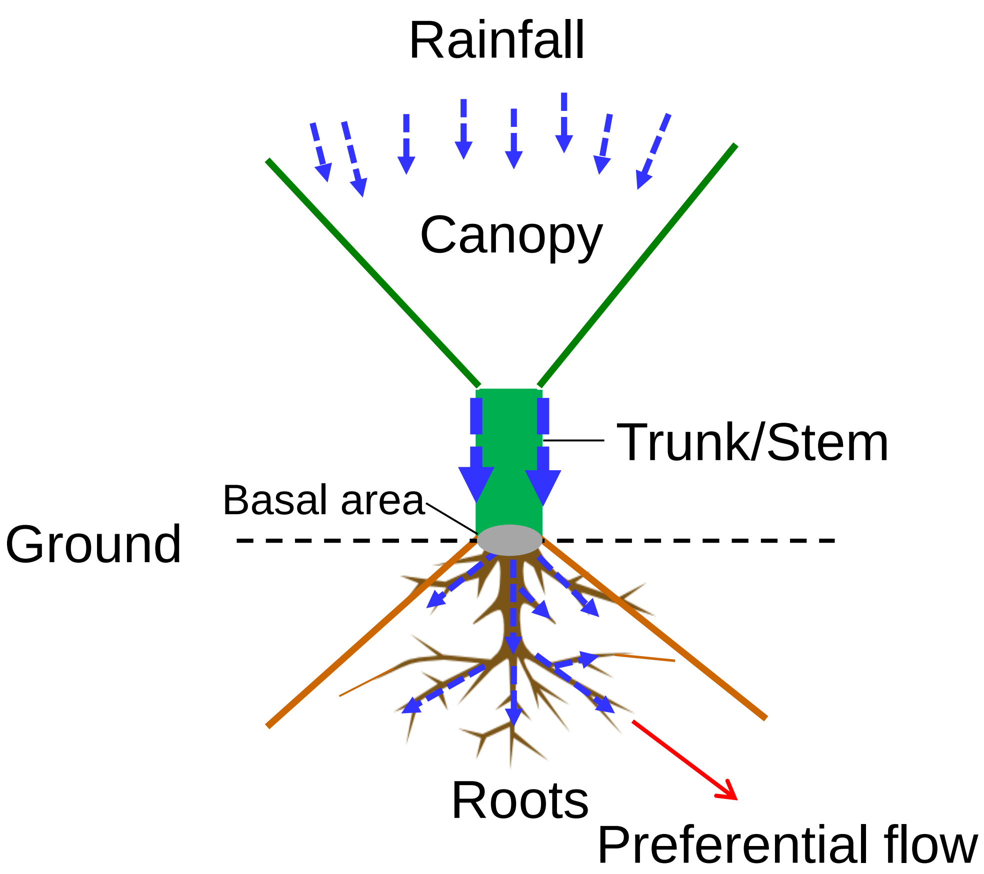


(Web of Science)



- Stemflow is under-represented in the literature in comparison to throughfall and interception
- Studies in shrub-dominated ecosystems are very limited

Double funneling effect



- Stemflow is an important localized source of soil water and nutrients available for shrubs

Research questions

❑ Factors affecting stemflow

Biotic factors

- **plant canopy size and structure**
- **bark morphology**
- **trunk/stem inclination**
- **phenology（leafed V.S. leafless）**

……

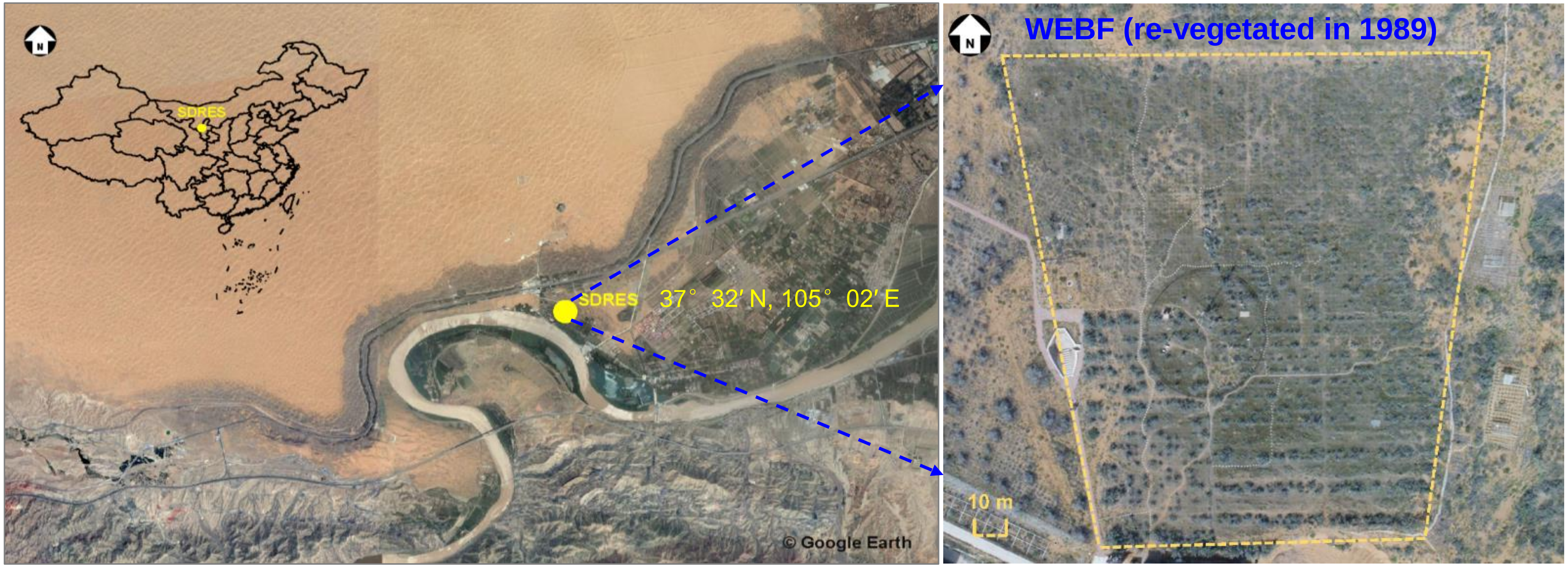
Abiotic factors

- **Rainfall characteristics：** amount, intensity, duration, intra-event intermittency, etc.
- **Other meteorological factors：** temperature, humidity, wind speed and direction, radiation, etc.

How do biotic and abiotic factors affect stemflow production and funneling efficiency of shrubs? What are their relative contributions?

Study site

❑ Water Balance Experimental Field (WEBF) of Shapotou Desert Research and Experiment Station (SDRES)



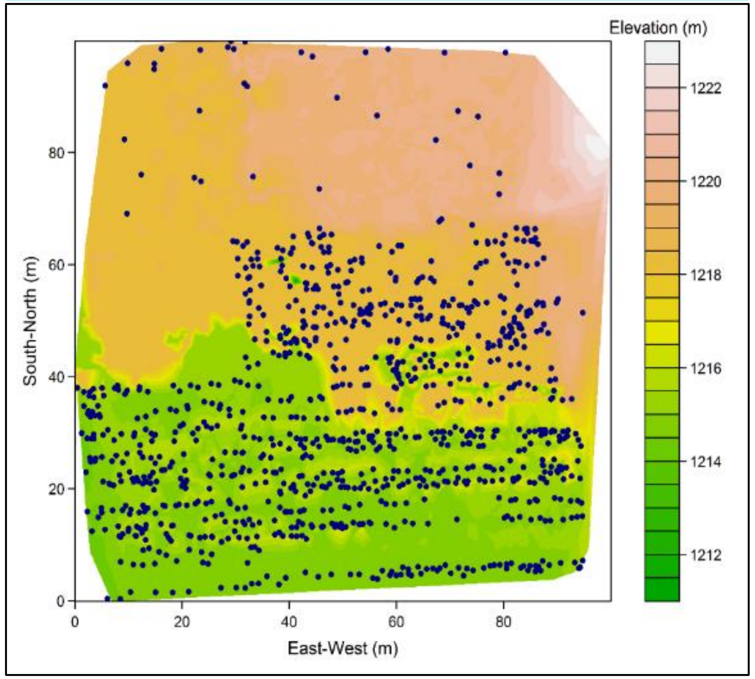
- Mean annual precipitation is 180 mm with 80 % of rain falling between July and September.
- Groundwater: 50 – 80 m.
- Potential evapotranspiration is approximately 2500 mm during the growing season (April – October).
- Mean maximum and minimum air temperature are 24.7 ℃ in July and – 6.1 ℃ in January.
- Annual mean wind velocity is 2.8 m s^{-1}.

Studied species

Caragana korshinskii

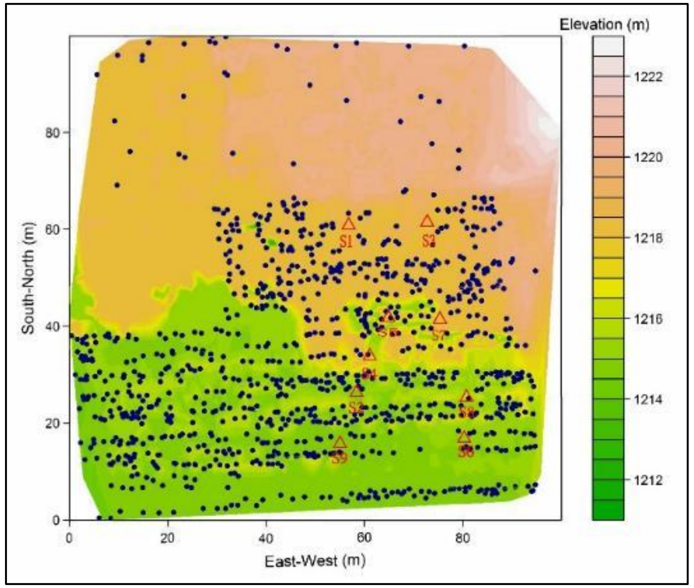
***C. korshinskii* in China**

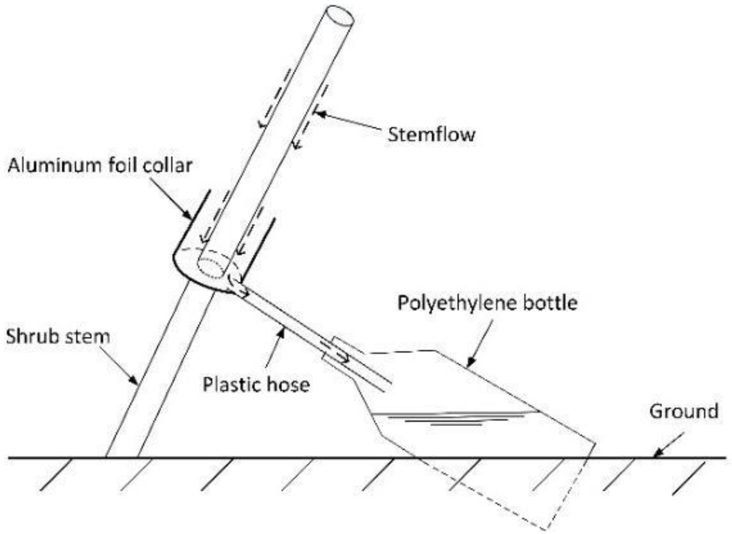
***C. Korshinskii* in WEBF**



- *C. korshinskii* is a multiple-stemmed perennial leguminous shrub, which has been extensively and successfully used in afforestation in arid and semi-arid areas of vast northern China.

Stemflow monitoring and collection





- Nine shrubs were chosen （S1-S9）

- Stemflow was measured after each rainfall events
- 89 rainfall events during 9 growing seasons of 2010-2018

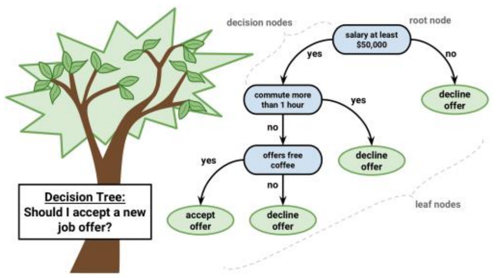
Data analysis

Conventional methods： Simple regression, multiple linear regressions

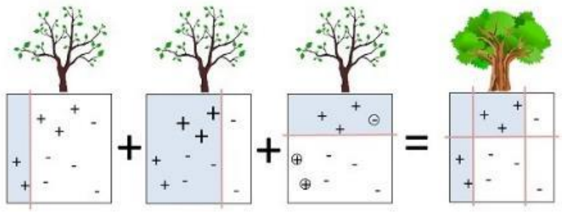
- many ecological relations are typically non-linear
- may lead to high unexplained variations because collinearity often exists among explanatory variables

Method used in our study： Boosted Regression Trees (BRT)

- handle different types of predictor variables and accommodate missing data
- no need for prior data transformation or elimination of outliers
- fit complex nonlinear relationships, and automatically handles interaction effects between predictors
- coincide the high predictive accuracy and the good interpretability of resulting input–output relationships



Boosted Regression Tree is a hierarchical and supervised machine learning method that combines weak learners (binary splits) to strong prediction rules that allow a flexible partition of the feature space.



De'ath, G., 2007. Boosted trees for ecological modeling and prediction. Ecology, 88(1): 243−251.
Elith, J., J. R. Leathwick, and T. Hastie. 2008. A working guide to boosted regression trees. Journal Of Animal Ecology 77:802-813.

BRT parameters

R “dismo” package (Hijmans et al., 2017)

- Bag fraction： specifies the percentage of the data that is used for model building at each step. We set 0.5.
- Learning rate： determines the contribution of each tree to the growing model; slower learning rates result in better predictions, but this demand should be balanced with computing resources and time. We set 0.001.
- Tree complexity： the number of nodes in a tree; it constrains the maximum size of each of the regression trees and sets the maximum number of interactions between predictor variables that are possible. We set 5.

Hijmans, R.J., Phillips S., Leathwick J. and Elith J., 2017. dismo: species distribution modeling. R package version 1.1–4. https://CRAN.R-project.org/package=dismo

Stemflow parameter (Response variable)

Production

1. Stemflow volume (L)

$$SF_v = \frac{\sum_{i=1}^{n} V_i}{1000}$$

SF_v: Stemflow volume (L)
V_i: Stemflow volume for one stem (ml)
n: Number of stems

2. Stemflow percentage (%)

$$SF_p = \frac{SF_d}{RA} \times 100$$

$$SF_d = \frac{SF_v}{PCA}$$

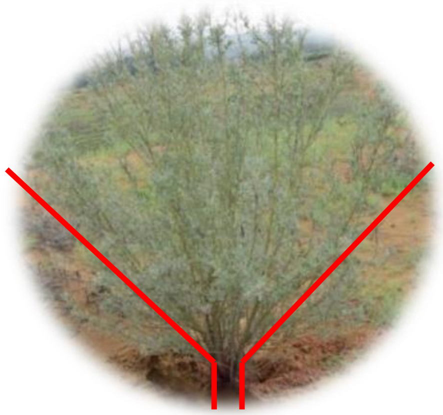
SF_p: Stemflow percentage (%)
SF_d: Stemflow depth (mm)
PCA: Projected canopy area (m^2)
RA: Rainfall amount (mm)

Efficiency

3. Funneling ratio

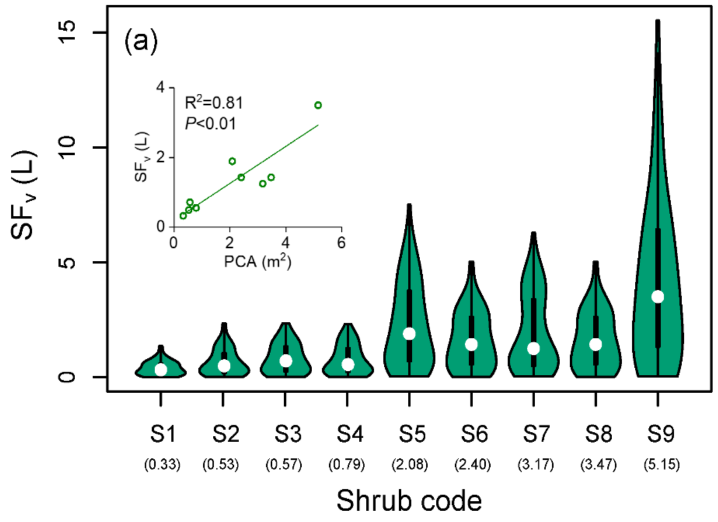
$$FR = \frac{SF_v}{BA \times RA}$$

FR: Funneling ratio
SF_v: Stemflow volume (L)
BA: Basal area (m^2)
RA: Rainfall amount (mm)

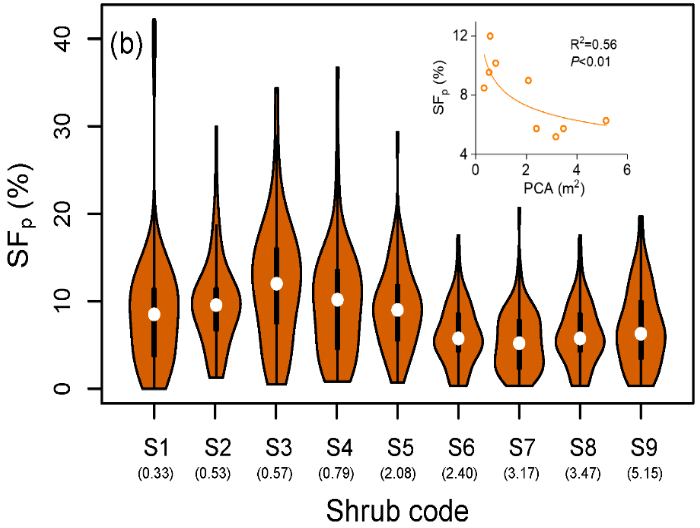


Data distribution of SFv, SFp, FR

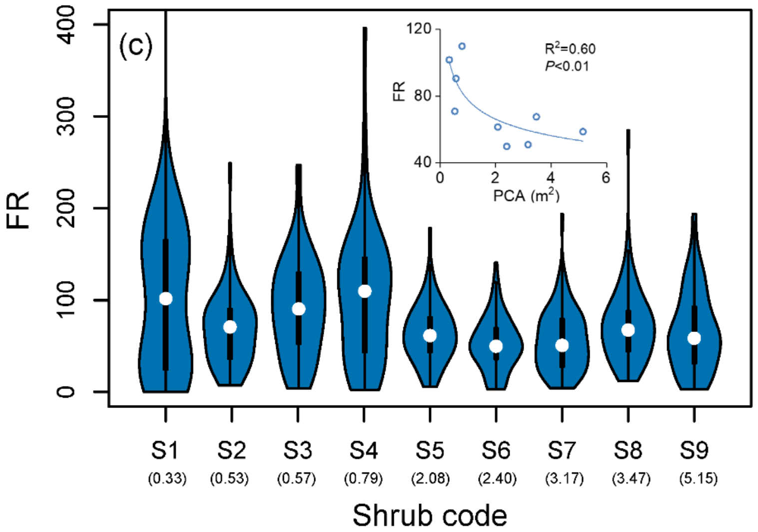
Median: 0.98L



Median: 8%



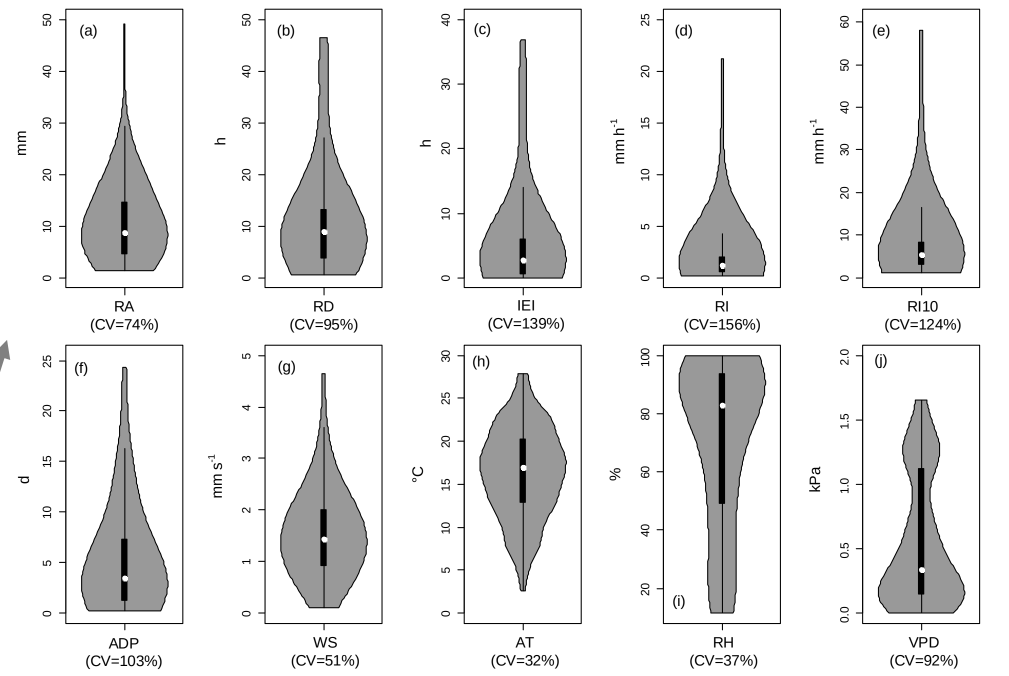
Median: 73



Model input
(Independent variables)

Category	Variable	Abbreviation	Unit
Abiotic	Rainfall amount	RA	mm
	Rainfall duration	RD	h
	Intra-event intermittency	IEI	h
	Rainfall intensity	RI	mm h^{-1}
	Maximum 10-min rainfall intensity	RI10	mm h^{-1}
	Antecedent dry period	ADP	d
	Wind speed	WS	m s^{-1}
	Air temperature	AT	° C
	Relative humidity	RH	%
	Vapor pressure deficit	VPD	kPa
Biotic	Projected canopy area	PCA	m^2
	Basal area	BA	cm^2
	Shrub height	SH	cm
	Number of stems	NS	dimensionless
	Plant area index	PAI	dimensionless
	Average stem inclination	ASI	°

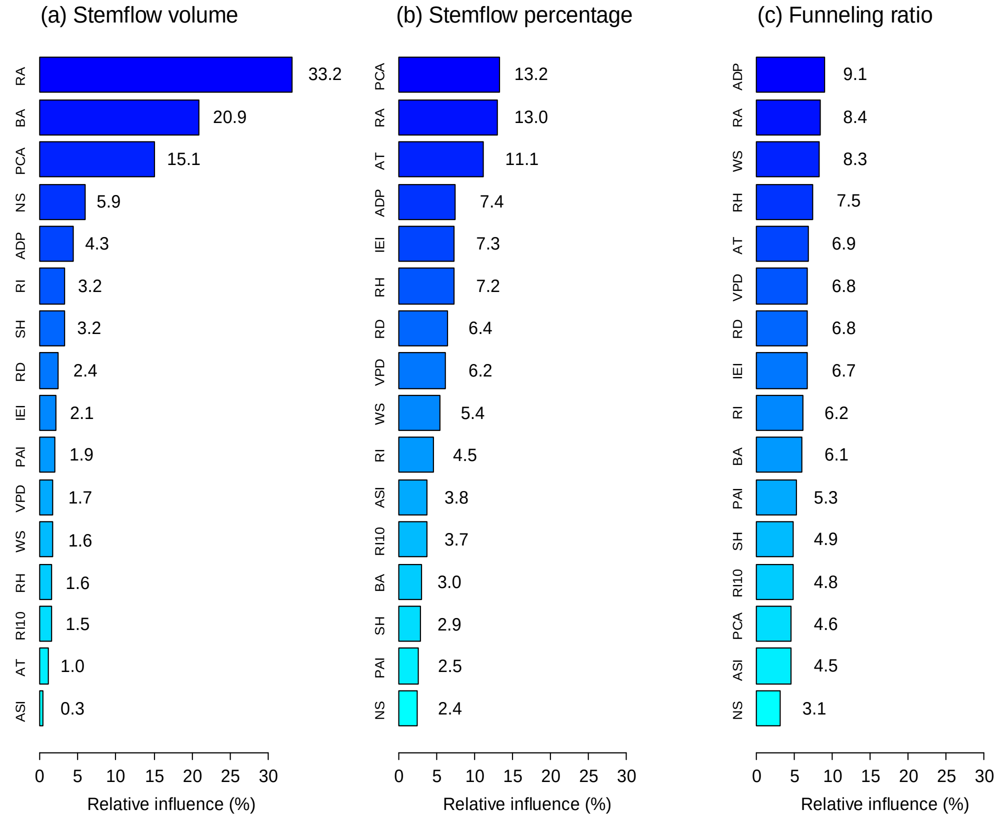
Abiotic



Biotic

No.	PCA	BA	NS	SH	LAI	ASI
S1	0.33	2.9	1	106	0.71	50
S2	0.53	7.8	5	93	0.79	59
S3	0.57	7.7	2	114	0.77	75
S4	0.79	6.3	3	130	0.60	60
S5	2.08	29.7	12.5	172	1.20	61
S6	2.40	27.1	7.5	210	0.73	70
S7	3.17	29.6	11	157	0.88	57
S8	3.47	32.1	6	240	0.71	73
S9	5.15	55.0	10	195	1.10	59
Mean	2.05	22.0	6.4	157	0.83	62.5
SD	1.65	17.2	4.1	51	0.20	8.2
CV (%)	81	78	64	32	24	13

Model output (Relative contribution)



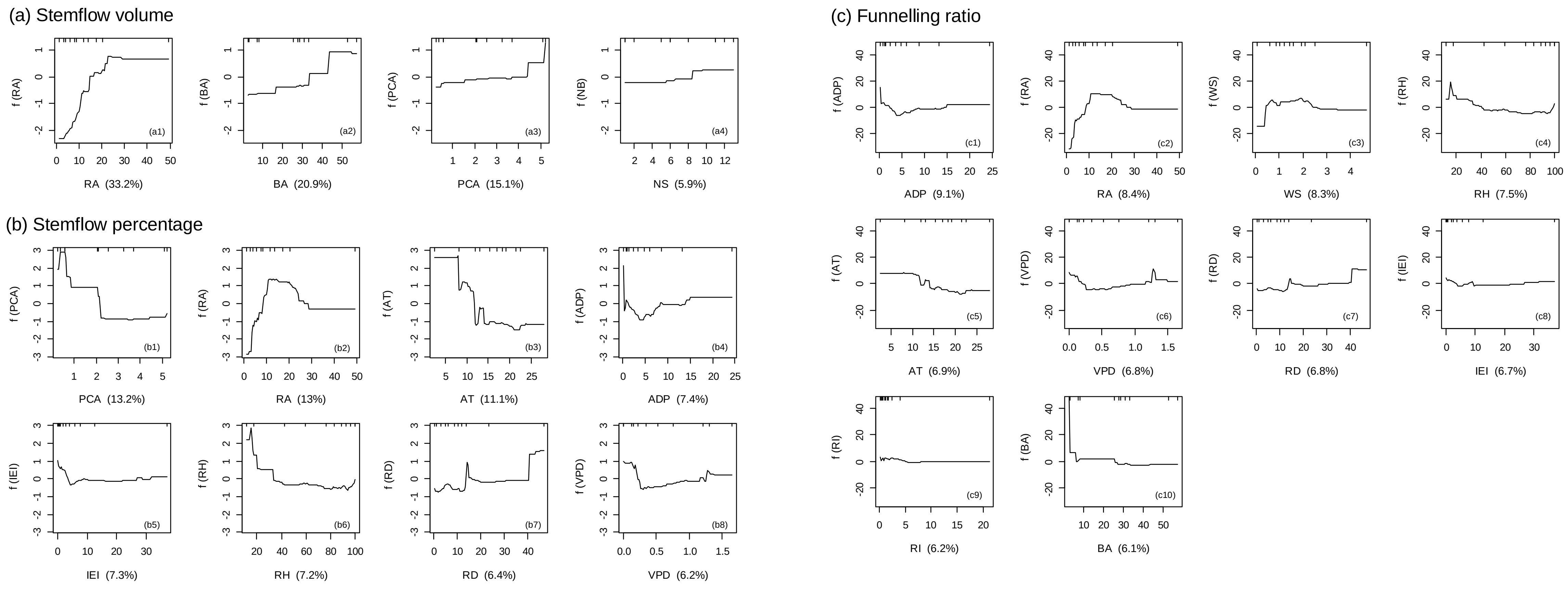
Stemflow parameter	Deviance explained	Cross-validation correlation
SFv (L)	81%	0.9
SFp (%)	66%	0.825
FR	49%	0.838

Stemflow parameter	Mean Relative contribution		biotic/ abiotic
	biotic	abiotic	
SFv (L)	7.90%	5.26%	1.50
SFp (%)	4.63%	7.22%	0.64
FR	4.75%	7.15%	0.67

- Relative contribution of each individual biotic and abiotic variables SFv, SFp, and FR

Zhang, Y.F., Wang, X.P., Pan, Y.X. and Hu, R., 2020. Relative contribution of biotic and abiotic factors to stemflow production and funneling efficiency: A long-term field study on a xerophytic shrub species in Tengger Desert of northern China. Agricultural and Forest Meteorology, 280: 107781.

Model output (Partial dependence plots)



- Effects of several most influential biotic and abiotic variables on SFv, SFp, and FR

Zhang, Y.F., Wang, X.P., Pan, Y.X. and Hu, R., 2020. Relative contribution of biotic and abiotic factors to stemflow production and funneling efficiency: A long-term field study on a xerophytic shrub species in Tengger Desert of northern China. Agricultural and Forest Meteorology, 280: 107781.

Conclusion

- Through BRT modeling associating with partial dependence plots, we provided the quantitative evaluation and mechanistic explanations on how exactly individual biotic (shrub morphological attributes) and abiotic variables (meteorological conditions) contribute to and affect stemflow production and funneling efficiency of shrub species, respectively

- BRT analysis demonstrated that biotic variables outweighed abiotic variables by 1.5-fold as to their contribution to SFv, whereas abiotic variables prevailed for SFp and FR, respectively

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