中国北方油松林生态系统资源利用效率的年际变化和干旱的关系

Interannual variation of resource use efficiency and its relationships between drought in *Pinus tabulaeformis* forest ecosystem in northern China

汇报人：靳川

主要内容

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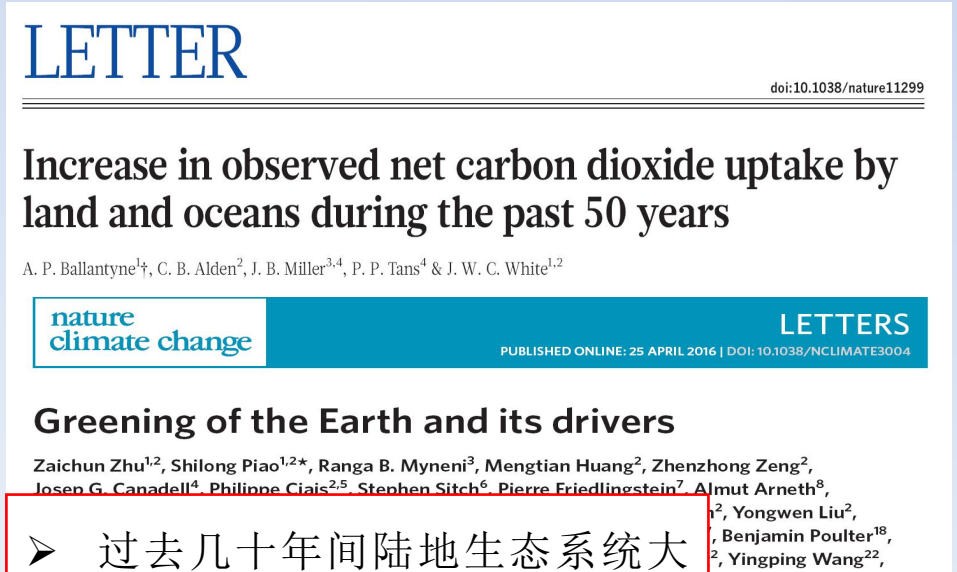
一、研究背景



LETTER

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Increase in observed net carbon dioxide uptake by land and oceans during the past 50 years

A. P. Ballantyne[1]†, C. B. Alden[2], J. B. Miller[3,4], P. P. Tans[4] & J. W. C. White[1,2]

nature climate change

LETTERS

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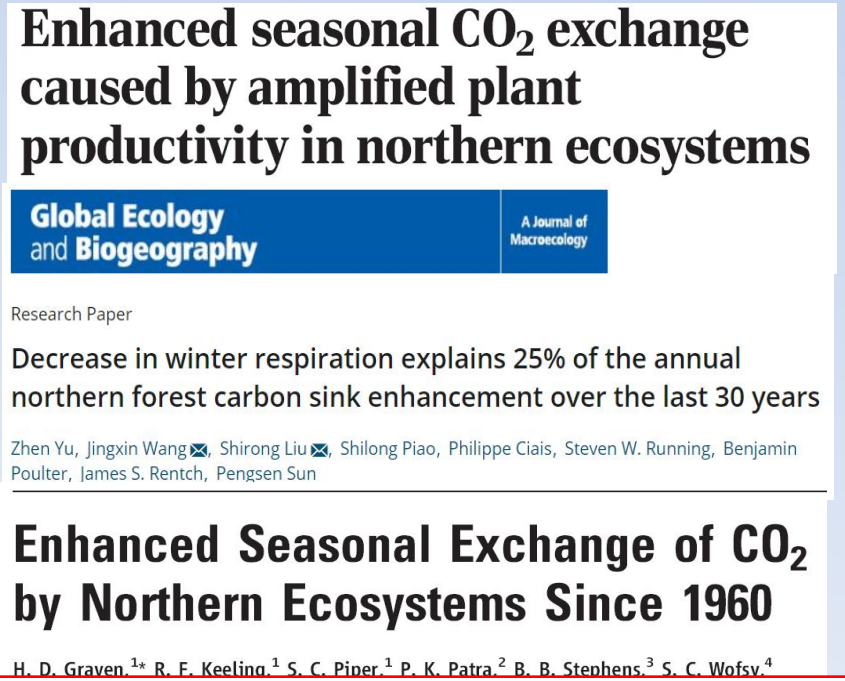
Greening of the Earth and its drivers

Zaichun Zhu[1,2], Shilong Piao[1,2]*, Ranga B. Myneni[3], Mengtian Huang[2], Zhenzhong Zeng[2], Josep G. Canadell[4], Philippe Ciais[2,5], Stephen Sitch[6], Pierre Friedlingstein[7], Almut Arneth[8], [2], Yongwen Liu[2], , Benjamin Poulter[18], [2], Yingping Wang[22],

- 过去几十年间陆地生态系统大气CO_2浓度的季节变化幅度极大的增加了。
- The seasonal variation of atmospheric CO_2 concentrations in terrestrial ecosystems has increased dramatically over the past few decades.



Enhanced seasonal CO_2 exchange caused by amplified plant productivity in northern ecosystems

Global Ecology and Biogeography

A Journal of Macroecology

Research Paper

Decrease in winter respiration explains 25% of the annual northern forest carbon sink enhancement over the last 30 years

Zhen Yu, Jingxin Wang, Shirong Liu, Shilong Piao, Philippe Ciais, Steven W. Running, Benjamin Poulter, James S. Rentch, Pengsen Sun

Enhanced Seasonal Exchange of CO_2 by Northern Ecosystems Since 1960

H. D. Graven,[1]* R. F. Keeling,[1] S. C. Piper,[1] P. K. Patra,[2] B. B. Stephens,[3] S. C. Wofsy,[4]

- 有的研究者认为，高纬地区植被覆盖增加是导致陆地生态系统碳循环年际变异的主要因素。
- Some researchers believe that the increase of vegetation cover in high latitudes is the main factor leading to the interannual variation of terrestrial ecosystem carbon cycle.

一、研究背景

Variations in atmospheric CO_2 growth rates coupled with tropical temperature

Interannual variation of terrestrial carbon cycle: Issues and perspectives

Shilong Piao ✉, Xuhui Wang, Kai Wang, Xiangyi Li, Ana Bastos, Josep G. Canadell, Philippe Ciais, Pierre Friedlingstein, Stephen Sitch

First published:31 October 2019 | https://doi.org/10.1111/gcb.14884 | Citations: 1

- 有研究归因于碳水交换年际变异
- Studies have attributed this to interannual variability in the exchange of carbon and water

Divergent long-term trends and interannual variation in ecosystem resource use efficiencies of a southern boreal old black spruce forest 1999–2017

- 资源利用效率是反映生态系统功能和碳水耦合的重要指标，因此，人工林生态系统CUE、LUE和WUE对气候变化和极端事件响应敏感性、过程与机理引起学者的极大关注

- 北方人工林比大多数温带和热带天然森林对气候变异，特别是极端天气事件（如干旱、高温和强降雨等）的响应往往比其它生态系统尤为敏感。
- Northern plantations tend to be more sensitive than most temperate and tropical natural forests to climate variability, especially extreme weather events such as droughts, high temperatures and heavy rainfall, than other ecosystems

二、研究目标

本研究重点解决以下关键科学问题：

(1)油松人工林生态系统碳水通量的年际变异特征是怎样的?与水分条件的关系是怎样的?

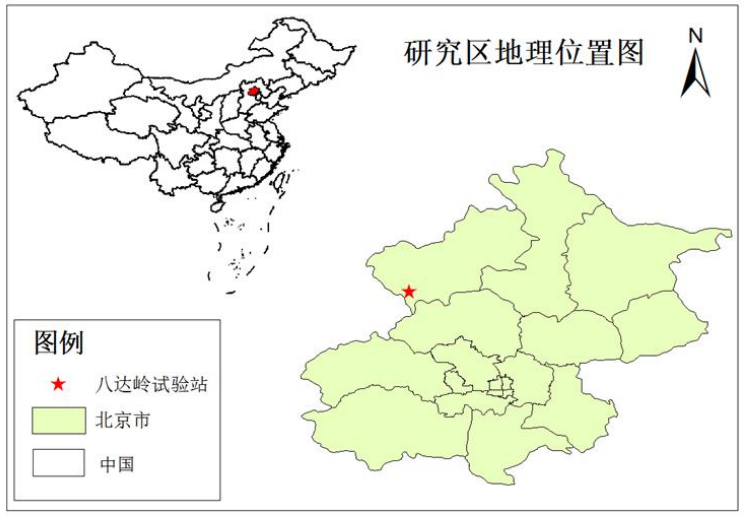
(2)油松人工林生态系统各资源利用效率的年际差异和长期趋势有何特征?如何响应干旱条件？

This study focused on solving the following key scientific questions:

(1) What is the interannual variability of carbon and water fluxes in *Pinus tabulaeformis* plantation ecosystem? How does it relate to water conditions?

(2) What are the characteristics of inter-annual differences and long-term trends of resource use efficiency of *Pinus tabulaeformis* plantation ecosystem? How to respond to drought conditions?

三、研究区概况

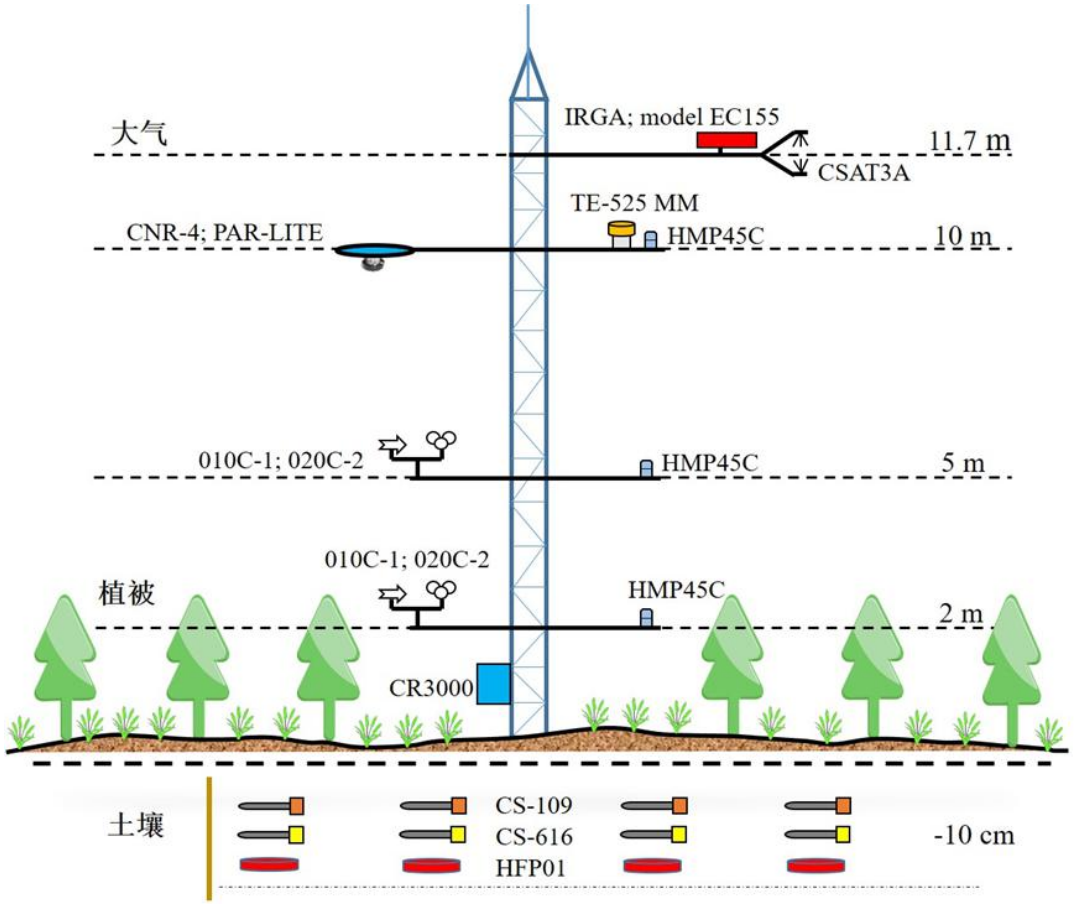


- 研究区位于北京延庆县八达岭“五七”林场（40.37°N，115.94°E，海拔535 m），地处万里长城八达岭和居庸关之间，属中山地形区，地势相对平坦，总占地面积约2940公顷。

- 试验区主要造林树种以油松（*Pinus tabuliformis* Carr.）为主，同时包括一些落叶阔叶树种，其中针阔混交比为7:3，混交方式为块状混交。
- The main afforested species in the experimental area were *Pinus tabuliformis* Carr. At the same time, some deciduous broad-leaved trees were included. The mixed ratio of conifer and broad-leaved trees was 7:3, and the mixed mode was block-mixed.

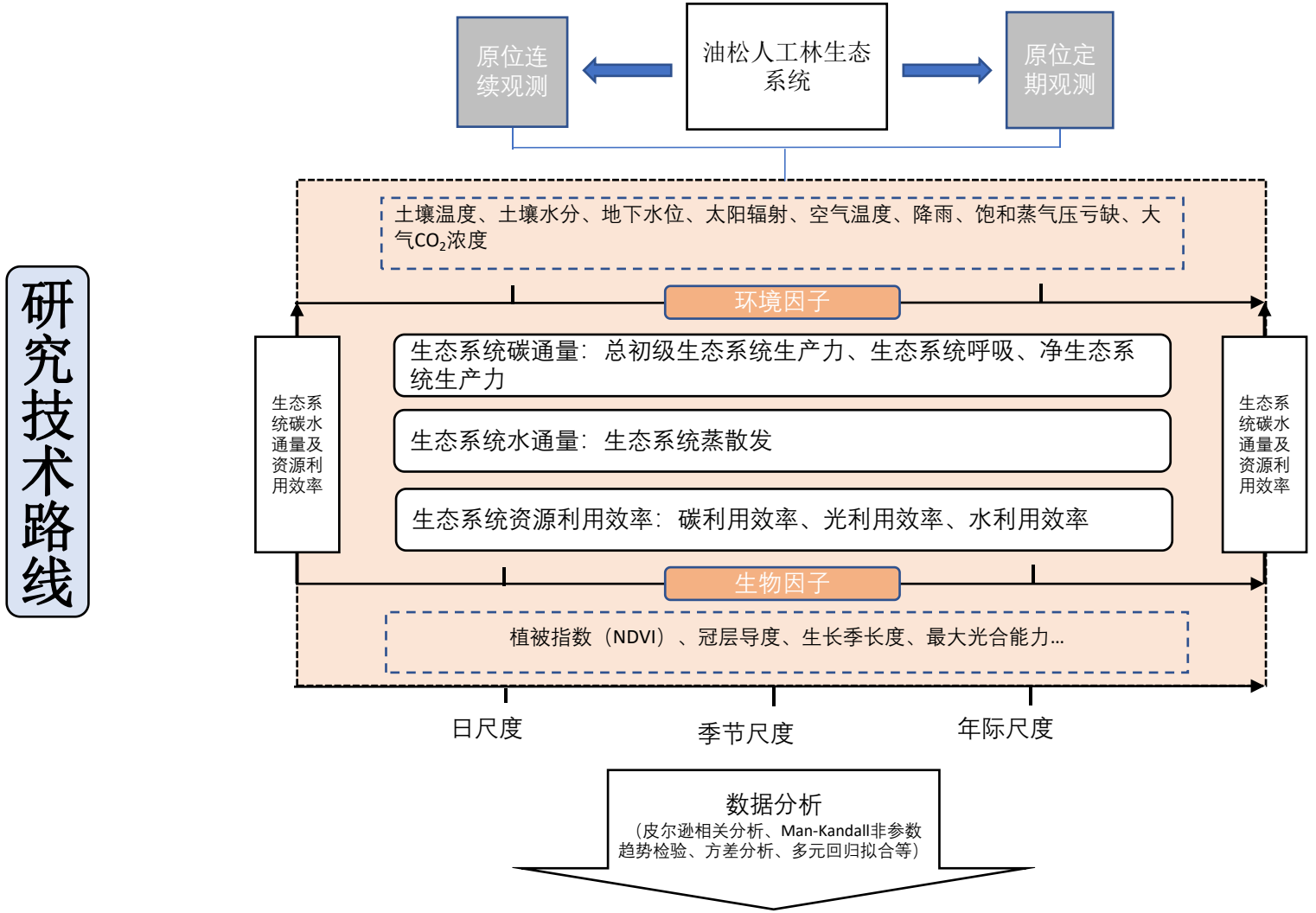
三、研究区概况

- 闭路式涡度相关系统：油松人工林生态系统的CO2和H2O交换浓度
- 微气象要素观测：长波辐射、短波辐射、光合有效辐射、风速、风向、空气温度、空气湿度、降雨量
- 植被测量：样地调查、每木检尺
- 土壤层观测：土壤热通量、土壤温度和土壤湿度



四、研究内容与研究方法

研究技术路线



- 油松人工林生态系统碳水通量年际变异特征及调控机制
- 油松人工林生态系统碳通量年际变异特征和资源利用效率比较

五、研究结果——相关生物物理因子计算公式

相对土壤含水量（REW）

$$\mathrm{REW}=\frac{SWC-SWC_{min}}{SWC_{max}-SWC_{min}}$$

冠层导度（gs）

$$g_S=\frac{\gamma LEg_a}{\Delta(Rn-G)+\rho C_p VPDg_a-LE(\Delta+\gamma)}$$

最大光合能力（Pmax）与表观量子效率（α）

$$\mathrm{GEP}=\frac{\alpha\times PAR\times P_{max}}{\alpha\times PAR+P_{max}}$$

蒸发比值（EF）

$$\mathrm{EF}=\frac{\mathrm{LE}}{\mathrm{LE}+\mathrm{H}}$$

五、研究结果——生态系统资源利用效率计算公式

碳利用效率（CUE）

$$\mathrm{NEP} = \mathrm{GEP} - R_{a\_}R_h = (1-m)\mathrm{GEP} - R_{\mathrm{h}}$$

光能利用效率（LUE）

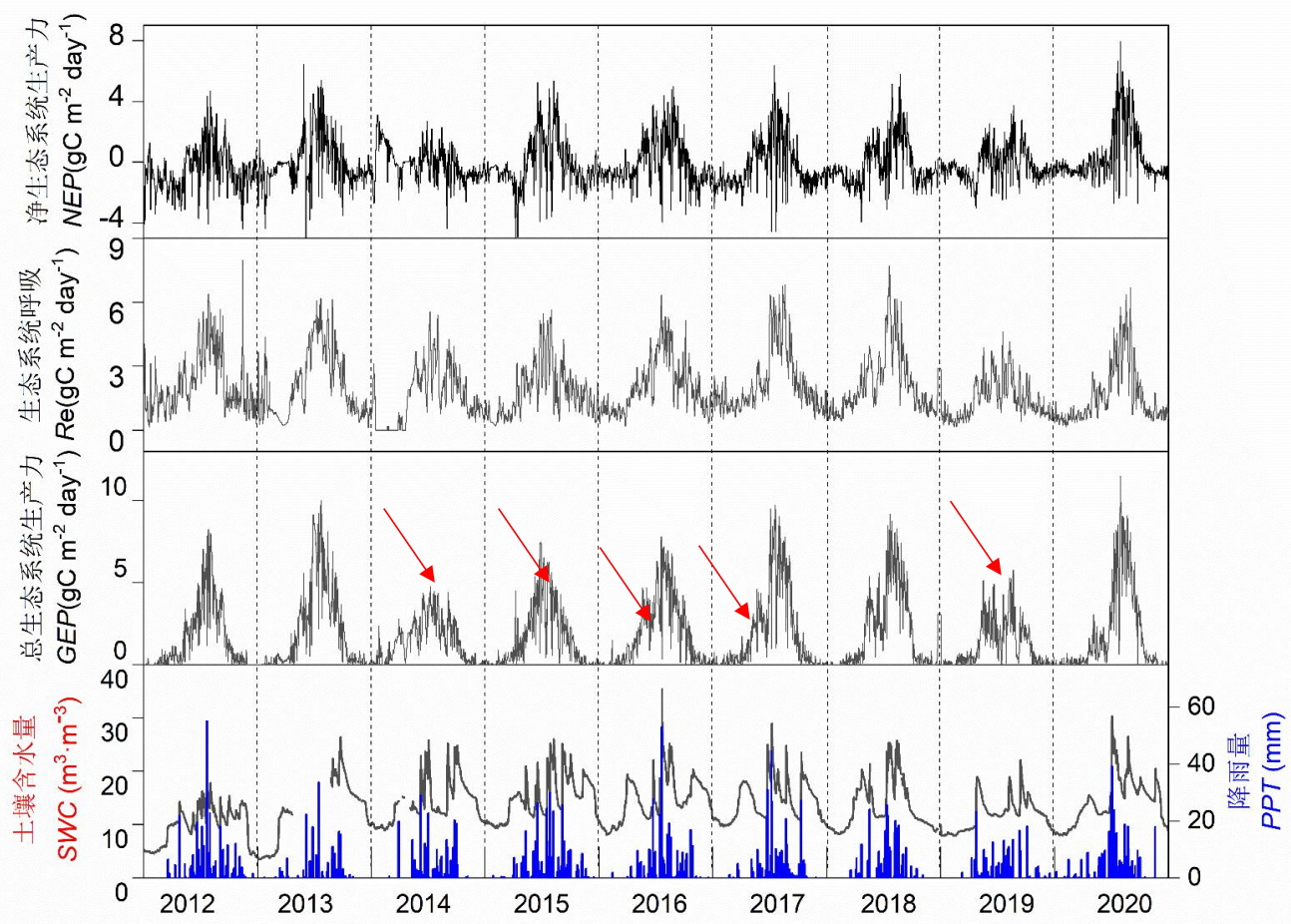
$$\mathrm{GEP} = \frac{\mathrm{LUE} \times \mathrm{PAR} \times \mathrm{P_{max}}}{\mathrm{LUE} \times \mathrm{PAR} + \mathrm{P_{max}}}$$

水利用效率（WUE）

$$\mathrm{WUE} = \frac{\mathrm{GEP}}{\mathrm{ET}}$$

五、研究结果——油松人工林生态系统碳水通量动态特征

- 2014年、2015年和2019年受夏季干旱的影响，GEP的峰值都表现出了下降的趋势。2016年和2017年，受春季干旱的影响，生长初期人工林生态系统GEP表现出现了明显下降的趋势。此外，2017年秋季干旱也造成了人工林生态系统GEP的减小。



- In 2014, 2015 and 2019, the peak value of GEP showed a decreasing trend due to summer drought. In 2016 and 2017, the peak value of GEP showed a significant decreasing trend due to spring drought. In addition, drought in autumn of 2017 also caused the decrease of GEP of plantation ecosystem.

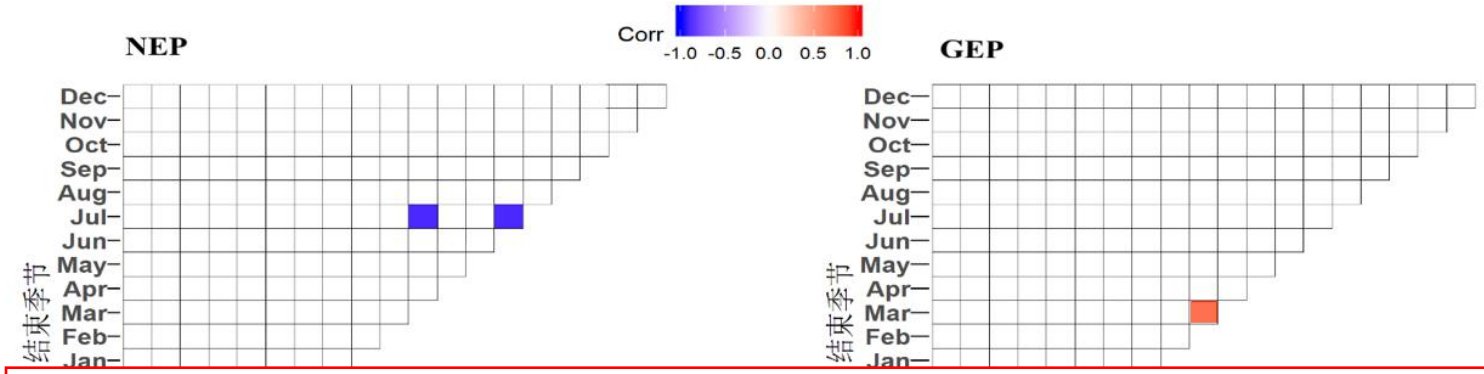
五、研究结果——油松人工林生态系统碳水通量年总值

变量	年份									多年平均值
	2012	2013	2014	2015	2016	2017	2018	2019	2020	
NEP（g C $^{-2}$ Yr^{-1}）	-219.37	-1.46	-26.45	-72.64	-26.04	-97.05	-56.98	-84.75	134.61	-50.01
Re（g C $^{-2}$ Yr^{-1}）	828.71	799.44	594.81	677.02	770.87	838.60	822.81	536.83	602.94	719.11
GEP（g C $^{-2}$ Yr^{-1}）	507.36	728.10	343.61	486.13	637.45	663.76	695.51	383.25	659.88	567.23
ET（mm Yr^{-1}）	327.21	371.06	289.94	326.09	333.59	364.15	258.37	166.34	114.52	283.47
PPT（mm Yr^{-1}）	357.50	229.50	299.40	414.30	504.40	346.20	311.60	256.50	401.70	346.79

- 油松人工林生态系统总体上为碳源
- NEP年际变异主要归因于GEP
- ET、PPT年总值与碳水通量有相关关系

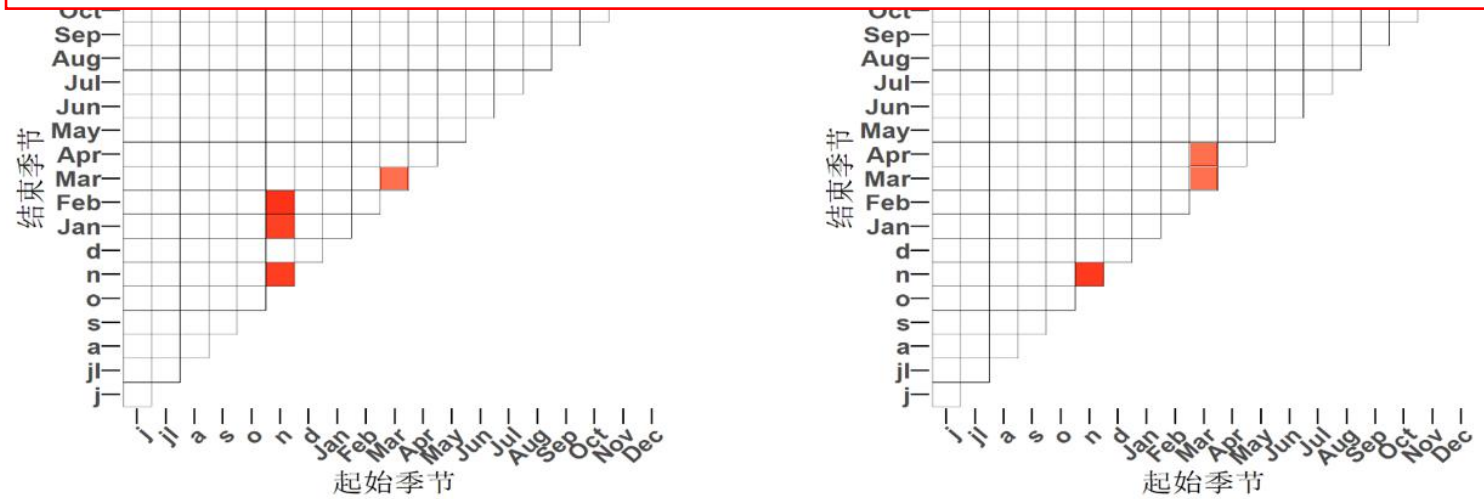
- The ecosystem of *Pinus tabulaeformis* plantation is the carbon source
- The interannual variation in NEP is mainly attributable to GEP
- ET PPT annual total value is correlated with carbon and water flux

五、研究结果——油松人工林生态系统碳水通量对降雨的响应

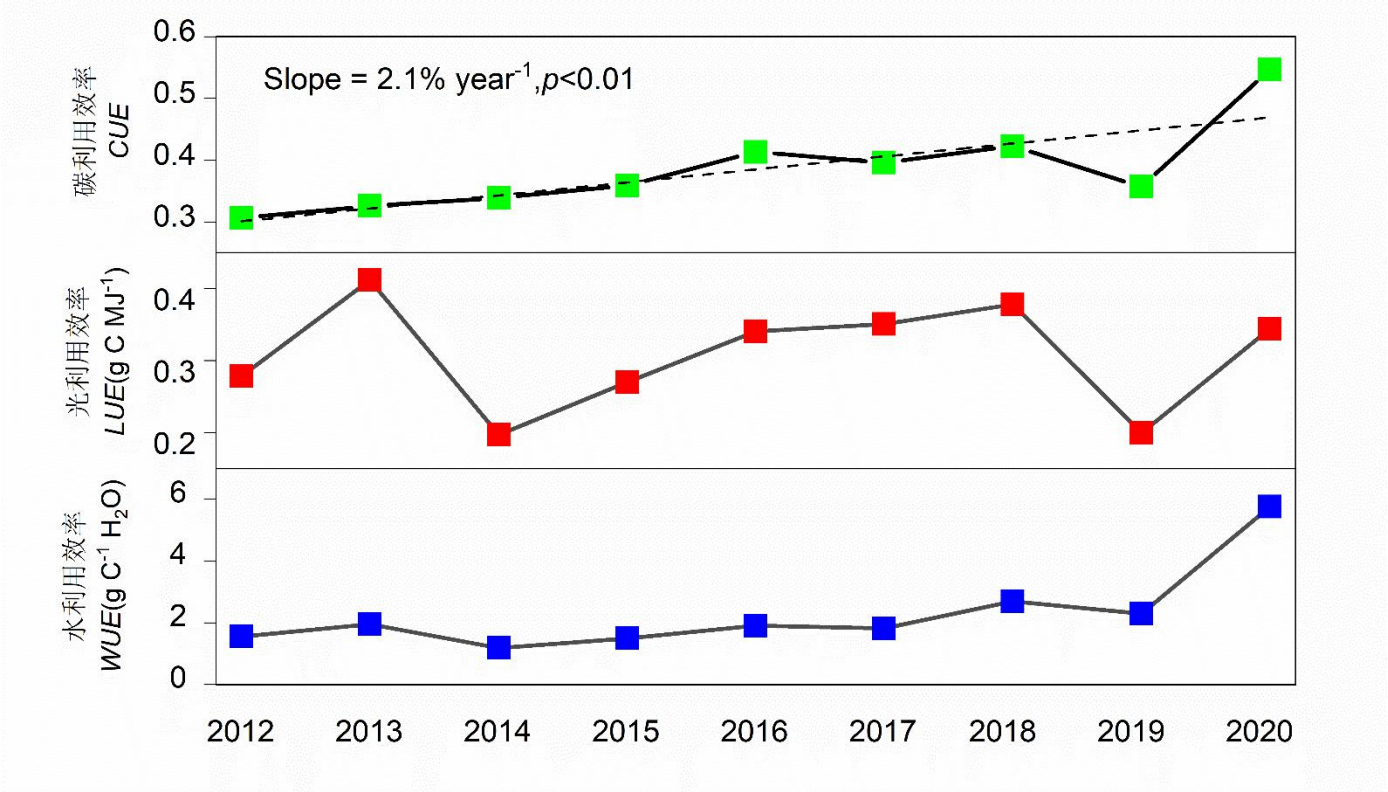


- NEP, GEP, Re, ET与前一年秋季降雨、当年春季降雨均存在相关关系

- NEP, GEP, Re, ET are correlated with the previous year's autumn rainfall and spring rainfall

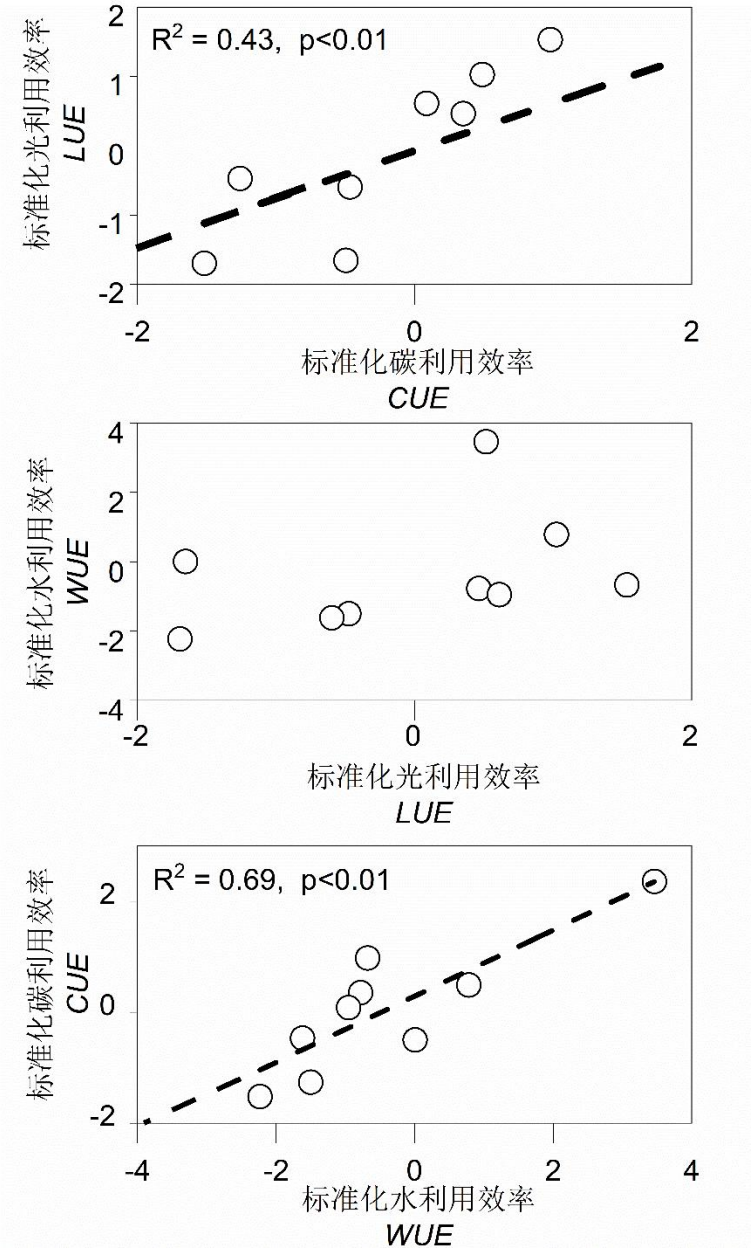


五、研究结果——油松人工林生态系统资源利用效率动态特征



- 虚线表示相应资源利用效率的长期趋势
- 油松人工林生态系统碳利用效率（CUE ）存在显著增加的长期趋势
- The dotted line shows the long-term trend of the corresponding resource use efficiency
- The carbon use efficiency (CUE) of *Pinus tabulaeformis* plantation ecosystem showed a long-term trend of significant increase

五、研究结果——油松人工林生态系统资源利用效率相关关系

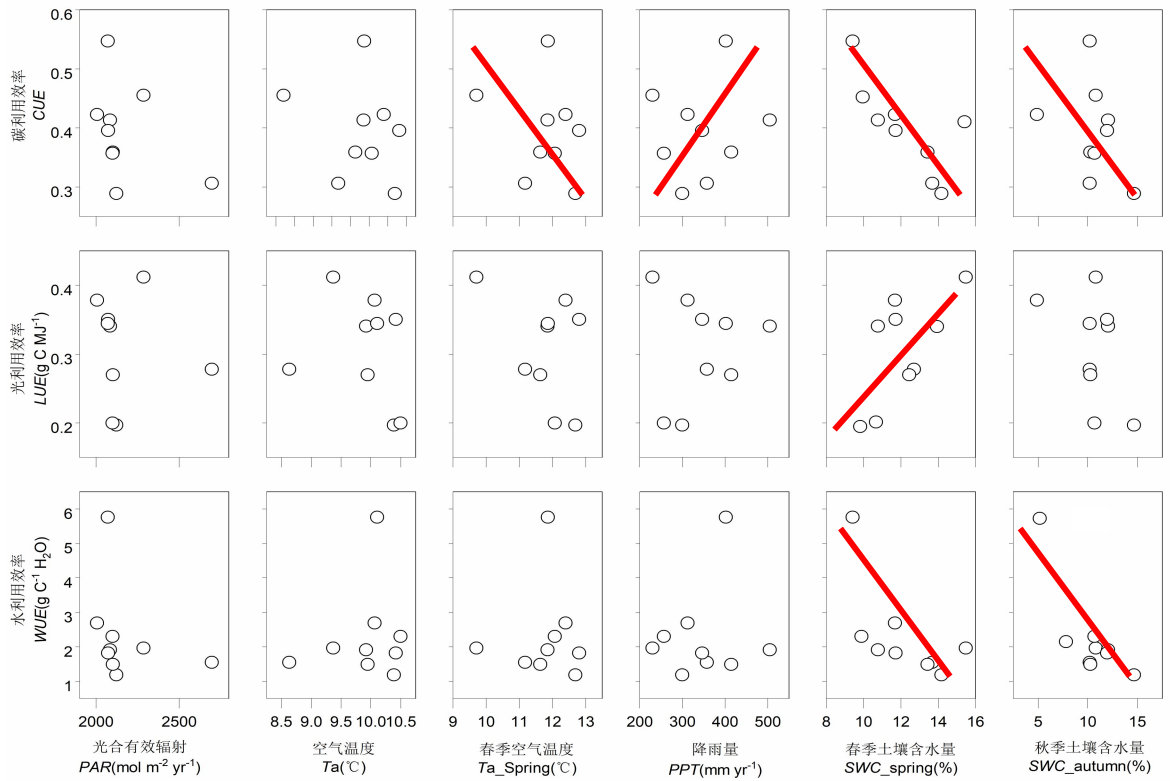


- CUE 是表征生态系统碳循环差异的重要参数，了解生态系统 CUE 有助于分析陆地生态系统是碳源还是碳汇。
- LUE 不仅是植被光合作用的重要概念，更是研究陆地生态系统不同尺度的GEP 估算模型的重要参数之一。
- WUE是表征陆地生态系统中植物光合碳同化与水消耗之间权衡关系的重要指标，能够很好的量化区域水资源对生态系统生产力和碳固定的支撑能力。
- 三者都展现出较大的年际变异，油松人工林生态系统 CUE 和 LUE 之间存在显著的正相关关系；CUE 和 WUE 之间存在显著的正相关关系；而 CUE和 WUE之间并不存在显著的相关关系。

- There was a significant positive correlation between CUE and LUE in *Pinus tabulaeformis* plantation ecosystem.
- There is a significant positive correlation between CUE and WUE.
- There is no significant correlation between CUE and WUE

五、研究结果——油松人工林生态系统资源利用效率的调控机制

- 年降雨量和CUE呈正相关，春季空气温度、春季土壤含水量、秋季土壤含水量和CUE呈负相关；
- 春季土壤含水量和LUE呈正相关；
- 春季土壤含水量、秋季土壤含水量和WUE呈负相关。



- There was a positive correlation between annual rainfall and CUE, and a negative correlation between spring air temperature and spring soil water content and autumn soil water content and CUE. There was a positive correlation between soil water content and LUE in spring. There was a negative correlation between WUE and soil water content in spring and autumn

五、研究结果——油松人工林生态系统资源利用效率的调控因子

- 春季空气温度、降雨量、春季土壤含水量、秋季土壤含水量是CUE年际变异的主要调控因素；
- 春季土壤含水量是LUE年际变异的主要调控因素；
- 春季土壤含水量、秋季土壤含水量是WUE年际变异的主要调控因素。

变量	环境因子相关系数			
	春季空气温度	降雨量	春季土壤含水量	秋季土壤含水量
碳利用效率 CUE	0.42	0.15	0.75	0.57
光利用效率 LUE	NaN	NaN	0.63	NaN
水利用效率 WUE	NaN	NaN	0.19	0.22

- Spring air temperature rainfall spring soil water content autumn soil water content is the main regulating factor of CUE interannual variability;
- Spring soil water content was the main regulating factor of interannual variation of LUE.
- Soil moisture content in spring and autumn is the main regulating factor of interannual variation of WUE

六、主要研究结论

- 油松人工林生态系统总体表现为碳源，降水季节分布、年际波动及其滞后效应是生态系统碳平衡的主要影响因素
- 油松人工林生态系统各资源利用效率展现出较大年际变异，CUE存在显著增加的长期趋势，CUE 和 LUE 、CUE 和 WUE 之间存在显著的正相关关系
- 限制油松人工林生态系统资源利用效率的主要因素是春季空气温度、降雨量、春季土壤含水量、秋季土壤含水量

- The ecosystem of *Pinus tabulaeaei* plantation was generally carbon source, and the inter-annual fluctuation and lag effect of precipitation seasonal distribution were the main factors affecting the carbon balance of the ecosystem
- The resource use efficiency of *Pinus tabulaeformis* plantation ecosystem showed a large interannual variation, CUE had a long-term trend of significant increase,CUE and LUE CUE and WUE had a significant positive correlation
- The main factors limiting the resource utilization efficiency of *Pinus tabulaeformis* plantation ecosystem were the air temperature and rainfall in spring and the soil water content in spring and the soil water content in autumn

七、展望

- 建议对人工林生态系统碳水通量更长时间序列的监测研究，探究生态系统碳水通量是否存在长期趋势，其资源利用效率调控机制在更长时间尺度上是否存在变化，其气候敏感性在长时间序列上如何变化。
- 在研究资源利用效率对干旱的响应时，只在生态系统水平上进行了研究，在单叶、个体等尺度上对干旱的响应并未涉及。由于组成人工林生态系统的树种各不相同，且不同的树种对干旱的响应也有所不同。在未来的研究中，可以进行单叶和个体水平上的资源利用效率及其对干旱胁迫的响应关系的研究，以期为生产实践提供理论指导。
- It is suggested to monitor the carbon and water flux of *Pinus tabulaeformis* plantation ecosystem in a longer time series to explore whether there is a long-term trend
- It is suggested to carry out research on resource use efficiency at leaf and individual level, in order to provide theoretical guidance for production practice.

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