Using Deuterium and Oxygen-18 Stable Isotopes to Understand Mechanisms of Stemflow Generation as a Function of Tree Species and Climate #59083

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Introduction

- Stemflow (SF) is a type of rain partitioning by the forest canopy that redirects water down tree trunks (FIG 1). During this process, nutrients are leached from tree surfaces delivering highly enriched water to the tree base (FIG 2)[1].
- Throughfall (TF) is the water intercepted by the canopy that falls through as enriched water to forest soils[1].
- Mechanisms of water exchange during the SF process have not been well established and prevent full integration of this process into hydrologic and biogeochemical models that include small-scale SF water cycles and bark water storage capacities.

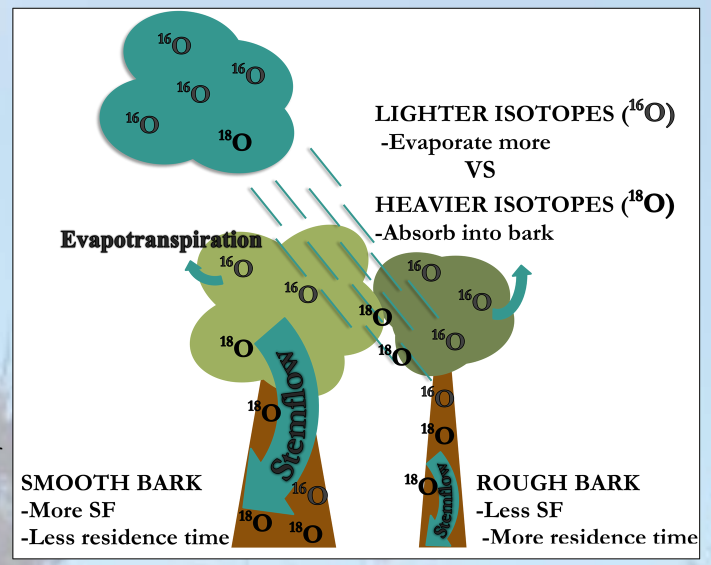

Figure 1. A schematic of heavy and light oxygen (^{18}O/^{16}O) isotopic compositions and processes.

- Stable deuterium (^{2}H/D) and oxygen (^{18}O) isotopic tracers can be used to follow water through hydrological cycles. Lighter isotopes (^{1}H and ^{16}O) are more readily evaporated back into the atmosphere from tree surfaces[2,3]. When SF water evaporates from bark surfaces, ^{1}H and ^{16}O are preferentially evaporated, leaving the heavier isotopes (D and ^{18}O) in the tree bark (FIG 3)[2,3].
- Different tree species (TAB 1) have unique bark characteristics (FIG 4) and variable effects on rain partitioning[4]. We look to examine species-specific effects on forest hydrological cycles via stable isotopes.

Figure 2. Polyethylene SF collars cut longitudinally, were attached to the tree with aluminum nails and silicone caulk; TF collectors consisted of an 20.3cm diameter funnel attached to a Nalgene bottle on a 1m high post.

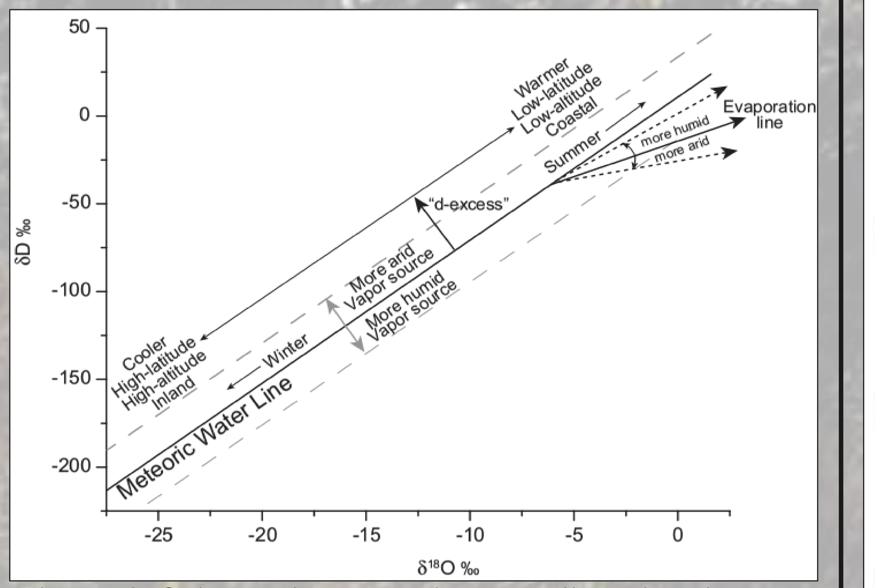

Figure 3. Schematic meteoric water line showing factors leading to deviations from the δ^{18}O-δD relationship[5].

Objectives

SF volume and isotopic composition (δD and δ^{18}O) were measured over a one-year period to address three main objectives:

1. Determine origins and pathways of SF water using stable water isotopes.
2. Identify differences in SF generation mechanisms between tree species.
3. Identify differences in SF generation mechanisms between storm events.

Materials & Methods

Table 1. A description of tree characteristics at SNA.

Tree Species	Latin Name	Species Code	# of SF Trees	Canopy Cover (m^2)	Average DBH (cm)
Cherrybark oak	*Quercus pagoda*	CBO	3	8.6	68.6
Shumard oak	*Quercus shumardii*	SO	3	3.8	65.4
White oak	*Quercus alba*	WO	3	6.4	66.6
Post oak	*Quercus stellata*	PO	3	6.8	59.1
Shagbark hickory	*Carya ovata*	CSH	3	3.3	35.7
Pignut hickory	*Carya glabra*	PNH	3	4.2	43.9

- This study was conducted at Sessum's Natural Area (SNA), an old growth oak-hickory stand in Starkville, MS (TAB 1 & FIG 5).

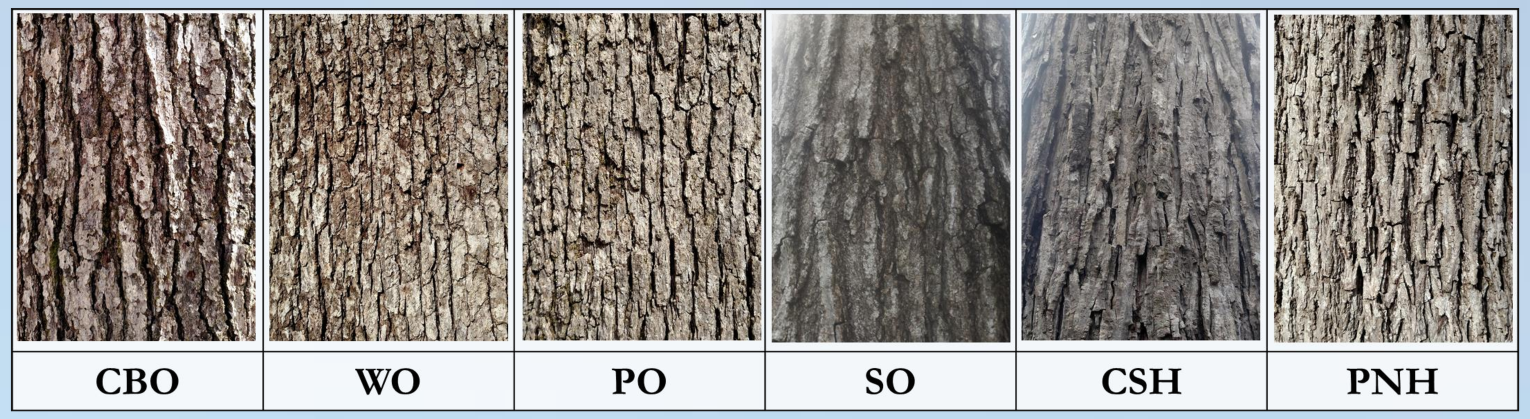

Figure 4. Bark roughness is quite variable between the six species.

- Storm events with at least 12mm of rainfall were sampled.
- One gross precipitation (PG) gauge was used along with four TF collection apparatuses at SNA (FIG 2) to compare isotopic compositions to that of SF water signatures.
- Water samples were collected in 20mL vials with no head space and later analyzed for δD and δ^{18}O with laser ablation spectroscopy at LSU and expressed relative to the Vienna Standard Mean Ocean Water (VSMOW), according to the following equation:

$$\delta\,(^{0}/_{00}) = \left(\frac{R_{(sample)}}{R_{(standard)}} - 1\right) x\, 1000$$

$R_{(sample)}$=the ratio of heavy to light isotopes in the sample

$R_{(standard)}$=the ratio of heavy to light isotopes of the standard

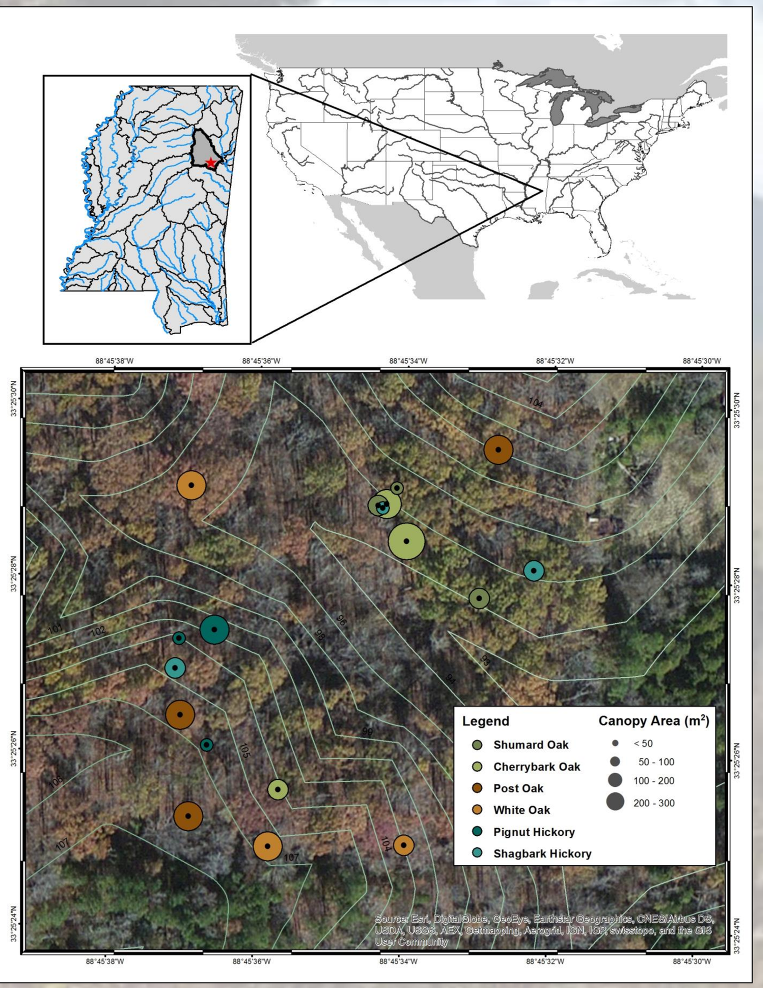

Figure 5. Map of SNA, Mississippi, including contour lines and canopy area of all six experimental species.

- Eight bark thickness measurements were taken per tree, with a bark gauge to determine differences between species (FIG 6); relation to total volumetric fluxes were recorded for SF, TF, and PG.

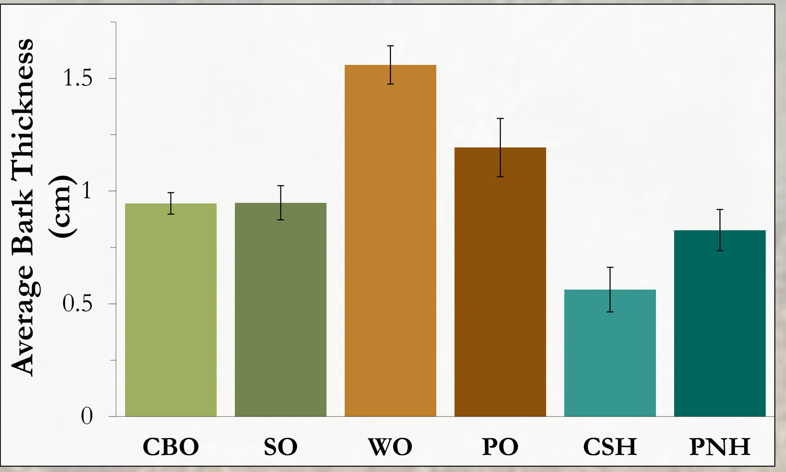

Figure 6. Bark roughness of the six evaluated species at SNA.

Results

- Greatest average bark thickness was in WO (1.56 ±0.08cm), followed by PO (1.19 ±0.13cm), SO (0.95 ±0.08cm), CBO (0.95 ±0.05cm), PNH (0.83 ±0.09cm), and CSH (0.56 ±0.10cm), respectively (FIG 6; n=24 for all species).
- Results suggest that the isotopic composition and volumetric content of SF are distinct from that of TF and PG, supporting the hypothesis that SF water is stored in tree bark (FIG 7 & 8).

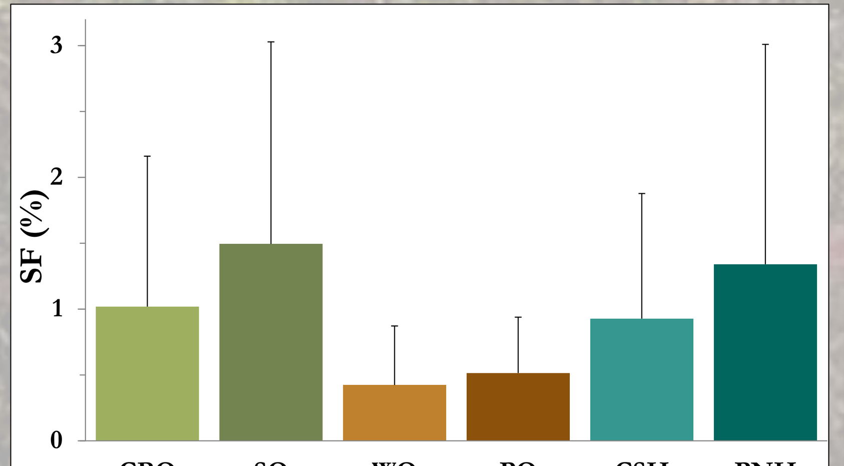

Figure 7. SF percentage of the six evaluated species at SNA including all 11 events.

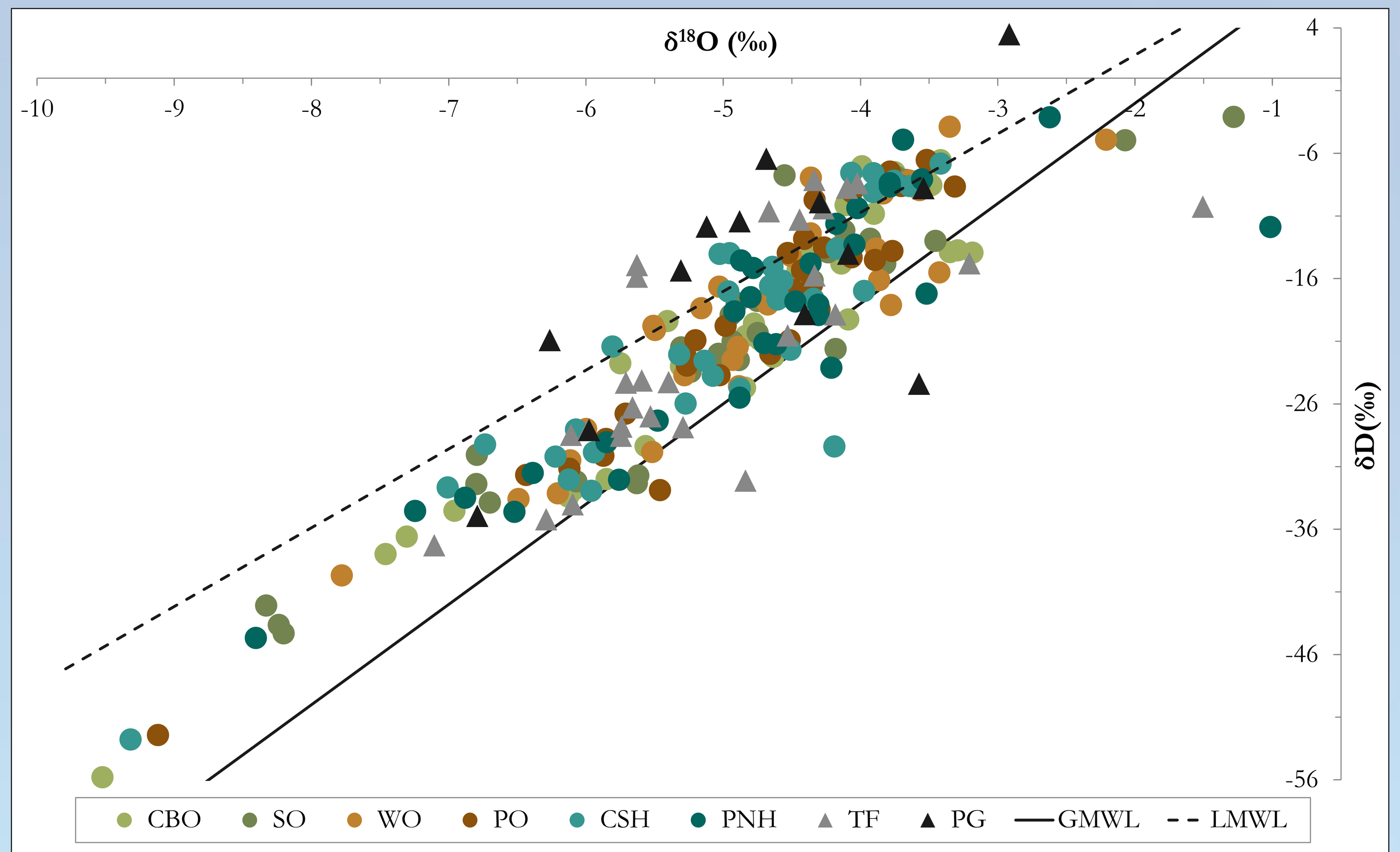

Figure 8. δD and δ^{18}O isotopic analysis of the six tree species, TF, and PG after all 11 sampled storm events. The GMWL shows variation of the SF water due to natural processes of evaporation and condensation at a global scale, whereas the Local Meteoric Water Line (LMWL) exhibits a local scale of variation (see FIG 3)[5].

- Results suggest lighter isotopes evaporate out of tree bark, leaving heavy isotopes to accumulate in SF water during the next storm event (FIG 9 and 10). These results vary between season (TAB 2) and species.

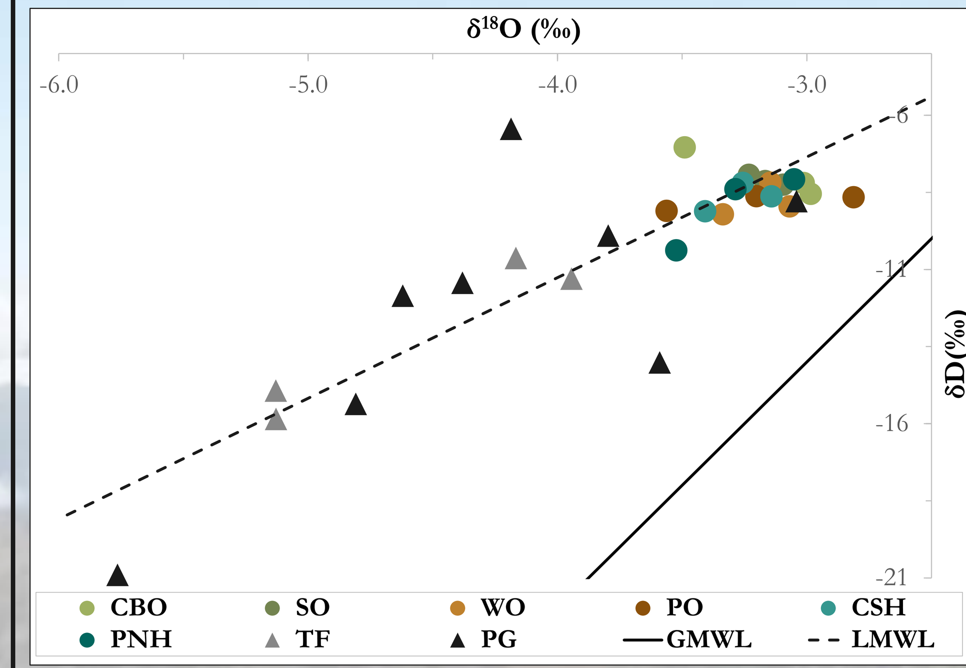

Figure 9. δD and δ^{18}O isotopic analysis of the six tree species, TF, and PG after a winter storm event on "March 4th, 2016".

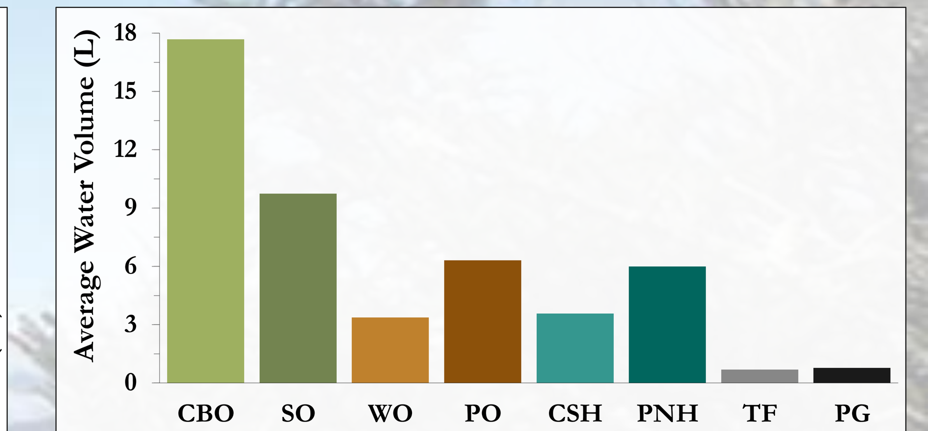

Figure 10. SF volumes (0.69% of PG) after the "March 4th, 2016" storm had 2.78cm of PG and 2.12cm of TF (76.3% of PG).

Table 2. A description of all collected events at SNA. Event 8 was too small of volume to accurately analyze. *Overflowed PG gauge.

Event	Season	Date	PG (cm)	δD	δ^{18}O
1	Fall	10/26/15-10/28/15	2.29	*	*
2	Fall	10/31/15-11/02/15	2.04	*	*
3	Fall	11/06/15-11/09/15	1.79	*	*
4	Fall	11/17/15-11/18/15	4.50	*	*
5	Fall	11/30/15-12/02/15	2.06	*	*
6	Fall	12/13/15-12/14/15	1.16	-28	-5.5
7	Winter	2/21/16-2/22/16	0.61	-19	-3.9
9	Winter	3/3/16-3/4/16	2.78	-15	-4.8
10	Spring	3/24/16	1.40	3.5	-2.4
11	Spring	3/27/16	0.70	-24	-3.1
12	Spring	6/3/16-6/5/16	2.92	-35	-6.3

Discussion

- CBO displayed the pattern we expected to see with smooth, medium-rough bark that generated large quantities of SF (FIG 10) with lower residence time for water on bark surfaces, resulting in lighter isotopic composition of SF.
- A better understanding of isotopic variations of inter-specific SF generation will help determine differences in bark water storage capacity of different species and bark structures. Thorough analysis of these results will allow for more accurate hydrological and biogeochemical models to be established.

Acknowledgements & References

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[1] Levia DF, Van Stan JT, Siegert CM, Inamdar SP, Mitchell MJ, Mage SM, McHale PJ. 2011. Atmospheric deposition and corresponding variability of stemflow chemistry across temporal scales in a mid-Atlantic broadleaved deciduous forest. *Atmospheric Environment* **45**: 3046-3054.
[2] Taniguchi M, Nakayama T, Tase N, Shimada J. 2000. Stable isotope studies of precipitation and river water in the Lake Biwa basin, Japan. *Hydrological Processes* **14**: 539-556.
[3] Guglielmo F, Risi C, Ottlé C, Valdayskikh V, Radchenko T, Nekrasova O, Cattani O, Stukova O, Jouzel J, Zakharov V, Dantec-Nedelec S, Ogée J. 2015. Simulating hydrology with an isotopic land surface model in western Siberia: What do we learn from water isotopes? *Hydrological Earth System Science* **12**: 9393-9436.
[4] Craig H. 1961. Isotopic variations in meteoric waters. *Science*. 133: 1702-1703.
[5] Michener R, Lajtha K. eds., 2008. *Stable isotopes in ecology and environmental science.* John Wiley & Sons.