

# 1 **Standardised drought indices in ecological research: why one size does not fit all**

2 *Running title: Drought indices in ecological research*

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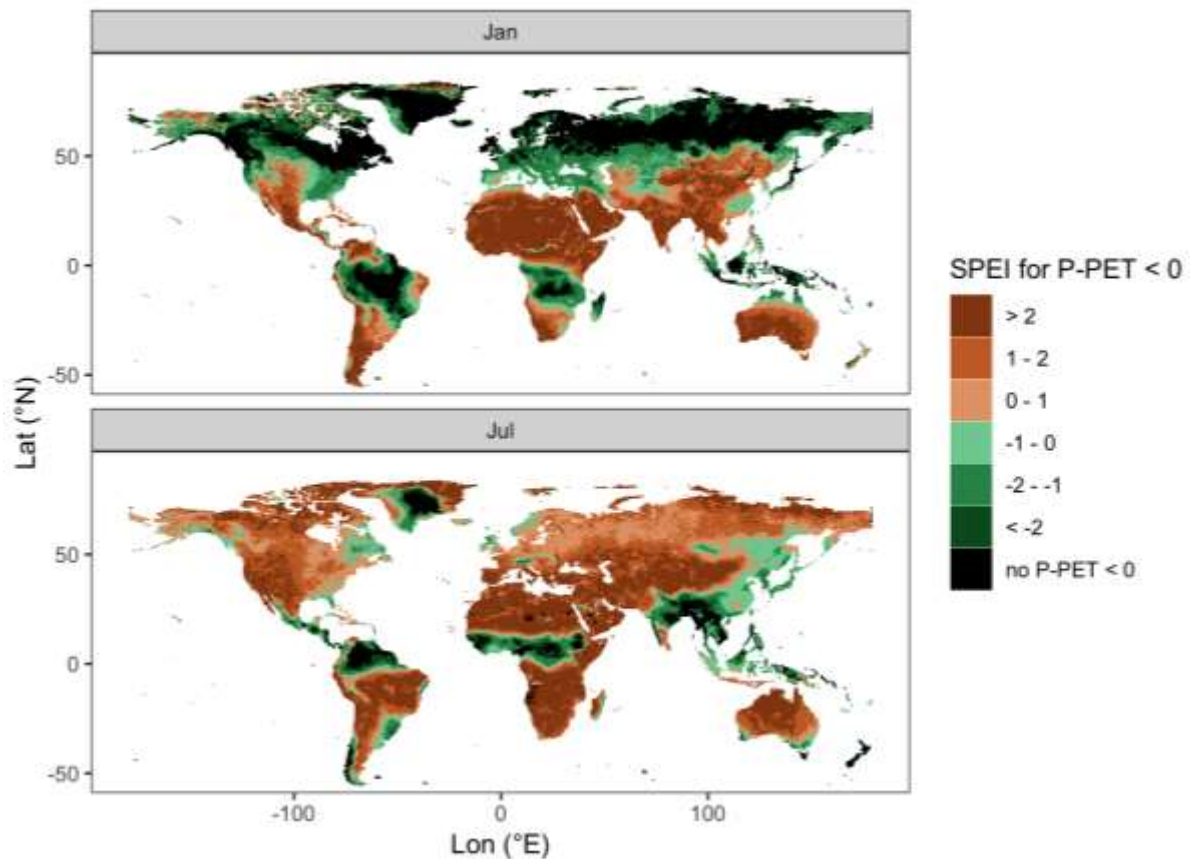
19 Defining and quantifying drought is essential when studying ecosystem responses to such  
20 events. Yet, many studies lack either a clear definition of drought, and/or erroneously assume  
21 drought under conditions within the range of “normal climatic variability” (c.f. Slette et al.,  
22 2019). To improve the general characterization of drought conditions in ecological studies,  
23 Slette et al. (2019) propose that drought studies should consistently relate to the local climatic  
24 context, assessing whether reported drought periods actually constitute extremes in water  
25 availability.

26 While we generally agree with their proposal, we argue that standardised climatic indices,  
27 such as the Standardized Precipitation and Evapotranspiration Index SPEI (Sergio M Vicente-  
28 Serrano, Beguería, & López-Moreno, 2010) as highlighted in Slette et al., cannot be  
29 recommended as stand-alone criteria for drought severity, especially when applied in a global  
30 context. We base our critique on three major points: (1) standardisation can lead to a  
31 misrepresentation of actual water supply, especially for moist climates, (2) standardised  
32 values are not directly comparable between different reference periods, (3) spatially coarsely  
33 resolved data sources are unlikely to represent site-level water supply.

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35 Due to standardization with respect to local conditions, negative index values always signify  
36 dryer than average conditions, while positive values represent wetter than average conditions.  
37 Yet in both cases, an index value alone cannot tell if the ecosystem under study is  
38 experiencing water shortage or surplus, as revealed by the synopsis of SPEI with the  
39 corresponding difference between potential evapotranspiration and precipitation (P-PET,  
40 Figure 1, Figure S1). A direct comparison of SPEI with P-PET underlines that negative SPEI  
41 values do not quantify water shortage (i.e.  $P-PET < 0$ ) per se; a picture which is consistent but  
42 systematically shifted for dry (mean  $P-PET < 0$ ) and moist (mean  $P-PET > 0$ ) climates (Figure  
43 2), with substantial differences across biomes (Figure S2). Consequently, interpreting SPEI  
44 uncritically as a drought indicator across ecosystems can lead to erroneous interpretation of  
45 ecosystem responses to climatic variability. A recent example is the global application of  
46 SPEI to quantify the effect of drought on the end of season dates in terrestrial vegetation  
47 phenology (Peng, Wu, Zhang, Wang, & Gonsamo, 2019), where spatial variations of mean  
48 annual SPEI are misinterpreted as a water balance gradient (see their Figure 7). Moreover, in  
49 their study, as well as in other studies correlating time series of ecosystem response with a  
50 standardized climatic index over a large geographical extent, sign changes occur in the  
51 correlation between ecosystem response and the index (Chen, Werf, Jeu, Wang, & Dolman,

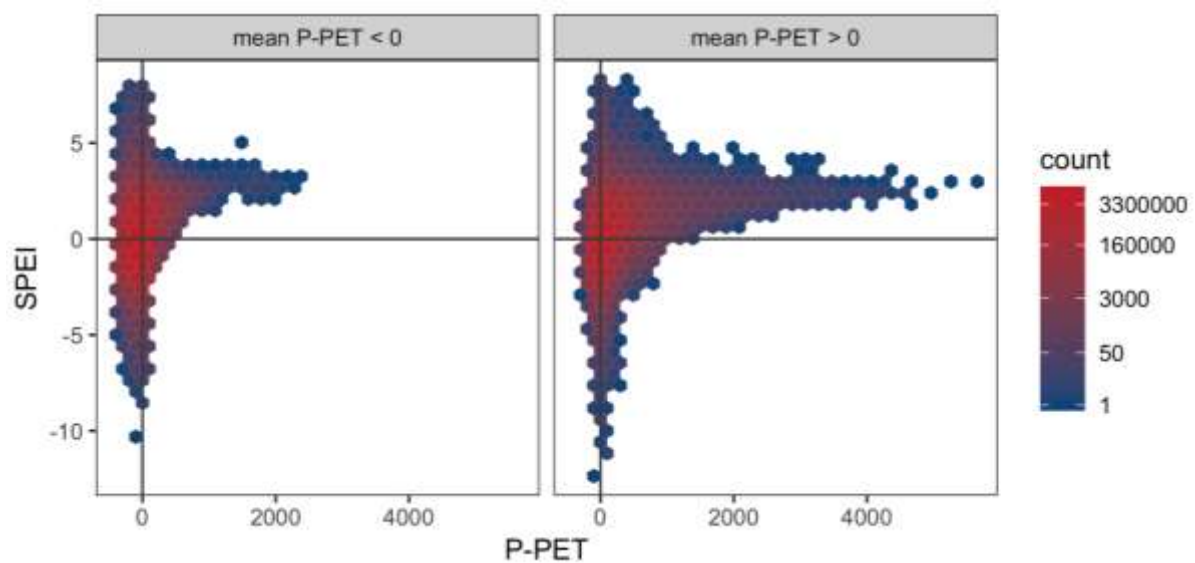
52 2013; Sergio M. Vicente-Serrano, Camarero, & Azorin-Molina, 2014). We argue that in  
53 regions where a negative index value does not directly correspond to the organismic  
54 experience of water shortage, variability in the index does not predominantly reflect the  
55 drought status of the corresponding ecosystems. Similar issues exist with other standardized  
56 indices, such as the scPDSI (Wells, Goddard, & Hayes, 2004; Figure S3). The described  
57 decoupling between standardised drought indices and ecosystem response to drought is  
58 widely acknowledged in tropical ecology, where non-standardised drought metrics,  
59 predominantly the Maximum Climatic Water Deficit, are preferred (e.g., Lewis, Brando,  
60 Phillips, Heijden, & Nepstad, 2011).



61  
62 **Fig. 1** Representation of water supply by a standardized drought index (SPEI: SPEI at 1  
63 month integration): critical SPEI values for January and July that mark the transition from  
64 negative to positive P-PET, i.e. from water shortage to water surplus. Note that depending on  
65 season and climate zone, SPEI values between -1 and -2, referred to as “moderately dry” to

66 “severely dry” by Slette et al. 2019, do not correspond to acute water shortage (dark green  
 67 colors). In large parts of the boreal zone and the tropics, negative SPEI values never indicate  
 68 water shortage since P-PET does not reach negative values (black colors). This pattern  
 69 changes across months as a consequence of monthly standardisation; an extended map  
 70 covering all months is provided with Figure S1. SPEI1 is extracted from the Global SPEIbase  
 71 v2.5 (Vicente-Serrano, Beguería, López-Moreno, Angulo, & El Kenawy, 2010), P-PET  
 72 (sometimes referred to as climatic water balance; Stephenson & Das, 2011) is computed as  
 73 the difference between precipitation and potential evapotranspiration (both from CRU TS  
 74 3.24.01, Mitchell & Jones, 2005, the data set underlying SPEIbase v2.5). We focus on SPEI1,  
 75 since with increasing temporal aggregation, drought metrics based on P-PET lose biological  
 76 meaning (Stephenson & Das, 2011).

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79 **Fig. 2** Comparison of monthly SPEI1 values and associated P-PET at the scale of one month  
 80 across all grid cells and monthly time steps of the SPEIbase data set. In dry climates (mean  
 81 P-PET < 0, left panel), 8% of observations with negative SPEI featured positive P-PET while  
 82 33% of observations with positive SPEI featured negative P-PET. In moist climates (mean P-  
 83 PET > 0, right panel) these patterns were reversed, i.e. 27% (10) of observations with

84 *negative (positive) SPEI featured positive (negative) P-PET. We show point densities (counts*  
85 *per hexagon, colour scale is log10) due to strong overplotting.*

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87 In a spatio-temporal context, the demonstrated limitation of large-scale applicability of  
88 standardized indices is aggravated by limitations in their temporal comparability. Since  
89 standardized indices are designed to reflect deviations from the mean state of a given drought  
90 metric (e.g. P-PET in the case of SPEI), their individual values depend on the distribution of  
91 all values in the reference period. As a consequence, retrospective evaluation of past drought  
92 events is systematically biased by climatic trends affecting the distribution of drought values  
93 in the reference period (Figure S4).

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95 Finally, Slette et al.'s recommendation to validate site-level water shortage for a given study  
96 site using easily accessible, but spatially coarsely resolved data sets, such as SPEIbase, can  
97 lead to substantial mischaracterisation of drought severity. As an example, P-PET of 95% of  
98 German weather stations varies by -70 to +126 mm in comparison to the nearest 0.5°  
99 SPEIbase grid cell (Figure S5).

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101 Consequently, it is not enough to report standardized climate index values alone in drought  
102 studies. In addition to considering the anomaly experienced by the system (as measured by a  
103 standardised index like SPEI), ecologists should also take into account the actual stress  
104 experienced, which could be estimated from P-PET or even better from the climatic water  
105 deficit, as the difference between PET and actual evapotranspiration (Stephenson & Das,  
106 2011).

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151 Additional **supporting information** may be found in the online version of this article:

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153 Figure S1: Representation of water supply by a standardised drought index (SPEI).

154 Figure S2: Percentage of biome area for which SPEI1  $\leq$  -2 does not indicate negative P-

155 PET, by month.

156 Figure S3: Representation of water supply by a standardised drought index (scPDSI).

157 Figure S4: Difference of SPEI1 (SPEI on a 1 month time scale) between the reference period

158 1901-1980 and the reference period 1901-2015 for Sierra Valley, California, USA.

159 Figure S5: Mean differences of P-PET (mean Delta P-PET) estimates as derived from DWD  
160 (German meteorological service) climate station data as well as gridded climate products.