DRAFT PROTOCOL V1
6 January 2015

The International Drought Experiment: a distributed approach to assess terrestrial ecosystem responses to extreme drought

The goal of the International Drought Experiment (IDE) is to determine how and why terrestrial ecosystems may differ in their sensitivity to extreme drought. To accomplish this goal, a coordinated, distributed experiment imposing an extreme drought over a four-year period will be established in range of ecosystem types across the globe. Below is a description of the IDE experimental design, measurements, and sampling protocols. Please refer to the Drought-Net website for additional details about IDE (www.drought-net.org).

I. Experimental Design

A. Site Selection

- Participation is encouraged for, but not limited to, unmanaged ecosystems.
- Because of the relatively low sample size at each site, the site selected for establishment of the experiment should be relatively homogeneous, with respect soil properties and plant species composition.
- Ideally, the study site should not have experienced a major disturbance event (such as nutrient addition, severe soil disturbance, seed addition, etc.) within past several years or have been recently grazed by livestock (i.e., within the last 3-5 years) to avoid confounding the effects of disturbance or grazing release with the experimental treatments.

B. Treatments

Drought will be imposed using fixed shelters that passively reduce precipitation events by a constant, site-specific percentage (Fig. 1; also see Yahdjian & Sala 2002, Gherardi & Sala 2013). The manipulation will occur year-round where possible. In those instances where snowfall is significant, alternative means of precipitation reduction may be used (e.g., snow removal) or, alternatively, the roof can be removed during the period of heavy snowfall. In all cases, the total amount of precipitation reduction that is imposed must be quantified.

1. Core treatments – The core treatments will consist of 1) an ambient precipitation treatment (unsheltered control) and 2) an extreme drought treatment. The extreme drought treatment will be imposed for four consecutive years. For the drought treatment, the percentage reduction of each

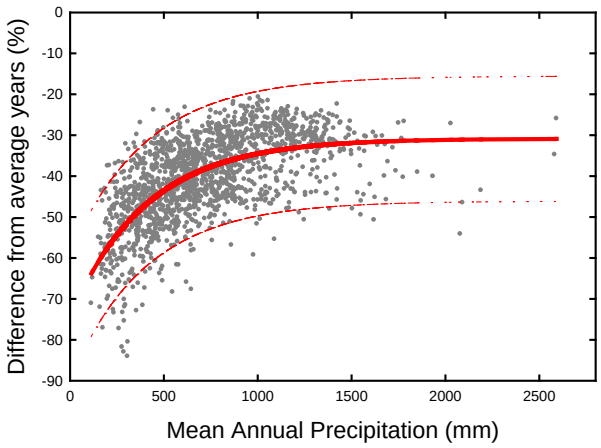

Fig. 1. Relationship between the difference (%) in precipitation amounts between normal years (amounts between the 45-55th % of years within a 100 year record) and extremely dry years (precipitation amounts in the lowest 10th % of years for a 100 yr record) and mean annual precipitation. Data (grey dots) are from 1614 climate stations arrayed across the globe, representing 12 ecoregions. Shown is the predicted relationship (solid red line) with upper and lower bounds of the 95% confidence interval (dashed red lines). Smith *et al*. in prep.

rainfall event will mimic an extreme drought, defined as an extreme reduction in precipitation (based on the 1st percentile of the long-term record), which is specific to a particular site. Sites will be asked to determine this level of extremity in one of two ways: 1) based on site-specific climate data greater than 50 years in length, or 2) based on interpolated 100-yr data. To assist with determination of extremity, an online tool will be made available on the Drought-Net website (www.drought-net.org).

2. Optional treatments – Sites are encouraged to implement the optional treatments, but these are not required for participation in the network.
    a. Fixed treatment - Each site will reduce annual precipitation by 50% using passive shelters.
    b. Infrastructure control – To account for shelter effects, sites are encouraged to establish infrastructure controls, which can be either inverted slats or deer netting (choice to be determined based on cost).

C. Replication and plot size

- The level or replication will, in part, be dependent upon cost. For herbaceous systems, each core treatment will be, at minimum, replicated three times. For those systems requiring larger plots (shrublands, forests), at least two replicates per core treatment are recommended (but not required). Plots can be set up randomly or in a blocked design if appropriate.
- Sampling plot size will be matched to vegetation structure (i.e., height, density, crown width). For short-stature vegetation (<2 m), minimum sampling plot size is 2 x 2 m with a 50 cm buffer surrounding the plot. In cases where larger plots are appropriate, a 4 x 4 m sampling plot with a 1 m buffer is recommended. Forest and savanna sites will need to scale their plot size appropriately.
- The shelter roof will be large enough to cover both the sampling plot plus buffer area (i.e. 3 x 3 m or 6 x 6 m). Shelters should not be installed lower than 80 cm above ground to avoid modifying microclimatic conditions.

D. Trenching

Trenching (to a depth of > 0.5 m) along the border of each shelter (and control plot) is encouraged but not mandatory in order to hydrologically isolate each plot. Depth will be dependent on vegetation; a depth of at least 0.5 m or greater is recommended for herbaceous systems, and deeper depths (at 1 m depth) are encouraged for shrublands and forests. Excavated trenches should be lined with an impermeable barrier (e.g., 6 mm plastic) and refilled prior to the initiation of the experiment. Given that trenching is not feasible at all sites, an alternative to trenching is to increase the size of the shelter to accommodate a larger buffer. If a site is located on a slope (>2%), the mitigation of run-on (e.g., via flashing or other means) is encouraged.

II. Measurements

Two levels of measurements are proposed. Level-1 measurements are designed to quantify three key response variables that will allow us to test network-level hypotheses, as well as provide important site characteristics. These measurements are required for inclusion in the network. Level-2 measurements provide additional response and explanatory variables. Level-2 measurements, although optional for inclusion in the network, should be made if possible. Many additional measurements may be of interest to network participants, but the two levels of measurements are meant to capture key responses and explanatory variables to address a range of network-level questions. Detailed methodologies will be provided on the Drought-Net website (www.drought-net.org).

A. Level 1 measurements

1. **Site level**

Each site must provide the following information:

- Latitude, longitude
- Bailey biogeographic region, biome type, ecosystem type, a more detailed description based on dominant vegetation/species
- Slope, aspect, elevation
- Long-term air temperature and precipitation data (preferably 50-100yr record, daily time scale)
    - These data can be from a nearby representative weather station or based on interpolated data
- Other site characteristics (if known)
    - Disturbance history
    - Depth of known soil impediment (shallow bedrock, caliche layer, etc.)
    - Average water table depth
    - Other unusual site characteristics (saline, serpentine, etc.)

In addition, each site is required to make the following measurements during the study period:

- Annual precipitation for each year of the study based on daily precipitation if possible, or less frequent data (i.e., weekly, monthly) if appropriate.
- Annual average air temperature of each year of the study based on daily measurements, or less frequently if appropriate.
- List of plant species for the study site.
- Soil texture, bulk density, chemical characterization (pH, Ca, C, N, P, %OM, etc.).

2. **Plot level**

The core measurements required for participation in the network are focused on primary productivity, soil CN, and plant community composition.

1. Aboveground productivity and standing biomass will be measured annually using methods appropriate for a particular ecosystem (refer Fahey & Knapp 2007). These can include both destructive and/or non-destructive measurements. Estimates of biomass will be separated into live and dead biomass. Live biomass will be further separated by growth form (grass, forb, woody). Dead biomass will be separated into current and previous year's when appropriate. For herbaceous-dominated systems, we recommend following the Nutrient Network protocol (www.nutnet.umn.edu). For destructive measurements, no more than 25% of the subplot dedicated to productivity measurements will be harvested each year to avoid resampling over the 4-year study period.

2. Soil C and N concentration will be measured twice, once during the pre-treatment data collection year and in year 4 of the drought. For each plot, two to three soil samples will be collected to a depth of 0-15 cm and composited. Samples will be sent to a central lab (tbd) for analysis and archived. Standard protocols will be used for the analysis (including correcting for inorganic C if necessary, Robertson *et al*. 2007).

3. Plant community composition will be measured at least on an annual basis. Abundance (cover, density) will be estimated separately for each species rooted within each plot. For herbaceous-dominated vegetation, the Nutrient Network protocol is recommended

(www.nutnet.umn.edu). This protocol utilizes 1 x 1 m permanent sampling plots. For other systems, sampling plot size will increase dependent on vegetation type and protocol used (e.g., line intercept, laser point frame/pin frame, etc.).

4. Each site will provide qualitative trait data for all species found in the species composition sampling plots. These traits include: growth form (grass, forb, shrub, tree, succulent), photosynthetic pathway (C4, C3, CAM), N-fixer, life history (perennial, biennial, annual), and clonality (stoloniferous, rhizomatous, and for grasses caespitose or not).

B. Level 2 measurements

Level 2 measurements are not required for participation in the network but are strongly encouraged. These measurements include quantifying shelter effects and performance, precipitation inputs and changes in soil moisture, belowground productivity, decomposition rates, and plant traits. Of these, quantifying soil moisture content is the ***highest priority*** and most valuable for understanding drought impacts.

1. Soil moisture content will be measured for the drought and control treatments at a depth of at least 10 cm (preferred >= 15 cm). These measurements will be made as frequently as possible (e.g., continuous, bi-weekly, monthly). Ideally, continuous soil moisture measurements at two depths (0-15 cm and a deeper depth) are recommended.

2. Quantifying shelter effects and performance
   - Shelter effects will be quantified by measuring PAR interception, air temperature and soil temperature beneath the shelters and outside the shelters.
   - Shelter performance will be quantified for as many precipitation events as possible by measuring the amount of precipitation reaching each sheltered plot relative to outside the plot.

3. Root production and biomass
   - Annual root production will be estimated with root-ingrowth cores (recommended minimum of n = 2 per plot; Smit *et al*. 2000). In-growth core diameter and depth may vary by soil depth and/or type of vegetation. In-growth cores will be installed at end of each growing season and removed a year later. Estimates of root production will be provided in 10 cm intervals (0-10, 10-20, 20-30, etc.) for all sites.
   - Standing root biomass will be estimated from the cores extracted for root-ingrowth measurements.

4. As an index of decomposition, standardized substrates and protocols will be used at all sites (e.g., tea bags for aboveground, Keuskamp *et al*. 2013; wooden dowels/ tongue depressors for belowground, Robertson *et al*. 2007).

5. Light availability will be measured at the beginning and end of each growing season in the subplot designated for the plant species composition measurements.

6. For the most common plant species (those collectively comprising 90% of relative cover in plots), additional plant traits will be measured, including height, specific leaf area, and estimated rooting depth.

Literature Cited

Fahey, T.J. and A.K. Knapp (eds). 2007. Principles and Standards for Measuring Primary Production. Oxford University Press.

Gherardi, L.A. & O.E. Sala. 2013. Automated rainfall manipulation system: a reliable and inexpensive tool for ecologists. Ecosphere 4:

Roberston, G.P., D.C. Coleman, C.S. Bledsoe, and P. Sollins (eds). 1999. Standard Soil Methods for Long-term Ecological Research. Oxford University Press.

Oliveira, M.R.G., M. van Noordwijk, S.R. Gaze, G. Brouwer, S. Bona, G. Mosca, and K. Hairiah. 2000. Auger sampling, ingrowth cores and pinboard methods. In: Root Methods, Smit, A.L., A.G. Bengough, C. Engels, M. van Noordwijk, S. Pellerin, and S.C. van de Geijn (eds). pp. 175-210.

Yahdjian, L. & O.E. Sala. 2002. A rainout shelter design for intercepting different amounts of rainfall. Oecologia 133:95-101.