The ARNOLD ARBORETUM of HARVARD UNIVERSITY

1300 Centre Street
Boston, MA, 20131

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Dear Dr. Chase and Dr. Hillebrand:

We propose a Review & Synthesis piece for *Ecology Letters* on experimental climate change.

For over three decades, ecologists have relied on field climate change experiments to understand and forecast ecological impacts of climate change. These experiments are still a prevalent current method, used across diverse sub-disciplines from ecophysiology (1) to foodweb ecology (2), for cutting-edge climate change research. They critically offer the ability to create "no-analog" climate scenarios forecasted for the future, to isolate effects of temperature and precipitation from other environmental changes, and to examine non-linear responses to climatic changes. Yet, increasingly these experiments have been shown to estimate effects much smaller than those seen in long-term observational studies (3). Despite calls for improved methods (4,5), even sophisticated approaches appear to suffer from this discrepancy (6). Such results highlight the need to synthesize across studies to assess how realistically experiments can alter climate conditions, as well as develop novel approaches for applying experimental results to forecasting biological impacts of global climate change.

Thus, we propose a Review & Synthesis piece that describes the limitations of how climate change experiments can actually alter soil and air climate and what new conceptual and statistical leaps are needed to usefully extrapolate from such experiments. We review how results from these experiments are frequently interpreted in misleading ways, in part because the common practice of summarizing and analyzing only the mean changes across treatments hides variation in treatment effects over space and time. In addition, we highlight how secondary, unintended treatment effects, which are rarely described or interpreted (e.g. soil drying with warming treatments), may under- or over-estimate climate change impacts. To support this, we would present the first meta-analysis of high-resolution climate data from some of the most advanced field-based climate change experiments, assembling daily climate data from 12 active warming experiments (containing an estimated 44 study years and 11594 study days of air and soil temperature and soil moisture data).

Our proposed paper would explain how new analyses of high-resolution data could allow researchers to use climate change experiments to more accurately identify and forecast species' responses to changes in climate. A case-study using some of our proposed statistical methods shows that improved analysis can even remove many of the previously noted discrepancies between long-term data and experimental results.

Our author team brings together an international and interdisciplinary team of researchers, which bridges perspectives from ecology, climatology, and land surface modeling. It is comprised of many of the scientists who execute major warming experiments, as well as those who have raised concerns over the findings of such experiments. We expect our proposed Review

& Synthesis will lead to improved mechanistic understanding of climatic drivers of biological responses, and inspire innovative experimental design and analysis; we hope you will consider it for *Ecology Letters*.

Sincerely,

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How do climate change experiments actually change climate?

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The biological impacts of climate change have been widely observed around the world, from shifting species' distributions to altered timing of important life events, and remain a major area of ecological research. With growing evidence and interest in these impacts, ecologists today are challenged to make quantitative, robust predictions of the ecological effects of climate change. One of the most important methods to achieve this goal is field-based climate change experiments that alter temperature and precipitation. The utility of these experiments, however, is directly dependent on the climate change they produce and how accurately researchers assess and present these changes. We describe how experimental results may be interpreted in misleading ways, especially through the common practice of summarizing and analyzing only the mean changes across treatments. Furthermore, treatments produce unintended secondary effects, such as soil drying in conjunction with warming. Using a new database of daily climate data from 12 active warming experiments we show that such methods mask important variation in treatment effects over space and time, and often have secondary effects. The implications of these complexities are rarely explored, but likely to have important biological consequences. We describe a case study of spring plant phenology, in which such simple mean-focused analysis and ignoring secondary effects would lead to inaccurate quantification of species' sensitivities to changes in temperature. We present our recommendations for future experimental design, analytical approaches, and data sharing that we believe will improve the ability of climate change experiments to accurately identify and forecast species' responses.