An Open Letter to Fairy Circle Researchers

by Walter R. Tschinkel

The first World Symposium on Fairy Circles that took place in February 2015 at Wolwedans, Namibia brought together most of the people who have published on fairy circles, or are simply interested in this fascinating phenomenon. The presentations at the conference, along with less formal discussions, gave voice to the varied approaches and hypotheses currently in the literature, or motivating ongoing research.

In view of the differences that came to light at the conference, and that are recorded in the fairy circle literature, I would like to propose for discussion a set of guidelines that should apply to all hypotheses of fairy circle formation, development, change and death.

The Basics

A hypothetical mechanism that seeks to explain fairy circle causation should consider all known characteristics of fairy circles, and the potential output of the hypothesis/mechanism should be consistent with the facts about fairy circles already in hand, and with physical/chemical principles.

Fairy Circle Facts

Here is a list I propose as widely accepted characteristics of fairy circles. (1) They are more or less round; (2) they may form in a matrix of any of multiple species of *Stipagrostis*; (3) they may or may not have a perimeter of taller grass; (4) their mean size and coverage generally becomes smaller with an increase in latitude; (5) their mean size and coverage increases with increasing aridity; (6) they occur almost only on the windblown sands of the Namib Desert; (7) they occur only in a narrow belt where the rainfall is between about 50 and 100 mm per annum; (8) they are not permanent features, but appear and disappear; (9) they appear on a short time scale, probably less than four years; (10) they disappear on an unknown time scale by revegetation; (11) at moderate to high densities, they are highly regular in their small scale dispersion; ; (12) this highly regular pattern is uniform across the landscape and thus causes a large-scale homogeneous distribution; (13) the size of circles is affected by the size of their immediate neighbors; (14) the bare circle contains more soil water after rains than does the matrix.

The Need for Experiments

To date, fairy circle research has been dominated by the description of correlates of fairy circles, correlates that have often been proposed, but not demonstrated, as causal. Few experiments have actually tested hypothesized causes. As a number of hypotheses derived from correlations are currently on the table, there is a great need for experiments to test these hypotheses.

Hypotheses and Their Tests

Hypotheses involving toxic soils, gases or vapors: The need for experimental testing applies equally to all proposals regarding fairy circles. Just as the mathematical models suggest physico-chemical mechanisms that can be experimentally tested (see below), so do several

alternative hypotheses. Those who want to pursue these hypotheses now need to show how the outputs of these hypotheses are consistent with physical, chemical and biological principles, and with the known characteristics of fairy circles listed above. In light of the fact that all toxic effects are dose-dependent, a necessary first step is to show that the hypothesized toxic material is present at a concentration sufficient to cause death or reduction of growth in the several species of grass.

This standard has not yet been met in Naude et al.'s (2011) paper that geochemical gas seeps cause fairy circles. The same applies to Juergen's (2015) suggestions that the methane produced by sand termites in their nests is responsible for killing grass and forming fairy circles. Naude et al.(2011) did not measure methane, but rather, a covariate (carbon monoxide) that requires us to accept a hypothetical series of steps without factual support. First, carbon monoxide is not toxic to plants and is converted to carbon dioxide before being shunted into photosynthesis. Second, the toxicity of methane is far too low to kill grass, as a paper by Smith et al. (2004) makes clear. Smith et al. injected natural gas (which is mostly methane) 1 m underground beneath three different kinds of vegetation at the rate of 100 L per hr for several months. They measured gas concentrations in their sampling tubes that ranged from 2 to 54%, and oxygen concentrations averaging 11%. In spite of this very high rate of gas delivery for a long time, they detected no plant death, but only decreased chlorophyll concentrations and some reduced growth in some of the plots. In the authors' own words, "Injection of natural gas into soil beneath an established grass crop caused a circle of chlorosis (a region of lighter green grass which became more yellow as the experiment progressed) approximately 50 cm in diameter, and reduction in growth of the grass around the area of gas injection." Other authors also report stress symptoms due to natural gas leaks, but not death.

The low toxicity of natural gas (methane) also appears to eliminate the hypothesis by Juergens (2015) that termites cause fairy circles partly through the medium of methane production in their nests. The in-nest methane concentrations that Juergens reported averaged about 0.001% (92 ppm). In light of the evidence from Smith et al. above, concentrations 2000 to 50,000 times as high produced only stress effects (not lethal effects), it seems highly unlikely that termite-generated methane is capable of killing grass.

Toxicity hypotheses need to be consistent with the attributes of fairy circles. Not only do the aforementioned mechanisms fail to prove toxicity, but they are also at pains to suggest mechanisms that could conceivably produce the multiple attributes of fairy circles and of the fairy circle landscape. Chief among these are the regular dispersion of circles, their limitation to sandy soils and their aridity-dependent occurrence and size. Naude (in an unpublished PowerPoint talk posted on the fairy circle website) cited a paper by Moss et al. (2012) as showing that geochemical gas seeps could result in overdispersion of fairy circles. However, the overdispersed features interpreted by Moss et al. (2012) as resulting from gas seeps occur on the deep seafloor in delta-deposited sediments, not in the arid, windblown, sterile sands of the Namib Desert that lie on top of highly metamorphic, ancient bedrock. Of equal importance, the pattern of regular gas seeps is not large-scale homogeneous as is typical for the fairy circles but “subtle clustering is observed and the distribution is no longer considered mathematically random” (Moss et al. 2012). This large-scale heterogeneous pattern typical of all studies of gas seepage, is in especially strong contradiction to the observed homogeneous pattern of fairy

circles (Getzin et al. 2015). The relevance of the citation of Moss et al. (2012) to fairy circles is doubtful, leaving open the question of how gas seeps can result in the highly regular dispersion of fairy circles.

Experiments testing toxic vapors can be indirect, for example, by providing diffusion barriers or transferring soil. Such experiments failed to support either a diffusing toxic vapor, or a toxic soil mechanism of fairy circle formation (Tschinkel 2015; http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0140099). Proponents of toxicity hypotheses are invited to do similar, perhaps more elaborated experiments. They should also propose how other attributes of fairy circles, as listed above, might result from their proposed mechanism.

Self organization: Mathematical self-organization models based on the physical principles of activation-inhibition through soil water (or nutrient) movement have been remarkably successful in producing outcomes that are consistent with many of the known fairy circle characteristics, including (1) the regular dispersion on the landscape; (2) the effect of aridity (and therefore geographic location) on circle size; (3) the location of newly forming circles with respect to existing circles; (4) the effect of multi-year sequences of higher or lower rainfall; (5) the effects of circles on their nearest neighbor size.

All causal hypotheses, including self-organization, need to be subjected to experimental tests, tests that may sometimes be difficult to carry out or even to conceive. The self-organization models account for patterns and *suggest* a mechanism, but in their current state, they consist primarily of correlations between model outputs and observable fairy circle characteristics. The models are not in themselves experimental tests of causal mechanisms, but they do suggest experimental manipulations capable of identifying the physical and biological processes of fairy circle formation, death and attributes. Because these models also assign a primary role to soil water, the manipulation of soil water should be a primary focus of future experiments. Because these models suggest that fairy circle processes play out on a neighborhood to landscape scale, these experiments promise to be large and difficult. Some cleverness of design and execution will be needed. Perhaps experiments that isolate individual components of the fairy circle system from the effects of the surrounding landscape will also provide meaningful tests of causation.

On the biological side, we need detailed knowledge of the biology of the grasses, as well as soil water levels and timing that lead to species-specific grass growth, stasis and death. Such knowledge will place the grass natural history and observed soil water levels into the proper landscape context for fairy circle formation and death.

Termite hypotheses: Similar standards of experimental testing should also be applied to hypotheses involving sand termites. First and foremost, if sand termites are indeed causing fairy circles (no matter what the mechanism might be), termite removal should cause fairy circles to disappear, while termite addition should cause them to appear. The former should be relatively easy to achieve, the latter perhaps not, but both are necessary to the claim that sand termites cause fairy circles. Until this claim has been established as fact through such experiments, there is little logical point in worrying about mechanisms, whether these are thought to be toxic

products of termites or the eating of roots or green grasses. Experiments such as those of Vlieghe et al. (2015) are of doubtful relevance because they were done under starvation conditions using domestic wheat. Even if one accepts their results as showing that termites eat grass roots, it is still a vast distance from showing that they thereby cause fairy circles. There are many examples of strong "micro-effects" that have no detectable population-level effects. For example, although ants can easily be seen to fight over baits, there is currently no good evidence that such dominance has an effect on ant populations.

Far too little is known about the biology of sand (and other) termites to propose a credible mechanism whereby these creatures could cause fairy circle formation. For many species of termites (including sand termites) there is no knowledge of what constitutes a colony, that is, the functional biological entity upon which natural selection acts, and that interacts with other such entities. The termite-fairy circle hypothesis proposes a role for territoriality and competition among colonies to create the regular spacing of circles, but in the absence of knowledge of either what constitutes a colony and whether competition plays any role in termite biology suggests that all speculation is premature. Demonstrating competition requires experiments that show that removal of one competitor results in an increase in the population of the other competitor. It is not even clear what termites would compete over--- food, space, water? None (except perhaps water) seem in short supply. Furthermore, the sand termite hypothesis proposed by Juergens (2013) only simply showed a correlation between *Psammotermes* and fairy circles without showing alternative correlations, or that the sand termite, a true habitat generalist, is not ubiquitous in sand, occurring in both the circles and the matrix. Indeed, Vlieghe et al. (2015) have shown that “sand termites occur in relatively high numbers in both areas”, i.e. the fairy circles and the surrounding matrix. Pursuit of the sand termite hypothesis therefore suggests an intense focus on the biological and natural history details of this widespread species. Until then, no credible hypotheses can be generated.

Other hypotheses and the future: As a mysterious phenomenon, fairy circles naturally seem to attract many hypotheses, but most of them are simply speculative at this point, and many of them are limited to the narrow field of knowledge of the hypothesizer. In my opinion, we are past the time for focusing on selected correlations. All future hypotheses should concord with physical, chemical and biological principles, and should at least propose a credible mechanism that might create the many attributes of fairy circles and their landscape. All proposals should not only be testable through experiments, but should be tested. The most productive role for modeling would then be to suggest experiments that test the model predictions. The experiments, in turn, should lead to improvement (or rejection) of the models.

We should all recognize one rather severe limitation on fairy circle research, and that is that none of us has cheap and easy access to fairy circle sites, and most of us cannot spend long periods of time on site. Moreover, as most of the changes in the fairy circle landscape probably occur during or shortly after rainy periods, most of us don't have the luxury of traveling to the sites on short notice. These realities place a constraint that needs to be recognized, a constraint that should make us cautious about "small" research results produced during short-duration visits, especially if the research is of a biological nature.

As a practical suggestion for creating a more collaborative community around fairy circle research, perhaps we can review each others' papers and grant proposals before submission. The documents could be posted on the fairy circle website, open to all registered, interested parties (but not the general public), who could provide input from diverse sets of expertise and viewpoints. Such a system would work if reviewer comments were non-partisan and without "territorial" intent, i.e. guarding a favored theory. Questions of methods and interpretation could then be aired and responded to. There would of course be no obligation on either the reviewer or the reviewee's part, but I expect that constructive comments will be very welcome.

I look forward to a spirited future for fairy circle research.

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