non-ageing-related deaths in calorie-restricted young-onset animals than in controls.

What might account for the differences between the studies' results? One possibility is diet composition. Whereas the diets were broadly similar in their overall content of carbohydrates, proteins and fats, they differed in the specific types of such nutrients. For instance, sucrose made up 28.5% of the WNPRC diet, but only 3.9% of the NIA diet. Possibly related to this difference, more than 40% of the WNPRC control animals and only 12.5% of the NIA controls developed diabetes — although this metabolic malfunction was completely absent in the WNPRC calorie-restricted animals, but not in the treated animals in the NIA study.

Another difference is that the NIA controls were given an apportioned amount of food to prevent obesity, whereas the WNPRC controls were fed *ad libitum* (that is, they could eat as much as they pleased). Consequently, NIA control animals weighed less and were considerably longer-lived than the WNPRC controls. One interpretation of this observation is that the NIA controls were partially restricted, which would account for the lack of a survival effect of the treatment in the NIA study. Nevertheless, all animals in both studies — even in the calorie-restricted groups — weighed more than wild-caught monkeys[6].

Taken together, the contrasting results raise an intriguing question about the nature and robustness of restricting calorie intake in primates. Is calorie restriction anything more than the elimination of excess fat? That might be concluded if one interprets the control animals in the NIA study as being restricted to a healthy weight, such that further restriction had little additional effect on longevity. However, researchers who use rodent models have long assumed that calorie restriction results in more than just leanness and that it extends life beyond its normal limits. It is known, for instance, that calorie restriction improves survival in obese and non-obese mice and rats[7], even at very high restriction levels[8], and that survival is affected by calorie restriction in a different way from exercise-driven leanness[9].

The same question arises in ongoing studies comparing overweight[10,11] or lean[12] people with normal-weight controls. If calorie restriction defines only the food intake needed to maintain a healthy body weight, then pharmacological mimicry of such an effect might improve the health of only the fraction of the population that is overweight. And, in that case — somewhat disappointingly — no spectacular increase in health or longevity should be expected. ■

Steven N. Austad *is at the Barshop Institute for Longevity and Aging Studies, Department of Cellular and Structural Biology, University of Texas Health Science Center at San Antonio, San Antonio, Texas 78245, USA.*
e-mail: austad@uthscsa.edu

1. Messaoudi, I. *et al. Proc. Natl Acad. Sci. USA* **103,** 19448–19453 (2006).
2. Colman, R. J., Beasley, T. M., Allison, D. B. & Weindruch, R. *J. Gerontol. A* **63,** 556–559 (2008).
3. Colman, R. J. *et al. Science* **325,** 201–204 (2009).
4. Mattison, J. A. *et al. Nature* **489,** 318–321 (2012).
5. Colman, R. J. & Kemnitz, J. W. in *Methods in Aging Research* (ed. Yu, B. P.) 249–267 (CRC Press, 1998).
6. Leutenegger, W. & Cheverud, J. *Int. J. Primatol.* **3,** 387–402 (1982).
7. Turturro, A. *et al. J. Gerontol. A* **54,** B492–B501 (1999).
8. Weindruch, R., Walford, R. L., Fligiel, S. & Guthrie, D. *J. Nutr.* **116,** 641–654 (1986).
9. Holloszy, J. O. *J. Appl. Physiol.* **82,** 399–403 (1997).
10. Heilbronn, L. K. *et al. J. Am. Med. Assoc.* **295,** 1539–1548 (2006).
11. Fontana, L. *et al. Am. J. Physiol. Endocrinol. Metab.* **293,** E197–E202 (2007).
12. Fontana, L., Meyer, T. E., Klein, S. & Holloszy, J. O. *Proc. Natl Acad. Sci. USA* **101,** 6659–6663 (2004).

BIOGEOCHEMISTRY

Drought and tropical soil emissions

Past research implied that positive feedback might exist between climate change and greenhouse-gas emissions from soil. A study finds that drought-induced declines in such emissions from tropical forests could counter climate change.

CORY C. CLEVELAND & BENJAMIN W. SULLIVAN

Tropical forests have been aptly described as the planet's lungs. Tropical vegetation inhales vast amounts of carbon dioxide and exhales oxygen to the atmosphere, and in so doing, provides a vital climate benefit by absorbing some of the nearly 9 petagrams (1 petagram is 10^{15} g) of carbon that human activities release into the atmosphere each year[1]. What's more, tropical soils influence climate by releasing large amounts of CO_2 as a by-product of the decomposition of organic matter, and through several other soil microbial processes that both emit and consume greenhouse gases, including nitrous oxide and methane[2].

Important questions remain about the effect of climate change on greenhouse-gas fluxes from soil, and hence to what extent the beneficial climate services provided by tropical forests will persist in the future. Writing in *Global Biogeochemical Cycles*, Wood and Silver[3] report that an experimentally induced drought had reduced greenhouse-gas emissions from tropical soil to the atmosphere, an effect that represents a negative feedback to climate change.

Many of the scenarios used to predict future climate focus on rising temperature, but changes in the water balance of tropical forests might have more immediate and pronounced effects. Although substantial uncertainty remains, most climate models predict significant declines in rainfall across large areas of the tropics[4,5]. So how might such declines alter the net balance of the gases that contribute to climate change?

To address this question, Wood and Silver manipulated rainfall in a Puerto Rican tropical forest (Fig. 1) to test how drought affects soil emissions of CO_2, methane and nitrous oxide. Such experimental manipulations remain the gold standard for directly assessing the potential effects of environmental change on ecosystem processes, and can provide critical input to the development of better Earth-system models. The authors simulated the effects of a prolonged dry season by preventing rainfall from reaching the forest floor for three months, and measured greenhouse-gas emissions from soil before, during and after the experiment.

After the simulated drought, Wood and Silver documented profound declines in the efflux of CO_2 from soil and increases in soil consumption of methane. In addition, the drought elicited surprising reductions in denitrification (the production of nitrous oxide), a process that is carried out by a tiny fraction of the soil's microbial community. Together, these effects lowered the global-warming potential of the soil emissions. When the heat-trapping ability of nitrous oxide is taken into account, a substantial reduction in total global-warming potential from all three gases was accounted for by the decline of denitrification. Because tropical forest soils are a major source of nitrous oxide emissions to the atmosphere[6], this result implies that a drier climate could cause substantial reductions in global emissions of nitrous oxide from soil.

However, extrapolating results from experiments such as these is particularly challenging for tropical forests. In Wood and Silver's experiment, drought effects varied depending on landscape position: ridge and valley plots had larger responses to experimental drought than did those on slopes. This variation has considerable implications for models used to simulate biogeochemical responses to climate

JERRY BAUER

Figure 1 | Luquillo Experimental Forest. Wood and Silver[3] have studied the effect of drought on greenhouse gases emitted from soils in the Luquillo Experimental Forest, Puerto Rico.

change, none of which is able to capture the complex interplay of factors that can create substantial biogeochemical heterogeneity within and across tropical forests[7]. The authors' results are a prime example of the challenge facing scientists — many tropical regions have highly complex landscapes with varying nutrient availability, which in turn can regulate biological processes that influence greenhouse-gas production[8,9].

The possibility of positive feedback between climate change and greenhouse-gas emissions from soil has been recognized for decades. Wood and Silver's results suggest the opposite: declines in greenhouse-gas emissions following drought would reduce climate forcing. But as the authors highlight, the handful of studies in which rainfall has been excluded from tropical forests have shown positive, negative or no net effects of drought on soil greenhouse-gas emissions. Moreover, although it is crucial to consider the effects of drought alone, real-world emissions will hinge on the combined effects of changing precipitation and temperature, along with chronic shifts in atmospheric CO_2 levels and nutrient deposition — factors that were not manipulated in the authors' experiment. Finally, studies[10,11] have shown that the growth and carbon uptake of trees in the tropics are highly sensitive to climate, but the experimental plots used in Wood and Silver's study (1.54 square metres) were not large enough to simulate the potentially negative effects of drought on carbon uptake through tree growth. The overall effects of drought on the greenhouse-gas balance of the sites therefore remain unknown.

In recent decades, tropical forests have given us a discount on anthropogenic CO_2 emissions by absorbing more greenhouse gases than human activity produces. Wood and Silver's findings suggest that tropical soils may continue to offset greenhouse-gas emissions during drought. Perhaps more notably, their study highlights the need for additional large-scale experiments that can more completely resolve the potential effects of climate change on trace gas emissions in tropical forests. The authors' data are critical for improving and validating models that predict ecosystem and climate responses over large spatial and temporal scales. Considering the pivotal role of tropical ecosystems in basic human health and welfare, our understanding of fundamental ecosystem processes, and their potential response to climate change, remains woefully incomplete in complex and diverse tropical forests. ■

Cory C. Cleveland *and* **Benjamin W. Sullivan** *are in the Department of Ecosystem and Conservation Sciences, University of Montana, Missoula, Montana 59812, USA.*
e-mails: cory.cleveland@cfc.umt.edu; benjamin.sullivan@cfc.umt.edu

1. Le Quéré, C. *et al. Nature Geosci.* **2,** 831–836 (2009).
2. Montzka, S. A., Dlugokencky, E. J. & Butler, J. H. *Nature* **476,** 43–50 (2011).
3. Wood, T. E. & Silver, W. L. *Glob. Biogeochem. Cycles* **26,** GB3005 http://dx.doi.org/10.1029/2010GB004014 (2012).
4. Cox, P. M. *et al. Theor. Appl. Climatol.* **78,** 137–156 (2004).
5. Neelin, J. D., Münnich, M., Su, H., Meyerson, J. E. & Holloway, C. E. *Proc. Natl Acad. Sci. USA* **103,** 6110–6115 (2006).
6. Matson, P. A. & Vitousek, P. M. *BioScience* **40,** 667–672 (1990).
7. Townsend, A. R., Asner, G. P. & Cleveland, C. C. *Trends Ecol. Evol.* **23,** 424–431 (2008).
8. Vitousek, P. M. *et al. Ecosystems* **6,** 762–772 (2003).
9. Porder, S. & Hilley, G. E. *Biogeochemistry* **102,** 153–166 (2011).
10. Clark, D. A., Piper, S. C., Keeling, C. D. & Clark, D. B. *Proc. Natl Acad. Sci. USA* **100,** 5852–5857 (2003).
11. Zhao, M. & Running, S. W. *Science* **329,** 940–943 (2010).

SOCIAL SCIENCE

Poked to vote

A Facebook message sent out during the 2010 US congressional elections influenced the voting behaviour of millions of people. The experiment illustrates the power of digital social networks to spread behavioural change. **SEE LETTER P.295**

SINAN ARAL

Social networks are the pathways through which information, advice, resources and support flow between people. They are essential for many people's decision-making, cooperation and complex interdependence. Yet although humans have almost always lived in networks, advances in computing power and new social technologies have only recently facilitated the development of forms of networked communication that are automating and accelerating the social signals that pulse through the human network on a daily basis. The rapid dissemination of social signals in these digital networks — status updates, tweets, likes, posts, shares and so on — raises serious scientific questions: how, when and to what extent do these signals influence decision-making and the spread of behaviours in society? If social influence drives behaviour, then digital social signals could be used to promote widespread behaviour change and thus to transform commerce, politics and public health. On page 295 of this issue, Bond *et al.*[1] present some of the most convincing evidence to date that peer influence and digital social signals can affect political mobilization.

Political mobilization has been central to recent discourse about the transformative effects of social media — for example, the part that technologies such as Facebook or Twitter played in the protests collectively known as the Arab Spring, or may play in the forthcoming US presidential election. The question is: what role do peer influence and digital social signals have in mobilizing political expression? Do our friends' behaviours inspire us to be politically active, to protest or to vote?

These questions may seem relatively simple to answer, given the right data. But several statistical challenges make it difficult to quantitatively estimate peer influence in networks. For example, networks are homophilous — we tend to make friends with people like ourselves and thus have preferences that are highly correlated with those of our friends[2]. If two friends adopt a behaviour, one immediately after the