of low-relief surfaces as markers of uplift. The researchers also present a model to explain how the uplift occurs, but this proposes a geometry of faults and folds — specifically, a 'relay ramp' — that has not previously been observed at such a large scale. So could there be an alternative explanation? An example from Australia suggests one possibility.

A mountainous region of Australia called the Adelaide fold-thrust belt reproduces much of the geometry of the Bolivian Andes, including narrowing and widening of the mountain belt with deeper erosion in the narrow portion of the range. The deep exhumation and narrowness of the Adelaide mountain belt results from its impingement on harder rocks in front of the range[5]. The Bolivian mountains studied by Whipple and Gasparini abut a feature called the Chapare Basement High, and the patterns of uplift and erosion observed by the authors are consistent with deformation due to interaction between this region of hard rock and the growing mountain belt in Bolivia.

It is notoriously difficult to discern the impact of climate on landscape topography, because steep and high-relief terrain may result from rock uplift but such terrain also tends to increase precipitation rates. In their second paper, Gasparini and Whipple[2] report a method to isolate climatic effects from tectonic ones. Their approach relies on the fact that precipitation reaches a maximum value midway up steep escarpments. The authors therefore compared the profiles of river channels that drain the dry, upper portion of an escarpment in the northern Bolivian Andes with those from rivers that originate within the wettest part of the topography. The difference in channel steepness reflects the impact of variable precipitation on erosional efficiency. The authors coupled the resulting data with process-based models of river incision, and concluded that climate alone is not responsible for the observed spatial patterns in river steepness and local relief: a gradient in rock uplift is required.

The researchers' analysis of channel profiles, coupled with the evidence of a shared history of surface uplift for the northern and southern Bolivian Andes, supports the view that tectonic deformation controls the topography of the northern Bolivian Andes, whereas climate passively responds. But it is not yet time to cancel the parade. Climate certainly does affect this landscape: the authors' modelling[2] of channel steepness suggests that climate is a secondary influence, and the best-fitting model includes both an uplift gradient and the effects of precipitation. Questions remain about interactions between climate, erosion and tectonics.

This research opens up two new directions for future work. First, we should find out how extreme precipitation gradients can be accommodated without an erosional response. Precipitation must be integrated into river discharge to influence river erosion, which means that larger rivers are less sensitive to precipitation gradients — the greater the volume of the river, the smaller the effect of adding precipitation. But precipitation gradients also produce variability in ecosystems and soil properties, which in turn influence discharge production. Vegetation and soil remain underexplored links between climate and erosion.

Second, glaciation seems to be a more powerful climatic driver of topographic and tectonic change than are precipitation gradients. Indeed, glaciation has been argued[6] to dictate large-scale deformation in the Patagonian Andes, but is probably not significant in the Bolivian Andes. The search for climatic controls on tectonics may thus require a push into glacial territory. ■

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1. Whipple, K. X. & Gasparini, N. M. *Lithosphere* http://dx.doi.org/10.1130/L325.1 (2014).
2. Gasparini, N. M. & Whipple, K. X. *Lithosphere* http://dx.doi.org/10.1130/L322.1 (2014).
3. Wobus, C. W., Crosby, B. T. & Whipple, K. X. *J. Geophys. Res. Earth Surf.* **111,** F02017 (2006).
4. Barke, R. & Lamb, S. *Earth Planet. Sci. Lett.* **249,** 350–367 (2006).
5. Marshak, S. in *Thrust Tectonics and Hydrocarbon Systems* (ed. McClay, K. R.) 131–156 (AAPG, 2004).
6. Thomson, S. N. *et al. Nature* **467,** 313–317 (2010).
7. Nesbitt, S. W. & Anders, A. M. *Geophys. Res. Lett.* **36,** L15815 (2009).

POPULATION BIOLOGY

Fur seals signal their own decline

Data on three generations of Antarctic fur seals suggest that climate change is reducing the survival of less-fit individuals with low genetic variation, but that overall seal numbers are falling. See Letter p.462

TIM COULSON & SONYA CLEGG

A little more than a century ago, humans had pushed Antarctic fur seals (*Arctocephalus gazella*) to the brink of extinction. Once hunting stopped, their numbers rose, and by the early twenty-first century their population had grown to a few million. On page 462 of this issue, Forcada and Hoffman[1] show that breeding fur seals on the beaches of South Georgia Island in the southern Atlantic are, on average, becoming more heterozygous — an indicator of individual genetic variability that is linked to improved survival and reproductive success. At face value, this seems to be good news, but a more detailed look reveals that it is a worrying symptom of a population that is again declining.

Offspring of sexually reproducing organisms receive one strand of DNA from their mother and another from their father. Some points along the two strands are the same and others are different; the more differences, the more heterozygous an individual is said to be. Higher heterozygosity frequently correlates with an individual's ability to successfully survive and reproduce — more-heterozygous individuals are fitter[2–4].

Using individual-level data on the survival, reproduction and genetics of multiple generations of fur seals coupled with data on stocks of krill (the seals' main food) and weather conditions in the southern oceans, Forcada and Hoffman tested whether there have been changes in the size of the population and the heterozygosity of the fur seals that are associated with changing environmental conditions. They found that there has been no change in the heterozygosity of seal pups born, but that there has been an increase in the mortality rates of less-heterozygous individuals compared with those of higher heterozygosity. This means that only the more-heterozygous individuals are surviving to breeding age. But the data also show that these individuals begin breeding later in life, and breed less frequently. During the course of the study, the authors report a decline in population size of nearly 25%, and a per-generation increase in the heterozygosity of breeding females of 8.5%.

The reason that these breeding animals are not producing more-heterozygous offspring is that heterozygosity is a complex function of how different each parent is at each point along the strands of DNA they pass to their offspring. Two highly heterozygous parents may be just as likely to produce an offspring with low heterozygosity as they are to produce one that is highly heterozygous. Heterozygosity itself is not heritable and, consequently, the population cannot adapt to change through evolving levels of heterozygosity (Fig. 1). But why are we seeing elevated mortality rates in the less-heterozygotic individuals?

To investigate this, Forcada and Hoffman

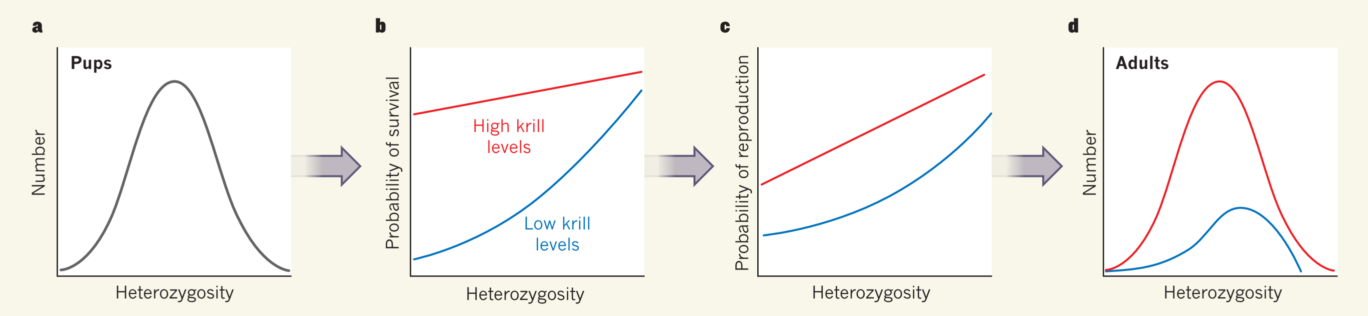

Figure 1 | Climate change in the genes. **a**, The heterozygosity of fur-seal pups remains constant with time. **b**, **c**, By contrast, the associations of heterozygosity with survival (**b**) and reproduction rate (**c**) vary with the availability of krill (fur seals' main food), which is influenced by climate. **d**, As a consequence, in years with low krill availability (owing to high sea surface temperatures), only more-heterozygous females survive to adulthood.

constructed a simulation model of the number of breeding females, incorporating a measure of climatic variation in the southern oceans and observed variation in the availability of krill. The model provided predictions that matched well with observed fluctuations in population size, suggesting that recent declines in fur-seal numbers have been driven to a large extent by changes in weather patterns that have reduced the availability of krill. Other factors may have also affected krill availability, including changes in fishing practices[5] and increased whale numbers[6].

The authors found that a model including krill availability and climatic variation predicted observed population sizes a little better than one that included only climatic variation, which suggests that increases in fishing pressure and whale numbers may have also contributed to the recent decline in the fur-seal population. These changes have had a disproportionately greater effect on fur seals with low heterozygosity than those with higher values, leading to a simultaneous decline in population size and an increase in the heterozygosity of breeding females (Fig. 1).

Why does any of this matter? One of the biggest unknowns in predicting how our planet's weather will continue to change in the future — arguably the biggest threat that humanity faces over the coming century — is how animals, plants and the ecosystems they form will respond to changing carbon dioxide levels, and how these changes will feed back to influence the global climate. We have few studies that adequately explore the response of natural systems to environmental change, because collecting the necessary data is challenging and simple surveys of one or two aspects of a population or ecosystem are often insufficient to provide useful understanding. If Forcada and Hoffman had solely focused on the trend in heterozygosity among seals, they might have concluded that the future for the seals is bright because they are getting fitter. But the detailed, long-term, individual-based data reveal a completely different, and altogether less rosy, picture.

Fortunately, technological advances now mean that ecologists and ecosystems scientists can gather considerably more data that are appropriate for assessing how the natural world is responding to climate change, and how these responses feed back to either decrease or accelerate rates of change. Such technology is not cheap, and investment from government and industry is required for its deployment. But once that happens, we will be able to get a much clearer picture as to whether the fur seals of South Georgia are unusual in their response to anthropogenic change, or whether such genetic and ecological dynamics are typical. Either way, it may be much harder to arrest the ongoing decline in fur seals in the twenty-first century than it was in the twentieth. ■

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1. Forcada, J. & Hoffman, J. I. *Nature* **511,** 462–465 (2014).
2. Amos, W. *et al. Proc. R. Soc. B* **268,** 2021–2027 (2001).
3. Chapman, J. R., Nakagawa, S., Coltman, D. W., Slate, J. & Sheldon, B. C. *Mol. Ecol.* **18,** 2746–2765 (2009).
4. Thelen, G. C. & Allendorf, F. W. *Evolution* **55,** 1180–1187 (2001).
5. Nicol, S., Foster, J. & Kawaguchi, S. *Fish Fish.* **13,** 30–40 (2012).
6. Magera, A. M., Mills Flemming, J. E., Kaschner, K., Christensen, L. B. & Lotze, H. K. *PLoS ONE* **8,** e77908 (2013).

CLIMATE SCIENCE

Cold carbon storage

Lakes that form in thawing permafrost emit substantial amounts of greenhouse gases to the atmosphere. It emerges that large quantities of carbon can also be stored in sediments at the lake bottoms. **SEE LETTER P.452**

SEBASTIAN SOBEK

Frozen soils in the Arctic contain more than twice the amount of carbon present as carbon dioxide in the atmosphere[1]. In the worst-case scenario, climate warming will thaw these permafrost soils and release the long-stored carbon, making it available to microbes that degrade it to the greenhouse gases CO_2 or methane[2,3]. This would further heat the atmosphere and accelerate permafrost thaw. However, it is by no means certain that the worst case is the most likely one. On page 452 of this issue, Walter Anthony *et al.*[4] show that lakes that formed in thawing permafrost thousands of years ago have accumulated vast amounts of plant remains in sediments at their bottoms, building up a large carbon sink that has had a cooling effect on climate.

Permafrost thaw is nothing new. During the most recent ice age, the majority of northeastern Siberia and Alaska was covered not by ice, but by permafrost soils called yedoma[5] up to 90 metres thick, which formed when wind-blown dust accumulated there and froze. The yedoma started to thaw some 15,000 years ago as the climate warmed, and the big chunks of ice contained within it melted to become lakes (called thaw or thermokarst lakes). As meltwater eroded the soils, large quantities of old carbon were released and degraded by aquatic microbes, leading to considerable emissions of methane gas — a process observed in present-day thaw lakes[2]. Given that rapid climate change has partially triggered carbon release in the past[6], future prospects are worrisome.

However, lakes almost always act as both carbon sources and sinks. Although CO_2