

## EXTINCTIONS

# A message from the frogs

Andrew R. Blaustein and Andy Dobson

**The harlequin frogs of tropical America are at the sharp end of climate change. About two-thirds of their species have died out, and altered patterns of infection because of changes in temperature seem to be the cause.**

One of the worries about global climate change is that it will raise the transmission rates of infectious diseases<sup>1</sup>. On page 161 of this issue, Pounds and colleagues<sup>2</sup> provide compelling evidence that anthropogenic climate change has already altered transmission of a pathogen that affects amphibians, leading to widespread population declines and extinctions.

According to the Global Amphibian Assessment (GAA)<sup>3</sup>, around a third of amphibian species (1,856) are classified globally as 'threatened'. The tenuous hold these animals have on life is especially evident in tropical America, where, for example, 67% of the 110 species of harlequin frog (*Atelopus*; Fig. 1) endemic to the region have died out in the past 20 years<sup>3</sup>. A pathogenic chytrid fungus, *Batrachochytrium dendrobatidis*, is implicated as the primary cause of *Atelopus* population crashes and species extinctions<sup>4,5</sup>. Now, Pounds *et al.* offer a mechanistic explanation of how climate change encourages outbreaks of *B. dendrobatidis* in the mountainous regions of Central and South America: night-time temperatures in these areas are shifting closer to the thermal optimum of *B. dendrobatidis*, and increased daytime cloudiness prevents frogs from finding 'thermal refuges' from the pathogen.

The authors defined an 'extinction' as the time when a frog species was last observed by professional teams of herpetologists working in these regions. Most extinctions (78–83%) occurred in years that were unusually warm across the tropics. The likelihood that this correlation arose by chance is less than one in a thousand.

Moreover, the observed patterns of extinction vary with altitude — as do the effects of climate change. Montane *Atelopus* species that live between 1,000 and 2,400 metres show higher rates of extinction than do those that live only in the lowlands (where extinctions are rare) or just in the highest elevations. Pounds *et al.* propose that this is because the extreme sites afford thermal refuges, with temperatures being either too high or too low for

optimal growth of the pathogen. Mid-elevation *Atelopus* communities are not only the hardest hit by extinction, but they also harbour the most species, so biodiversity in these areas is in double jeopardy. These results corroborate the GAA findings<sup>3</sup> for a broad array of amphibians that the percentage of extinct or threatened species is largest at middle elevations. This is contrary to the expectation that higher-elevation species would be more prone

change had been stymied by the so-called 'climate–chytrid paradox', because the climatic conditions favouring chytrid growth seemed to be the very opposite of those created by current climate trends.

Pounds and colleagues' work<sup>2</sup> is a breakthrough as it resolves the paradox and offers a theory to explain the widespread 'enigmatic' declines of *Atelopus* and other amphibians<sup>3</sup>. The authors combine two disparate approaches

into one unifying theory, simultaneously explaining how shifting temperatures are the ultimate trigger for the expansion of a pathogenic fungus, and that this infection is the direct cause of *Atelopus* extinctions.

There may be a tragic irony here. The oldest-known hosts of *Batrachochytrium* are African-clawed frogs (*Xenopus*)<sup>7</sup>, first recorded in South Africa in 1938. Global trade in these frogs burgeoned in the 1950s following the development of pregnancy tests that used *Xenopus* tissue<sup>7,8</sup>. Museum records suggest that the pathogen achieved a worldwide distribution in the 1960s. So it seems that the expansion in one frog species through trade may have led to the extinction of other amphibian species — a totally unexpected, indirect consequence of human ingenuity.

Frogs and *Batrachochytrium* fungi are not the only example of synergistic interactions between pathogens and climate change that are affecting biodiversity. The climate change in the Arctic and sub-Arctic has modified the life cycle of the nematode parasites of musk oxen<sup>9</sup>. These worms can now complete their life cycle in one year, instead of two, and their rising numbers are having a significant impact on the survival and fecundity of musk oxen.

Similarly, warmer climate conditions in montane regions in the western United States allow the mountain pine beetle (*Dendroctonus ponderosae*) to complete its life cycle in one year, rather than two. These beetles transmit pine blister rust (*Cronartium ribicola*), and as they become more abundant, the fungus they



**Figure 1 | Amphibian alarm call.** The Panamanian golden frog is one of roughly 110 species of harlequin frog (*Atelopus*), many of which are dying out. Although this species still survives, its numbers have fallen significantly.

to extinction because they generally have smaller environmental ranges over which they can survive.

Although the little-known *Batrachochytrium* fungus was proposed to be potentially the sole reason for declines in amphibian populations in the tropics<sup>4,5</sup>, no one had come up with an explanation for the sudden emergence of this pathogen. Moreover, although chytrid disease was a common condition in many areas experiencing declines, it was not clear whether *Batrachochytrium* was directly responsible or whether the infection was a secondary effect associated with dead or dying animals<sup>6</sup>. Previous attempts to explain the prevalence of the disease in terms of climate

F. BREM

carry is beginning to have a serious effect on the pine trees in the highest-elevation forests along the Rocky Mountains<sup>10,11</sup>. Like *Batrachochytrium*, pine blister rust has the potential to eradicate several host species, so it could lower tree lines throughout the Rockies and cause increased run-off and flooding.

The powerful synergy between pathogen transmission and climate change should give us cause for concern about human health in a warmer world<sup>12,13</sup>. The ubiquity, complexity and cascading effects of host–pathogen interactions make their dynamics extremely difficult to predict. As global change is occurring at an unprecedented pace, we should expect many other host taxa, from ants to zebras, to be confronted with challenges similar to those faced by *Atelopus*. We should also expect the unexpected: terms such as ‘enigmatic decline’ and ‘pathogen–climate paradox’ will probably dominate explanations of extinctions until we develop a better understanding of the relationships between global change, pathogens and their hosts. Few of the current models and assessments of biodiversity that are used to forecast extinctions or identify taxa at risk include information on how climate affects disease dynamics. Until they do, they will enjoy limited success and will probably give overly optimistic prognoses of how biodiversity will

be affected by climate change. The frogs are sending an alarm call to all concerned about the future of biodiversity and the need to protect the greatest of all open-access resources — the atmosphere. ■

Andrew R. Blaustein is in the Department of Zoology, 3029 Cordley Hall, Oregon State University, Corvallis, Oregon 97331-2914, USA. e-mail: blaustea@science.oregonstate.edu

Andy Dobson is in the Department of Ecology and Evolutionary Biology, Princeton University, Princeton, New Jersey 08544-1003, USA. e-mail: andy@eno.princeton.edu

1. Dobson, A. P. & Carper, E. R. *Lancet* **342**, 1096–1099 (1993).
2. Pounds, J. A. *et al.* *Nature* **439**, 161–167 (2006).
3. [www.globalamphibians.org](http://www.globalamphibians.org) (2004).
4. Daszak, P. *et al.* *Emerg. Infect. Dis.* **5**, 735–748 (1999).
5. Berger, L. *et al.* *Proc. Natl Acad. Sci. USA* **95**, 9031–9036 (1998).
6. McCallum, H. *Conserv. Biol.* **19**, 1421–1430 (2005).
7. Ouellet, M. *et al.* *Conserv. Biol.* **19**, 1431–1440 (2005).
8. Rachowicz, L. J. *et al.* *Conserv. Biol.* **19**, 1441–1448 (2005).
9. Kutz, S. J. *et al.* *Proc. R. Soc. Lond. B* doi:10.1098/rspb.2005.3285 (2005).
10. Kendall, C. K. & Roberts, E. K. in *Whitebark Pine Communities: Ecology and Restoration* (eds Tomback, D. F., Arno, S. E. & Keane, R. E.) 221–242 (Island Press, Washington DC, 2001).
11. Logan, J. A. & Powell, J. A. *Am. Entomol.* **47**, 160–172 (2001).
12. Dobson, A. P., Kutz, S., Pascual, M. & Winfree, R. in *Climate Change and Biodiversity: Synergistic Impacts* (eds Lovejoy, T. & Hannah, L.) (Yale Univ. Press, 2003).
13. Patz, J. A. *et al.* *Nature* **438**, 310–317 (2005).

Field lines in neighbouring planes may also reconnect, resulting in an ‘X-line’ linking many X-points (Fig. 1c). This is essentially what happens when the solar wind encounters Earth’s magnetic field. The solar wind transports the Sun’s magnetic field into interplanetary space, so it could not penetrate Earth’s field if the frozen-in theorem held. But direct and indirect observations<sup>5–7</sup> show that the frozen-in condition breaks down on the magnetopause, the surface that separates the solar wind and Earth’s magnetic field. This allows terrestrial magnetic field lines to become connected directly with the Sun, and so the solar-wind plasma flows along reconnected field lines into Earth’s magnetosphere.

But can reconnection happen within the solar wind itself? Because of the complex spatial and temporal variations in conditions near the Sun’s surface, there are abrupt changes in the density and velocity of the solar wind, and associated rotations in the direction of its magnetic field. Without the breakdown of the frozen-in theorem, the plasmas on the two sides of such a transition would never mix. If such a breakdown occurs, so, by necessity, does magnetic reconnection: a spacecraft positioned in the solar wind would see the passage of a transition not just through sudden changes in the properties of the plasma and magnetic field, but through high-speed plasma flows characteristic of reconnection. NASA’s Advanced Composition Explorer, ACE, has recently observed exactly this<sup>8,9</sup>.

The ACE observations used a single spacecraft, so ACE could not measure the length of the X-line causing the plasma flows. It was also not clear whether reconnection was active for longer than the few minutes it took the reconnection layer to sweep over the spacecraft at solar-wind speed. Phan *et al.*<sup>1</sup> address these open questions by taking advantage of a fortuitous configuration of three spacecraft — NASA’s ACE and Wind, and one of the European Space Agency’s four Cluster spacecraft — that gave the researchers a large baseline for their measurement (see Fig. 1 on page 175). On 2 February 2002, one after the other, all three spacecraft recorded the passage of a reconnection layer with essentially identical characteristics, in particular the same net plasma and magnetic field changes and the same plasma flows.

The observed plasma flows agreed quantitatively with theoretical predictions based on the change in magnetic field across the layer and the local plasma density. Once the authors had inferred the direction of the X-line from a simple geometrical argument, they could calculate that the X-line must have been at least 2.5 million kilometres long — almost 200 times the diameter of Earth. And from the spacing of the passage times over the three spacecraft, it was evident that reconnection was not explosive, but instead operated steadily for at least two-and-a-half hours.

Phan and colleagues’ observations<sup>1</sup> of the

## SPACE PHYSICS

# Breaking through the lines

Götz Paschmann

**Magnetic field lines are known to reorganize themselves in plasmas, converting magnetic to particle energy. Evidence harvested from the solar wind implies that the scale of the effect is larger than was thought.**

The reconnection of magnetic fields that occurs in the ionized gases known as plasmas is a fascinating and enigmatic phenomenon. It transforms magnetic field configurations, converting energy stored in those fields into kinetic energy of the electrically charged particles that make up the plasma. Direct and indirect proof for the existence of the effect comes from many different quarters, ranging from explosive energy releases in the Sun’s atmosphere to catastrophic disruptions in nuclear fusion reactors. On page 175 of this issue, Phan *et al.*<sup>1</sup> present the latest observations of magnetic reconnection in the solar wind — a stream of plasma that is continuously emitted by the Sun — and in doing so clarify the spatial and temporal scales that govern the process.

Plasmas, which in space consist mainly of protons and electrons, are commonly permeated by magnetic fields. Plasma and field tend to behave as if frozen together: the plasma’s particles lend magnetic field lines physical

form by gyrating around them; equally, when the particles move, the magnetic field lines move with them. This means that, rather like an individual strand in a bowl of spaghetti that is being stirred, the same field line — although constantly changing position and shape — always connects the same particles of the plasma (Fig. 1a).

But what happens if the plasma’s motion brings together two magnetic field lines that point in opposite directions? The frozen-in picture assures us that all particles will remain on their respective field lines, regardless of how hard these are pushed together. But this picture is only an approximation, and in some circumstances — poorly understood at present — field lines slip relative to the plasma, and break and cross-link at an ‘X-point’ (Fig. 1b). The field lines, now sharply bent, act as a slingshot, imparting their stored energy to the particles and ejecting them at high speeds. This is the phenomenon known as magnetic reconnection<sup>2–4</sup>.