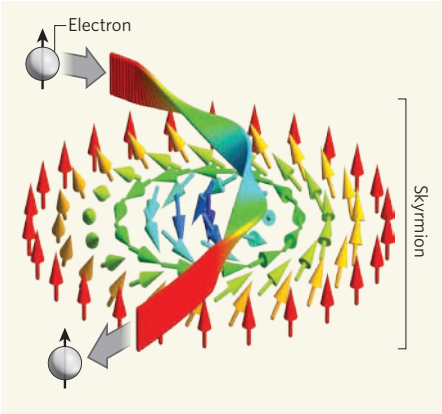

Figure 1 | Roaming through a skyrmion. When an electron moves through a special type of magnetic texture called a skyrmion, its magnetic moment (spin) twists to adjust to the skyrmion's local spin structure (ribbon-like pattern). This twisting changes the electron's direction of travel and pushes the electron and the skyrmion in opposite directions (not shown).

untied as long as the magnetization remains smooth and finite. Skyrmions are therefore classified as topologically stable — a characteristic drawn from the mathematical discipline of topology, which classifies geometric configurations according to properties, such as the winding number, that are robust against all small distortions or perturbations.

In the field of nanomagnetism, magnetic whirls that share similarities with skyrmions have long been known to exist at interfaces between magnetic domains within ferromagnets or in specially tailored magnetic nanosystems[3]. But the skyrmions now discovered by Yu *et al.* arise from a completely different microscopic mechanism: from magnetic interactions that have a unique handedness in materials that lack a centre of inversion symmetry. These 'chiral' magnetic interactions, also known as Dzyaloshinsky–Moriya interactions, favour the twisting of the magnetization and thus lead to the formation of structures such as spirals or skyrmions.

Yu and colleagues' study[1] was inspired by recent neutron-scattering experiments and related theoretical work that established that lattices of skyrmions form spontaneously in a class of chiral magnet in a tiny temperature window and in the presence of a weak magnetic field[4,5]. But because neutron scattering can detect only periodic structures such as lattices, it didn't allow the direct identification of individual skyrmions. To observe individual skyrmions, Yu *et al.* studied thin samples (just several tenths of a nanometre thick) of the chiral magnet $Fe_{0.5}Co_{0.5}Si$ in a weak magnetic field.

They found that the formation of skyrmions is strongly favoured if the distance over which the winding caused by the chiral interactions takes place is larger than the sample's thickness — an observation that is in accord with numerical simulations devised by the authors[1]. To image the magnetic structure, they used Lorentz force microscopy, in which they observed the component of the magnetization that is parallel to the sample with a resolution much smaller than the typical 90-nanometre radius of the skyrmions[6]. Depending on the strength of the magnetic field and the temperature, they observed either perfect periodic arrangements of skyrmions, lattices with defects, glassy and amorphous configurations or even single skyrmions. As conjectured previously[4,5], because of the chiral interactions, all of these skyrmions wind in the same direction.

As exciting as the observation of single skyrmions is, the real excitement lies in the prospect of using them for a very efficient coupling of an electric or spin current to a magnetic structure. Such a coupling would underlie most potential applications of skyrmions, such as for magnetic storage devices or perhaps even transistors.

To illustrate the nature of this coupling, consider an electron traversing a skyrmion (Fig. 1). As the electron travels through the skyrmion, its spin orientation is twisted back and forth to adjust to the direction of the skyrmion's local spin structure. While doing so, the electron acquires a quantum-mechanical phase known as the Berry phase. From the viewpoint of the electron, the net effect of the change in its spin orientation is an effective force perpendicular to its motion that is similar to the Lorentz force it experiences in the presence of a magnetic field. This 'topological' force is directly proportional to the winding that characterizes the skyrmion and has recently been observed in measurements of the Hall effect in a skyrmion lattice[7]. But as the electron feels the topological force, it must also counteract it by exerting a force on the skyrmion. This force could be exploited to manipulate skyrmions with electrons.

Yu and colleagues' work[1] shows that skyrmions in chiral magnets can be created either in regular lattices or as topologically stable 'stand-alone' particles. These structures could provide the building blocks for new complex textures, which could then be either manipulated with electric or spin currents or, conversely, used to direct the motion of spins and charges. Taken together with the realization that the chiral magnetic interactions that underlie skyrmions are a general feature of essentially all systems that lack inversion symmetry, in particular surfaces and interfaces[8], Yu and colleagues' study pushes the door wide open for many applications. ■

Christian Pfleiderer is at the Lehrstuhl für Experimentalphysik E21, Technische Universität München, D-85748 Garching, Germany. Achim Rosch is at the Institute for Theoretical Physics, Universität zu Köln, D-50937 Köln, Germany.
e-mails: christian.pfleiderer@frm2.tum.de; rosch@thp.uni-koeln.de

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CONSERVATION BIOLOGY

When an infection turns lethal

Andrew R. Blaustein and Pieter T. J. Johnson

Losses in biodiversity and the emergence of new infectious diseases are among the greatest threats to life on the planet. The declines in amphibian populations lie at the interface between these issues.

It is estimated[1] that roughly one-third of amphibian species are under threat of extinction and that more than 100 species may have become extinct since 1980. The reasons for the decline and extinction of amphibian populations are probably complex and multifactorial[2]. But growing evidence[3] indicates that, in many cases, infectious disease is driving amphibian losses. In particular, the pathogenic fungus *Batrachochytrium dendrobatidis* has been linked to the decline of amphibian populations throughout the world. Two related papers published in *Proceedings of the National Academy of Sciences*, by Vredenburg *et al.*[4] and Briggs *et al.*[5], considerably improve our understanding of the dynamics of *B. dendrobatidis* infection.

This pathogen causes the often-lethal disease chytridiomycosis, which disrupts the function of epidermal structures such as the skin and teeth and the regulation of osmosis[6] to varying degrees, depending on the amphibian species and its life stage[7]. Since its description in the late 1990s, *B. dendrobatidis* has been the subject of hundreds of studies by researchers from various disciplines. Nonetheless, many ecological questions remain. Why does *B. dendrobatidis* cause extinction of the host population (through inducing an epidemic) in some regions but persist in the population in an endemic state in other regions? In addition, how does this pathogen induce host losses without a concomitant decrease in its transmission (as would be expected to occur for a density-dependent parasite)? After all, as infected hosts die, one would expect the disease to decline in prevalence as well.

Vredenburg and colleagues[4] and Briggs *et al.*[5] carried out long-term, large-scale monitoring and sampling of amphibian populations in the Sierra Nevada in California, focusing on yellow-legged frogs — *Rana muscosa* and *Rana sierrae* — the populations of which have declined in recent decades. Previous studies focused exclusively on the prevalence of infection (that is, the proportion of infected hosts), ignoring the role of infection intensity (the amount of infection per individual host) in controlling host-population losses. Instead of simply cataloguing the presence or absence of *B. dendrobatidis* and its spread among host populations, these investigators[4,5] identify a 'lethal threshold' of pathogen infection intensity, which may be the key to understanding how *B. dendrobatidis* epidemics can be controlled.

Vredenburg *et al.*[4] carried out intensive sampling of 88 frog populations over 9–13 years. Among the lakes they studied, they found that, within three years of its arrival, *B. dendrobatidis* had spread in a wave-like pattern — that is, the area covered by the pathogen increased steadily in size over time — until nearly all of the frog populations at the lake were infected. The amphibian populations did not, however, collapse until a lethal threshold of about 10,000 zoospores of the fungus per frog was reached.

The existence of such an intensity threshold may help to explain how *B. dendrobatidis* causes almost complete losses of amphibian hosts. Because of this threshold, there is a time lag between exposure and mortality, so the pathogen can spread through much of the amphibian population before disease-driven reductions in host density negatively affect the transmission of *B. dendrobatidis*. Consequently, the pathogen can cause the loss and extinction of its host population, unlike the many other pathogens that disappear as their hosts decline in numbers.

Briggs *et al.*[5] combine long-term field data with modelling analysis to investigate how some amphibian populations persist even though *B. dendrobatidis* is present in their habitat. The authors' intensive data — involving marking the animals and later recapturing them — show that, in populations that survive, infected yellow-legged frogs have fungal loads well below the lethal intensity threshold, and that these frogs have cleared fungal infection and become reinfected over the course of years, with no effect on their survival.

Previous studies suggested that genetic changes that alter host tolerance of the pathogen or pathogen virulence might explain how some amphibian populations persist in the presence of *B. dendrobatidis*. Briggs and colleagues' modelling efforts, however, hint that simple decreases in host density and the resultant reduction in pathogen transmission could account for such an outcome. This is particularly true when there are environmental reservoirs of *B. dendrobatidis*, including amphibian species or life stages (such as tadpoles) that can persist with the infection for long periods and spread it to more sensitive hosts.

This modelling work[5], which was based on a variety of biological scenarios, offers insight into both the epidemic and endemic aspects of *B. dendrobatidis* dynamics. For instance, the study predicts that infection intensity builds up rapidly when frog populations are dense, as well as under conditions that promote reinfection. If *B. dendrobatidis* reaches its intensity threshold, the infected amphibian population can become extinct. By contrast, if some members of the host population survive, then a new endemic state develops, with persistent infection in the remaining frogs.

Intriguingly, both studies[4,5] indicate that the traditional dichotomous classification of pathogens as either microparasites or macroparasites may be overly simplistic, as the dynamics of infection with *B. dendrobatidis* — a microparasite — strongly depend on infection intensity (which is usually considered only for macroparasites). This finding suggests that incorporating infection intensity into other microparasite disease models could provide insight into other host–pathogen systems.

The new papers[4,5] markedly increase the understanding of a disease that affects many amphibian populations. In particular, the types of data presented — based on long-term, extensive monitoring that generates detailed records — are largely unprecedented for analyses of many wildlife disease systems.

Nevertheless, large gaps remain in the knowledge of *B. dendrobatidis* and in how the dynamics of chytridiomycosis vary between geographical regions. The populations that these researchers[4,5] studied are from montane ecosystems that have low species diversity and relatively harsh winter conditions. Will the reported dynamics for *B. dendrobatidis* in this system explain the spread of this pathogen in, for example, lowland regions of Europe or in the tropics, where host-species density is substantially higher?

Moreover, it is still not clear precisely which vectors spread the infection, in which systems it is endemic and in which ones it is epidemic, and whether environmental changes can trigger the emergence of this pathogen. By focusing on infection intensity and the differences between epidemic and endemic states of *B. dendrobatidis* infection, Vredenburg *et al.* and Briggs *et al.* lay a valuable foundation for addressing questions such as how the intensity threshold of *B. dendrobatidis* varies across species or with environmental conditions, and what part is played by environmental cofactors such as climate change[8] in affecting the dynamics of endemic infection.

How can this information be applied so as to slow, or even prevent, population declines? As the authors of both papers propose, interventions designed to prevent *B. dendrobatidis* infection from reaching the lethal-intensity threshold could reduce extinction events. Because it is unlikely that the pathogen will be completely eradicated, the only realistic option may be to manage sensitive amphibian populations in such a way as to create an endemic state of infection. For instance, as described in a News Feature in these pages last week[9], reducing the density of susceptible frogs by capturing them before the infection wave, or by treating a subset of individuals with an antifungal agent, could reduce transmission of *B. dendrobatidis* and prevent infection intensities from becoming lethal. ■

Andrew R. Blaustein is in the Department of Zoology, 3029 Cordley Hall, Oregon State University, Corvallis, Oregon 97331-2914, USA. Pieter T. J. Johnson is in the Department of Ecology and Evolutionary Biology, N122, CB334 University of Colorado, Boulder, Colorado 80309-0334, USA.
e-mails: blaustea@science.oregonstate.edu; pieter.johnson@colorado.edu

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STRUCTURAL BIOLOGY

Immunity takes a heavy Toll

Steven A. Wasserman

Toll receptors trigger immune responses through adaptor proteins and kinase enzymes. Structural studies reveal that hierarchical assembly of these proteins into a helical tower initiates downstream signalling events.

Communication within cells often involves a series of molecular handshakes, each protein contacting the next and modifying its activity. An accessory protein may serve as a matchmaker, holding components together for the exchange of information. Until now, this model fitted well with what was known about signalling in mammalian Toll pathways, which activate innate immune defences[1]. Three proteins — MyD88 and two members of the IRAK