generated in their experiments can be inferred through theoretical predictions, Smith *et al.* cannot directly measure the actual temperatures. In addition, it is not currently possible to use their methods to determine crystal structures at terapascal pressures. These are exciting challenges for the future. Important progress has been made in this direction[8], and there is hope that laser-driven dynamic compression, coupled with free-electron lasers, will provide diagnostic snapshots of structures and their dynamics.

Planets form over many millions of years, whereas the reported dynamic ramped compression procedure is over in a flash. It is not clear whether these experiments, despite reaching relevant temperatures and pressures, are able to closely model the largely equilibrated, dense rocks and ices existing within giant planets. However, the brevity of the experiments does have an advantage. Just as nanotechnology has been a gift to theoreticians, allowing meaningful computations of manageable numbers of atoms, the short experimental timescales actually make the behaviour of compressed atoms easier to model in dynamical simulations. Through mutual benchmarking and the testing of predictions, we expect that experiment and theory will together improve our understanding of matter under extreme compression.

A final note of perspective. Although the pressures and densities probed in the current experiments are immense, nature is even more ambitious. The giant exoplanets are a stepping stone to the stars, where petapascal pressures (1 petapascal is 10^{15} Pa) are reached. The predictions of rich terapascal-pressure physics should caution against assumptions of simple structures. Indeed, a recent theoretical study[9] anticipates a complex metallurgy for the crusts of neutron stars. Over to the experimenters! ■

Chris J. Pickard *is in the Department of Physics and Astronomy, University College London, London WC1E 6BT, UK, and at the London Institute for Mathematical Sciences.* **Richard J. Needs** *is in the Theory of Condensed Matter Group, Cavendish Laboratory, Cambridge CB3 0HE, UK.*
e-mail: c.pickard@ucl.ac.uk

1. Smith, R. F. *et al. Nature* **511,** 330–333 (2014).
2. Ball, P. *Nature* http://dx.doi.org/10.1038/nature.2014.14710 (2014).
3. Jeanloz, R. *et al. Proc. Natl Acad. Sci. USA* **104,** 9172–9177 (2006).
4. Wagner, F. W., Sohl, F., Hussmann, H., Grott, M. & Rauer, H. *Icarus* **214,** 366–376 (2011).
5. Martinez-Canales, M., Pickard, C. J. & Needs, R. J. *Phys. Rev. Lett.* **108,** 045704 (2012).
6. Pickard, C. J. & Needs, R. J. *Nature Mater.* **9,** 624 (2010).
7. Driver, K. P. & Militzer, B. *Phys. Rev. Lett.* **108,** 115502 (2012).
8. Rygg, J. R. *et al. Rev. Sci. Instrum.* **83,** 113904 (2012).
9. Kobyakov, D. & Pethick, C. J. *Phys. Rev. Lett.* **112,** 112504 (2014).

ECOLOGY

Pesticides linked to bird declines

Decreases in bird numbers are most rapid in areas that are most heavily polluted with neonicotinoids, suggesting that the environmental damage inflicted by these insecticides may be much broader than previously thought. SEE LETTER P.341

DAVE GOULSON

The debate over the environmental risks posed by neonicotinoid insecticides has raged since the late 1990s, when French beekeepers began blaming the chemicals for losses of honeybee colonies. The discussion has focused closely on bees, particularly the risks posed by the use of neonicotinoid treatments on flowering crops that bees visit. But on page 341 of this issue, Hallmann *et al.*[1] provide strong evidence that this debate may have missed the bigger picture. Analysing long-term data sets on bird populations in the Netherlands, the authors demonstrate that regional patterns of population decline in insect-eating birds are neatly predicted by levels of neonicotinoids detected in environmental samples. In other words, birds have declined faster in places with more neonicotinoid pollution.

Dozens of papers have been published on the effects of neonicotinoids on bees and, following a review of the evidence, the European Food Safety Authority declared in 2013 that neonicotinoids posed an “unacceptable risk” to the insects. Shortly afterwards, the European Union voted in favour of a two-year moratorium on the use of three widely used neonicotinoids on flowering crops. It has already been suggested that the impacts of these chemicals are likely to extend far beyond bees[2], but Hallmann and colleagues’ study is the first to provide direct evidence that the widespread depletion of insect populations by neonicotinoids has knock-on effects on vertebrates.

Neonicotinoids are neurotoxins that are exceptionally toxic to insects but much less so to birds[3]. Because of this, the observed bird declines are unlikely to be due to direct toxicity. As Hallmann *et al.* argue, it is much more plausible that the effects are the result of a depletion of the birds’ food — insects. However, it is worth noting that none of the bird species studied would ordinarily eat bees in any quantity.

Hallmann and colleagues essentially infer cause and effect from correlation, but this is made more convincing because they consider a range of other measures of land use that are known to affect bird and insect populations, but found none that predicted bird declines as powerfully as environmental neonicotinoid concentration. Of course, an experimental, manipulative approach to test cause and effect would be more compelling, but that would be almost impossible on a realistic scale, with replication, in organisms as highly mobile as birds, and in any case would face severe ethical issues.

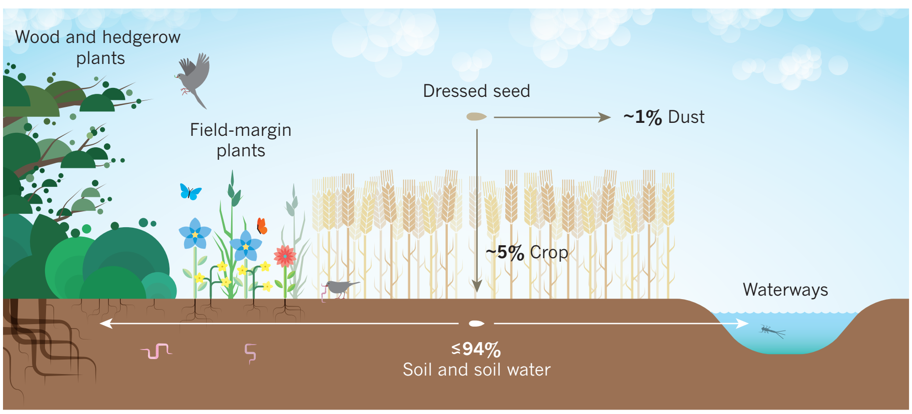

Figure 1 | The environmental fate of neonicotinoids. When neonicotinoids are applied as a seed dressing to crops, the bulk of the active ingredients (80–98%) enter the soil and soil water. There, they can persist for long periods, accumulate, be taken up by the roots of vegetation at the margins of fields and follow-on crops, or leach into aquatic systems. Neonicotinoids are highly toxic to insects, which are exposed to the chemicals in plants, soil and water. Hallmann *et al.*[1] have observed rapid declines in bird populations in regions with high environmental neonicotinoid concentrations, and suggest that they are the result of insect poisoning depleting the birds’ food supply.

How might neonicotinoids, most of which are applied as seed dressings to arable crops, come to have such widespread impacts on the environment? The insecticides' intended mechanism of action is that the dressing should dissolve around the seed, be absorbed by the growing seedling and spread through its tissues, protecting all parts of the crop from herbivorous insects. However, only approximately 5% of the active ingredient is taken up by the crop[4] (Fig. 1). A little is lost as toxic dust that blows away and may affect flying insects or be deposited on non-target vegetation[5], but most enters the soil and soil water. The half-life of neonicotinoids in soil varies with soil type, but can exceed 1,000 days, such that they can accumulate over time. The consequences of this accumulation for soil fauna and soil health are poorly understood[2].

The chemicals can also be washed from soils into waterways, where they are likely to affect aquatic insects[6], which are key sources of food for both birds and fish. And they can be taken up by the roots of hedgerow plants, where they will have the same systemic action as in crops, spreading through the leaves and flowers. Non-target herbivorous insects such as grasshoppers, beetles, shield bugs and the caterpillars of butterflies, moths and sawflies will all be exposed through this route, and these form the food supply for a broad range of predatory insects, birds and some mammals, such as shrews and bats.

The persistent nature of neonicotinoids and their high solubility in water mean that such broad contamination is also probable with other methods of application, such as foliar sprays or soil drenches. Given these manifold routes of spread, it is perhaps not surprising that, after 20 years of steadily increasing use, there is now evidence that neonicotinoids are having broad effects through the food chain — as shown by Hallmann *et al.* and by a recent meta-analysis[7] of studies on the ecosystem effects of systemic pesticides.

The European two-year moratorium came into effect in December 2013, but it is designed to protect bees from exposure only to mass-flowering crops. As such, neonicotinoids are still used as seed dressings on other major crops, such as wheat and barley, and they are still widely sprayed in horticulture and sold for use in gardens and public areas. Hence, impacts on birds and other insectivores might be expected to continue. Elsewhere in the world, the emerging evidence for environmental harm has not yet resulted in any new restrictions on their use.

The story is reminiscent of Rachel Carson's *Silent Spring*[8], published in 1962. She wrote: "These sprays, dusts, and aerosols are now applied almost universally to farms, gardens, forests, and homes — nonselective chemicals that have the power to kill every insect, the 'good' and the 'bad', to still the song of birds and the leaping of fish in the streams …"

Carson was describing the environmental devastation caused by the over-reliance on and overuse of organochloride insecticides such as DDT (dichlorodiphenyltrichloroethane) in the 1950s and 1960s, which led to major problems with outbreaks of pesticide-resistant pests, widespread contamination of the environment and knock-on effects through the food chain, including chronic poisoning of people. She would undoubtedly think that we seem to have learnt little from our past mistakes. ■

Dave Goulson *is in the School of Life Sciences, Sussex University, Falmer BN1 9QG, UK.*
e-mail: d.goulson@sussex.ac.uk
Twitter: @DaveGoulson

1. Hallmann, C. A., Foppen, R. P. B., van Turnhout, C. A. M., de Kroon, H. & Jongejans, E. *Nature* **511,** 341–343 (2014).
2. Goulson, D. *J. Appl. Ecol.* **50,** 977–987 (2013).
3. Tomizawa, M. & Casida, J. E. *Annu. Rev. Pharmacol. Toxicol.* **45,** 247–268 (2005).
4. Sur, R. & Stork, A. *Bull. Insectol.* **56,** 35–40 (2003).
5. Tapparo, A. *et al. Environ. Sci. Technol.* **46,** 2592–2599 (2012).
6. Van Dijk, T. C., Van Staalduinen, M. A. & Van der Sluijs, J. P. *PLoS ONE* **8,** e62374 (2013).
7. van der Sluijs, J. P. *et al. Environ. Sci. Pollut. Res.* http://dx.doi.org/10.1007/s11356-014-3229-5 (in the press).
8. Carson, R. *Silent Spring* (Houghton Mifflin, 1962).

This article was published online on 9 July 2014.

ASTROPHYSICS

Survival of the largest

Whether supernovae create most of the dust in the cosmos is a controversial question. Observations of a distant supernova have revealed signs of freshly formed dust, but the properties of the dust are unexpected. **SEE LETTER P.326**

HALEY GOMEZ

Dust grains play a crucial part in galaxy evolution. They aid in the formation of stars and provide the building blocks of rocky planets and life itself. However, the origin of dust is a contentious topic: it remains unclear whether dust is formed in the violent deaths of massive stars. Supernova explosions are often portrayed as the villains in the life cycle of dust in galaxies, with the harsh million-kelvin gas of the debris thought to efficiently destroy dust grains — produced by the supernova and in the surrounding material — through high-speed collisions with atoms and other grains[1,2]. But indirect observations of considerable quantities of dust in galaxies at low and high redshifts suggest either that supernovae are producing lots of dust[3–6] or that dust destruction by the supernovae is inefficient. In this issue, Gall *et al.*[7] (page 326) describe observations of telltale signatures from dust in an extragalactic supernova. The results reveal, for the first time, that both of these scenarios are likely to be true.

Over the past few years, thanks in part to far-infrared, millimetre and submillimetre telescopes such as the European Space Agency's Herschel Space Observatory[8,9] and the Atacama Large Millimeter/submillimeter Array (ALMA)[10,11], evidence has slowly mounted that dust formation in the aftermath of a supernova may in fact be ubiquitous[12]. In their study, Gall and colleagues investigated whether dust grains were present in the distant supernova 2010jl (Fig. 1). They did this by checking for signs of absorption of light — owing to dust within the supernova — from

X-RAY: NASA/CXC/R. MILIT. COLL. CANADA/P. CHANDRA *ET AL.*; OPTICAL: NASA/STSCI

Figure 1 | Supernova explosion in a distant galaxy. Gall and colleagues[7] examined the dust content of supernova 2010jl, which exploded in a galaxy about 50 million parsecs away from Earth. The system is seen here in an image that combines X-ray and optical observations. The image is about 46 arcseconds across.

debris moving towards and away from us, and by searching for thermal emission from dust in the near-infrared (NIR) part of the electromagnetic spectrum.

Using the Very Large Telescope in Chile, the team observed the supernova over 10 epochs starting 26 days after the initial explosion, and found clear evidence that dust grains were formed in the dense shell that lies just behind the expanding supernova shock. They found that, by day 868 after the explosion, the amount of dust in the supernova had grown considerably compared with their observations at earlier