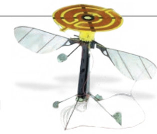
EDITORIALS

POSTDOCS More pay but fewer jobs on the way **p.438**

WORLD VIEW Treat antibiotic resistance as an ecological crisis **p.439**



DRONES Tiny flying robots with power to stick around **p.441**

Reality check on reproducibility

A survey of Nature *readers revealed a high level of concern about the problem of irreproducible results. Researchers, funders and journals need to work together to make research more reliable.*

Is there a reproducibility crisis in science? Yes, according to the readers of *Nature*. As we report on page 452, two-thirds of researchers who responded to a survey by this journal said that current levels of reproducibility are a major problem.

The ability to reproduce experiments is at the heart of science, yet failure to do so is a routine part of research. Some amount of irreproducibility is inevitable: profound insights can start as fragile signals, and sources of variability are infinite. But, the survey suggests, there is a bigger issue — and something that needs to be fixed. One-third of the survey respondents said that they think about the reproducibility of their own research daily, and more than two-thirds discuss it with colleagues at least monthly. The survey, of course, probably attracted researchers most interested in these issues. But it would be foolish to pretend that there is not serious concern.

What does 'reproducibility' mean? Those who study the science of science joke that the definition of reproducibility itself is not reproducible. Reproducibility can occur across different realms: empirical, computational and statistical. Replication can be analytical, direct, systematic or conceptual. Different people use reproducibility to mean repeatability, robustness, reliability and generalizability.

Economists and social scientists often use the term to mean that computer code and data are available so that someone would be able, if so inclined, to redo the same analysis using the same data. For bench scientists, who made up most of our respondents, it usually means that another scientist using the same methods gets similar results and can draw the same conclusions. We asked respondents to use this definition.

Even with a fixed definition, the criteria for reproducibility can vary dramatically between scientists. Senior scientists will not expect each tumour sample they examine under a microscope to look exactly like the images presented in a scientific publication; less experienced scientists might worry that such a result shows lack of reproducibility.

Scientists will need more rigorous use of terminology to get to grips with the problem. For now, broad-brush discussions and solutions are useful. Researchers lament that experiments that cannot be repeated do not give a solid foundation to build on.

Pressure to publish, selective reporting, poor use of statistics and finicky protocols can all contribute to wobbly work. Researchers can also be hampered from building on basically solid work by difficult techniques, poorly described methods and incompletely reported data. Funding agencies and publishers are helping to reduce these problems. Funders have changed their grant requirements and awarded grants for the design of courses to improve statistical literacy; journals are supporting technologies and policies that help to address inadequate documentation. For example, *Nature*'s Protocol Exchange website is available to host a protocol for any experiment, pre- or post-publication.

One-third of survey respondents report that they have taken the initiative to improve reproducibility. The simple presence of another person ready to question whether a data point or a sample should really be excluded from analysis can help to cut down on cherry-picking, conscious or not. A couple of senior scientists have set up workflows that avoid having a single researcher in charge of preparing images or collecting results. Dozens of respondents reported steps to make better use of statistics, randomization or blinding. One described an institution-level initiative to teach scientists computer tools so they could share and analyse data collaboratively. Key to success was making sure that their data-management system also saved time. Another respondent spent three months working on a set of tools that enables different researchers to apply the same equations across different software and computing environments and found that it led to praise, publications and collaborations.

> ***"The criteria for reproducibility can vary dramatically between scientists."***

Nature's survey was launched before the US National Institutes of Health revised its grant requirements to improve reproducibility, and no survey questions asked explicitly about how research institutions might contribute, or how much time and money respondents would be willing to allocate to dedicated efforts to enhance reliability or replicate work. Our respondents seemed in principle receptive to such initiatives, which is encouraging for those — including *Nature* — who have already introduced steps to improve reproducibility. More steps are needed — starting with a discussion in the research community on how to properly credit, and talk to each other about, attempted replications. ■

Source material

Geneticists and historians need to work together on using DNA to explore the past.

Who brought down Rome? Few questions vex historians as much as the identity of the invaders who transformed the last vestiges of the great empire into a series of warring medieval territories. Was it long-distance migrants, the infamous barbarian hordes? Or was it diverse, local militias who moved to fill the power vacuums left by the diminished capital? Both?

This is not a question typically asked in these pages — historians have their own meetings and journals, after all. But as scholars continue to discuss the past, a new breed of scientists is trying to muscle in on the work of the present. These researchers want to use modern genetic techniques to answer historical questions, and as they do so, they are firmly treading on the toes of their colleagues in the humanities. These geneticists promise answers: using analysis of DNA to discover what 'really' happened during the Bronze Age and the Viking sagas and replace 'biased' histories with cold, hard data.

Not all historians are embracing this new world. Many such studies, they complain, take a 'sequence first, historicize later' approach, in which researchers discover some shift in the genetic make-up in the inhabitants of a region, for example, and then postulate a historical event that might be responsible for the demographic change.

Some historians and linguists felt uneasy about papers published in this journal last year that found similarities between the genomes of people living on the Russian steppe 5,000 years ago and in Western Europe 4,500 years ago. The studies speculated that this correlation was the result of a massive migration to Europe of steppe people who also imported Indo-European languages, a family that includes nearly every dialect spoken on the continent (see *Nature* **522,** 140–141; 2015).

So, one might expect historians to be hostile to the latest sequencing effort. It aims to analyse DNA from 1,100 sets of ancient remains from across Italy, Austria, Hungary and the Czech Republic, to work out who filled the void left by the fall of the Roman Empire — or at least how the empire turned into the Lombard kingdom, which ruled parts of Italy between the sixth and eighth centuries AD.

Yet among the project leaders is a card-carrying medieval historian. Patrick Geary at the Institute for Advanced Study in Princeton, New Jersey, has shaped the questions that the project will tackle and how they will be asked. His colleagues must fight for the soul of their field before it is cannibalized, Geary argues. "If historians do not get involved and engage with this technology seriously, we're going to see more and more studies that are done by geneticists with very little input from historians, or from frankly second-rate historians," he says.

This week, he will lead a workshop that will gather 20 or so early-career historians and archaeologists at the Max Planck Institute for the Science of Human History in Jena, Germany, to learn about ancient DNA and other quantitative tools that are disrupting how scholars probe the past.

Among the issues niggling at historians is the concern that an individual's genetic make-up might be used interchangeably with his or her ethnic identity. Historians prefer to see ethnic groups, such as Anglo-Saxons or Franks, as fluid categories that involve identifying with one group while rejecting others. As such, the Lombard sequencing effort will not use DNA to define a genetic profile of the kingdom's founders, but to ask nuanced questions about migration, continuity between earlier and later inhabitants, and whether their ancestry relates to how and where they were buried.

"Historians will be left behind if they fail to incorporate genetics into their research."

Other efforts to get geneticists and historians speaking the same language are under way. A consortium led by ancient-DNA researcher Hannes Schroeder, at the University of Copenhagen, recently won a €1.2-million (US$1.3-million) grant for a collaborative research project called CITIGEN to make his field more accessible to historians and other humanities scholars. Like Geary, Schroeder worries that historians will be left behind if they fail to incorporate genetics into their research. "The train is running, and you jump on it or you miss it," says Schroeder, who is also involved with an effort using ancient DNA to study the transatlantic slave trade.

The young historians and archaeologists who will get their first taste of molecular genetics this week will hopefully come away with a new tool to bring to their research. But they should be prepared — not just to understand genetics enough to read a paper, but to challenge insights gleaned with ancient DNA and to shape how the technology is used to interpret the past. After all, there are barbarians at the gates. ■

Crunch time

Overtime pay for postdoctoral scientists is welcome — but could mean fewer positions.

Low pay and dwindling prospects of a permanent position have left many postdoctoral scientists feeling unloved. Yet last week, postdocs received appreciation from an unusual place: the US Department of Labor. In a long-overdue revision of the country's overtime regulations, the department explicitly included postdocs among those who are eligible for overtime pay if they earn less than US$47,476 per year. As we report on page 450, rather than pay overtime, many funders and universities are expected to raise the minimum wage for postdocs above that threshold.

The regulations are not perfect. They leave out those whose main responsibility is teaching, and the 1 December 2016 deadline to comply is tough for labs that operate on long-term budgets keyed to multi-year grant cycles. And the overtime threshold, which may become the de facto minimum pay for postdocs, still fails to meet the $50,000 per year minimum recommended in a 2014 report on the biomedical workforce by the US National Academies.

Many established scientists look back on their postdoc wistfully as a time of unparallelled focus on research. Yet the postdoc now too often gives way to the 'permadoc'. Postdocs may languish in that position for more than a decade, sometimes bouncing from one position to another. Their careers are in stasis even as their lives march on. Today's postdocs are older than ever. They raise families and care for elderly parents. Many can hardly be considered trainees: they are functioning as lab managers or staff scientists, but are paid at a lower rate.

The stagnation comes because the number of academic faculty positions has not kept pace with the swelling postdoc ranks — a reality that is now receiving more attention, thanks in part to the laudable efforts of a cadre of established scientists who have made it their mission to address the postdoc plight. Francis Collins, head of the US National Institutes of Health (NIH), joined their ranks last week, when he announced plans to raise the pay for some NIH-funded postdocs to match the new overtime threshold. Other funding agencies should do the same.

Such changes do not come without trade-offs. The NIH budget is finite and higher postdoc salaries, however funded, are likely to translate into fewer postdoc positions — a consequence that worries the US National Postdoctoral Association in Washington DC. It also concerns principal investigators already struggling under flat research budgets.

But the change is needed. Principal investigators should take a hard look at their own labs and hiring practices. Do they need so many postdocs? A bigger lab does not necessarily mean greater impact.

Even graduate students can help to ease the postdoc glut. Many do not think hard about their own careers until they are well into their studies. Postdoc positions are so abundant — because they are cheap — that they have become the default career choice even for graduate students who have begun to doubt that they want to continue in science.

Graduate students should be encouraged to prepare earlier for careers outside academia. For example, the University of Massachusetts Medical School in Worcester has gone beyond the standard 'alternative' career seminars and made career preparation a mandatory part of the curriculum, with required workshops held periodically throughout a graduate student's education. Students initially grumbled at being asked to spend more time away from the laboratory. By the end of the programme, 92% of them said they are glad that they did.

Such changes can go far to bring about reform — not just in the United States, but around the postdoc world. ■