restricted to the more shady environments.

Pollinator species varied considerably in their thoracic temperatures: mean values for different species ranged from 27 °C to 43 °C, with the hymenopterans having consistently higher thoracic temperatures than the dipterans. Similarly, the excess temperature of the thorax over the air temperature at the point of capture was greater in the hymenopterans — often greater than 15 °C, compared with less than 10 °C for the dipterans. Herrera also found that the tendency to generate a thoracic temperature that is greater than that of ambient air is positively correlated with body size, because the processes of warming up and cooling down are related to body form and mass. The conclusion is that the sun-seekers are generally smaller and maintain lower thoracic temperatures than the shade-preferring taxa, which are larger and can keep their body temperatures well above their surroundings. So, the thermal biology of insect species determines what microhabitat they select for their foraging activities. This means that a plant species such as lavender, which can grow and flower both in shaded and open-sun conditions, attracts a different set of pollinators depending on the microclimate of its habitat: a lavender plant in a sunny spot will be visited mainly by small bees, whereas lavender in the shade will attract more dipterans and larger bees.

The biological and evolutionary implications of these findings are considerable. Various insects will have different seasonal abundances, pollination behaviour, efficiency in pollen collection and delivery, and distances over which they travel between plants. All of these factors will present the host plant with a number of selective pressures to which, over evolutionary time, it will respond. And because these pressures will differ between 'sun' and 'shade' populations of the plant, pollination could be an important influence on the course of evolutionary development. Previously, the existence of sun and shade ecotypes (or even closely related species) of plants has usually been explained in terms of their photosynthetic physiology, including energy trapping and their ability to maintain a positive carbon balance under different light climates[5]. But the new study by Herrera[1] shows that botanists cannot afford to neglect the energetic properties and predilections of the insect visitors in the process of speciation. ☐

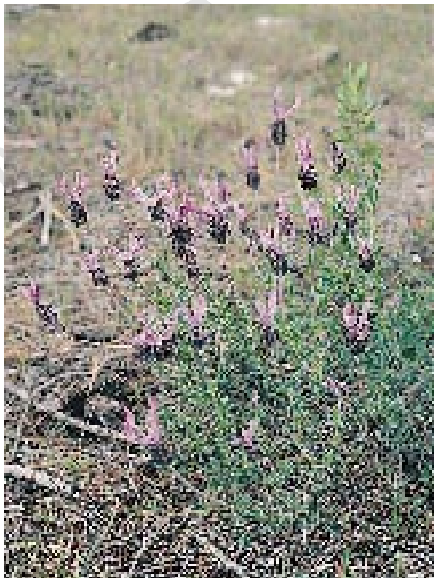
P. D. MOORE

Figure 1 **When sunny gets blue — plants such as lavender, which can grow and flower in both sunny and shaded areas, are visited by different insect pollinators depending on light intensity. According to Herrera[1], whereas large insects such as flies visit plants in shaded areas, smaller insects preferentially visit plants in sunny spots.**

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Demography

Taking the measure of uncertainty

Shripad Tuljapurkar

Judged on performance, population forecasts (usually published by institutions such as the United Nations or census bureaux) have a mixed record. They are no worse than forecasts by economists, meteorologists and others who have to deal with complex and partially understood systems, but demographers have been understandably concerned about error in their predictions. Part of their response is a new wave of demographic work focused on the forecasting of uncertainty, *per se.* Such work aims to forecast a range of demographic outcomes along with associated probabilities, rather than one prediction that will almost surely be wrong.

This new approach is illustrated by Lutz, Sanderson and Scherbov (page 803 of this issue[1]), who present a forecast of world population through the year 2050 and up to 2100. They conclude that the odds of world population doubling by 2050 are less than a third, whereas a doubling of the fraction of the population that is over the age of 60 is essentially a sure thing. Their results stem from a consensus of expert opinion that human fertility will continue to fall everywhere, trailing the decline of mortality by about a half-century. Their result is also noteworthy for its assignment of explicit probabilities to alternative futures.

Traditional forecasts use a 'high–medium–low' method, making a central forecast bracketed by two variants. Although the range between 'high' and 'low' indicates uncertainty, no probabilities are associated with the alternative outcomes, so it is difficult to interpret, employ and evaluate them[2]. In contrast, a probabilistic forecast is valuable to anyone who must make a decision that turns on future events, because one may compute the odds of happy and nasty outcomes, and turn decisions into informed gambles. This is no radical idea; investors, for example, routinely use estimated uncertainty to shape their decisions[3]. But the idea is new to demography, for there are technical challenges, and the forecaster has to educate the people who actually use the forecasts.

A forecaster begins with today's known conditions and projects to a future date that is characterized by unknown demographic conditions such as the level of fertility or mortality. The expert makes assertions about demographic characteristics (for example the level of fertility or the expected length of life) at the end-point, and the trajectories along which those characteristics will change between start and end. I refer to the first of these as 'static' scenarios, because they describe possible conditions at a single future time, and to the second as 'dynamic' scenarios. Finally, one must attach *a priori* probabilities to each static or dynamic scenario.

Lutz *et al.* establish static scenarios, alternative conditions of fertility and mortality in 2050, with attached probabilities. To make a forecast, select one final fertility and mortality ('there'), specify a time-course along which the starting fertility and mortality ('here') changes to 'there', and project the starting population over that time-course. Repeat for each ending scenario, and weight the projected population by the probability associated with the ending scenario. Astute readers will ask how probabilities are assigned to scenarios, and how one gets to each 'there' from 'here'? Lutz *et al.* employ subjective probabilities based on a sampling of expert opinion; this is a version of what used to be called (with some chutzpah) the Delphi method. A more systematic approach uses a retrospective analysis of expert predictions to quantify their bias and error[4,5], and is more objective about assigning probabilities.

The dynamics of getting 'there' from 'here' are largely ignored in the static approach (it is usual to pick some smooth trajectory between initial and final conditions). The usual reasons are a lack of information or a belief that it isn't really important. Neither is convincing in a probabilistic forecast that is motivated precisely by uncertainty.

In contrast, dynamic forecasts employ a stochastic model of changes in fertility, mortality and migration, typically fitted to historical data. The resulting models have uncertainty embedded within them, as reflected in historical change, and yield probabilities for alternative trajectories of future population[6,7]. The trajectories in such models typically contain brief episodes of rapid change and are far from smooth. Such an approach is particularly valuable in assessing social programmes (for instance the US social security system) whose future is sensitive to the timing and pattern of demographic change.

Dynamic approaches tend to be ‘formal’, requiring an explicit mapping from historical information into processes of change. Static scenarios tend to be ‘subjective’, because they rarely make explicit how history is mapped into the future. Dynamic approaches are criticized for an over-reliance on history, on the grounds that the future may hold unknown revolutionary change. That may be true, but the history of this century is surely characterized by tumult and sudden change. Besides, the static approach relies just as heavily on analysing history — which is what makes experts.

The difference between static and dynamic approaches is partly a matter of timescales: fertility change between 1997 and 2050, for instance, is driven by processes that work over two or more human generations. The actual course of transition is marked by changes on a generational timescale, of the sort whose signature is writ large in the demographic history of any country. The overarching goal is the enterprise of developing probabilistic forecasts that are directly useful tools for decision and analysis. With luck, demographers will point the way for ecological and environmental forecasts, which are also bedevilled by uncertainty.

Lutz *et al.* make a persuasive case that global population growth is slowing down, which should soothe those who see population as the primary cause of the world’s ills. But they predict high odds of at least a half-century of substantial global population growth as well as a tremendous increase in the proportion of older people in every country. Those involved in economic, social and population policy still have lots to worry about. International economic policy has a large part to play in helping today’s most populous countries stay on their courses of fertility decline. This is an important role if we are to steer away from the unlikely but real possibility that fertility will start to rise again. For individuals, families and countries everywhere, the largest question of the next few decades will almost surely be, how to age gracefully.

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Lubricants

Super slippery solids

Somuri Prasad and Jeffrey Zabinski

It would appear that primitive man had a clear understanding of the importance of friction and lubrication — transportation of massive objects by the Egyptians in 2000 BC, for example, was facilitated by using sledges dragged over lubricated wooden boards. The role of a lubricant is similar to that of a peace-keeping force: its main function is to prevent the opposing surfaces from coming into close contact with each other at the atomic level. Most lubricants are liquids, but when the operating conditions (such as high or low temperature, or vacuum) are beyond the liquid realm, attention turns to solid materials. The most common solid lubricants are graphite and the transition-metal dichalcogenides, MX_2 (where M is molybdenum or tungsten, and X is sulphur, selenium or tellurium). But both graphite and the metal dichalcogenides have certain inherent deficiencies. The synthesis of hollow nanoparticles of tungsten disulphide (WS_2) similar to fullerenes and nanotubes, reported by Tenne and co-workers on page 791 of this issue[1], offers some exciting possibilities for a new generation of solid lubricants.

First, how do traditional solid lubricants work? The low friction of both graphite and metal dichalcogenides is usually due to interplanar mechanical weakness, intrinsic to their crystal structures. For example, WS_2 crystallizes in the hexagonal structure, in which a sheet of tungsten atoms is sandwiched between two hexagonally packed sulphur layers (Fig. 1, overleaf). The bonding within the S–W–S sandwich is covalent, whereas the sandwiches themselves are held together by weak Van der Waals forces, resulting in interplanar mechanical weakness. Under the action of a shear force, intracrystalline slip occurs in the weak interplanar regions. This mechanism is responsible for the formation of smooth transfer films by wear: the new surfaces, created by separating the weakly bonded sandwiches, are quite inert. They can easily slide back and forth over one another (by intercrystalline slip), thereby providing lubrication.

But there is a major obstacle to lubrication by metal dichalcogenides: the presence of unsaturated or dangling bonds. In a typical layered structure ($2H\text{-}WS_2$), the obvious

100 YEARS AGO

Another name must be added to the long list of martyrs who have given up their lives while endeavouring to effect the conquest of the air. The latest victim is Dr. Wölfert, who had devoted many years to the problem of aerial navigation, and who claimed to have invented a navigable balloon. The Berlin correspondent of the *Times* says that Dr. Wölfert had made an arrangement with the officers of the ballooning section of the army to put his invention to a practical test at Tempelhof on Saturday last. … At first the balloon ascended steadily and began to make good progress… . Suddenly, however, when the balloon was sailing at a height of about 1000 feet, flames shot up from the car and the balloon exploded with a loud report and was precipitated, a burning mass, into a wood-yard below. The mounted officers hurried to the spot, and, after the flames had with great difficulty been partially extinguished, the mutilated remains of Dr. Wölfert and his companion were found amidst the ruins of the car. It is believed that the valve of the balloon was opened with the intention of descending, and that the gas, in escaping from the balloon, became ignited by the benzene.

From *Nature* 17 June 1897.

50 YEARS AGO

The Committee’s programme, as outlined in communications recently received from Prof. Einstein, is to see that the following simple facts, which are accepted by all scientific workers, are given the widest possible publicity. They are: (1) that atomic bombs can now be made cheaply and in quantity, with future bombs likely to be even more powerful and destructive; (2) that there is no military defence against atomic bombs; (3) that other nations can discover for themselves the processes kept secret by the United States; (4) that preparedness against atomic warfare is futile and, if attempted, will ruin the structure of social order; (5) that if war does occur, atomic bombs will definitely be used, and will surely destroy our civilization; and (6) that international control of atomic energy and, ultimately, the elimination of war, is the only solution to the problem. – ‘Emergency Committee of Atomic Scientists’

From *Nature* 21 June 1947.