metres lower than today. This configuration removed much of the present regions of shallow-water energy dissipation and changed the deep-ocean tides, presumably affecting oceanic heat transport. Over longer periods in the past, the entire continental configuration was different, with radically different tidal distributions and mixing. It appears that the tides are, surprisingly, an intricate part of the story of climate change, as is the history of the lunar orbit. ■

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Demography

Greater lifetime expectations

Shiro Horiuchi

For early humans, the average lifespan was around 20 years, as estimated from skeletal remains. Now, in several industrialized countries, it is about 80 years. Much of this increase has happened in the past 150 years. But it was widely expected that as life expectancy became very high and approached the 'biological limit of human longevity', the rapid 'mortality decline' would slow down and eventually level off.

Such a deceleration has not occurred yet. On page 789 of this issue, Tuljapurkar *et al.*[1] show that during the second half of the twentieth century, age-specific death rates in the G7 industrialized countries — the United States, Canada, Japan, France, Germany, Italy and the United Kingdom — continued to decline at a remarkably constant pace. There was no noticeable sign of a slowing down. This report follows one by Wilmoth[2], published two years ago, which indicated that the mortality reduction in the United States, measured by the age-standardized death rate, was even faster in the second half of the century than in the first half.

Assuming a further continuation of the stable pace of mortality decline, Tuljapurkar *et al.* forecast that the life expectancy at birth is likely to increase faster than predicted by the governments of the G7 countries (Fig. 1). This implies that the elderly population in the near future will be greater than in the official forecasts. Depending on the general state of health, the larger elderly population could entail higher medical costs and demands for long-term care and other services, and higher pension payments.

The findings give rise to two interrelated questions. Why has mortality decline not started to slow down? And will it continue into the future? Studies in demography, epidemiology and the biology of ageing and longevity provide clues to the answers. Underlying the steady decrease in mortality level were shifts in the pattern of mortality reduction[3]. In the second half of the nineteenth century and the first half of the twentieth century, there were large decreases in the number of deaths from infectious and parasitic diseases, and from poor nutrition and disorders associated with pregnancy and childbirth. The reduction was pronounced among infants, children and young adults, but modest among the elderly. This led to a view that the fall in death rates at young and middle ages to low levels would soon exhaust the potential to prolong life expectancy further.

	Official forecasts for 2050	Forecasts of Tuljapurkar et al.[1] for 2050	Gap
United States	80.45	82.91	2.5
Canada	81.67	85.26	3.6
Japan	82.95	90.91	8.0
France	83.50	87.01	3.5
Germany	81.50	83.12	1.6
Italy	82.50	86.26	3.8
United Kingdom	82.50	83.79	1.3

Figure 1 **Official medium-variant forecasts of life expectancy in the G7 countries in 2050 compared with the forecasts of Tuljapurkar *et al.*[1]. The figures are for life expectancy for the sexes combined. They are taken from Table 3 of the paper on page 792, and those in the 'gap' column have been rounded to the nearest decimal point.**

But that view did not — and could not — take account of developments in the second half of the twentieth century. Mortality from degenerative diseases, most notably heart diseases and stroke, started to fall[4]. The reduction was pronounced among the elderly[5,6], and some suspected that it might have been achieved through postponing the deaths of seriously ill people. But in the United States at least[7,8], it seems that the health of the elderly greatly improved in the 1980s and 1990s, suggesting that the extended length of life in old age is mainly due to better health rather than prolonged survival in sickness.

Another shift in the pattern of mortality reduction might also have occurred. Despite the marked decrease in deaths from various degenerative diseases, the overall level of cancer mortality remained the same for many years. But, around 1990, a long-awaited decline in total cancer mortality finally started in economically developed countries. Whether that downward trend will continue for long remains to be seen.

These days, the existence of a biological limit to human longevity is considered questionable[9]. Biologists used to think that senescent processes might be programmed into the biological clock of the human body. But they have largely shifted to the view that senescence is mainly due to the body's imperfect systems of maintenance and repair, which allow the long-term accumulation of unrepaired damage in macromolecules, cells, tissues and organs[10]. Progress in ageing research may eventually lead to new medical approaches that lower the rates of damage accumulation[11].

Overall, the evidence supports the expectation that scientific, technological and economic developments will lead to more effective control of degenerative diseases and ageing processes, making it possible to sustain the rapid pace of mortality decline. However, this prospect is not unconditional. New threats to health and survival are arising, including the emergence and re-emergence of infectious diseases, increasing pollution, and the proliferation of nuclear, biological and chemical weapons. If we fail to control these hazards, some of the large gain in the life expectancy of the past 150 years may well be lost[3].

What about the world outside the G7 nations? The prospect of life expectancy soon exceeding 80 years is limited to these and other countries with highly developed market economies. They are mostly in Western Europe, North America and Eastern Asia. In the rest of the world, the life expectancy is on average still under 65 years[12]. In subSaharan Africa, it is under 50 years and may be falling because of the AIDS epidemic, as well as stagnated economic development and political conflicts. Some industrialized nations in Eastern Europe and the former Soviet Union have seen only slow increases, and even occasional reversals, in life expectancy.

It is not surprising that government forecasts of life expectancy and the size of the elderly population in G7 countries are much more conservative than those of Tuljapurkar *et al.*[1]. In the past, national governments, as well as international organizations and academic researchers, have almost invariably underpredicted life expectancy in industrialized market-economy countries. For example, in 1984 the United Nations prepared international population projections based on the assumption that the maximal life expectancy in human populations is 75 years for males and 82.5 years for females. The assumption soon proved wrong: in Japan, for instance, the figures in 1998 were 77.2 years and 84 years respectively. The reason for the underestimates is partly because forecasters regard conservative prospects as less controversial and so 'safe'; and partly because they have often extrapolated past trends in death rates by cause of death or age (or both), missing future transitions in the cause-of-death pattern and age pattern of mortality reduction. It looks as if the same error is still being made. ■

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Fluid dynamics

Smart polymer solutions

Jacob Klein

The proverbial water stays off a duck's back because the duck has waxy water-repellent layers on its feathers. Similarly hydrophobic layers on the surface of most leaves ensure that raindrops bounce or roll off them[1]. This is sometimes known as the Lotus effect — after the leaves of the Lotus flower, which are particularly hydrophobic — and makes it easier for rain to wash away dust and dirt and keep the foliage healthy[2]. But these same waxy layers can have less desirable consequences: for example, they cause droplets of herbicide and pesticide sprays to bounce off plants[3]. As a consequence, over 50% of these toxic sprays are wasted, making it difficult to protect crops and meet environmental regulations.

On page 772 of this issue, Bergeron and co-workers[4] show that by adding low concentrations of long, flexible polymers to water droplets, they can prevent the droplets from bouncing off hydrophobic surfaces. As well as showing how plants could be more effectively sprayed, the work has applications in other areas, such as the efficiency of water-based inks or paints to coat water-repellent surfaces. In this case, polymer additives would eliminate the unwanted side effects associated with the use of noxious organic solvents, which wet such surfaces more readily.

Liquid drops hitting a flat, solid surface expand and flatten, because of their momentum. Most studies to date[5,6] — driven by the need to coat surfaces with liquids as efficiently as possible — have focused on the behaviour of so-called newtonian fluids[7], such as water, whose viscosity is essentially unchanged by most rates of deformation or 'shear'. In the case of water hitting a hydrophobic material, the drops retract after flattening to minimize their contact with the surface; this retraction may be so rapid that part of the drop is ejected and lost from the surface (Fig. 1). Bergeron *et al.*[4] found that a small concentration of a long, flexible polymer added to the water dramatically slows down the retraction rate of the flattened drop on a hydrophobic surface. This prevents it from reaching 'escape velocity', ensuring that the drop — and anything delivered within it — remains on the surface.

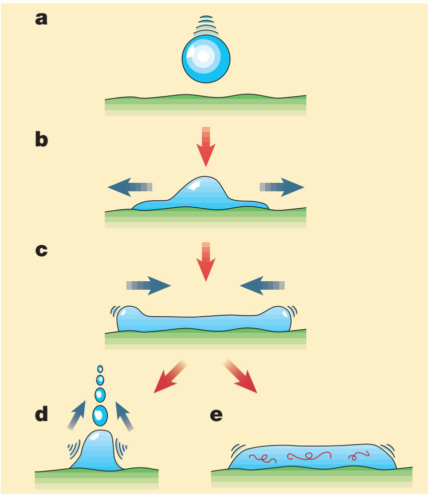

Figure 1 **How to save on weedkiller.** a–c, **The progressive flattening of a water drop hitting a solid surface.** c, **The drop has reached its maximum radius and begins to retract from the hydrophobic surface.** d, **Pure water then retracts rapidly enough to be ejected from the surface.** e, **Bergeron *et al.*[4] show that adding a low concentration of long, flexible polymers slows down retraction — as a result of increasing elongational viscosity — to the extent that ejection does not occur.**

Why does the addition of such small amounts of polymer (typically 0.1 g of polymer per litre of water) have such a large effect? One way that very low concentrations of polymer additives could produce a large surface effect is through adsorption, by which the polymers adhere to the solid surface. Indeed, studies have shown that polymers attached to non-wetting surfaces can stabilize liquid films and prevent 'dewetting'[8,9]. A simple calculation suggests that the duration of the droplet spreading in the experiments of Bergeron *et al.*[4] is sufficient for a polymer layer to adsorb onto the surface. But the authors report that the surfaces remain similarly hydrophobic both before and after the polymer solution has made contact with them.

From this, they conclude that adsorption of the polymer — which would reduce the water repellency and would therefore slow down the drop retraction — is negligible and is unlikely to provide the answer. In fact, they suggest a different origin for the slowing down of the retraction phase. They propose that the flexible polymer coils provide a large resistance to being stretched in the rapidly deforming drop as it retracts after spreading. Such resistance results in a drag on the flowing liquid that is known as elongational or extensional viscosity[7], and it is this, they suggest, that is responsible for the sluggish retraction rate and that stops the drop from bouncing off. The initial flattening is dominated by the drop's momentum, and is much less affected by the elongational viscosity. But the retraction is driven by hydrophobicity, a weaker driving force, which is therefore more affected.

Elongational viscosity in polymer solutions is a non-newtonian effect that comes into play only at deformation rates comparable to or larger than the molecular relaxation rates of the polymer molecules. It can then be orders of magnitude larger than the more familiar shear viscosity, which arises from the drag of the solvent on the undistorted polymer coils and manifests itself at all deformation rates. Elongational viscosity has long been exploited in firefighting, where a tiny concentration of dissolved polymers can dramatically increase the range of the water jet emerging from the hose.

This effect, known as turbulent drag reduction[10], is thought to result mainly from an increase in elongational viscosity, which suppresses the spread of turbulence and so