that they dubbed the self-formed ectodermal autonomous multi-zone (SEAM), which contained four defined concentric zones that in some ways mimicked the developing eye. The authors found that different SEAM zones contained cells with characteristics of the ocular surface ectoderm, the lens, the neuroretina and the retinal pigment epithelium.

Blocking BMP signalling — an intracellular pathway required for the development of surface ectoderm cells — abolished zone 3 of the SEAM. Hayashi and colleagues tested the therapeutic potential of cells from this zone by harvesting the cells and selecting those that expressed genes characteristic of epithelial stem cells (Fig. 1a). The authors cultured transplantable sheets of corneal epithelium from the selected cells, and demonstrated that these sheets could restore a healthy corneal epithelium in rabbits in which corneal epithelial stem cells had been experimentally depleted.

Cataracts, which cause sight-threatening lens clouding[8], are surgically treated by removing the lens from its supporting capsule and replacing it with an artificial intraocular lens (IOL). In children with congenital cataracts, a major cause of childhood blindness, the success of IOL implantation is limited[9,10] — surgery can cause opacity in the line of vision and, because the eye is still growing, it is difficult to provide good vision with spectacles. Rather than attempting to create a living lens *in vitro*, Lin *et al.*[2] investigated the possibility of regenerating a naturally transparent lens in the body.

The authors discovered that lens epithelial stem/progenitor cells (LECs) expressing the genes *PAX6* and *SOX2* self-renew and differentiate into lens fibre cells that can form a 3D transparent lens-like structure that refracts light. In mice, mutation of the stem-cell-maintenance gene *Bmi-1*, which is expressed in LECs, impaired LEC proliferation and induced cataract formation. These data led Lin *et al.* to reason that, by refining the technique for surgical cataract removal to minimize the damage done to LECs *in situ*, they could promote lens regeneration (Fig. 1b).

In rabbits, the authors' minimally invasive technique led to lens regeneration around seven weeks after surgery. The approach achieved similar results in macaques, in which lens regeneration took several months and no complications arose. Finally, the researchers performed a clinical trial, in which transparent lenses were regenerated in both eyes of 12 infants within 3 months, all without complication.

These two studies illustrate the remarkable regenerative and therapeutic potential of stem cells. Hayashi and colleagues' approach involved substantial *in vitro* cell manipulation to obtain a sheet of cultured corneal epithelium for transplantation. When considering the expense involved in following good manufacturing practices for cell therapies, the current protocol is unlikely to be economically viable. However, the real value of this research lies in the possibility that the SEAM model will facilitate the discovery of fundamental mechanisms that underlie the early development of each type of ocular tissue. Such an understanding might eventually enable *in situ* manipulation of stem-cell populations throughout the eye, as Lin *et al.* have elegantly shown to be achievable for the lens. Furthermore, lens regeneration might also turn out to be possible in ageing adults in whom LEC proliferation has declined — for example, research on the SEAM could identify small molecules able to stimulate such regeneration.

Whether either of the reported therapies will lead to cornea or lens transparency that can be maintained in the long term remains uncertain. However, these exciting studies take us away from simple therapies that involve like-for-like replacement of single mature cell types, and open up the possibility of therapeutic manipulation of the broader stem-cell environment in the eye. ■

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1. Hayashi, R. *et al. Nature* **531,** 376–380 (2016).
2. Lin, H. *et al. Nature* **531,** 323–328 (2016).
3. Armitage, W. J., Tullo, A. B. & Larkin, D. F. P. *Brit. J. Ophthalmol.* **90,** 1222–1223 (2006).
4. Borderie, V. M. *et al. Ophthalmology* **116,** 2354–2360 (2009).
5. Pellegrini, G. *et al. Lancet* **349,** 990–993 (1997).
6. Rama, P. *et al. N. Engl. J. Med.* **363,** 147–155 (2010).
7. Takahashi, K. & Yamanaka, S. *Cell* **126,** 663–676 (2006).
8. Stevens, G. A. *et al. Ophthalmology* **120,** 2377–2384 (2013).
9. Visser, N., Bauer, N. J. C. & Nuijts, R. M. M. A. *J. Cataract Refract. Surg.* **39,** 624–637 (2013).
10. Mamalis, N., Davis, B., Nilson, C. D., Hickman, M. S. & LeBoyer, R. M. *J. Cataract Refract. Surg.* **30,** 2209–2218 (2004).

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GLOBAL WARMING

China's contribution to climate change

Carbon dioxide emissions from fossil-fuel use in China have grown dramatically in the past few decades, yet it emerges that the country's relative contribution to global climate change has remained surprisingly constant. **See Letter p.357**

DOMINICK V. SPRACKLEN

In December 2015, world leaders agreed to limit the increase in global average temperature to less than 2 °C above pre-industrial temperatures (see *Nature* **528,** 315–316; 2015). Meeting this aspiration will require large and rapid reductions in greenhouse-gas emissions, making it imperative to understand and account for the emissions from different countries. China has undergone rapid economic development over the past few decades and now has one of the world's largest economies — and greenhouse-gas emissions to match. On page 357 of this issue, Li *et al.*[1] comprehensively assess China's contribution to climate change and explore how this has altered as the Chinese economy has grown.

Humans affect Earth's climate through many mechanisms by changing the abundance of greenhouse gases and air pollutants, and by altering the reflectivity of Earth's surface through changes in land use. The relative strengths of these different drivers can be compared through a metric known as radiative forcing, which quantifies the impact of each process on Earth's energy budget.

Li *et al.* used a model that couples biogeochemistry and climate to estimate China's contribution to global radiative forcing over the period 1980–2010. Crucially, they account for almost all anthropogenic drivers of climate change. They find that China's relative contribution to global radiative forcing from carbon dioxide emissions associated with fossil-fuel use increased almost threefold in these 30 years. This is to be expected, given the surge in China's economy over this period. More surprisingly, they find that China's relative contribution to total global radiative forcing has remained at 10% over this time.

To understand the reasons behind this remarkable result, Li and colleagues made a detailed analysis of the different drivers of radiative forcing. They found that the air pollutants that cause China's notorious pollution haze have had complex effects on climate, counteracting some of the increase in radiative forcing from greenhouse gases. Some components of air pollution, such as black-carbon particles, absorb sunlight and warm Earth's climate. By contrast, sulfate particles scatter light, resulting in climate cooling.

Over the past few decades, China's relative contribution to global radiative forcing from sulfate has increased dramatically. This

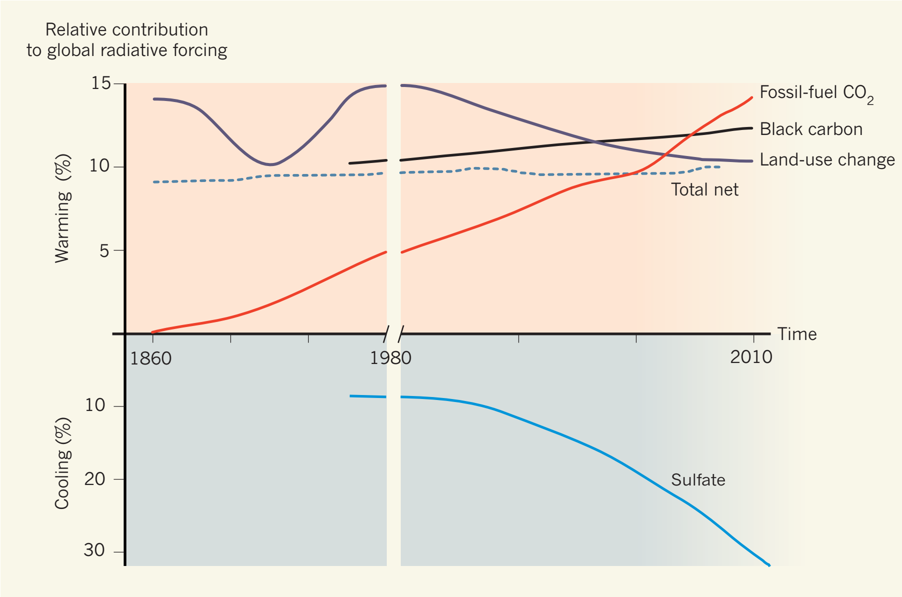

Figure 1 | No net change. Li *et al.*[1] report that China's relative contribution to global radiative forcing — a measure of how strongly different factors affect climate change — has remained constant over the past three decades (broken blue line). The total net effect has several contributors. Carbon dioxide emissions from fossil-fuel combustion have increased, as have black-carbon emissions, both of which lead to climate warming (positive radiative forcing). Land-use change can also contribute to warming, but the effects of this have declined. Conversely, sulfate emissions that cool climate have increased, and the negative radiative forcing associated with this has offset that from warming factors. Plotted lines are approximate.

is because Chinese sulfate emissions soared at the same time that Europe and the United States instigated controls that slashed their sulfate emissions. It has long been known that some air pollutants cool the climate[2]; what is remarkable in the present study is that the concurrent changes in different emissions have led to a stable overall contribution of China to global radiative forcing (Fig. 1).

Air pollution is a serious environmental issue in China, where 1.3 million people die each year because of exposure to poor-quality air outdoors[3]. Reductions in the emissions of air pollutants are urgently required to improve air quality, but this will also affect Earth's climate. Li *et al.* find that the current composition of Chinese air pollution causes almost no net radiative forcing — the cooling effects of sulfate aerosols balance the warming impacts of black-carbon emissions.

This means that it will be difficult to achieve rapid reductions in near-term global warming through the control of Chinese air pollutants overall — a focus on greenhouse-gas emissions in particular will be required. It also means that carefully managed mitigation of air pollution that focuses on reducing both black-carbon and sulfate emissions might have a minimal impact on climate, because their effects seem to counteract each other. Controlling the combustion of solid fuels for cooking and heating in the home is important in this context, because domestic solid fuel accounts for 40% of Chinese black-carbon emissions[4] and causes half a million deaths annually through poor outdoor air quality[3,4].

Li and co-workers went on to explore China's contributions to emissions of CO_2 and methane from pre-industrial times (1750) to the present day. They find that China's relative contribution to radiative forcing from these greenhouse gases has remained remarkably constant over this much longer period as well. The extensive conversion of China's natural forests to agricultural land resulted in substantial CO_2 emissions in the early part of this period. The rate of deforestation has declined in recent decades, but this has been counteracted by increasing fossil-fuel emissions. China is now planting forests on a larger scale than anywhere else on the planet. These plantations sequester CO_2 from the atmosphere, so that Chinese forests are now a net sink of this gas.

Mitigating climate change and air quality without unintended consequences will require an understanding of many complex interactions. Current models, including the one used by Li *et al.*, do not cover many of these complexities. In particular, the authors' study does not consider the formation of secondary organic aerosols — which might dominate in the haze over China[5] — from gaseous pollutants. Detailed monitoring of Chinese air pollution is urgently needed to inform the development of effective mitigation policies[6].

Air pollutants also interact in complex ways with ecosystems: land-use change alters air quality[7], and deposition of pollution can alter forest growth and carbon sequestration[8]. But these effects are not included in many models. Recent work[9] has shown that fast-growing forest plantations in Europe store less biomass

50 Years Ago

The winds of change are sometimes almost indistinguishable from placid summer breezes. The decision of the British Government that British money must now be decimal … would bring some benefit, not disaster … There will be those who claim that the duodecimal system is better because twelve has several integral factors, though it is at least as sensible to argue that the base of all arithmetic should be a prime number in order that people should not be encouraged to manipulate vulgar fractions … More distantly, other feats of rationalization may now be attempted. Why not, for example, decimalize the day? … A decimalized day should be a much more practical proposition. From midnight to midnight would be a million new seconds. One per cent of a day, or 10^4 new seconds, would be a convenient sub-unit roughly equal to a quarter of what is now an hour. Astronomers and airline travellers alike would welcome — in due course — that further proof that decimals are not merely reasonable but inevitable.

From *Nature* 19 March 1966

100 Years Ago

Scientific men in their most august society are banded together "for the improvement of natural knowledge." They are by implication a body of students working in the temple of Nature for truth's sake alone, heedless of the world and its rewards. What they garner is their gift to the world: they fill another page in the Revelation that brings men nearer to the angels. Let a man wander into the world with his science as wares to sell for money profit, and he has passed from true brotherhood. Surely this idea, perhaps rather fancifully stated, is at the bottom of much of our exclusiveness.

From *Nature* 16 March 1916

and absorb more sunlight than do natural forests; both of these features reduce the forests' benefit to the climate. Whether similar issues are at play across China requires investigation, but it is possible that a greater focus than at present on protecting and restoring natural forests in China might also provide greater benefits for global climate. ■

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1. Li, B. *et al. Nature* **531,** 357–361 (2016).
2. Fiore, A. M. *et al. Chem. Soc. Rev.* **41,** 6663–6683 (2012).
3. Lelieveld, J., Evans, J. S., Fnais, M., Giannadaki, D. & Pozzer, A. *Nature* **525,** 367–371 (2015).
4. Butt, E. W. *et al. Atmos. Chem. Phys.* **16,** 873–905 (2016).
5. Huang, R.-J. *et al. Nature* **514,** 218–222 (2014).
6. Kulmala, M. *Nature* **526,** 497–499 (2015).
7. Heald, C. L. & Spracklen, D. V. *Chem. Rev.* **115,** 4476-4496 (2015).
8. Mahowald, N. *Science* **334,** 794–796 (2011).
9. Naudts, K. *et al. Science* **351,** 597–600 (2016).

MICROROBOTICS

Swimmers by design

Scientists have created soft microrobots whose body shapes can be controlled by structured light, and which self-propel by means of travelling-wave body deformations similar to those exhibited by swimming protozoa.

IGOR S. ARANSON

Swarms of 'smart' microrobots scouting the human body, delivering medicines or assembling complex micromachines have long been a popular theme in blockbuster films and best-selling novels. Take, for example, the 1966 film *Fantastic Voyage*, or Michael Crichton's 2002 novel *Prey*. Although at present the concept remains in the realm of science fiction, researchers are taking strides towards bringing the vision closer to reality. Writing in *Nature Materials*, Palagi and colleagues[1] report a big advance towards this goal: the creation of a synthetic light-powered microrobot inspired by swimming *Paramecium* protozoa.

Designing a robust microscopic robotic swimmer that can navigate complex environments and perform useful functions is a key component of the quest. To operate autonomously or on demand, a microswimmer should be able to harvest energy, propel itself through fluid towards its target and respond to external signals. Energy is needed both to overcome the friction of the fluid and to maintain motion for a long time — up to an hour for some biomedical applications.

Several designs exist. One is a microscopic gold–platinum rod that self-propels in an aqueous solution of hydrogen peroxide (H_2O_2; ref. 2). The microrod decomposes H_2O_2 and transfers the energy released by this process to the water. Ensuing water flow pushes the rod forward like a miniature submarine. A similar design[3,4] sees a microscopic, rocket-shaped, composite platinum–polymer tube generate gas bubbles from the decomposition of H_2O_2, with the detaching bubbles propelling the microrocket.

External magnetic and electric fields can also be used to power microswimmers[5–9]. Some swimmers move like snakes or worms, gliding on the surface of water by periodically bending their bodies[8,9]. Scientists foresee microswimmers being used to unclog arteries[10], and to deliver immobile sperm to fertilize eggs[11].

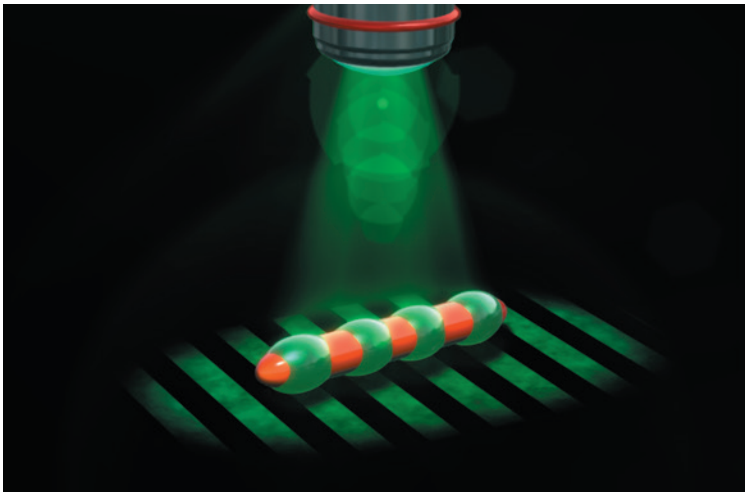
Nature has mastered highly effective means of micrometre-scale propulsion, exemplified by the rotation of helical bacterial flagella, and the wavy beating of the cilia (tiny hair-like structures) that cover *Paramecium*. This metachronal wave — the sequential movement of thousands of cilia — enables paramecia to swim at astounding speeds[12], up to ten body lengths per second. (For comparison, a dolphin barely makes two to three body lengths per second when in a hurry.)

Synthetic microswimmers exhibiting this amazing wavy propulsion would be highly desirable. However, implementing the coordinated wavy deformation of the microscopic swimmer's body presents a technical challenge: the need to manufacture myriad minuscule actuators and joints that can be individually controlled.

Palagi and colleagues propose an elegant means of microscopic propulsion afforded by travelling waves. Instead of a cumbersome array of addressable actuators, the authors use a synthetic polymer — a liquid-crystal elastomer. This rubbery material, made up of molecules oriented in a certain direction, exhibits remarkably strong coupling between molecule orientation and mechanical deformation. The liquid-crystal elastomer elongates when the molecules are fully aligned with each other and shrinks when this molecular ordering is lost, typically when it is heated or exposed to intense light. As a result, this material can be highly sensitive to external stimuli such as light and heat[13].

To make a swimmer, the authors illuminated a millimetre-long rod of this photoresponsive material with a laser beam, using a rectangular array of microscopic computer-controlled mirrors to project a moving sequence of light and dark stripes onto the rod (see Fig. 1). The material responded by expanding or shrinking. Thus, a moving sequence of projected light and dark stripes created a pattern of travelling bumps along the rod, resembling the wavy beating of cilia. Remarkably, the rod swam.

Palagi *et al.* could tune the speed of their soft microrobots by adjusting the speed at which the projected stripes moved, and the motion could be started or stopped by turning the light on or off, respectively. By changing the light patterns, it was also possible to control several microswimmers simultaneously and coerce them into rotating or travelling along a designated path. Theoretically, their swimming speed should increase proportionally with the speed at which the light stripes move. However, the authors found that the material's time response limits the



ALEJANDRO POSADA/MAX PLANCK INST. INTELLIGENT SYSTEMS

Figure 1 | Light-powered swimmer. A microscope (top) projects a moving sequence of light (green) and dark (black) stripes onto a photoresponsive, millimetre-long polymer rod, inducing periodic deformations (visible as bumps) on the rod's surface. Palagi *et al.*[1] show that these travelling deformations propel the soft rod through a fluid in a manner that mimics the locomotion of protozoa.