Although he overemphasizes the perils of regulating new science, Carlson's conclusions are sound. In the Internet era, it is impossible to keep information away from potential bioterrorists. Doing so would fuel a black market and the parallel development of technologies beyond the view of the public and regulators. Carlson cites the example of the drug methamphetamine, which commands a larger illegal market now than it did when enforcement began. By making information widely available, scientists can keep cutting-edge developments in the public eye and ensure that the best tools for combating terrorism are left in the hands of authorities. "Restricting research," he says, "will merely leave us less prepared for the inevitable emergency of natural and artificial biological threats."

Carlson is also concerned about the web of patent protections and licensing fees that threaten to stifle innovation. His solution is 'open-source biology', analogous to open-source software — a commons-based rights framework that allows rapid and inexpensive licensing and minimizes litigation. Open source, he says, "works precisely because it gives value to the process of innovation and allows innovators to set the terms under which their exclusive right is utilized by others". He sees a part of this implementation in the work of the BioBricks Foundation (see http://bbf.openwetware.org), a non-profit organization that encourages the development and use of a standard set of biological parts, made available in the Registry of Standard Biological Parts at the Massachusetts Institute of Technology in Cambridge (see http://partsregistry.org).

The parallels between information technology and synthetic biology break down when we recognize that we are looking at more than the movement of biological information and electrons. Carlson quotes one of the founders of the open-source software movement, Bruce Perens, who asserted that the open-source model works best for products whose value lies mostly in their design: "It only takes a cent's worth of resources to make a copy of a piece of software, but it takes a pound of flour to make a loaf of bread." For the foreseeable future, the engineering of biological systems will remain a costly team effort, requiring investment in reagents, personnel and equipment. It could be a long time before we see real open-source biotechnology: after all, we still pay for bread. ■

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A. NICHOLSON/ STONE/GETTY

Why twins age differently

Epigenetics of Aging
Edited by Trygve O. Tollefsbol
Springer: 2009. 448 pp. $199, £135

Signs of ageing in animals originate from accumulated damage to the genome, proteins or corrupted cell components that reflect a decline in bodily maintenance. Others arise not from this primary damage, but through damage-limitation mechanisms that are provoked by cellular malfunctions. These frequently involve epigenetic processes — mechanisms that modify the information content of the genome without changing its DNA sequence.

Epigenetics of Aging, a collection of articles assembled by molecular biologist Trygve Tollefsbol, gives us a contemporary view of the epigenetic processes involved in ageing. The most significant of these, and the subject of several chapters, is the development of cellular senescence: a major reorientation of cell behaviour that becomes a formidable barrier to cancer.

Cellular senescence is a response to genomic damage and other insults, which activate the tumour suppressor proteins $p16^{INK4a}$ and p53 that promote DNA repair and stop cell division. The genome is then reorganized so that large regions form tight clumps in which genes that are normally active in cell proliferation are silenced. Senescent cells contribute to many characteristics of the ageing body, such as wrinkles.

The book explores a number of epigenetic mechanisms. However, by confining their scope to biochemistry, the authors divulge little of the recent progress in understanding the nature of senescent cells, from the ways in which they induce their neighbours to become senescent using secreted signals, to their capacity to remodel the cell interior and exterior — including loss of skin elasticity.

The book describes how, in the transition to senescence, the epigenetic role of Polycomb proteins — which sustain cell proliferation and repress differentiation genes — is abandoned. The sirtuins are another family of proteins with many epigenetic roles; by modifying the structure of histones and other proteins that are bound to DNA, they control how tightly clumped the genome becomes and facilitate DNA repair.

The advance of senescence is marked epigenetically by a steady loss of methyl groups from some genes and by sporadic gains of these groups in others. These random events can activate or suppress other genes. An important and intriguing contribution to the book shows that in humans, epigenetic markings change in response to life experience: by middle age, a cohort of identical twins developed diversity in their patterns of DNA methylation. This may be related to the variation in lifespan noted between identical twins.

Other articles link the loss of DNA methylation to the development of pathology, including the breakdown of cartilage in osteoarthritis and the production of the amyloid protein associated with Alzheimer's disease. The loss of methylation from critical genes impairs learning and memory function as studied at the cellular level. Several chapters reflect on the possibilities of finding pharmaceuticals that target epigenetic processes and which may be useful for delaying ageing or fighting cancer and other chronic conditions. However, that subject is in its infancy.

Surprisingly, the book ignores the vast body of work indicating that prenatal nutrition and other factors affect the prospects of the mammalian fetus through epigenetic mechanisms. A discussion of the consequences of the Dutch famine of 1944–45 would have been apposite: researchers have shown that, six decades on, children who were conceived during the Nazi-enforced famine suffered more cardiovascular disease and type 2 diabetes than a control group. This was linked to an undermethylated version of the gene for insulin-like growth factor 2. Another curious omission is any discussion of methylation and longevity in honeybees: the queen develops with an unmethylated genome and lives 20 times longer than a worker, whose genome is selectively silenced by methylation. There is more to the biochemistry of epigenetics than is recorded in this volume, including the role of poly(ADP-ribose) and chaperone proteins that help newly formed proteins fold into the correct shape and prevent the formation of toxic aggregates in cells.

Epigenetics of Aging reminds us that mysterious and fascinating processes govern the last phase of life in all organisms. ■

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Where the wilderness line blurs

Living Through the End of Nature: The Future of American Environmentalism
by Paul Wapner
MIT Press: 2010. 252 pp. $21.95

Seen from a distance, some of the wild lynx of Colorado seem to have three ears. As the book *Living Through the End of Nature* explains, behind their trademark pointed ears, the lynx sport an antenna wire that is connected to a radio collar. All of the lynx in that state have been reintroduced. In the late 1990s, their ancestors were trapped in Canada, sedated, given a health check-up, collared and transported by truck, plane and snowmobile to Colorado.

Paul Wapner, director of the Global Environmental Politics Program at the American University in Washington DC, is discomforted by such interventions: "The silver metal wire would in some undefinable way remove a bit of the untamed character of the lynx." Yet he argues that environmentalists must put such fastidiousness about nature aside in a world where a lynx with an antenna is the only alternative to no lynx at all.

It has been more than 20 years since environmentalist Bill McKibben's book announced *The End of Nature*, a state he diagnosed after observing that humans have now affected every square centimetre of Earth by clearing, burning, logging, fishing, moving species around, introducing pollutants and — most pervasively — changing the climate. At the same time, a group of scholars called ecocritics have been pointing out that the concept of nature as a wilderness untouched by humanity does not exist as a concrete entity, but is an abstract concept shared by some peoples in some eras.

Although Wapner does not mention it, this concept of nature is getting a second look among scientists too. It may be that treating humans as something outside nature, rather than as an influential species of animal, has subtly coloured the field of ecology. For example, there is a move among some ecologists to fold the study of invasive species — those species that have been shifted from one place to another by humans — into subdisciplines such as community ecology and biogeography that study species movement more generally.

Lynx reintroductions in Colorado: back to the wild?

A. TOENSING/EDIT/GETTY

What does the 'end of nature' — both the destruction of wild places and the unravelling of a certain Western idea of nature — mean for environmentalism? Wapner imagines a movement that does not worship pristine wilderness, paint humanity as a cancer or alienate those who trust human ingenuity to solve problems. As he points out, "misanthropy is a difficult politics to advertise and sustain". Today's environmentalists, he contends, must stop seeing humanity as the enemy and work for a sustainable future in which people and all the other species on the planet coexist happily.

What would such an ideology look like on the ground? Wapner suggests that we take our cue from the increasingly blurred dividing line between humans and nature, and create soft boundaries between wilderness and developed areas. Instead of a park fence meeting a concrete car park or a clear-cut forest plantation, he sees zones of selective logging shading into wildlife-friendly suburbs. These would be landscaped in a natural style and criss-crossed by wildlife corridors, with pavements and driveways surfaced with "materials that retain rainwater and approximate soil to encourage the encroachment of wildlife into our lives". Inside the wilderness area, we should act as stewards or shepherds, gently working to help other species flourish. As inspiration, he cites natives of the Pacific Northwest, who tidied up streams so that salmon could come home to spawn.

Some wilderness fans will cringe at the prospect of nature management, but Wapner is not advocating aggressive intervention — he is too much in love with the old idea of the untamed wild. For example, he finds the idea of geoengineering our way out of climate change "distasteful" and arrogant. Instead, he recommends focusing on the inexhaustibility of renewable-energy sources rather than stressing the cataclysms that await if we continue to burn fossil fuels, and proposes public meetings to discuss "shared ways of working with pain as a strategy for assisting in our collective ability to live through the greenhouse age in a humane manner". These ideas are representative of the few concrete suggestions he provides: neither particularly daring nor new.

Wapner is right: environmentalists have to adjust to a world without pristine nature. And once they do, they are bound to invent environmental techniques that go beyond creating protected areas. In future, the wilderness may be less wild, but our cities, suburbs, farms and industrial sites will be wilder. ■

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