In practice, however, strict equalization is sometimes inappropriate. For example, if a founder has only one offspring and then dies, only half of its genes survive.

Similarly, family sizes can be equalized by allowing each animal in a captive population to contribute the same number of offspring to the next generation. The Australian team found that equalizing family sizes effectively halved the captive breeding space required to maintain a given degree of genetic diversity[2]. This implication matters because there is a great shortage of captive breeding space for endangered species[7].

IMAGE UNAVAILABLE FOR COPYRIGHT REASONS

Golden lion tamarins (*Leontopithecus rosalia*) — as with many other species, captive breeding programmes may be essential for their survival.

Jessie Cohen/National Zoological Park

Another way to increase the effective size of the captive breeding space is to equalize the breeding sex ratio (R. Frankham, personal communication). Allowing equal numbers of males and females to contribute to the next generation is easy in species that are monogamous, but difficult in those that are polygynous; most mammals and some birds are polygynous. Although artificial insemination is a potential solution, the appropriate techniques have not yet been developed for most endangered species. Available approaches include keeping fewer females with each breeding male and replacing breeding males frequently.

What of the disturbing surprises? The experiments show that even 'properly managed' populations of captive *Drosophila* lost 74 per cent of their reproductive fitness after 11 generations and had lower genetic diversity than large wild populations. Frankham and his colleagues found that this decrease in reproductive fitness can be mitigated by introducing new animals to captive populations[3] — introduction of a single immigrant from one partially inbred population to another increased the second population's reproductive fitness from 0.29 to 0.63 (relative to a fitness of unity in the outbred base population). Unfortunately, this strategy is not an option for captive populations of California condors (*Gymnogyps californianus*), black-footed ferrets (*Mustela nigripes*) and other species that are extinct in the wild.

Another sobering finding is that captive animals rapidly adapt genetically to captivity[4]. Animals adapted to captive conditions are likely to reproduce more poorly in the wild, meaning that captive endangered species should be returned to the wild as soon as possible. Furthermore, the observations suggest that even very large captive populations may lose genetic variation at rates greater than expected[5]. For example, a population of 1,000 *Drosophila* lost 86 per cent of its genetic variation in 2.5 years, making its effective population size much smaller than its census size. This finding is supported by independent work on fish[12].

Overall, the implications of these studies with *Drosophila* are twofold — genetic management is necessary even for very large captive populations, and many small populations may be even more endangered than is generally recognized. Perhaps even more importantly in the long run, they show that work in the laboratory has a great deal to offer in the validation and refinement of conservation genetics theories. ☐

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1. Loebel, D. A., Nurthen, R. K., Frankham, R., Briscoe, D. A. & Craven, D. *Zoo Biol.* **11**, 319–332 (1992).
2. Borlase, S. C. *et al. Conserv. Biol.* (in the press).
3. Spielman, D. & Frankham, R. *Zoo Biol.* **11**, 343–351 (1992).
4. Frankham, R. & Loebel, D. A. *Zoo Biol.* **11**, 333–342 (1992).
5. Briscoe, D. A. *et al. Conserv. Biol.* **6**, 416–425 (1992).
6. Frankel, O. H. & Soulé, M. E. *Conservation and Evolution* (Cambridge University Press, 1981).
7. Ralls, K. & Ballou, J. (eds) *Zoo Biol.* **5**, 81–238 (1986).
8. Wright, S. *Evolution and Genetics of Populations* Vol. 2, *The Theory of Gene Frequencies* (University of Chicago Press, 1969).
9. Robertson, A. *Proc. X Int. Congr. Genet.* **1**, 199–205 (1959).
10. Hammond, K. *Proc. 1st World Congr. Genet. Appl. Livestock Prod.* **1**, 425–437 (1974).
11. Frankham, R. *Proc. 2nd World Congr. Genet. Appl. Livestock Prod.* **5**, 43–56 (1982).
12. Bartley, D., Bagley, M., Gall, G. & Bentley, B. *Conserv. Biol.* **6**, 365–375 (1992).

DAEDALUS

The nuclear mole

THE melt-down of a nuclear reactor has been dubbed 'The China Syndrome', after the country towards which a melting-down Western reactor would head, as it sank white-hot into the Earth. What an excellent method, says Daedalus, of getting rid of a reactor! How much cheaper than painfully decommissioning and dismantling the radioactive hulk! Sadly, modern reactors are not designed as geological submarines. Attempts to melt them down would throw a lot of radioactive material into the atmosphere.

This method of disposal would be better applied to high-level radioactive waste, which generates heat more predictably. Daedalus envisages a dense mass of such waste confined in a container of some high-melting, inert material such as tungsten or tantalum carbide, and left to melt its way steadily down into the Earth.

The waste need not even be ferociously hot. Daedalus reckons that it should be lowered down a very deep borehole, geothermally heated at the bottom already, which would then be filled with water. Pressurized by the hydrostatic head and heated further by the radioactive capsule, the water at the bottom would become supercritical. Supercritical water is an excellent solvent for silica and silicate rocks, so the capsule would dissolve its way into the depths. The shaft above it would slump shut and be sealed by recrystallized rock, trapping the water and raising its pressure further. In due course the capsule would reach rock so hot that it could progress by actual melting. Soon it would be sinking freely through already molten rock. Ultimately, its refractory container would itself melt. The deadly contents would dissolve and disperse safely, hundreds of kilometres down in the Earth's mantle.

Daedalus's 'nuclear mole' could also act as a useful deep-Earth probe. With luck, the resolidified channel left behind it would act as an acoustic fibre or sound-pipe, transmitting seismic pulses without the attenuation of a freely spreading signal. Impulses launched from the surface would then be reflected back by each discontinuity in the channel, as well as by the probe itself. Their travel time and doppler shift would establish the depth and sinking speed of the probe, and the acoustic character of the strata through which it had passed. If the probe or some sensor on it had a resonant frequency sensitive to temperature and pressure, it could relay these conditions too. Even when the probe itself had melted, the acoustic channel would remain, a sensitive geological stethoscope transmitting intimate rumbles from the very bowels of the Earth.

David Jones