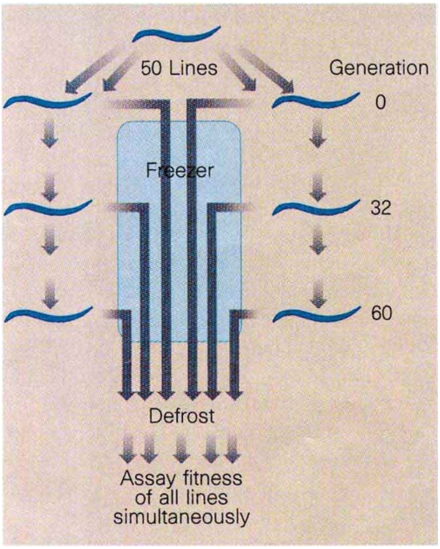

Figure 1 **Keightley and Caballero[6] used the self-fertilizing nematode *C. elegans* to measure the effect of mild deleterious mutations. They established 50 lines from the progeny of a single individual, and these were propagated for 60 generations. In each generation, a single, randomly selected larva was used to propagate each line. This breeding scheme minimizes the effect of natural selection. A sample of individuals was preserved alive by freezing at generations 0, 32 and 60, and frozen individuals were revived at the end of the experiment for simultaneous fitness assays.**

roughly agree with those obtained using a control chromosome (although Keightley has questioned the validity of this finding[5]). In addition, plants that are highly inbred in their natural populations can be used to produce indirect estimates of the rate of mild deleterious mutations. Calculations from these studies[7,8] suggest mutation rates that are in line with Mukai *et al.*'s estimates for *Drosophila*. However, the plant studies do not provide estimates of the magnitude of the effects of deleterious mutations.

A final possibility is that the new experimental results[4,6] are misleading. Keightley and Caballero's experiment[6], like those of Mukai *et al.*, depends on sheltering mild deleterious mutations from the effects of natural selection. But, because *C. elegans* is a self-fertilizing hermaphrodite, deleterious mutations cannot be protected from selection by keeping them in heterozygous form. So the authors had to rely mainly on the sheltering effects of small population sizes and good rearing conditions, as did Fernández and López-Fanjul[4], who used inbred lines in their experiments on *Drosophila*. This should not matter much unless the damage caused by most deleterious mutations is considerably more than twice as large when they are homozygous, as when they are heterozygous. Furthermore, the population sizes used should have been small enough to allow many of the deleterious mutations to accumulate, even if they decreased fitness by as much as 40 per cent when in homozygous form[6,9]. More troubling is that, during the tests of fitness, Mukai *et al.*'s flies were probably faced with more intense competition for food than were the animals in the new experiments. Moreover, the competing genotypes were more diverse than in the new studies. The conditions used in Mukai *et al.*'s tests may be more natural, and more likely to reveal differences in fitness. Keightley and Caballero address the concerns about competitive versus non-competitive tests, but the matter is not settled.

Previous estimates of the rate and magnitude of deleterious mutations are now seriously in doubt. Nevertheless, a solid understanding of these phenomena is within reach. It is not impossible to address any of the problems that have been discussed here, and studies could be extended to cover a wider range of populations and species. The procedure developed by Keightley and Caballero seems to be particularly promising for future investigations as it relies on freezing animals and then reviving them (Fig. 1), allowing the problems that are inherent in measuring experimental populations at a different time from the controls to be eliminated. (Note that the procedure of Fernández and López-Fanjul is susceptible to exactly this sort of problem.) With Keightley and Caballero's procedure, fitness can be assessed simultaneously in a population in which mutations have accumulated, and in the ancestors of that population (which act as a control). A similar advantage might be obtained by using organisms with very long-lasting eggs or seeds.

A better understanding of the characteristics of deleterious mutations is not only possible, it is imperative. Apart from the importance of the issues from a scientific perspective, the rate and magnitude of deleterious mutations have substantial implications for conservation genetics and, therefore, for preserving the diversity of life on Earth[10,11]. □

Joel R. Peck and Adam Eyre-Walker are at the Centre for the Study of Evolution, University of Sussex, Brighton BN1 9QG, UK.

1. Mukai, T. S., Chigusa, S. J., Mettler, L. E. & Crow, J. F. *Genetics* **72,** 339–355 (1972).
2. Charlesworth, B., Morgan, M. T. & Charlesworth, D. *Genetics* **134,** 1289–1303 (1993).
3. Kondrashov, A. S. *Nature* **336,** 435–440 (1988).
4. Fernández, J. & López-Fanjul, C. *Genetics* **143,** 829–837 (1996).
5. Keightley, P. D. *Genetics* **144,** 1993–1999 (1996).
6. Keightley, P. D. & Caballero, A. *Proc. Natl Acad. Sci. USA* **94,** 3823–3827 (1997).
7. Johnston, M. O. & Schoen, D. J. *Science* **267,** 226–229 (1995).
8. Charlesworth, D., Lyons, E. E. & Litchfield, L. B. *Proc. R. Soc. Lond. B* **258,** 209–214 (1994).
9. Crow, J. F. & Kimura, M. *An Introduction to Population Genetics Theory* (Burgess, Minneapolis, 1970).
10. Lande, R. *Conserv. Biol.* **9,** 782–791 (1995).
11. Lynch, M., Connery, J. & Burger, R. *Am. Nat.* **146,** 489–518 (1995).

Daedalus

Tall ships

The fastest-reacting control systems are inherently unstable. This is why a bicycle is so manoeuvrable, and why modern fighter aircraft are so unstable that they must be flown by computer. Daedalus is now carrying this message into new waters. He is designing an unstable boat.

Imagine, he says, a twin-hulled catamaran, turned through 90° about its axis of travel. One hull would then be under the water, the other would be held clear of it, and the two would be joined by vertical spars passing through the water surface. If the submerged hull had sufficient buoyancy to support the exposed one, the craft, though unstable, would be in formal hydrostatic balance.

This novel 'vertimaran' has many virtues. Most ships waste a vast amount of power making waves. But with almost no waterline, the vertimaran will make no waves. Properly streamlined, its lower hull will have relatively little viscous drag; its exposed upper hull will only feel wind resistance; so its fuel costs will be very low. Even better, the vertimaran will be wonderfully unaffected by rough seas. The cross-section of its waterline being negligible, passing waves will produce almost no change of upthrust. A wave crest would have to reach the upper hull, or its trough expose the lower one, before the vessel felt any perturbation.

But how to overcome the craft's instability? Left to itself, the vertimaran would simply fall over sideways, bringing both hulls back to the surface. Daedalus notes that many passenger vessels already have gyro-controlled stabilizer vanes under the water, twisting on command to oppose rolling forces. He is extending and improving this technique. The vertimaran's submerged hull will have several sets of active, servo-powered vanes, always keeping the lower hull vertically under the upper one, thus holding the craft upright.

Like a bicycle, the vertimaran will lose balance if it slows down. When it nears a port, ballast tanks in the submerged hull will be filled with water. The craft will sink down until the upper hull is afloat, converting it to a stable vessel. On leaving harbour with its new cargo, the tanks will be pumped out again; it will rise out of the water and speed on its way.

The vertimaran, with its high speed and utter stability, will be a perfect passenger vessel. Ferry companies and cruise lines will rush to adopt it. And a small one-seater version would make an ideal sporting craft, a sort of sea-going motorbike.

David Jones