Negative interaction between the two groups does not, however, prove that there is a direct relationship. The mesopredators, especially cats, reduced their use of fragments when coyotes were present. Furthermore, coyotes often killed cats. This suggests that mesopredators actively avoid coyotes to reduce the risk of becoming prey.

The changes in the structure of the carnivore community, which were caused by habitat fragmentation, strongly affected the composition of the bird community — as predicted by the mesopredator-release hypothesis. When coyotes became rarer in a fragment, the diversity of bird species decreased, probably because of more efficient predation, especially by cats. The decrease was larger in older fragments. These results are a good illustration of a general principle in conservation biology: it takes a relatively long time to properly assess the impact of human interference on ecosystems.

Crooks and Soulé’s study is an important addition to a small, but exclusive, list that lets us see how changes in the composition of carnivore communities affect species at lower trophic levels. Although based on very few studies, these complicated indirect effects seem to be more of a rule than an exception. For example, when red fox populations in the boreal forests of northern Europe were greatly reduced by an outbreak of sarcoptic mange during the late 1970s and the 1980s, the number of pine martens shot up, most likely because fewer were killed by foxes. The reduction in the fox population was also associated with an increase in the population density of mountain hares and grouse. Similarly, there is experimental evidence that the species composition of the predator community strongly affects the way the prey population fluctuates through time.

Large predators get a mixed press. Many hunters consider them as a severe competitor for ungulates, such as deer. However, if Crooks and Soulé’s results represent a general pattern they caution against simply labelling the ecological effects of a species as ‘good’ or ‘bad’. For example, we can only speculate whether the replacement of the red fox as the top predator in many Scandinavian boreal ecosystems by the rapidly expanding grey wolf population will lead to lower fox densities, resulting in more hare and grouse because of reduced predation by foxes. The reintroduction, or unfortunate disappearance, of top predators provides a unique opportunity to study complex trophic interactions. The ecological consequences are very hard to predict, but they are likely to be considerable.

An ultimate limiting nutrient

Severl elements in the ocean — most notably nitrogen, phosphorus, iron and silicate — are essential for the growth of phytoplankton. Like fertilizers applied to the land, the supply of N, P, Fe and Si in seawater upwelling from below, or in airborne dust deposition from above, determines the rate of production of new organic matter at the surface. It is unlikely, however, that all four elements are equally limiting to growth. Is one clearly more important than the others and, if so, on what timescales? On page 525 of this issue, Tyrrell set himself the goal of building a simple model to describe the relative abundances of NO3- and PO4^3- in the ocean. The nitrogen fixers and those that cannot. The nitrogen fixers can fix N2 from the air (‘nitrogen fixers’) and silicate — are essential for the growth of phytoplankton. Like fertilizers applied to the land, the supply of N, P, Fe and Si in seawater upwelling from below, or in airborne dust deposition from above, determines the rate of production of new organic matter at the surface. It is unlikely, however, that all four elements are equally limiting to growth. Is one clearly more important than the others and, if so, on what timescales? On page 525 of this issue, Tyrrell makes a strong case that it is phosphorus, in the form of dissolved phosphate (PO4^3-), that is the ocean’s ‘ultimate limiting nutrient’.

Of all the nutrients in the ocean, PO4^3- has the longest residence time at around 50,000 years. Residence times of the other nutrients are much shorter — 5,000 years for NO3- (nitrate), 15,000 years for SiO2 (silica) and perhaps 30 years for Fe. Phosphate enters the ocean in rivers, as a product of continental weathering; it is lost from the ocean by being buried in sediments. But like Houdini, PO4^3- is remarkable in its ability to escape burial. Only 1% or so of the upwelled phosphorus taken up by phytoplankton is trapped in sediments. So, considering its rate of input and output from the system, the marine standing stock of PO4^3- is fairly large.

Much of the recent interest in ocean nutrients has centred on the fast-throughput nutrients NO3- and Fe which have relatively low stocks in relation to their delivery to the system. Addition of NO3- and Fe has been shown to increase phytoplankton biomass dramatically (see ref. 6 for instance). Tyrrell’s work makes us appreciate that these dramatic effects are relatively short lived; on long timescales, it is the PO4^3- content of the ocean that sets the standing stocks of the other nutrients.

Tyrrell set himself the goal of building a simple model to describe the relative abundances of NO3- and PO4^3- in the ocean. The model is based on the ecological competition between two types of phytoplankton, those that can fix N2 from the air (‘nitrogen fixers’) and those that cannot. The nitrogen fixers have an advantage in growth rate when nitrate is scarce, but are limited by a lower growth rate when it is abundant. Tyrrell assumes that both kinds of phytoplankton...
Superdiffusion in solid helium

Robert W. Cahn

Low-temperature physics is a field that can appear sealed off from much of the rest of science, and metallurgy in particular. Its practitioners think in terms of millikelvins rather than, like metallurgists, in thousands of kelvins, and observe strange quantum-linked phenomena such as superfluidity and superconductivity. But when a group of low-temperature physicists — in this case, Emil Polturak and colleagues at the Technion in Israel — focus, exceptionally, on the mechanical behaviour of solid helium their results hold particular interest for metallurgists.

Following on from their discovery of unusually rapid diffusion in solid helium, Polturak and co-workers have shown that this ‘superdiffusion’ occurs at the exact temperature at which solid helium changes crystal structure and is linked to a reduction in resistance to stress at this temperature. In a computer simulation, they relate this anomalous behaviour to a new theory of melting. This work covers a whole range of phenomena normally studied by metallurgists, but all within one or two kelvin of absolute zero.

Helium cannot be solidified at ambient pressure, but at pressures exceeding 25 atmospheres and below about 2.5 K it can be turned into a hexagonal-close-packed (h.c.p.) crystal. Over a narrow range of pressures and temperatures near 30 atmospheres and 1.8 K, this structure changes allotropically to a body-centred cubic (b.c.c.) form. Natural helium consists almost exclusively of the $^4$He isotope, but there is another stable isotope, $^3$He, a by-product of the production of tritium in nuclear reactors, which has quite different quantum characteristics. This rare isotope has also been extensively studied, both alone and in the form of $^3$He–$^4$He mixtures (the two isotopes are partially soluble in each other).

Polturak and his team have studied solid $^3$He–$^4$He ‘alloys’ (their term) by using nuclear magnetic resonance (NMR). The basic measurement here is the ‘motional narrowing’ of the NMR resonance line of $^3$He, which allows the speed of diffusion of this isotope to be assessed. Over a narrow temperature range, the helium ‘alloy’ consists of a mixture of solid plus superfluid in equilibrium, and, because the two phases are of different isotopic composition, the two He isotopes can be regarded as distinct components (at least in terms of the phase rule). Three years ago Polturak’s group made the surprising discovery that the mobility of $^3$He in the solid is higher than in the superfluid. No other solid is known in which atoms move faster than in the melt at the same temperature: we have here a remarkable case of superdiffusion, to add to the other ‘super’ characteristics of helium at low temperatures. It turns out that the solubility of $^3$He in $^4$He increases hand in hand with the appearance of crystal vacancies — the authors suggest that the $^3$He is attracted to vacancies because $^3$He has a larger zero-point vibration than $^4$He, and so should migrate preferentially into a vacancy. Something similar had been deduced some years ago from the anomalously fast motion of $^{11}$B impurities in solid Pb.

In two sets of experiments, Polturak’s group observed slow plastic flow (creep) in single crystals of solid $^4$He and of $^3$He–$^4$He mixtures. Stress was imposed on the solid helium (without any heating) by passing a current through a superconducting metal wire embedded in the crystal in the presence of a magnetic field. The diffusion of vacancies and the counterflow of atoms allowed the wire to move through the crystal (Fig. 1a). A separate coil was used as a sensor to measure the rate of movement of the wire, and velocities as low as $10^{-8}$ mm s$^{-1}$ could be measured. For low stress, the creep rate was proportional to the imposed stress, and this is consistent with deformation by the well-established Herring–Nabarro mechanism, also called ‘vacancy creep’ (Fig. 1a).

The velocity of the wire through a pure $^3$He crystal reaches a very high peak due to superdiffusion at the exact temperature at which the h.c.p structure changes to b.c.c. (Fig. 1b). (Various tests prove that the phase transition and the diffusion peak coincide within 1 mK.) Similar maxima, though far less extreme, are seen in b.c.c. metals such as $\text{Ti}$, and have been attributed to the so-called