Daisy gives an evolutionary answer

Jared M. Diamond

It is not often that evolution by natural selection is actually witnessed in plants or animals. A study of little weeds on Canadian islands now provides a striking example of the phenomenon.

CREATIONISTS attack evolutionary biologists for only inferring evolutionary change without observing it directly. Biologists respond that the large-scale evolutionary changes of most interest to us simply cannot be followed, because they take place over times far longer than a human lifespan. In a remarkable paper (*Journal of Ecology* **84**, 53–62; 1996), Martin Cody and Jacob Overton now report the direct detection of both rapid evolutionary change and the 'founder effect' in populations of wild plants. (The founder effect is the phenomenon whereby new colonies of a species may become instantly distinct from the parent population, as a result of their few founding individuals being an atypical sample.)

The evolutionary phenomenon they studied is the loss of dispersal ability by plants and animals confined to islands. Many species that are endemic to remote oceanic islands lack any visible means for having reached the island in the first place (S. Carlquist, *Island Biology*, Columbia University Press, New York; 1974). These species include large flightless birds such as the now-extinct dodo and many surviving rails, as well as trees with gigantic fruits that are intolerant of saltwater and are far too big to be blown by the wind or carried by a bird.

Photos by Martin Cody

A Ross islet, one of the 240 or so islands involved in Cody and Overton's research, and (inset) *Lactuca muralis*, one of the species studied.

Many biogeographers assume that these island populations were founded by colonists from mainland populations that were well adapted for dispersal, such as small flying birds or weedy plants with small wind-dispersed seeds. Once an island population is established, several selective factors would then drive a reduction in dispersal ability. For example, sedentary individuals would remain on the island and contribute to future generations; highly mobile individuals would tend to end up in the ocean and leave no progeny; and stable insular environments would select for high competitive ability at the expense of dispersal. However, without direct demonstration of losses of dispersal ability with time, other biogeographers are sceptical of this reconstruction, instead suggesting that already flightless ancestors arrived from the mainland over land bridges, then both the mainland ancestors and the land bridges vanished. So many land bridges have been thus postulated that the oceans would have been criss-crossed with land if all of them had existed.

Cody and Overton sampled some 240 islands off the Pacific coast of Canada, ranging in area from a few square metres up to 1 km^2. A flora of short-lived weedy plants lives in disturbed habitats on the adjacent mainland, including many species of the daisy family (Asteraceae) which have wind-dispersed seeds. The dispersal unit of these daisies, the diaspore, has two parts: a tiny seed within a covering (the achene), surrounded by or connected to an enormously larger ball of fluff (the pappus). The diaspore thus constitutes a parachute that is well adapted to being carried by the wind, as is familiar to anyone who has watched wind-borne dandelion fluff.

The bigger the fluff ball and the lighter the seed, the longer the diaspore remains aloft, and the farther it is likely to be carried. Cody and Overton quantified this relation by measuring the ratio of pappus volume to achene volume (V_p/V_a, which reaches values as high as 17,000) for 20 diaspores from each of 155 plant populations, dropping each diaspore in still air from a height of 2 m and measuring the drop time (T_d) before it hit the ground. In a vacuum, or for a cannonball in air, T_d for that height would be a mere 0.6 seconds. But for the fluffy light diaspores, T_d is much larger and is correlated with individual variation in diaspore morphology within each species. For instance, T_d of the weed *Hypochaeris radicata* increases from 3 to 6 seconds as the ratio V_p/V_a increases from about 1,000 to 17,000. That doubling of drop time would presumably permit the diaspores to be carried twice as far by the wind.

These humble Canadian island weeds show the reduced dispersal ability that one normally associates with endemic species of distant oceanic islands such as Hawaii. The weeds *H. radicata* and *Lactuca muralis* both have smaller parachutes (V_p respectively 34% and 28% less) on the islands than on the mainland, while *H. radicata* also loads a heavy achene on the parachute (V_a 25% greater). What intrigued Cody and Overton about these evolutionary changes was the possibility that they had developed very quickly, because many of the populations consisted of just a few dozen individuals and were likely to be short-lived.

This possibility was confirmed by taking a census of island plants for eight summers over the course of a decade. Population turnover proved high, with populations often becoming extinct and new ones becoming established. The new populations evidently represented fresh colonizations rather than just reappearances of old populations from buried seeds, because the initial populations invariably consisted of just one or a few individuals and appeared after absence of the species for up to 9 years. Cody and Overton were thereby able to measure parachute and payload sizes in populations of known ages, from an age of 1 year (just founded) up to 10 years or more.

For *L. muralis*, the species with the largest sample size, the youngest island populations prove to have significantly smaller achenes (by about 15%) than do mainland populations. This represents a founder effect: among mainland individuals, those with smaller achenes (lighter payloads on their parachutes) are more likely to get blown to islands. Achene size then increases with population age, until by about 8 years insular achenes return to mainland sizes. Conversely, parachutes (V_p) decrease in size with population age and become significantly smaller than mainland values by about 6 years. Because V_p decreases and V_a rises with population age, the ratio V_p/V_a decreases and so do drop times — probably at least in part because plant individuals with larger parachutes, lighter achenes and longer drop-times tend to remain aloft for longer, get blown out to sea, and fail to contribute to the next generation. These weeds are mostly biennials, so that all of these evolutionary changes are taking place over just 1–5 generations.

Although weeds lack the exotic appeal of Galápagos finches, they constitute much more tractable systems for studying evolutionary change. They are not endangered, protected or confined to remote locations; and they can be ground up for DNA analyses, and experimentally exterminated or introduced into experimental plots without legal or ethical obstacles. Similar advantages apply in principle to a wide variety of other ephemeral small populations of small plants and invertebrates. It is ironic that, after sweating to gain insights from endemics of remote islands for a century and a half, island biogeographers are only now appreciating the virtues of backyard weeds as study objects.

Meantime, Cody and Overton's study is likely to prove highly influential. It is an especially clear and simple example of evolution through natural selection, witnessed historically. □

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MATERIALS SCIENCE

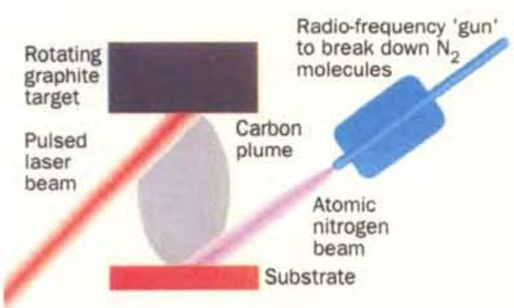
Harder than diamond?

Robert W. Cahn

THE design of exceptional materials from first principles is the philosopher's stone of the modern materials scientist, but alas for ambition, improvements in useful materials have not often sprung from theoretical inspiration. Nevertheless, one very active new experimental research field does spring directly from a theoretical precursor: the search for a superhard carbon nitride. Indeed, it is more complicated than that — theory has spawned experiment, and the recent disappointments of the experimentalists have stimulated the theorists to renewed efforts, as exemplified by a paper by Teter and Hemley on low-compressibility carbon nitrides[1].

The search for carbon nitride sprang from a much-cited trio of papers by Cohen and Liu[2–4]. They made calculations from first principles, on the basis of the shortness and predominantly covalent character of the C–N bond, to predict a very high elastic modulus and correspondingly high hardness for a postulated compound, C_3N_4, with a structure equivalent to Si_3N_4. The correlation between modulus and hardness in ceramics has generally proved to be close.

A comparison of bond characteristics in the two compounds indicated clearly that the carbon nitride should be much the harder — indeed, harder than diamond, and considerably harder than the next best candidate in the hardness stakes, cubic boron nitride. Marvin Cohen's papers, with Liu, occasioned great excitement among many physicists, chemists and materials scientists, and a large number of studies, both experimental and theoretical, have since been devoted to the carbon nitrides (C_3N_4 is only one of the currently predicted compounds, and even a fullerene-like version has been proposed[5]). After six years' work, the very existence of any carbon nitride is still disputed, but the search for this family of compounds continues at an accelerating pace.



Synthesis of carbon nitrides by laser ablation. Inside a vacuum chamber, carbon and nitrogen are allowed to react at the substrate surface. (Adapted from ref. 10.)

Teter and Hemley examined models of carbon nitride in silicon-nitride-like configurations (two subtly different hexagonal versions, α and γ), as well as a graphitic version and a cubic version based on the structure of high-pressure willemite, Zn_2SiO_4. From a quantum mechanical treatment of the different possible electron density functions, they calculated the elastic constants of this postulated cubic C_3N_4 and found it to meet the Born criterion, which checks for stability against loss of rigidity and collapse into another crystal structure or an amorphous configuration. Their value for the bulk modulus is 496 GPa, compared with experimental and theoretical values for diamond of 442 and 468 GPa respectively. All that remains is to make the substance. Teter and Hemley calculated the effect of pressure on the relative stability of the various postulated forms of C_3N_4, and predicted that the cubic form would be stable at high pressure. They conclude that "high-pressure synthesis should be important in the search for new carbon nitrides", and they opine that such phases might be pressure-quenchable, that is, they might remain stable if brought down to low pressures quickly enough.

I turn now to the experimental attempts to prepare carbon nitrides. Fang has written a survey[6] on the "β-C_3N_4 search", including studies made long before Liu and Cohen's papers; he noted the great difficulty of inserting a sufficient proportion of nitrogen into the material and concluded that "there is no credible evidence of this incredible material with chemical composition C_3N_4 and an isostructure of β-Si_3N_4". A few months later, in the same journal, a Chinese group[7] claimed success in making just this compound by graphite ablation in an atmosphere of atomic nitrogen (see below), using infrared spectrometry and X-ray diffraction to characterize the composition and structure of their polycrystalline films. In Australia another group[8] claimed success in making a film with equal amounts of C and N — the highest nitrogen ratio yet achieved — using a reactive sputtering approach (C and N atoms are vaporized from solid targets by ion bombardment into the same space, allowing them to react). However, the structure is graphite-like (having large, flat monolayers weakly bound to each other) and thus not likely to be hard. Similar structures have been made by nitrogen implantation into diamond-like carbon films[9].

The most persistent attempts to form carbon nitrides, by a variety of approaches, have been made by the American chemist Charles Lieber and his group[10]; very recently he has published a detailed survey of the current state of his own and other people's experiments[11]. The principal methods have been reactive sputtering and laser-ablation