expressing a dominant-negative *let-60* allele could lead to discovery of *gf* mutations in genes for proteins that act downstream of *let-60 ras* in vulval differentiation.

Beitel *et al.*[2] also sequenced eight independent *let-60* reduction-of-function mutations that produce a recessive Vul phenotype. The locations of amino acids substituted in such mutants should be of negligible interest, because mutations can disable a *ras* protein in many ways. But in fact the three-dimensional structure of p21[ras] shows that five of these eight mutations are remarkably close to one another on the protein's surface. Of these five, four (including three substitutions of alanine at position 66, and a substitution for glycine at position 75) are located at either end of an α-helix whose conformation changes in response to binding of GTP[16-18]. This proximity is not likely to have resulted from coincidence. Instead, it probably reflects a selection procedure favouring mutant *let-60* alleles that retain partial function. All five of these recessive mutants were obtained in a procedure that required a large proportion of the mutant animals to reach a stage at which vulval differentiation can be scored — this stage is later than the point at which severe loss of *let-60* function kills most *C. elegans* larvae[3,12,19,20]. Perhaps one of the simplest ways for a mutation to induce a partial loss of function is to impair interaction of *let-60 ras* protein with a specific protein; if so, the locations of the substituted amino acids indicate the binding site of the putative protein ligand, which might be a GNRP or the elusive effector. □

*Henry R. Bourne is in the Departments of Pharmacology and Medicine, and Lisa Wrischnik and Cynthia Kenyon are in the Department of Biochemistry and Biophysics, University of California at San Francisco, Box 0450, S-1210, San Francisco, California 94143, USA.*


1. Aroian, R.V., Koga, M., Mendel, J.E., Ohshima, Y. & Sternberg, P.W. *Nature* **348**, 693–698 (1990).
2. Beitel, G.J., Clark, S.G. & Horvitz, H.R. *Nature* **348**, 503–509 (1990).
3. Han, M. & Sternberg, P.W. *Cell* **63**, 921–931 (1990).
4. Herman, R.K. & Hedgecock, E.M. *Nature* **348**, 169–171 (1990).
5. McCormick, F. *Cell* **56**, 5–8 (1989).
6. Satoh, T., Endo, M., Nakafuku, M., Nakamura, S. & Kaziro, Y. *Proc. natn. Acad. Sci U.S.A.* **87**, 5993–5997 (1990).
7. Bourne, H.R., Sanders, D.A. & McCormick, F. *Nature* **348**, 125–132 (1990).
8. Xu, G. *et al. Cell* **63**, 835–841 (1990).
9. Martin, G. A. *et al. Cell* **63**, 843–849 (1990).
10. Ballester, R. *et al. Cell* **63**, 851–859 (1990).
11. Barbacid, M. *A. Rev. Biochem.* **56**, 779–827 (1987).
12. Ferguson, E. L., Sternberg, P. W. & Horvitz, H. R. *Nature* **326**, 259–267 (1987).
13. Wigler, M. *et al. Cold Spring Harb. Symp. quant. Biol.* **53**, 649–655 (1988).
14. Powers, S., O'Neill, K. & Wigler, M. *Molec. cell. Biol.* **9**, 390–395 (1989).
15. Hwang, Y. W., Sanchez, A. & Miller, D. L. *J. biol. Chem.* **264**, 8304–8309 (1989).
16. Milburn, M. V. *et al. Science* **247**, 939–945 (1990).
17. Pai, E. F. *et al. EMBO J.* **9**, 2351–2359 (1990).
18. Schlichting, I. *et al. Nature* **345**, 309–315 (1990).
19. Rogalski, T. M., Moerman, D. G. & Baillie, D. L. *Genetics* **102**, 725–736 (1982).
20. Clark, D. V., Rogalski, T. M., Donati, L. M. & Baillie, D. L. *Genetics* **119**, 345–353 (1988).


GREENHOUSE WARMING

# Vegetation an unlikely answer

*William H. Schlesinger*

WHETHER land plants and soils can act as a net source or a sink for $CO_2$ is a critical and controversial issue for understanding the current increase in atmospheric $CO_2$ and the potential for greenhouse warming during the next century. Using the past as an indication of the future, Adams *et al.*, on page 711 of this issue[1], suggest that the terrestrial biosphere contained significantly less carbon during the last ice age than it does today. They base their analysis on their best estimates of the distribution of land vegetation at the last glacial maximum which they compared with maps of the present-day distribution. The increase in carbon storage is due to the regrowth of forests on areas formerly covered by glacial ice and to the accumulation of soil organic matter in peatlands. Thus, vegetation took up $CO_2$ as the temperature warmed. Over the same interval, the atmospheric $CO_2$ concentration increased[2] from 200 to 280 parts per million (p.p.m.). Adams *et al.* suggest that the current concentration of $CO_2$ (350 p.p.m.) might be even higher if it were not for the uptake by land vegetation.

The maps of the distribution of vegetation 18,000 years ago show that the area of desert was 83 per cent greater than today — a conclusion roughly in line with most studies of lake palynology and measurements of desert dust in the Vostok Antarctic ice core[3]. As forests and woodlands have expanded onto these lands during the past 10,000 years, they have also acted to remove $CO_2$ from the atmosphere and store carbon in organic matter. The total storage of carbon on land during the Holocene is large enough to have removed the entire atmospheric content of $CO_2$, but equilibrium concentrations of $CO_2$ are maintained by degassing of $CO_2$ from the oceans.

That land plants and soils take up $CO_2$ is also indicated by the recent model of Prentice and Fung[4]; however, their estimate of the net storage of carbon on land during the past 10,000 years is smaller, mainly because they assume an unrealistically small area of desert during the last glacial. More significantly, Prentice and Fung suggest that land vegetation could act as a large carbon sink in the potentially warmer climate of the future. The storage could exceed $2 \times 10^{15}$ grams of carbon a year ($g\,C\,yr^{-1}$), which would significantly slow the rate of greenhouse warming due to $CO_2$. Tans, Fung and Takahashi[5] indicate that the terrestrial vegetation and soils must already be acting as a sink for $CO_2$, as the atmosphere does not contain as much of the fossil fuel $CO_2$ as it should, a result they obtain by way of a new estimate for the oceanic uptake of atmospheric $CO_2$ that is derived from human activities. Tans *et al.* suggest that the terrestrial storage of carbon was 2–3.4 × $10^{15}\,g\,C\,yr^{-1}$ in the mid 1980s.

Although all these analyses appear to show that the terrestrial biosphere may act as a sink for $CO_2$ in warmer climates, they differ in degree. The vegetation changes indicated by Adams *et al.* yield an average storage of only $0.13 \times 10^{15}\,g\,C\,yr^{-1}$ on land during the Holocene. I estimate[6] that the maximum potential sink in soils is not now likely to exceed $0.4 \times 10^{15}\,g\,C\,yr^{-1}$. These values are much smaller than the accumulation rates needed to reduce the potential for global warming due to $CO_2$.

The analyses by Adams *et al.* and Prentice and Fung are based only on changes in the distribution of vegetation in response to past and future climates. They do not include stimulation of photosynthesis and carbon storage as a response to higher $CO_2$ concentrations in the atmosphere. Indeed, to achieve the storage of carbon required by the model of Tans *et al.* would seem to require a substantial $CO_2$ fertilization effect, when most field-fertilization studies show little[7,8]. In most cases net primary production is quickly limited by the low supply of nutrients in soils.

The potential for the terrestrial biosphere to store carbon is also limited by degradation of natural vegetation and soils in response to human population growth and agricultural expansion, particularly in the tropics. Houghton[9], Woodwell[10] and their collaborators have shown that there is a significant net release of $CO_2$ to the atmosphere from biomass destruction. As the human population continues to grow exponentially, the potential for vegetation shifts and $CO_2$ fertilization to create a carbon sink on land may become largely academic. The Earth's surface will be too disturbed. □

*William H. Schlesinger is in the Department of Botany, Duke University, Durham, North Carolina 27706, USA.*


1. Adams, J.M., Faure, H., Faure-Denard, L., McGlade, J.M. & Woodward, F.I. *Nature* **348**, 711–714 (1990).
2. Barnola, J.M., Raynaud, D., Korotkevich, Y.S. & Lorius, C. *Nature* **329**, 408–414 (1987).
3. De Angelis, M., Barkov, N.I. & Petrov, N.V. *Nature* **325**, 318–321 (1987).
4. Prentice, K.C. & Fung, I.Y. *Nature* **346**, 48–51 (1990).
5. Tans, P.P., Fung, I.Y. & T. Takahashi. *Science* **247**, 1431–1438 (1990).
6. Schlesinger, W.H. *Nature* **348**, 232–234 (1990).
7. Grulke, N.E., Riechers, G.H., Oechel, W.C., Hjelm, U. & Jaeger, C. *Oecologia* **83**, 485–494 (1990).
8. Billings, W.D., Luken, J.O., Mortensen, D.A. & Peterson, K.M. *Oecologia* **53**, 7–11 (1982).
9. Houghton, R.A. *et al. Tellus* **39B**, 122–139 (1987).
10. Woodwell, G.M. *et al. Science* **199**, 141–146 (1979).