These investigators report that perturbing the expression and site of production of FGF8, a member of the fibroblast growth factor family, can profoundly alter the map of the mouse cerebral cortex. FGF8 is normally expressed at the anterior pole of the telencephalic vesicles and is suspected of influencing neocortical patterning of the telencephalon as it does in the developing hindbrain. To test this hypothesis, the authors used an elegant gene transfer technique—in utero microelectroporation—to alter production of FGF8 in the developing neocortex on embryonic day 11, well before the formation of thalamo-cortical connections. In this way, the authors avoided the early embryonic lethality that occurs in mice engineered to completely lack FGF8 (*15*). Their strategy paid off as the mice survived and displayed a dramatic reorganization of their cortical maps. This reorganization included a shift in boundaries among the frontal, parietal, and occipital areas with no visible disturbances in other brain regions. An increase in FGF8 in the frontal pole displaces the representation of the facial whiskers, the familiar "barrel field," more posteriorly (see the figure). In contrast, blocking FGF8 activity with a soluble FGF8 receptor moved the fields in the opposite direction. Remarkably, introduction of an extra source of FGF8 into the occipital pole produced an extra barrel field situated in the occipital lobe of the cerebral cortex (see the figure). Histological staining clearly revealed the presence and morphology of the barrel fields, leaving little doubt as to the validity of the results.

The ability to rearrange and create new cortical maps at will in a laboratory setting is a great achievement. The results of the Fukuchi-Shimogori and Grove study have important implications for understanding how cytoarchitectonic areas could have been duplicated or added during evolution of the cerebral cortex. It is especially intriguing that the misplaced extra barrel field has a reverse (mirror image) representation of the whiskers, as would be predicted for an area that was duplicated during evolution (*1*). Given that it is now possible to duplicate the sensory representations of the periphery and to create a new functional area in the cerebral cortex, we have an unprecedented opportunity to study how cortical maps develop. For example, it will be important to determine whether the misplaced area induced by the investigators attracts the appropriate thalamic input. Although input from the thalamus appears to have little influence on the initial regionalization of the cortex, it is essential for its appropriate maturation (*4*). Intriguingly, the overall size of the cerebrum in the experimental animals was reduced, prompting speculation about the status of other cortical areas. It is likely that many other competing signaling pathways besides the FGF8 signaling pathway are also involved in cortical map formation (*7–14*). Most important, the new work illustrates how a single mutation in a growth factor could have a sudden and profound effect during evolution on the pattern of cortical map formation. Recent evidence indicates that FGF8 affects cellular proliferation, apoptosis, and differentiation in the mammalian forebrain through modulation of Otx2 and Emx2 expression (*16*). But this is far from the end of the story. As a next step, it will be important to search for additional genes and morphoregulatory molecules that may be involved in cortical specification. It will also be necessary to develop rodent and possibly primate models of cortical dysgenesis that mimic specific genetic or acquired cortical disorders of development (*17*).

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PERSPECTIVES: CLIMATE CHANGE

Storing Carbon on Land

R. J. Scholes and I. R. Noble

The negotiations over the Kyoto Protocol have swung from imminent collapse in The Hague to unexpected advances at Bonn. But terrestrial sinks of carbon continue to be problematic. How important are they in the global carbon cycle? How may they change in the future? And what use might nations make of land management to reduce greenhouse gases in the atmosphere in compliance with the Kyoto Protocol?

Each year, about 120 PgC (1 PgC = 10^{15} g of carbon) is exchanged in each direction between terrestrial ecosystems and the atmosphere; another 90 PgC is exchanged between ocean and atmosphere. For comparison, 6.3 PgC is emitted by burning fossil fuels, about half of which is taken up again by the biosphere within years to a decade (*1*). This net uptake, or "sink," is currently fairly evenly split between land and ocean, but the uptake processes are different, as are projected future behaviors of the two sinks.

The ocean sink is projected to increase from the current 1.7 ± 0.5 PgC/year to around 5 PgC/year by 2100 (*2*). The land, believed to have been a net carbon source before 1950, is currently a net sink of 1.4 ± 0.7 PgC/year. Given that deforestation is thought to be a source of 1.6 PgC/year, the land not undergoing deforestation must be a sink of 2 to 4 PgC/year (*3*). Models project that the land sink excluding deforestation will increase to around 5 PgC/year by 2050 and then level off or decline, possibly steeply (*4*). Whatever decisions are made about sinks in the Kyoto compliance mechanisms, it is essential that these carbon fluxes continue to be monitored.

Several processes may contribute to the net land sink, including the stimulation of plant growth by the rising atmospheric CO_2 concentration, fertilization of ecosystems by airborne nitrogen pollutants, early effects of climate change, recent and historical changes in land management, and time delays between carbon uptake by plants and its eventual release. The relative proportions of these contributions remain uncertain, as does their geographic distribution (*3*). Forest inventory data from North America reveal little evidence of enhanced growth rates (*5*), suggesting that virtually the entire North American sink can be explained by changes in land management. Neither this mechanism nor nitrogen fertilization may be adequate to explain the large tropical sink. The experimentally confirmed increase in plant productivity resulting from increased CO_2 concentrations is theoretically sufficient to account for a large part of the global sink,

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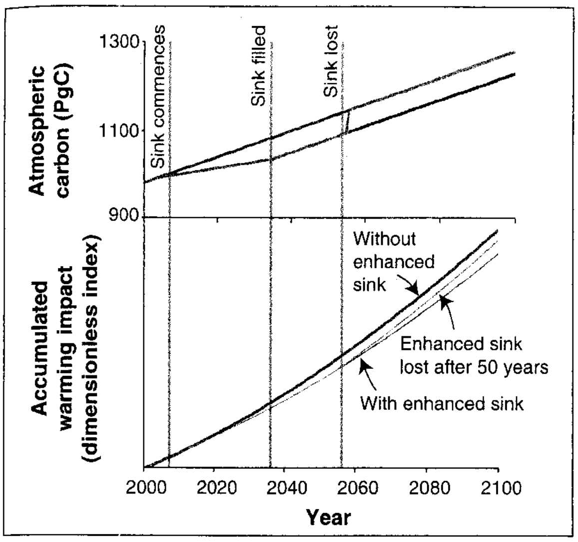

The benefits of carbon storage on land. If the land carbon sink is maximized, it provides some relief from atmospheric warming due to CO_2, while the sink lasts and reduces the accumulated warming impact of atmospheric CO_2 relative to a "no enhanced sink" option. This positive effect occurs even if the enhanced sink has a finite capacity (here shown as 30 years of accumulation at 1.6 PgC/year, beginning in 2005) or if the stored carbon is later catastrophically lost (here in 2055). This graphic is illustrative only and does not refer to any previously published scenario.

but there is some doubt whether this carbon is retained in the ecosystem (*6*). The high interannual variability of the land sink suggests that at least the tropical component is strongly linked to climate (*7*).

The "natural assistance" provided by the biosphere to the mitigation of climate change is much larger than the modest first-round mitigation commitments under the Kyoto Protocol, which amount to about 0.6 PgC/year. If nations could claim a substantial part of the natural sink toward their commitment, they could avoid action on reducing fossil fuel emissions. However, only those sinks arising from direct human action are credited under the protocol (*8*), excluding the mechanisms described above. This decision will challenge scientists to factor out the indirect and "natural" effects and policy-makers to define precisely the boundary between direct and indirect human actions.

Fortuitous biospheric sinks are not to be claimed as greenhouse gas reduction actions. But what about sinks brought about by deliberate action? The existing land sink could, in theory, be enhanced by up to 1.6 PgC/year by 2010 through demonstrated carbon-storing approaches to forest, cropland, and grazing land management (*9*). This rate of storage could be maintained for several decades at relatively low cost compared with the cost of reducing fossil fuel emissions and in most cases without compromising other land-use objectives. Where is the catch, other than letting fossil fuel off the hook? Sink opponents focus on the issues of verification and permanence.

Verification requires that the small increase in the land carbon pool resulting from carbon management be detected and separated from natural variation (*10*). The accuracy with which plant and soil carbon stocks can be estimated is a function of the effort invested: Current error ranges are large because there has been little incentive to measure terrestrial sinks accurately. In our opinion, adequate accuracy is achievable at affordable cost, provided the study area and rate of carbon uptake are sufficiently large.

Permanence is the probability that stored carbon will remain out of the atmosphere. If the conditions that created the sink are not maintained, carbon in the form of plant biomass or soil organic matter is liable to return to the atmosphere, either abruptly (for example, through fires, storms, or pest outbreaks) or more gradually through respiration.

Avoiding deforestation remains the top priority. The charred remains of logging slash in the Brazilian rainforest, after burning.

Biospheric carbon is in a state of continuous turnover through many interconnected pools with different retention times. But even though a particular atom of carbon taken up by the land may be released seconds, days, or centuries later, the net statistical balance-sheet of carbon may still show a credit to the land because another carbon atom has replaced it. The same logic applies at larger scales: An individual tree may grow, die, and decay while the forest persists. There are no plausible circumstances where the world would be worse off, in terms of future atmospheric CO_2 concentrations, for having undertaken measures to promote land sinks (see the first figure), provided that steps to reduce emissions from fossil fuel combustion are not compromised and deforestation is avoided (see the second figure).

The promotion of land sinks can demonstrate early commitment to avoiding climate change. Even if used to the maximum, however, these sinks will make only a minor difference to the final concentration at which atmospheric CO_2 stabilizes. There are practical limits to the amount of carbon that can be stored on land. A realistic upper estimate is the amount of carbon released to the atmosphere as a result of land-use changes over the past 250 years (about 200 PgC). Returning this carbon to the land over the next century would make at most a 70 part per million (ppm) difference to the CO_2 concentration by 2100. This is not insignificant, but it is small relative to the projected atmospheric CO_2 concentration (500 to 950 ppm) (*1*).

The compromise reached in Bonn allows for a strictly limited use of sinks in meeting initial Kyoto Protocol commitments. Three major technical and implementation issues must be resolved well before negotiations begin on commitments for the second period (2012 onward). First, robust techniques must be developed for apportioning carbon sinks between natural and human agencies. Second, it must be demonstrated that carbon stocks and fluxes can be determined reliably and cost efficiently at project and national scales. Third, a set of accounting rules must be developed that allows for the variability of biospheric carbon without rewarding perverse actions.

The main challenges for avoiding excessive climate change are to curb carbon emissions from energy and transport systems and to avoid deforestation. Enhanced carbon storage on land can play a small but important role in this endeavor.

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