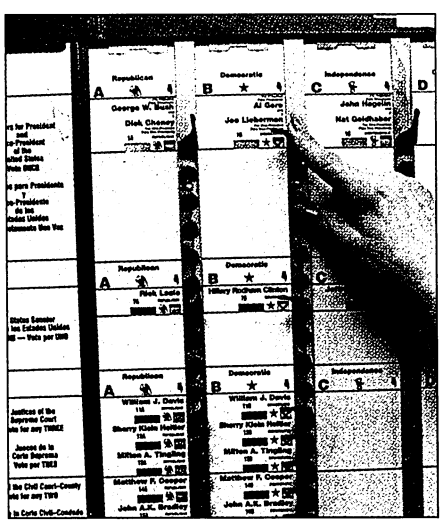
**"[T]he United States clings to the notion that a single vote can be decisive," but, it is pointed out, that is not possible given the error associated with any quantitative measurement. What should be included in calculating the carbon budget and the implications such choices have for forest management decisions are examined. And, on the topic of biological control, "the ecological safety of organisms for the biological control of insects has rarely been considered, much less scientifically addressed."**

## How Much Does One Vote Count in an Election?

In the presidential election, United States citizens encountered a scientific reality—error attends all quantitative measurements. All quantitative observations are to some extent inaccurate, and proper treatment of experimental error has become an important field of science. Yet, in deciding election winners, the United States clings to the notion that a single vote can be decisive, that, for example, a candidate may legitimately win by a vote count of



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1,000,001 to 1,000,000. The uncertainty of measurement is much greater than one vote. Within experimental error, that vote count is a tie.

Scientific realities are widely recognized in other aspects of our lives, so why not in something so fundamental to the United States as the election process? This matter should be studied by statisticians, perhaps as a National Research Council committee, and their recommendation should be considered seriously by Congress. What is needed is a system that is clear and simple, yet scientifically sound. One option, for example, would be to declare a tie if the number of votes for the two top candidates differed by less than 0.1% of total votes cast. In a presidential election, a state's electoral votes might then be split between the candidates, with any odd electoral vote directed by the state's governor.

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## "Kyoto Forests" and a Broader Perspective on Management

Ernst-Detlef Schulze, Christian Wirth, and Martin Heimann argue in their Perspective, "Managing forests after Kyoto," that replacing old-growth boreal forests with young stands will lead to "massive carbon losses to the atmosphere" during the first two decades or so of the growth of a replacement stand (*Science*'s Compass, 22 Sept., p. 2058). These early losses follow a stand-replacing fire and are attributed to decomposition of residual dead biomass from the previous forest. This process returns carbon to the atmosphere faster than young trees can sequester it. Early carbon loss is followed by an extended period of reduced flux of carbon into a "permanent pool of soil organic matter." The authors conclude that in managed ecosystems, both effects "may override the anticipated aim*...[of increasing] the terrestrial sink capacity by afforestation and reforestation."

In managed ecosystems, most old-growth forests are harvested rather than burned. Schultze *et al.* note that harvesting exports carbon instantaneously from an ecosystem. However, policy-makers need to know the net effects of storing this carbon in forest products, with varying longevity and prospects for recycling, and know the effects on carbon uptake in replacement stands of planting fast-growing genetically improved trees, practicing intensive silviculture, and reducing losses to pests and fire. All of these factors could lead to a long succession of short rotations and accelerated storage of carbon in durable forest products. Only when these effects are included in models will policy-makers be able to make an informed choice between forest conservation and forest management.

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*(of the Kyoto Protocol)

Schulze, Wirth, and Heimann's main conclusion in their Perspective is that replacing unmanaged old-growth forests by young "Kyoto stands" will lead to massive carbon losses. Such an outcome is possible in principle but is not proposed in the Kyoto Protocol, and to manage forests in this way would violate the spirit of the Protocol. Most countries seem committed to ensuring that methods of accounting adopted in support of the Protocol will not reward such action. The concerns expressed by the authors have been acknowledged previously, and options have been proposed that would prevent carbon credits from being awarded under the Protocol in situations involving loss of mature forests (*1*). A frequently proposed solution is to allow carbon credits for reforestation only on lands that were not forest in 1990, thus eliminating the incentive for harvesting old-growth forests.

Another point to consider in a discussion of forest management in the context of the Kyoto Protocol is the system boundaries that are chosen for analysis. The full effect of forest management choices on the global carbon cycle can be accounted for only if the system boundaries encompass the impact of forestry projects on the supply of consumer products, and on forests elsewhere. Looking at the carbon balance of a forest stand is not sufficient (*2, 3*). Changes in carbon stocks in wood products and the fossil-fuel implications of materials and energy substitution, for example, should be included. In analyses of forest greenhouse gas balances, inclusion of such factors significantly influenced the results and conclusions drawn (*4*). Harvested wood can be used in place of other materials that are often more energy-intensive. Wood fuel, often derived as a by-product of harvesting and processing, can be used as a replacement for fossil fuels. Less intensive management of existing production forests and lack of new forest establishment could lead to lower availability of wood and result in increased use of other materials and fossil fuels (*2–4*). Afforestation and reforestation programs can help provide additional wood resources for meeting future timber demands and for increasing the use of bioenergy, an important tool for climate change mitigation (*5*). Such programs can also increase carbon stocks in the biosphere and reduce pressure for the harvest of old-growth forests elsewhere (*6*). Ultimately, the carbon balance is only one of many criteria that will influence forest management decisions.

We agree with Schulze *et al.* that protection of old-growth forests is the preferable

strategy in many circumstances. The need for protection of old-growth forests should not, however, be used as an argument against afforestation, reforestation, or appropriate use of forest resources as a means to slow the increase of atmospheric carbon dioxide.

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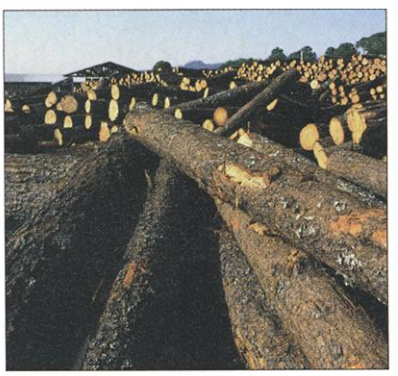
### *Response*

We are glad to see that both replies agree in principle with our conclusion. Here we provide some additional clarifications.

Marland and colleagues refer to a proposal often mentioned in which carbon credits for afforestation and reforestation would be awarded for areas that were bare of forest in 1990, to avoid incentives that are not in the spirit of the Kyoto protocol. However, this time limit must be approved by national governments, no time limit exists for the Clean Development Mechanisms (CDMs, reforestation projects in developing countries), and the time limit for future commitment periods has not been set. During the climate conference in The Hague in November [the sixth Conference of the Parties (COP6)], 1990 was not mentioned for CDM projects in the "Note by the President of COP6," and 2000 was under discussion for some activities.

As to the commitment by countries to the spirit of the Protocol, the conference demonstrated that industrial nations are not willing to accept a debt in afforestation-reforestation-deforestation activities. They requested to write off such debt or to balance it by other activities, such as management of plantations. To avoid accounting of business as usual, the president of COP6 suggested that carbon gains by forest management be discounted by 85%. But this discount would also hold for debits (decreasing carbon stocks due to management). Thus, converting 100 hectares of primary forest would only count as 15 hectares. The reality of negotiations was different from the vision of Marland *et al.*, and it remains to be hoped that the spirit of Kyoto emerges again in the continuation of COP6.

In our Perspective (*1*), we avoided the problems associated with defining "forest management" by taking an example of forests exposed to repeated ground fires (*2*). However, in response to Borden, ground fires have a similar effect as thinning operations (*3*). The Intergovernmental Panel on Climate Change (IPCC) special report describes in detail carbon losses after harvest (*4*). The net carbon balance of a clear-cut forest was still zero 14 years after harvest despite massive growth of a regenerating forest (*3*). In terms of total effects on the atmosphere, it is expected that afforestation and reforestation may decrease atmospheric $CO_2$ concentration at most by about 40 parts per million (ppm), but deforestation and conversion of previously nonmanaged forests (that is, forests in which wood extraction has not taken place) to plantations is expected to increase atmospheric $CO_2$ by 100 to 200 ppm (*5*). Thus, preventing deforestation, degradation, and conversion would be much more effective in stabilizing atmospheric $CO_2$ concentrations than reforestation.



**How do sources of carbon and forms of carbon storage stack up in forest management decisions?**

We agree that a complete carbon budget should include the energy cost of wood substitutes. But differences in mean residence time (average lifetime of products) become important. Forest products have a mean residence time of 10 to 15 years versus decades and centuries in old trees and in soils (*6, 7*). A molecule of $CO_2$ assimilated today is expected to have a longer lifetime as organic matter not in fast-rotating plantations and their products, but in unmanaged forests and undisturbed soil (*7*). It takes time and protection from disturbance to pipe carbon through the ecosystem pools until it reaches a nonlabile state. If rotation time of forests is increased, there is not enough time to deliver carbon to nonlabile pools (*7*).

With regard to fuel substitution, Canadian studies have shown a negative carbon balance (*8*) due to the cost of transport. Wood as an energy source would only save carbon if it were transported for other reasons. It will depend on the carbon cost of transport whether biomass is profitable as a renewable energy source.

Lastly, we agree with Marland *et al.* that "the carbon balance is only one of many criteria that will influence forest management decisions," and decisions are made on the basis of volume growth and not with respect to a net ecosystem carbon balance (*8*). This is why we think a focussed view is needed to define a tolerable window that cannot be abused. Timber products will be needed in the future and should be produced on plantations. At the same time, old-growth unmanaged forests have a separate, important function in the global carbon cycle and in biodiversity.

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6. G. C. Nabuurs *et al.*, *Climate Change* (2000, in press)
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## Safety Data Crucial for Biological Control Insect Agents

In our Policy Forum entitled "Biocontrol of invading species—risk and reform," we discussed past and potential environmental problems (harm to nontarget native species) associated with biological control practice (*Science*'s Compass, 16 June, p. 1969). We argued for a more selective, ecologically safer use of biological control and for safety testing of biological control of insect agents, and we made suggestions for revising regulations and review processes (modeled largely on biological control of weeds) to safeguard this valuable pest management tool and the environment.

In a letter commenting on our article, David Pimentel says that we "do not make the essential ecological assessment of alternative strategies and trade-offs [to using biological control]" (Letters, 11 Aug., p. 869).