magnetic tip, SP-STM exploits the dependence of the tunneling current on the relative orientation of the magnetization of tip and sample. The magnetic tip acts as a source of spin-polarized electrons, probing the spin-split density of states of the magnetic sample. This technique allows imaging with atomic spatial resolution and, like conventional STM, is mostly sensitive to the topmost atomic layer. The ability to probe topography, crystallography, magnetism, and surface chemistry at the same time renders SP-STM a very powerful tool for the investigation of magnetic surfaces and monolayers. Heinze *et al.* (*1*) now demonstrate that SP-STM can be successfully applied not only to ferromagnetic surfaces (*7*) but also to the compensated surface of antiferromagnets. Using a ferromagnetic tip, the SP-STM image shows a superposition of the crystallographic and the antiferromagnetic structure of the surface. The magnetic contribution even exceeds the effect of the crystallography of the sample. The authors attribute the perhaps unexpected strength of the spin-dependent contrast to the enhanced tunneling intensity of periodic features oscillating with reduced spatial frequency, compared with the lattice periodicity. The larger magnetic unit cell causes a comparatively enlarged tip corrugation, explaining the remarkable sensitivity to the antiferromagnetic structure.

Heinze *et al.*'s approach is generally applicable to the investigation of antiferromagnetic and ferromagnetic conductive surfaces. Its particular strength lies in its unrivaled spatial resolution, allowing the detailed investigation of the magnetic structure inside antiferromagnetic domain walls, at steps, and near impurities or defects. Because of its sensitivity to antiferromagnetic and ferromagnetic order at the same time, SP-STM is an ideal tool for investigating the initial stages of growth of a ferromagnetic material on an antiferromagnetic surface. This may help answer the question whether, and if so how, the magnetic structure of the antiferromagnet is imprinted on the ferromagnet by magnetic exchange coupling, because frustration at the interface between alternating moments in the antiferromagnetic layer and preferably aligned moments in the ferromagnetic layer might cause complex magnetic configurations, e.g., 90° coupling (see the figure) (*9*). The method may also provide valuable information about the role played by steps, surface texture, and surface roughness.

The key strength of Heinze *et al.*'s approach, its extreme surface sensitivity, may also be its only weakness with regard to the investigation of coupling phenomena, because the STM signal primarily originates from the topmost atomic layer. Possible changes in the magnetic configuration of buried layers therefore are hidden from the eye of the observer. It is thus a complementary technique to x-ray spectro-microscopy techniques (*5*, *6*), which because of their elemental specificity and relatively long probing depth (3 to 5 nm) excel at the investigation of layered systems at more modest spatial resolution. However, SP-STM is clearly unrivaled for the investigation of the antiferromagnetic structure of magnetic monolayers, surfaces, or surface alloys, as Heinze *et al.* have compellingly demonstrated.

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PERSPECTIVES: ENVIRONMENTAL POLICY

Counting the Cost of Deforestation

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The free market is generally not thought of as an ally of forest conservation. Although societies value forests in myriad ways, traditionally the marketplace has assigned a high value to wood products and nonforest uses of forestland such as agriculture. The marketplace often fails to value the "ecosystem services" that forests provide, such as watershed protection, biodiversity conservation, carbon sequestration and the consequent reduction in greenhouse gas (GHG) emissions. These ecosystem services have enormous value to society (*1*), yet forests continue to be degraded or lost at alarming rates. Currently, 14×10^6 ha of tropical forests are lost annually worldwide (*2*).

Increasingly, forest conservationists have sought to use market economics to protect natural forests from liquidation and conversion to nonforest uses. Examples include ecotourism, certification of wood products from sustainably managed forests, and selling nontimber forest products such as Brazil nuts and mushrooms. In response to global efforts to address climate change, there is increased interest in the benefits of carbon sequestration that accompany forest conservation. Successful marketing of the carbon benefits provided by forest conservation will depend on instigation of international GHG emissions targets such as those contained in the Kyoto Protocol (a treaty of the United Nations Framework Convention on Climate Change). Although such targets have yet to enter into force, investments have already been made in forest conservation projects by energy companies and other industries seeking to secure "credits" for reducing GHG emissions. For example, American Electric Power, PacifiCorp, and BP-Amoco have invested nearly $10 million in the Noel Kempff Mercado Climate Action Project, covering some 600,000 ha of Bolivian rainforest (see the figure). Efforts such as this are a valuable supplement to decreasing fossil fuel consumption, an essential step in the reduction of GHG emissions.

Amazonian rainforest in Bolivia's Noel Kempff National Park.

On page 1828 of this issue, Kremen *et al.* (*3*) demonstrate that the formal adoption of forest carbon markets (as proposed under the Kyoto Protocol) by the international community could dramatically increase incentives for developing nations to protect forests. Using a case study in Madagascar, the authors analyze the costs and benefits associated with preserving a 33,000-ha area of tropical forest (Masaola National Park and surrounding buffer zone) or, alternatively, authorizing large-scale industrial logging. From the standpoint of the local inhabitants and the global community, the financial benefits from designation of the park outweigh those provided by logging. In contrast, at the na-

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tional level, the state would benefit more by offering logging concessions. This benefit to the state is important because it is often the state that has the greatest voice in the future of its forests. However, Kremen and co-workers demonstrate that establishing the Masaola National Park would still be financially preferable for the state provided it received compensation for the reduction in GHG emissions associated with this forest conservation project.

Of course, loss of intact forests often defies economic rationality on any scale. Road building has been the underlying cause of increased deforestation in the Brazilian Amazon since the 1970s. The decision to promote colonization of forest boundaries by building roads was a geopolitical one, and yet the major colonization projects it fostered were economic failures. Current infrastructure development plans for the Brazilian Amazon (the $100 billion *Avança Brasil* program), designed to expand soy exports, would result in a further 18 million ha of deforestation. Further clouding the cost accounting, many of the large-scale projects most destructive to tropical forests depend on international public-sector subsidies, notably from export credit agencies.

Even where developing countries have taken steps to conserve forests, ways to compensate forest and forest-dependent communities and nations for protecting tropical ecosystem services are essential. Indigenous and traditional forest communities that now have rights to and control over large expanses of forest (for example, the 20% of the Brazilian Amazon that is indigenous land) need access to markets and the cash income they provide. If other options are unavailable they will resort to unsustainable mining of forest resources. Even where there are subsidies or where public goods are privately appropriated with broad social and environmental costs, deforestation has developed substantial momentum. Significant private and public costs in halting or reversing deforestation will be incurred by, for example, restoring degraded areas, instigating sustainable agriculture or agroforestry, and monitoring and enforcing forest protection.

In the Madagascar case, after considerable international pressure, the country did establish the Masaola National Park. Kremen *et al.* argue that as industrial logging and its successor, slash-and-burn agriculture, result in dramatic emissions of carbon dioxide and other GHGs, Madagascar is providing substantial global reductions in GHG emissions free-of-charge by protecting a large area of tropical forest.

The Intergovernmental Panel on Climate Change estimates that tropical deforestation was responsible for 20 to 30% of global, anthropogenic GHG emissions during the 1990s (see note 5 in Kremen *et al.*). These data argue strongly for finding ways to reduce emissions from tropical deforestation. Despite this, international negotiators have yet to decide whether forest conservation and certain other land use activities that provide GHG benefits will count toward meeting the GHG emissions reduction targets of the Kyoto Protocol.

Specifically, in the coming months, nations have to decide whether forest conservation should be an eligible activity under the Clean Development Mechanism (CDM) of the Kyoto Protocol. The CDM allows industrialized nations to secure "certified emissions reductions" by undertaking projects to reduce GHG emissions in developing countries. Such certified emissions reductions would count toward achieving the emissions targets set for industrialized nations. If regulations are formulated to guard against the possibility of perverse outcomes, such as violation of indigenous people's land tenure, these CDM projects will also contribute to the sustainable development of poorer nations.

Seeking to curb tropical deforestation (together with the primary objective of reducing GHG emissions from fossil fuels) should be one goal of international efforts to address climate change. But there are complexities associated with accurate quantification of GHG benefits from forest conservation. Baselines must be established that account for the rate of deforestation that would have occurred in the absence of the conservation project.

Satellite photographs suggest how objective baselines for deforestation can be established (*4*). Deforestation is neither homogeneously nor randomly distributed throughout the world. Stratified deforestation maps for the Brazilian Amazon between 1991 and 1996 showed that nearly 90% of the new clearing was within 25 km of areas deforested in 1978, whereas 74% occurred within 50 km of major roads. Using this type of historical evidence, the location and extent of future deforestation can be predicted. For example, the Instituto de Pesquisa Ambiental na Amazônia (IPAM) and Instituto Socioambiental in Brazil predict that between 8 and 18 million ha of the Amazonian rainforest will be deforested in the next 25 to 35 years because of the building of four major roads (*5*). IPAM and the Woods Hole Research Center have developed and are testing a computer mapping model for fire prediction in the Amazon (*6*). Developing such modeling tools and applying conservative assumptions in program design will allow reliable formulation of deforestation baselines.

In addition to the question of baselines, international negotiators must develop accounting rules that ensure countries do not receive credit for forest conservation in one region if the project merely shifts logging to other forests, thereby negating the project's GHG benefits. It will also be necessary to use accounting systems that capture the fluctuations in forest carbon stocks caused by natural disturbances such as fire and pests. Some countries and even environmental organizations believe that these complexities cannot be overcome and that forest conservation, therefore, should not be an eligible activity under the CDM.

In considering the fate of forests under the CDM, nations should be guided by the Special Report on Land Use, Land-Use Change, and Forestry. Released by the International Panel on Climate Change in May of this year, the Special Report was written by many of the world's leading experts on carbon sequestration in forests and other land uses. Much of the report analyzes alternative interpretations of the Kyoto Protocol's somewhat opaque language regarding carbon sequestration. Of most relevance to the CDM, the Special Report devotes an entire chapter to "project-based activities." This chapter and other sections of the report suggest that accounting systems can be developed to ensure the integrity of carbon credits generated though forest conservation.

Kremen *et al.*'s analysis provides further insight into how carbon sequestration and forest conservation under the CDM might work. Their case study concludes that the maximum cost of reducing carbon emissions through establishing the Masaola National Park would be $4.34 per metric tonne of carbon. Given that the marginal cost of carbon is likely to be higher if the Kyoto Protocol enters into force, sale of carbon credits could provide ample funding to compensate the state for the cost of forgoing logging concessions and to buffer against project failure. For example, forest conservation projects might choose to hold some carbon credits in reserve as self-insurance against project risks. Alternatively, other mechanisms may also be developed, such as "carbon insurance" that could be purchased by project investors.

Inclusion of forest conservation in the CDM holds real promise for securing reductions in GHG emissions by providing substantial financial incentives to developing nations to reduce deforestation. Formulating appropriate accounting policies will take much effort, but given the magnitude of the ancillary benefits such as conservation of biodiversity that would also result, international negotiators should seize the opportunity to alter the way global markets value forests.

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