References and Notes

1. Statistical Bureau of Tibet 2005. Annual Economic Statistical Data of Tibet. Lasa, Tibet Press. (In Chinese).
2. Liu, J., Zhan, J. and Deng, X. 2005. Spatio-temporal patterns and driving forces of urban land expansion in China during the economic reform era. *Ambio 34*, 450–455.
3. Gansu Grassland Ecological Research Institute 1991. *Grassland and Livestock Resources in Naqu Prefecture of Tibet*. Lanzhou, Gansu Science and Technology Press (In Chinese).
4. Shengxiu, J. 1982. Grassland Science. Beijing, Agricultural Press (in Chinese).
5. Peng, X. 1985. The rules and systems of grassland classification in China. *Sichuan Grassland 2*, 13–15. (In Chinese).
6. Zizhi, H. 1996. *Introduction to Grassland Classification*. Beijing, Agricultural Press (In Chinese).
7. This work has been supported by China's Special Fund for Major State Basic Research Project (2007CB714406), Knowledge Innovation Program of the Chinese Academy of Sciences (approved KZCX2-YW-313 and KZCX1-Y-02), foundation of the Chinese State Key Laboratory of Remote Sensing Science (KQ060006).

Wang Liwen
The State Key Laboratory of Remote Sensing Science
Institute of Remote Sensing Applications
Chinese Academy of Sciences
Beijing 100101, China
wlw9585@163.com

Wei Yaxing
Department of Geography Liaoning Normal University Dalian 116029, China

Niu Zheng
The State Key Laboratory of Remote Sensing Science
Institute of Remote Sensing Applications
Chinese Academy of Sciences
Beijing 100101, China

Synopsis

This synopsis was not peer reviewed.

The Contribution of Ironstone Outcrops to Plant Diversity in the Iron Quadrangle, a Threatened Brazilian Landscape

INTRODUCTION

Due to the contribution of a hitherto neglected ecosystem, one of the richest mineral provinces in the world, at the heart of a center of floristic diversity, may prove much more diverse and vulnerable than the current figures show.

The Iron Quadrangle (local name Quadrilátero Ferrífero), located in southeast Brazil, covers an area of approximately 7200 km^2 and represents one of the most important and well-studied geological sites on the planet. It is contained entirely within the wealthy state of Minas Gerais, the area of which is approximately 587 000 km^2, larger than France. The Portuguese name, "general mines," attests to the historical ties of this state with the mining industry since colonial times. Constituted by very old—Archean and Paleoproterozoic—terrains, the Iron Quadrangle landscape is presently a mosaic at the ecotone of two Brazilian hotspots, Cerrado and Atlantic Forest, which have been profoundly transformed by human activities, namely urbanization and mining.

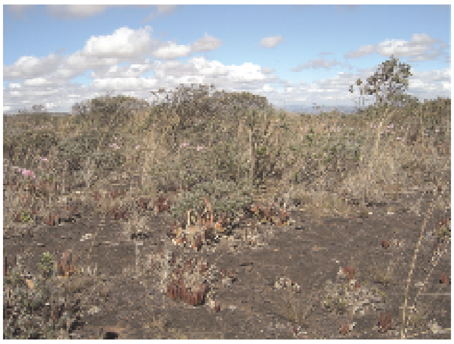
The region is one of the leading producers of metallic minerals in the world, especially superficial iron ore. The intense mining activity entails a complete alteration of the landscape, with enormous impacts on the local and regional biodiversity. The superficial iron crusts, locally known as *canga*, are the result of weathering of minerals derived from banded-iron formations (BIFs), compact hematite, and limonite (1), and they are distributed on the tops and sides of some mountains formed by the huge deposits of iron ore that set the limits of the Iron Quadrangle. These outcrops form islands on top of hills at altitudes ranging from ~1000 to 2000 m.

Currently, there are about 50 iron-ore opencast mines, the extents of which may reach 2000 ha. Opencast mining is highly aggressive to the environment because the ironstone outcrops, and their associated biota, are discarded so that the iron-ore deposits can be reached, and the excavations can reach 300 m depth and expose the water table. Furthermore, the waste derived from these activities contaminates nearby watersheds with heavy metals and toxic elements (2).

These outcrops harbor characteristic rupestral vegetation, which is shrub-dominated, together with a large number of sedges, grasses, and orchids, most of which are epilithic. Due to their very restricted area, difficult access, and because they are associated with high-quality iron-ore deposits, the plant communities over *canga* are among the most threatened and least studied in the otherwise thoroughly surveyed ecosystems of southeast Brazil. Until recently, rupestral plant communities in the region had been given no differentiation with respect to the type of substrate that harbored them. Hence, plants growing over iron ore were frequently recorded together with those

General landscape of the Iron Quadrangle viewed from an ironstone outcrop.

Partial view of an opencast iron-ore mine, showing the superficial crust removal.



Ironstone outcrop plant community.

Table 1. Public conservation units in southeast Brazil containing rock outcrops.

Rock type	National parks	Minas Gerais state parks	Total park area (ha)
Ironstone	–	1	3900
Granite	5	2	210 361
Sandstone	4	11	676 976

Sources: http://www.mma.gov.br/ and http://www.ief.mg.gov.br/.

growing over sandstone or granite. The historical lack of differentiation among lithologies has prevented us from fully comprehending the role of the flora and fauna biodiversity associated with these ironstone outcrops. Recent studies, however, have begun to reveal that the plant communities over ironstone outcrops, which are almost exclusively found in the Iron Quadrangle, with exception of Carajás in north Brazil (equally threatened by iron-ore mining), have a floristic identity and an extremely high local and regional diversity that equals or surpasses those of the other two lithologies.

Preliminary comparative surveys among the two major outcrop types in the Iron Quadrangle, sandstone and ironstone, suggest that the plant communities established over the latter contribute more heavily to the biodiversity of the region than had been previously imagined. In only six ironstones outcrops recently surveyed, which together barely reach 100 ha, 430 angiosperm species distributed among 78 families were catalogued. This number represents 36% of all the families in Brazil, the country with the highest plant diversity. Notably, some of these species are endemic to very few outcrops within the Iron Quadrangle, such as the milkweed *Ditassa monocoronata* and the cactus *Arthrocereus glaziovii*. These surveys illustrate the need to accelerate studies of this particular environment, which, in contrast to the well-documented and world-known sandstone outcrops (the predominant rock type in the area), is undergoing increasing economic pressure.

WHY RESEARCH IRONSTONE OUTCROPS?

The Iron Quadrangle makes up the southern end of an orographic group known as Espinhaço Range, which is recognized as one of the regions with highest floristic diversity in South America, having more than 30% endemic species, most of which are associated with rock outcrop environments (3). These, among other peculiarities, recently granted the Espinhaço Range the status of Biosphere Reserve by the United Nations Educational, Scientific and Cultural Organization.

Following this lead, and with the aim of establishing their identity, an ongoing project at the Federal University of Minas Gerais is devoted to determining the contribution of the flora on ironstone outcrops to the regional plant diversity and to ascertaining the conservation status of these ecosystems throughout the Iron Quadrangle. The initiative, which combines botanists and ecologists, has already revealed a very high local diversity showing astonishing numbers, such as 16 species of vascular plants in a single square meter. This variety is the result of the small size of plants, the rich matrix in which they are embedded, and the mineral and topographical heterogeneity of these outcrops, which create distinct microhabitats side by side and result in a unique association of plants (4). Aside from the more typical communities that are also common to other lithologies, virtually nothing is known about two plant communities typical of ironstone outcrops: temporal ponds, and penumbral rock communities associated with cliffs and cave entrances.

The high diversity contrasts with the severe edapho-climatic conditions typical of outcrops in general, such as high ultraviolet (UV) intensities, daily thermal substrate variations that can reach 45°C, rapid water loss, and poorly developed soil cover, which, in the case of ironstones are further aggravated by a high content of heavy metals. One of the most relevant plant communities for conservation in regions with intense mining activities are metallophyle plants, which encompass those species that have mechanisms of resistance, tolerance, or bioaccumulation regarding metals, usually taxa that are endemic to metalliferous areas. These communities are being investigated for ecological services such as phytoextraction, phytostabilization, and phytoprospection. At present, several research groups are focusing on the conservation and sustainable use of these communities, following the recommendations of the Convention on Biological Diversity to identify and conserve metallophyles. These recommendations have even been proposed for inclusion in the Environmental Management System ISO 14 000 (5). This proposal is fundamental to the short-term conservation of plant communities on ironstone outcrops, because to date, there is no specific environmental legislation that protects this ecosystem. In Brazil, there are important regions with rock outcrops rich in metals, like the Iron Quadrangle itself. However, metallophyle communities, in spite of their evident environmental importance, have yet to become the focus of attention.

Aside from the applications for sustainable use or for recovery of areas degraded by mining, the isolation among outcrops and plant and physiological adaptations make these environments a model system for fundamental ecological and evolutionary questions such as patterns of species richness and distribution of species.

BIODIVERSITY LOSS AND CONSERVATION STATUS

Habitat loss and alteration have long been recognized as leading threats to world biodiversity. In Brazilian ironstone outcrops, this process occurs basically in association with mining activities. Recently, this historical regional vocation has been heavily accelerated as a consequence of the economic emergence of China, which has generated unprecedented demand for raw materials worldwide, in particular high-quality iron ore, a phenomenon that has been termed "the China effect" in the commodities jargon. Mining activities contribute heavily to the Brazilian gross domestic product (GDP). In 2000, the iron ore produced in the region accounted for ~12% of the total value of Brazilian mineral production, excluding the fossil fuels petroleum and gas (6).

Most floristic surveys of ironstone outcrops in the Iron Quadrangle are very recent. Of the handful outcrops surveyed, only one is located within a conservation unit. The others are located in areas owned by mining companies, which unfortunately reflects the vulnerable status of this ecosystem. The mineral rights granted to industry until 2002 cover an area of ~207 000 ha of the Iron Quadrangle. This represents roughly 28% of the total Iron Quadrangle area, and probably 90% of all ironstone outcrops in the region, and illustrates that iron-ore exploitation overlaps heavily with these environments.

Currently, there are nine national parks in southeast Brazil that contain rock outcrops, and these are distributed throughout extensive mountain ranges such as the Mantiqueira and Serra do Mar (granite outcrops), and Canastra and Espinhaço (sandstone outcrops), which together cover ~679 000 ha. In the state of Minas Gerais alone, there are 14 state parks that together cover around 212 000 ha. Only one of these, however, encloses a few mountaintops with ironstone outcrops (Table 1). In order to boost regulatory measures to protect these ecosystems, while maintaining sustainable mining activities in the region, a sound proof of the biological value and floristic identity of these outcrops is mandatory and urgent.

References and Notes

1. Dorr, J.N. 1964. Supergene iron ores of Minas Gerais, Brazil. *Econ. Geol. 59*, 1203–1240.
2. Veado, M.A.R.V., Arantes, I.A., Oliveira, A.H., Almeida, M.R.M.G., Miguel, R.A., Severo, M.I. and Cabaleiro, H.L. 2006. Metal pollution in the environment of Minas Gerais State, Brazil. *Environ. Monit. Assess. 117*, 157–172.
3. Giulietti, A.M., Pirani, J.R. and Harley, R.M. 1997. Espinhaço Range region, Eastern Brazil. In: *Centres of Plant Diversity: A Guide and Strategy for Their Conservation. Vol. 3. The Americas*. Davis, S.D., Heywood, V.H., Herrera-MacBryde, O., Villa-Lobos, J. and Hamilton, A.C. (eds). WWF/IUCN Publications Unit, Cambridge, pp. 397–404.
4. Jacobi, C.M., Carmo, F.F., Vincent, R.C. and Stehmann, J.R. 2007. Plant communities on ironstone outcrops—a diverse and endangered Brazilian ecosystem. *Biodivers. Conserv. 16*, 2185–2200.
5. Whiting, S.N., Reeves, R.D., Richards, D., Johnson, M.S., Cooke, J.A., Malaisse, F., Paton, A., Smith, J.A.C., et al. 2004. Research priorities for conservation of metallophyte biodiversity and their potential for restoration and site remediation. *Restor. Ecol. 12*, 106–116.
6. Brazilian Mining Institute (IBRAM). 2003. *Contribution of IBRAM to the Ecological-Economic Zonation and Environmental Planning of Municipalities Integrating the South Environmental Protection Area, APA Sul*. IBRAM, Brasília, 322 pp (In Portuguese).

7. This research was supported by FAPEM IG (Minas Gerais Research Funding Agency, grant CRA 806/06). Collection permits were issued by IBAMA (Brazilian Institute of Environment and Renewable Natural Resources) and IEF/MG (Minas Gerais Forest Institute).

Claudia Maria Jacobi
jacobi@icb.ufmg.br

Flávio Fonseca do Carmo
flaviodaserra@click21.com.br

Their address:
Departamento de Biologia Geral
Instituto de Ciéncias Biológicas
Universidade Federal de Minas Gerais
Avenida Antonio Carlos 6627
31270-901 Belo Horizonte – MG

Synopsis

This synopsis was not peer reviewed.

Applying a Reverse Auction to Reduce Stormwater Runoff

The effects of stormwater runoff on stream ecosystems are exacerbated by urbanization and the concurrent increase in impervious surface area in a watershed. Proliferation of impervious surfaces creates higher peak flows and higher flow volume during storm events, and it increases the frequency of flows that result in stream-habitat degradation, pollutant loading, and biotic impairment. Current trends suggest that stormwater management should focus on restoring natural drainage processes and through small-scale decentralized efforts at the community level (1). Recent efforts by the US Environmental Protection Agency (US EPA) are focusing attention on the potential use of what is being called green infrastructure to control stormwater flows (2). The US EPA's green infrastructure website highlights a number of municipalities, ranging from large cities, such as New York and Atlanta, to smaller communities nationwide, that have adopted green infrastructure practices as part of their solution to stormwater and wastewater management. Green infrastructure projects have resulted from two regulatory avenues: *i)* the implementation of the National Pollutant Discharge Elimination System Phase I and Phase II stormwater regulations for municipal dischargers, and *ii)* enforcement actions for combined and sanitary sewer overflows (CSO and SSO), where the alleged violators agree to undertake Supplemental Environmental Projects (SEP) in exchange for mitigation of monetary penalties. These SEP are based on the premise, detailed in the National Resource Defense Council's 2006 report *Rooftops to Rivers* (3), that they will control stormwater volume at the source, thereby reducing overall volume in the system during storm events.

Incentives for commercial properties to adopt stormwater runoff control are usually employed through command-and-control tactics such as stormwater fees and rebates for implementation of certain best management practices (BMP). In recently built housing developments around the country, in part due to increased awareness of the inimical effects of stormwater runoff, municipalities often have sufficient public support to be able to require stormwater runoff BMP. However, property rights issues and lack of impervious surface restrictions during past building periods conspire to cause built residential property to be one of the hardest-to-control sources of stormwater runoff. Parikh et al. (4) suggested a reverse auction as the preferred economic mechanism to create incentives for construction of retrofit, low-technology stormwater runoff retention practices in established residential neighborhoods. Currently, the popular alternative is to offer a fixed payment to residents to install certain BMP on their property (5). We show the auction to be more cost effective.

The Shepherd Creek Project, initiated in 2003 by the US EPA's Office of Research and Development, used a reverse auction mechanism as an incentive to convince homeowners in an urban residential neighborhood in Cincinnati, OH, to accept rain gardens and rain barrels on their properties as a means to reduce stormwater runoff. In the spring of 2007, we conducted a reverse auction in the Shepherd Creek neighborhood. The auction was designed to compensate residents for their costs of adopting BMP (rain barrels and rain gardens) on their property. Each of approximately 350 homeowners residing in the neighborhood received one educational mailing and one door hanging that summarized information regarding the practical benefits of rain gardens and rain barrels, their appearance, their hydrological effectiveness, and their purported effect on stream ecology. Using a bid form that was mailed to each home approximately two weeks after the informational material, participants submitted bids for the minimum compensation that they would require to accept a rain garden and/or up to four rain barrels. A discriminative price auction was employed because of its theoretical "truth-revelation" properties, including optimal bidding strategy, and it would reflect the actual opportunity cost of BMP adoption.

The goal was to pay those landowners who adopted the most effective BMP at the lowest price. Individual bids were