Mining, deforestation and conservation opportunities: A case study of the Quadrilátero Ferrífero land use change dynamics

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Abstract: Mining and mineral processing operations fundamentally oppose the objectives of conservation programs. Environmental compensation (or biodiversity offset) policies, however, present a unique opportunity to expand conservation reserves within mining regions. In this study, we quantified the land use change dynamics that have occurred within Minas Gerais' intensive iron ore mining region, the Quadrilátero Ferrífero. Specifically, the objectives of the study were to: 1) quantify the direct impact of mining operations on native vegetation extent and compare this to that caused by other land uses, and 2) to investigate the conservation effectiveness of previously established environmental compensation areas in preventing vegetation loss. To do this we quantified the land use change in the region at four time points over 20 years using Landsat images. Results illustrate that the region has undergone rapid and extensive change. In 2010 only 46% of native (unproductive) vegetation remained. Deforestation was the result of multiple pressures that emerged from multiple land users in the region. Mining accounted for 14% of vegetation loss since 1990, with the remainder caused by a combination of expanding cattle pastures, Eucalyptus plantations and urbanization. In 2010, only 20% of the region was under some form of conservation tenure, with less than 0.05% of native vegetation protected for the purposes of environmental compensation. Within these compensation reserves, however, almost no vegetation loss was observed. If all mining companies in the region had been required to compensate for the deforestation caused by their operations at least an additional 15,000 ha of native vegetation would be protected. We conclude that while the direct impacts of mining on deforestation is relatively small, mining companies can play a much larger role in regional dynamics as there is a great opportunity to expand the protected area network in the Quadrilátero Ferrífero through the use and implementation of environmental compensation policies.

Keywords: biodiversity offsets, environmental compensation, land use classification, Landsat

1. Introduction

Mining and mineral processing operations fundamentally oppose the objectives of conservation programs. Mine establishment and expansion involves deforestation and soil displacement, consumption of energy and water resources and large-scale development of industrial infrastructure to support processing and exportation requirements. Previous research has highlighted the potentially negative environmental impacts of these processes on biodiversity, ecosystem function and ecosystem services (e.g. Barrett et al. 2009; Malaviya et al. 2010; Simmons et al. 2008).

In most of the world's resource regions, the direct area occupied by mines is a small proportion of the total land surface area. Beyond the boundaries of site leases, however, mines are often situated within a complex mosaic of other land uses and users. In these regions change and development often occurs rapidly due to the extensive socioeconomic opportunities that mineral production brings to a region. These off-site (or indirect) development effects also pose significant environmental impacts, some of which can be far more extensive than the direct impacts of mining itself (Schueler et al. 2011).

Biological conservation in such rapidly changing regions is extremely important to preserve and manage natural resources. Governments, however, often do not have the resources required to enable strict enforcement of such conservation initiatives (Soares-Filho et al. 2012), especially when change occurs rapidly. One opportunity for conservation is available through the use of environmental compensation (or biodiversity offsets) policies, where mining companies are legally required to 'compensate' for their direct impacts. Under many jurisdictions, these policies involve revegetation or conservation activities and are generally required to be larger than the impacted area (in this case the area cleared for mining). This is said to therefore achieve a 'net positive benefit' at the regional scale (ten Kate et al. 2004).

Previous research in the field of land change science has failed to incorporate the effects of mining in regional dynamics, despite their role in both direct and indirect impacts as described above. One reason this land use is often overlooked is associated with the difficulties involved in accurately quantifying changes in multiple land uses that occur at different spatial and temporal scales. In this study, we present a methodology to do this: we quantify the land use change dynamics within Minas Gerais' intensive iron ore mining region, the Quadrilátero Ferrífero. Specifically, the objectives of doing so were to: 1) quantify the direct impact of mining operations on native vegetation extent, 2) compare this to that caused by other land uses, and 3) investigate the conservation effectiveness of previously established environmental compensation areas in preventing deforestation.

The Quadrilátero Ferrífero is located within Brazil's semi-arid zone between the Atlantic Forest and Cerrado biomes. It is the largest iron ore producing region in Latin America and third largest in the world. In addition to mining and mineral processing, the region is also important for biodiversity conservation, water resource management, silviculture (bioenergy and paper production) and urban development (Ferreira et al. 2009; Jacobi e do Carmo 2008).

2. Methodology

Regional land use change dynamics were quantified following a 5-step methodology: 1) image acquisition and pre-processing; 2) land cover classification of a 2010 baseline image, 3) change detection and land cover classification of historic images, 4) conversion of land cover categories to land use information; and 5) accuracy assessment.

2.1. Image acquisition and pre-processing

Landsat was the chosen sensor for analysis since its spatial and temporal scale (resolution and extent) allowed identification of both small and large-scale mining operations over time. Performing classification at a 30 m spatial resolution was also important for accurately detecting vegetation extent and change, since the region is extremely fragmented.

Two Landsat scenes cover the study region (217 064 and 218 064). For these scenes, near-date images were acquired at four time steps over a period of 20 years. Where possible, dates were chosen from the end of the wet season (July) to enhance spectral differences between grassy and woody vegetation. Due to cloud cover and the limited images available for the required scenes, it was not always possible to collect pairs from similar years.

Acquired images were converted to exoatmospheric reflectance (using the published post-launch gain and offset values; NASA Goddard Space Flight Center 2011). Images were combined using a geographical mosaic and clipped to the ROI boundary. The ROI was defined by the intersection of local municipalities boundaries (IBGE 2005) and the region officially defined by CODEMIG (2011) as the Quadrilátero Ferrífero.

2.2. Land cover classification of 2010 baseline image

A supervised classification method was used to classify the baseline (2010) image into 6 land cover classes (Forest, Grass, Mining, Plantation, Urban and Water). The classification utilised bands 1–7 (excluding band 6), NDVI and Tasseled Cap. The Spectral Angle Mapper classification algorithm was used to classify the image with the processing software ENVI. Training pixels were randomly distributed and selected based on field knowledge and Quickbird imagery. The spectral signatures and ROI separability tests illustrate significant separation between land cover classes (both Jeffries-Matursita and Transformed Divergence separability statistics were >1.9 for all comparisons).

2.3. Change detection and land cover classification of historic images

Pre-baseline images were classified using an image differencing and thresholding (10%) method (applied to NDVI) to identify and mask regions that had undergone a change in land cover (Jensen 2005). This technique is illustrated by Figure 2 and requires: 1) a classified baseline image; 2) a ‘change image’, produced by subtracting a band (NDVI was used) of the pre-baseline image from the baseline image; 3) a threshold value to identify change and no change regions (a 10% change threshold of NDVI difference was applied); 5) the binary mask (illustrating change regions) overlaid with the pre-baseline image to classify change regions.

The change regions were classified using the end members (spectral signatures of training pixels) collected and used to classify the baseline image. The advantage of this method is that it can reduce the physical effort of classification, especially when multiple images require analysis. It may also reduce omission and commission errors. The limitation, however, is that the accuracy depends on the threshold’s ability to detect change between land cover categories.

2.4. Conversion of land cover categories to land use

Land cover classes were then converted into land use information using a combination of cartographic information and land use decision rules. For the land cover class of Grass, a native vegetation map (IEF 2009) was used to distinguish between Native Grasses (vegetation of Campo, Canga and Cerrado) and non-native grassy Pastures. Table 1 describes the remaining land use decision rules.

Table 1: Land use decision rules

Classified transition	Reclassified transition	Explanation
Plantation -> Grassy	Plantation -> Plantation	The classified transition of Plantation to Grasses represented harvested plantations. This was not considered a change in land use.
Plantation -> Forests	Plantation -> Plantation	The classified transition of Plantation to Forests was considered an error in classification.
Urban -> ‘non-urban’	Urban -> Urban	The classified transition of Urban to any other non-Urban category (Native Grass, Forest and Plantation were all observed) did not represent a change in land use.
Pasture -> Forests -> Pasture	Pasture -> Pasture	The classified transition of Native Grasses to Forest was only permitted if Forest persisted.
Mining -> Grassy	Mining -> Mining	The classified transition of Mining to Native Grasses or Forest did not represent a change in land use. This assumption was made even if revegetation occurred, since revegetated mines were still a mining land use.

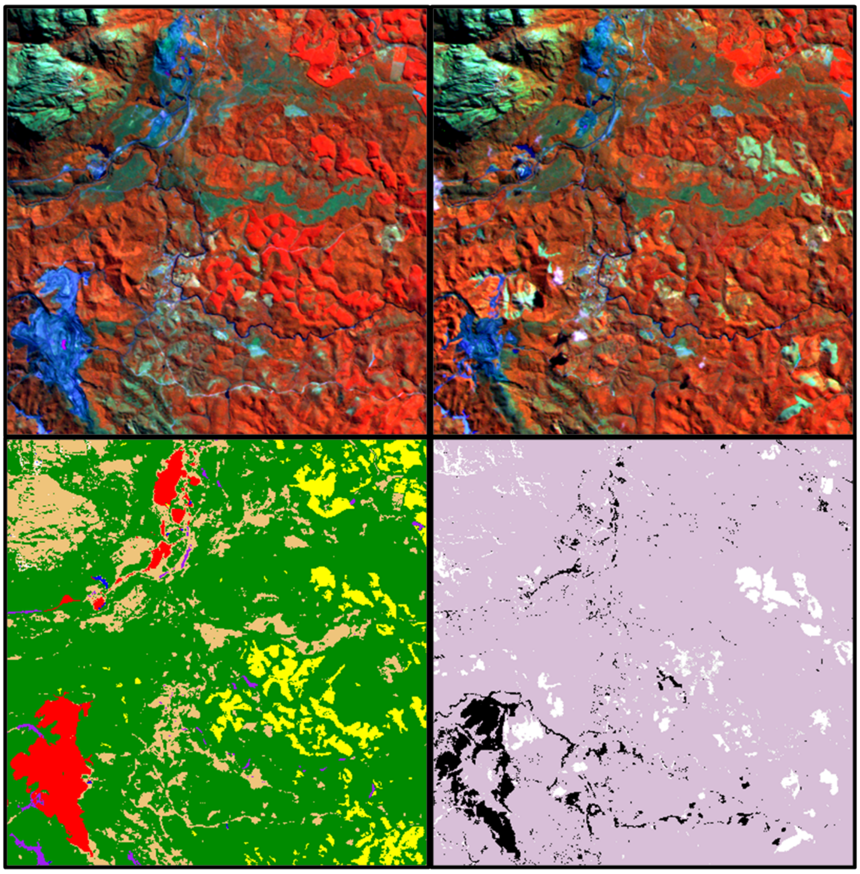

Figure 1: Clockwise from top left: 2010 543 colour composite; 2004 543 colour composite; 2010 classified land cover; NDVI difference threshold mask, purple indicates no-change, dark regions indicate decrease in NDVI, lighter regions indicate increase in NDVI.

2.5. Accuracy assessment

To perform an accuracy assessment, a crisp (one class per pixel), pixel-based assessment was used to collect spectra. A stratified (disproportionate sample size to ensure sampling of rare classes) random sampling protocol was used to select ground truth points (Foody 2011; Stehman 2009). Sample locations were generated using ENVI and ground truth information was collected from higher-resolution imagery when the class could be determined with confidence. Due to data limitations, only the 2010, 2004 and 1990 classifications were assessed, using Quickbird imagery (2010 and 2004) and an orthorectified digital photograph (1990s). A confusion matrix was generated to illustrate the errors of omission and commission of 2010 classified image Table 2.

Table 2: Accuracy assessment of the baseline (2010) image classification

		Quickbird (Observed)								
		Mine	**Urban**	**Grass**	**Plant-ation**	**Forest**	**Water**	**Total**	**Omission %**	**Commis-sion %**
Classification (Predicted)	**Mine**	85	2	7	0	0	0	94	100.00	90.43
	Urban	0	88	4	0	1	1	94	93.12	93.62
	Grass		11	189				200	90.80	94.50
	Plantation	0	0	0	88	8	0	96	96.70	91.67
	Forest	0	0	5	3	190	0	198	95.47	95.96
	Water	0	0	0	0	0	50	50	98.03	100.00
	Total (n+i)	85	101	205	91	199	51	732		

3. Results and Discussion

The land use classification methodology presented here accurately quantified change in multiple land uses that occurred at different spatial and temporal scales (Table 2). Studies often ignore the effects of mining, since it occurs at a smaller spatial and temporal scale compared to other land uses. Incorporating mining in our context, however, was important in understanding the threats and opportunities for environmental management.

Our results illustrate that the Quadrilátero Ferrífero is composed of a complex mosaic of productive land uses interspersed throughout highly fragmented forests and native grasslands (Figure 2). In 2010 only 46% of the region remained as unproductive (or 'native') vegetation, consisting of 858,319 ha of forests and 68,000 ha of native grasses. Comparatively, the majority (54%) of the region was used for some form of productive use. Pastures were the dominant productive land use (82%), followed by Eucalyptus plantations (10.5%), urban areas (6%) and mining operations (1.5%).

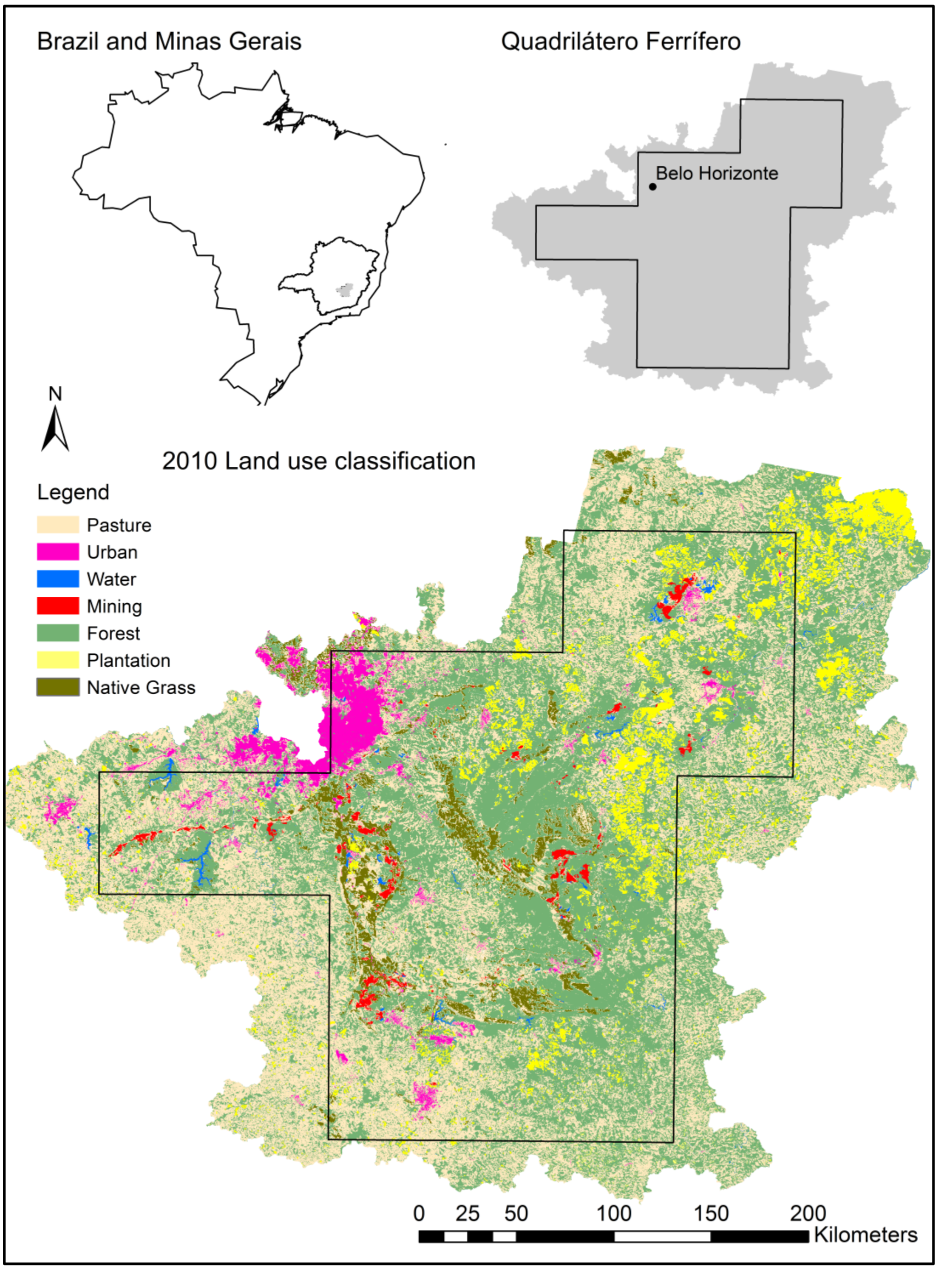

Figure 2: Study region and 2010 land use classification

Analyzing the land use change dynamics illustrated that the Quadrilátero Ferrífero has undergone rapid and extensive change over the past 20 years (Figure 3). By 2010, over 6.5% of the 1990 native vegetation extent had been removed, which included a loss of 63,025 ha of forests and 2,695 ha of native grasses. Mining accounted for 14% of these declines, while the remaining native vegetation was cleared for expansion of other land uses. While the majority of plantation expansion occurred at the loss of the cattle pastures, native forests and grasslands continued to be cleared for pasture expansion and urban development (Figure 4). These extensive and rapid land use change dynamics illustrate the importance of establishing and enforcing conservation programs within the region.

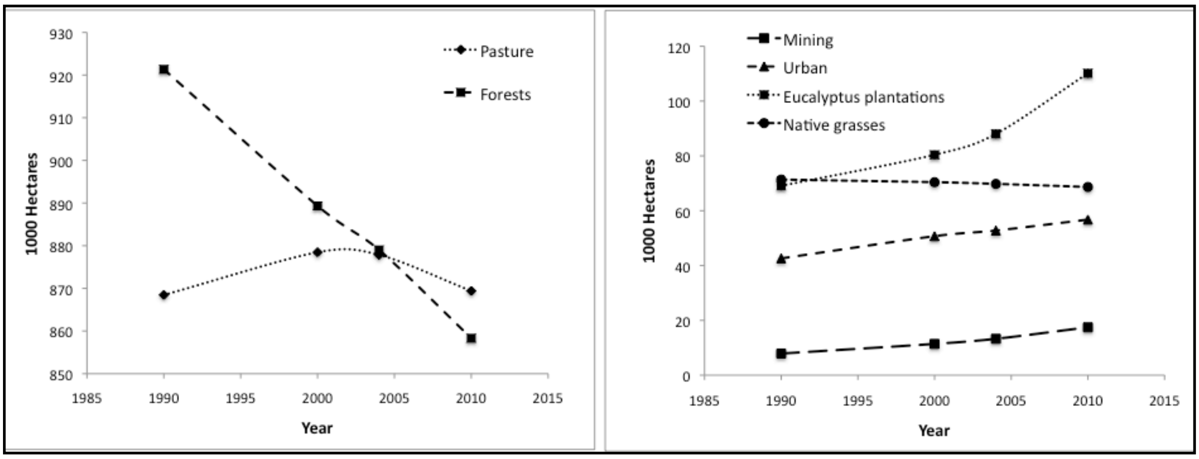

Figure 3: Land use within the Quadrilátero Ferrífero over time

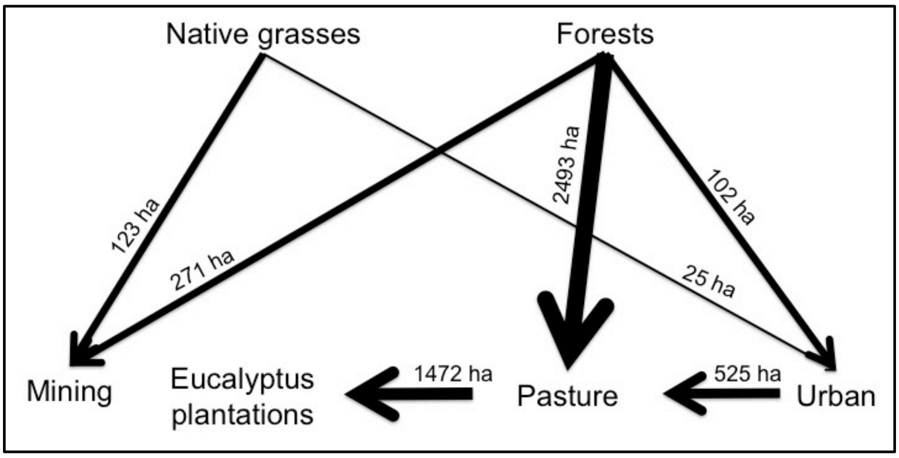

Figure 4: Observed land use transitions. The arrow weight and quantities illustrate the average annual area of transition within the region.

In 2010, about 20% of the Quadrilátero Ferrífero was under some form of conservation tenure, leaving 72% of forests and 44% of native grasses unprotected (MMA 2010). The majority of conservation areas are that of ‘sustainable use’, which have a limited effect in protecting against vegetation loss compared to non-protected areas (Figure 5). In comparison, there are currently only seven environmental compensation reserves (RPPN established for the purposes of compensating for the impacts of mining) within the region, with a combined area of 1,052 ha. These reserves, however small, show a high protection against vegetation loss (we observed almost none within these reserves; Figure 5).

While our results suggests that environmental compensation conservation reserves can be extremely effective in preserving native vegetation, their combined area represents less than

10% of the forests removed by mining operations. If all mining companies in the region were required to compensate for their deforestation (at a 1:1 ratio) an additional 15,000 ha of native vegetation could have been protected.

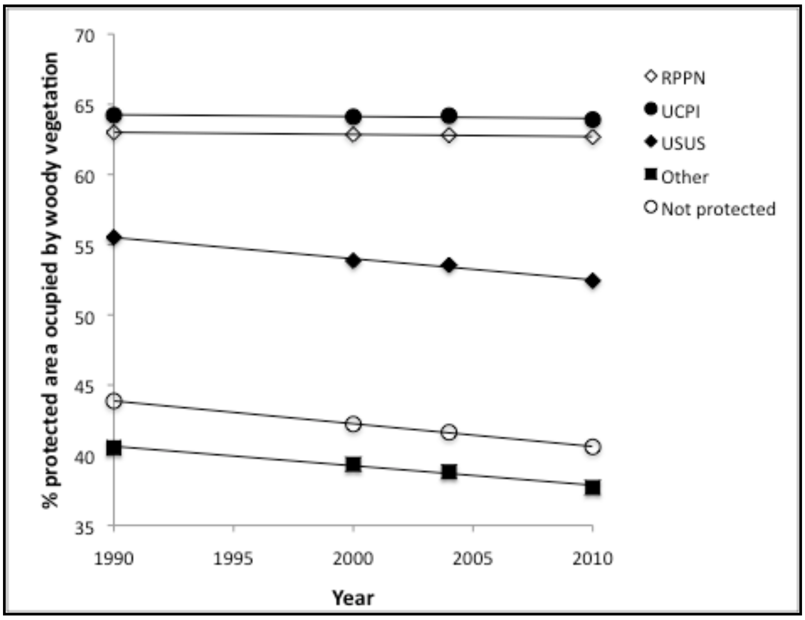

Figure 5: Percentage of protected areas that contain Forests over time

4. Conclusions

Mining operations are often overlooked in land use change studies since they occur at a much finer spatial and temporal resolution than other land uses such as silviculture and productive pastures. The methodology presented in this paper allowed us to quantify land use change dynamics that occurred at multiple spatial scales. Our results illustrate the significance of incorporating this more intensive land use.

The direct impacts of mining on deforestation was small compared to that caused by other land uses; however, our results illustrate that mining companies can play a much larger role in regional dynamics and environmental management. Many opportunities remain to expand the protected area network in the Quadrilátero Ferrífero through the use and implementation of environmental compensation policies.

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References

Barrett, D.J. Thinking outside the lease- towards a strategic view of regional water management by the mining industry. **Mining Technology**, v. 118, n. 3, p. 131-141 2009.

Companhia de Desenvolvimento Economico de Minas Gerais (CODEMIG) **Geological Mapping of Minas Gerais** (2010). Disponivel em: <http://www.comig.com.br/>. Accesso em: Jun.2011.

Ferreira, J.D.; Costa, L.M.; Rodrigues, M. Aves de um remanescente florestal do Quadrilátero Ferrífero, Minas Gerais. **Biota Neotropica**, v. 9, p. 39-54, 2009.

Foody, G.M. Classification Accuracy Assessment. **IEEE Geoscience and Remote Sensing Society Newsletter**, p. 8-14, 2011.

Instituto Brasileiro de Geografia e Estatística (IBGE) **Digital Municipal Mesh** (2005). Disponivel em: <http://www.ibge.gov.br/>. Accesso em: Dec.2011.

Jacobi, C.M.; do Carmo, F.F. The contribution of ironstone outcrops to plant diversity in the Iron Quadrangle, a threatened Brazilian landscape. **Ambio**, v. 37, p. 324-326, 2008.

Jensen, J.R. **Introductory digital image processing: a remote sensing perspective**. Prentice Hall: Upper Saddle River, 2005. 526 p.

Malaviya, S.; Munsi, M.; Oinam, G.; Joshi, P. Landscape approach for quantifying land use land cover change (1972–2006) and habitat diversity in a mining area in Central India (Bokaro, Jharkhand). **Environmental Monitoring and Assessment**, v. 170, p. 215-229, 2010.

NASA Goddard Space Flight Center. **Landsat 7 Science Data Users Handbook** (2011) Disponivel em: <http://landsathandbook.gsfc.nasa.gov>. Accesso em: Mar.2011.

Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA) **Unidades de Conservação** (2010) Disponivel em: <http://www.ibama.gov.br>. Disponivel em: Jun.2011.

Secretaria de Estado de Meio Ambiente e Desenvolvimento Sustentável (SEMAD) **Mapeamento da Cobertura Vegetal**. Minas Gerais, Brazil.

Simmons, J.A; Currie, W.S.; Eshleman, K.N.; Kuers, K.; Monteleone, S.; Negley, T.L.; Pohlad, B.R.; Thomas, C.L. Forest to reclaimed mine land use change leads to altered ecosystem structure and function. **Ecological Applications**, v.18, p. 104-118, 2008.

Schueler, V.; Kuemmerle, T.; Schroder, H. Impacts of Surface Gold Mining on Land Use Systems in Western Ghana. **Ambio**, v. 40, p. 528-539, 2011.

Soares-Filho, B.S.; Mountinho, P.; Nepstad, D.; Anderson, A.; Rodrigues, H.; Garcia, R.; Dietzsch, L.; Merry, F.; Bowman, M.; Hissa, L.; Silvestrini, R.; Maretti, C. Role of Brazilian Amazon protected areas in climate change mitigation. **Proceedings of the National Academy of Sciences of the United States of America**, v. 107, n. 24, p. 10821-10826.

Stehman, S.V. Sampling designs for accuracy assessment of land cover. **International Journal of Remote Sensing**, v. 30, p. 5243-5272, 2009.

ten Kate, K.; Bishop, J.; Bayon, R. **Biodiversity offsets: Views, experience, and the business case.** Gland, Switzerland, IUCN and Insight Investment, 2004.