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Abstract: *The Atlantic rainforest of southern Bahia is one of the last remnants of the lowland forest of eastern Brazil that once covered the entire coastal area from Rio Grande do Norte to Rio Grande do Sul (lat 8°-28° S) and has been deforested to a small fraction of its original cover (1-12%). All recent vegetation surveys have been based on optical satellite data, which is hampered by cloud cover and by southern Bahia's intricate mix of forest patches with other tree crops, especially cocoa. We describe the application of radar remote-sensing data to distinguish forest patches from cocoa planted in the shade of natural-forest trees. Radar, unlike optical sensors, is not obstructed by cloud cover and can acquire information about forest structure by penetrating into the vegetation canopy. The vegetation map generated from radar data clearly separates forest patches based on the degree of structural disturbance such as the density of shaded trees, the openness of the canopy, and the density of the monodominant* Erythyrina *shaded trees. The structural classification based on the radar data, and shown on the map, can help researchers assess the degree of fragmentation of the original Atlantic coastal forest and delineate areas of less disturbance with higher potential for conservation of biodiversity. This information can then be applied to conservation planning, especially the design and monitoring of nature reserves and the modeling of biological corridors.*

Exámen de la Fragmentación y de la Pérdida de Bosque Primario en el Bosque del Atlántico de Bahía del Sur en Brasil Utilizando Imágenes de Radar

Resumen: *El bosque lluvioso del Atlántico de Bahía del Sur es uno de los últimos remanentes de bosque de tierras bajas del Este Brasileño que alguna vez cubriera completamente el área costera comprendida desde el Rio Grande do Norte hasta el Rio Grande do Sul (8° S hasta 28° S) y que ha sido deforestada hasta una pequeña fracción de su cobertura original (1-12%). Todas las prospecciones recientes de vegetación han sido basadas en datos ópticos de satélite, el cual es obstaculizado por la cubierta de nubes y por la intricada mezcla de parches de bosque de Bahía del Sur con ábóles de plantaciones, especialmente de cacao. Describimos la aplicación de datos de percepción remota por radar para distinguir parches de bosque de plantíos de cacao bajo la sombra de árboles naturales del bosque. Los datos de radar, a diferencia de los sensores ópticos, no son obstruídos por la cubierta de nubes y pueden adquirir información sobre la estructura del bosque al penetrar el dosel de la vegetación. Los mapas de vegetación generados con datos de radar separan claramente los parches de bosque con base al grado de perturbación estructural, como lo es la densidad de árboles sombreados, la apertura del dosel y la densidad de los monodominantes árboles sombreados de* Erythrina. *La clasificación estructural basada en los datos de radar y mostrados en un mapa puede ayudar a los investigadores a evaluar el grado de fragmentación del bosque costero del Atlántico y a delinear áreas menos perturbadas con un potencial más alto para la conservación de la biodiversidad. Esta información puede ser posteriormente aplicada en la planeación de la conservación, especialmente para el diseño y monitoreo de reservas naturales y el modelado de corredores biológicos.*

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Introduction

The Brazilian Atlantic moist forest has one of the highest levels of plant diversity in the world (Mori et al. 1981; Thomas & de Carvalho 1997). The loss of this forest to timber exploitation, crop plantations, and pasture has been more severe than that of other forests in South America. The high level of endemism and the continuous threat of deforestation and fragmentation (Thomas et al. 1998) have made the moist forests of the Atlantic coastal strip of Brazil a global biodiversity hotspot (Stotz et al. 1996; Myers et al. 2000).

Estimates of the remaining forest in this region vary from 1% to 12% (Table 1). This variation is due primarily to the use of different survey methods, different temporal and spatial scales of analysis, and varying degrees of accuracy in separating forest patches from other types of land use. For example, the application of optical remote-sensing data, such as that from Landsat, to estimate forest cover has been hampered in the case of the Atlantic forest by the extensive cloud cover in the region. In addition, the difficulty of distinguishing intact forest patches from secondary forests, agroforestry, and mangroves along the coast has affected the mapping of forest distribution in the region.

Estimates not significantly hampered by cloud cover or by the land-use matrix from southern states such as Santa Catarina (lat 28°S) show that 31% of the original forest cover may be intact (Instituto de Pesquisas Espaciais and Instituto Brasileiro do Mei Ambiente e dos Recursos Naturais Renováveis 1990; CIMA 1991 in Viana et al. 1997). In the southern part of the state of Bahia (lat 15°S), on the other hand, crude estimates based on optical methods show only 5% of the original forest is intact. Optical estimates of southern Bahian forest are hampered by cloud cover associated with the average 150 days of rainfall per year (Mori et al. 1983) and by natural forest fragments embedded in a complex matrix of secondary forest and forest-like land uses.

Because the Atlantic forest is known to have distinct centers of endemism (Müller 1973; Brown 1982; Prance 1982), conservation planning for states such as Santa Catarina is of little relevance in southern Bahia, where forest cover is harder to measure and monitor. The Bahian Atlantic forest is also particularly at risk from road construction, tourism development, and land reforms that are causing the elimination of natural forest and the conversion of forest-like agriculture to pasture (da Fonseca 1985; Dean 1995; Alger 1998). All these factors contribute to the isolation of populations of endemic species and their vulnerability to changes in land cover and land use.

The southern Bahian Atlantic moist forest has been subject to deforestation for at least 500 years since the arrival of Portuguese colonists in the sixteenth century (Fig. 1). The climate's year-round distribution of 1200–1800 mm of rainfall at temperatures that almost never fall below 20° C makes the region ideal for the cultivation of various cocoa species. Cocoa cultivation only began to dominate the southern Bahian landscape in the twentieth century, undertaken principally by large landholders who preferred to leave large areas of unused land in forest (Alger & Caldas 1994). The varying economic history of the Atlantic coastal region and the surrounding land uses have given populations of species different time scales to respond to the effects of fragmentation (Viana et al. 1997).

The forest-like structure of cocoa plantations simulates to varying degrees the native forest ecosystem. Where cocoa is planted under native tree species, a system known locally as cabruca, the understory is thinned and replaced with cocoa trees (Alves 1990; Johns 1999). The larger trees that are kept, at lower densities than in natural forest, are usually higher-value species whose shade encourages fruit production in cocoa. The understory is cleaned continually by farm workers, to permit cocoa trimming and harvesting. Because this eliminates seedlings of the native canopy trees, older cabruca plan-

Table 1. Remaining primary vegetation of the Atlantic forest.

| Area	Remaining vegetation of original extent (%)	Year	Source	Comment
Atlantic forest	2–5	1982	Gentry 1996	highly fragmented remnants
Atlantic forest	8	1990	Ranta et al. 1998 (citing Instituto de Pesquisas Espaciais and Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis 1990)	highly fragmented (>>10,000 fragments)
Atlantic forest	2–5	1991	Oliver & Santos 1991	
Atlantic forest	1–2	1992	Ranta et al. 1998 (citing Por 1992)	
Brazil's Atlantic forest	12	1992	Brown & Brown 1992	
Atlantic forest (Brazil)	9.2	1992	Fearnside 1996 (citing SOS Mata Atlântica 1992)	not including *Araucaria* forest
Brazil's Atlantic forest	7.5	2000	Myers et al. 2000	
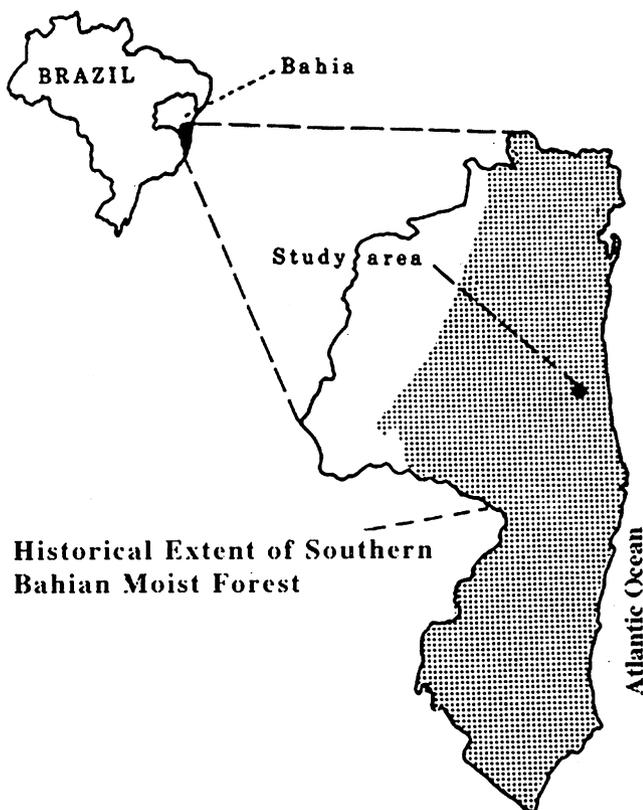
Figure 1. Geographical location of the original Atlantic forest in South America.

tations steadily lose shade trees to old age. They are replaced with exotics such as *Erythrina*. Cabruca plantations that have been abandoned have dense regrowth in the subcanopy.

Some farmers have totally eliminated native understory and shade trees, planting cocoa in rows and using bananas and regularly spaced *Erythrina* for shade. Current technical recommendations for increasing cocoa productivity prescribe minimal shade from short-stature exotics, a higher density of genetically improved cocoa clones, and an increased use of chemical fertilizer to compensate for evapotranspiration stress (Mori et al. 1983). Along a continuum of their resemblance to natu-

ral forest structure, abandoned cabruca farms are closest and "row crop," low-shade cocoa is the most distant. To the extent that these tree-crop plantations are adjacent to fragments of natural forest, and depending on the intensity of hunting, they all serve in varying degrees as a medium through which forest-dwelling species can move to repopulate forest fragments (Alves 1990).

In the 1970s and early 1980s, the high value of the cocoa cash crop stimulated expansion and deforestation for cocoa. Starting in 1989 and throughout the 1990s, however, prices fell to less than $US1000/ton from their 1980's average of more than $US2000/ton. In addition, the witches broom fungus (*Crinipellus perniciosa*), which coevolved with cocoa in the Amazon and handicapped plantation production there, arrived and spread through all plantations in Bahia. With higher labor costs to clean fungal-infected cocoa, combined with lower productivity and prices, farmers abandoned plantations and obtained income from logging and deforesting large areas for cattle ranching and production of robusta coffee. Currently the landscape of southern Bahia is a matrix of pasture and secondary-forest fragments intermixed with a variety of tree crops, including cocoa, rubber, bananas, palm oil, and coffee. Most of the forestland, with the exception of the Una Biological Reserve (7058 ha), is privately owned. Figure 2 shows two types of land use in the region: (1) a typical cocoa plantation with an almost complete coverage of soil surface with cocoa trees, herbaceous plants, and shade trees (Fig. 2a) and (2) a fragmented landscape with a matrix of recently deforested area, secondary regrowth, and dense forest (Fig. 2b).

Recent studies in Atlantic coastal forests show that forest fragmentation is a major cause of the extinction of forest species within the isolated forest remnants (Cardoso da Silva & Tabarelli 2000). This suggests that conservation planning in the region must shift from preserving medium-to-large forest remnants to a bioregional planning approach that seeks to connect isolated forest fragments. In the case of southern Bahia, the existing system of protected areas, which does not adequately represent vegetation types or species distribution, is also inadequate because these fragments are growing more isolated.

Figure 2. Typical land use in the study area: (a) a typical cocoa plantation with shaded trees and (b) a fragmented scene with areas of clearcuts and forest regeneration.

Currently, a landscape-level ecological corridor, which consists of a network of protected areas and other biodiversity-friendly land uses, is being developed. The corridor is managed to ensure survival of the largest spectrum of species unique to this region, which cannot be achieved at the scale of individual parks or buffer zones (Ayres et al. 1997; G7 Pilot Program 1997). The development of this corridor requires an accurate baseline map of forest fragments, their size distribution, and their spatial relation to various types of tree crops and cabruca forests. Without the ability to establish the precise location and degree of degradation in "forest-like" land uses, policy makers are unable to target incentives toward more densely and naturally shaded agroforestry practices or to establish credible monitoring and enforcement of landowner maintenance of these systems. Our methodology provides a baseline map of land cover and land-use units for building the biological corridor and linking the existing forest fragments to maintain biodiversity connectivity in the region.

Existing land cover data are from a 1974 photogrammetric analysis and a 1990 study based on Landsat imagery at the scale of 1:250,000. The latter study does not include fragments of <400 ha, has cloud cover over southern Bahia of >30%, and one cannot distinguish cocoa and other tree crops from primary forest (SOS Mata Atlântica & Instituto de Pesquisas Espaciais 1993). In the most recent survey of the Atlantic forest by SOS Mata Atlântica, the southern Bahian forest was excluded because Landsat images could not be obtained when cloud cover was <50% (SOS Mata Atlântica et al. 1998).

In general, optical remote sensing technologies that rely on light reflected from the vegetation canopy cannot easily differentiate between cocoa plantations and other types of forest. This distinction is important because even though tree crops like cocoa permit some species' movement among natural forest fragments, only the natural forest fragments themselves permit the reproduction of the full range of endemic species. Radar instruments working in microwave frequencies penetrate the forest canopy and can thus be used to assess vegetation structure and related characteristics, such as biomass and distribution of branches and foliage through the canopy. Information on vegetation structure, in turn, can be used to distinguish among various forest types. In addition, clouds limit optical remote sensing, whereas radar data can be obtained independent of weather or sunlight (Evans et al. 1993). Radar data can thus be used to monitor land-use change and forest conversion as frequently as desired in areas such as southern Bahia. We made use of the radar data obtained by NASA's Space Shuttle Endeavor in October 1994 to map the forest fragments and land use around the Una Biological Reserve in South of Ilhéus, Bahia. The results obtained by classifying the shuttle radar instrument can be readily used to

identify locations with high conservation potential and to improve models of landscape capacity for hosting endangered species.

Methods

The radar image we used was acquired by the Shuttle Imaging Radar-C abroad the Shuttle Imaging Radar-C/X-Band Synthetic Aperture Radar mission (SIR-C/X-SAR) in October 1994. The SIR-C instrument operates at two microwave wavelengths: 24 cm (L-band) and 6 cm (C-band) (Evans et al. 1993). At each wavelength, the instrument has two antennas for transmitting and receiving waves. The radar illuminates the surface by transmitting waves at an off-nadir angle and receiving the waves scattered from the surface. Because the operating wavelengths of the radar are long (radio waves), they penetrate into the vegetated surface and scatter from vegetation components back to the radar receiver. The received waves are processed into high-resolution images and carry information about the structure of vegetation, underlying soil roughness, and the moisture condition of vegetation and soil. Waves at longer wavelengths penetrate deeper into the vegetation canopy and thus are more sensitive to large structural components of the vegetation. Thus, when a forest stand is imaged with L-band, the information in the image can be related to the size and geometrical distribution of branches and tree trunks. At C-band the waves only partially penetrate into the forest canopy and are sensitive to elements of the canopy structure such as leaves and small branches. The penetration depth depends directly on the density and moisture of the vegetation (Saatchi & Moghaddam 2000). In addition to wavelength, the radar waves also differ in polarization, that is the orientation of the electromagnetic fields that constitute waves. In the case of SIR-C, for example, the radar instruments both transmit and receive with horizontal (H) or vertical (V) polarization. The polarization of the wave also carries information about the geometry and the structure of the vegetation.

The SIR-C radar data we used has two bands (L-band and C-band) and three polarization channels (HH, VV, HV) (Fig. 3a). The colors in Figure 3 indicate the relative intensity of the backscatter received from the surface within a unit of ground resolution in the imaged scene. The image resolution is approximately 25 × 25 m. Most of the images acquired from existing radar satellites have only one channel and thus limited capability for mapping vegetation types. The Shuttle radar has several channels with high spatial resolution, but there was limited coverage because it collected data over only two 10-day missions.

Figure legend:
- Pasture
- Cocoa(*Erythrina*)
- Cocoa(thinly shaded)
- Cocoa(densely shaded)
- Urban
- Primary forest
- Secondary forest
- Mangrove
- Flooded vegetation
- Restinga
- Seringa
- Plantation
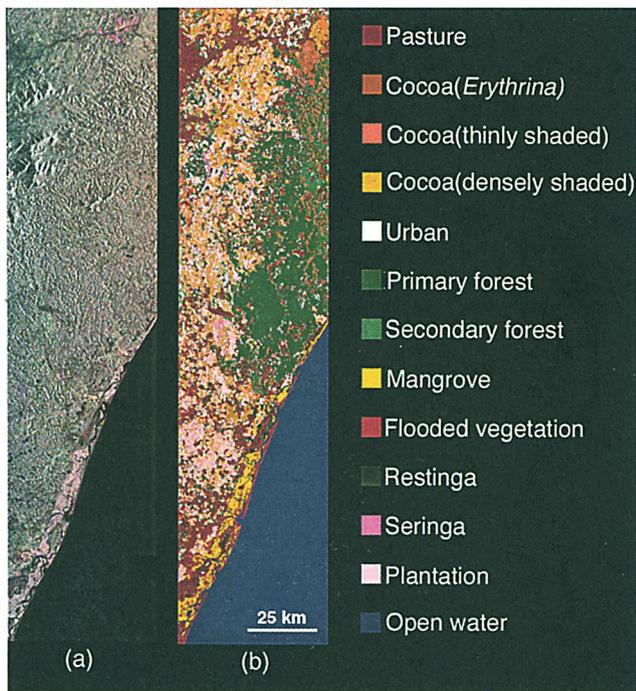- Open water

25 km

(a)   (b)

Figure 3. (a) A color composite of SIR-C imagery of Una Biological Reserve in Southern Bahia. The colors are L-band HH polarization (LHH) as red, L-band HH polarization (LHV) as green, and C-band HH polarization (CHH) as blue. (b) Land-cover map derived from SIR-C data.

We classified images with a standard supervised maximum-likelihood classifier. First, we created first-order texture images through the coefficient of variation over a 4×4 window (100 m resolution) for each of the six SIR-C channels (LHH, LHV, LVV, CHH, CHV, and CVV). A total of 12 channels was produced to provide input layers for the classifier. Certain theoretical aspects of the classifier and the methodology are described in detail elsewhere (Saatchi et al. 1997; 2000).

The supervised nature of this classifier required a learning procedure based on a set of training areas. These training areas, which determined the class labels, were chosen from the images on the basis of a priori knowledge of the scene and with the help of information gathered during several field surveys. To implement the maximum-likelihood classifier, we assumed that the radar backscatter data and textures of training areas had Gaussian distributions. According to their importance, we concentrated on the following vegetation types in the region: (1) pasture, (2) cocoa plantation with *Erythrina*, (3) thinly shaded cocoa plantation, (4) densely shaded cocoa plantation, (5) urban, (6) primary forest, (7) secondary forest, (8) mangrove, (9) flooded vegetation, (10) restinga forest, (11) rubber plantation (Seringal), and (12) other plantations (e.g., palm oil). The characteristics of cover types have been discussed in detail by Mori et al. (1983). For each cover type, we selected large and fairly homogeneous areas as training sites. For primary forest and cocoa plantations, we included more than one training area to cover natural variations of radar signatures related to topography and slope effects. We used all 12 channels to produce the map even though for some cover types certain channels did not contribute significantly to the classifier (Fig. 3b).

We estimated the accuracy of our classification by choosing a set of test sites prior to the classification. The test sites were chosen in areas of known vegetation types identified during the field surveys and were different from the training sites used in the classifier earlier. Separating cabruca from forest patches through common photogrammetry techniques is difficult (Fig. 4). Figures 5a and 5b show typical cabruca and primary forests as seen on the ground during fieldwork. These pictures show that the major difference between the two stands is the structure of the understory.
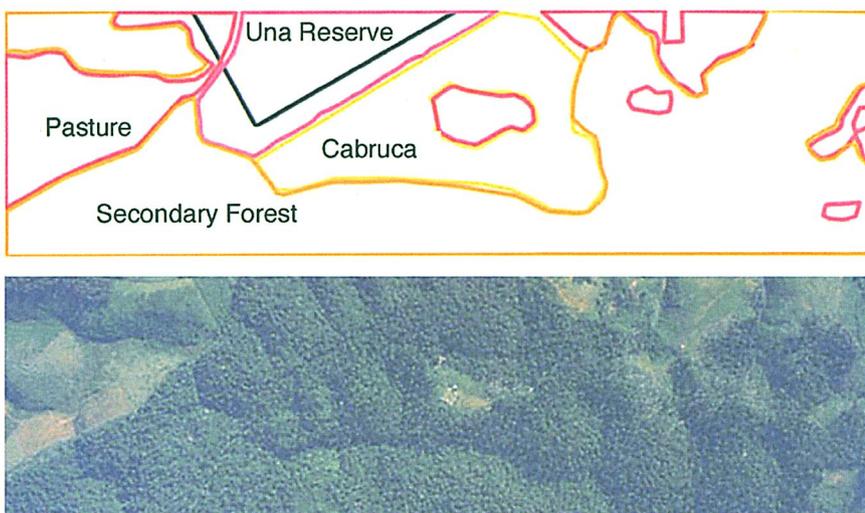

Labels: Una Reserve, Pasture, Cabruca, Secondary Forest

Figure 4. Fragmented landscape near the Una Biological Reserve in southern Bahia observed by aerial photography.
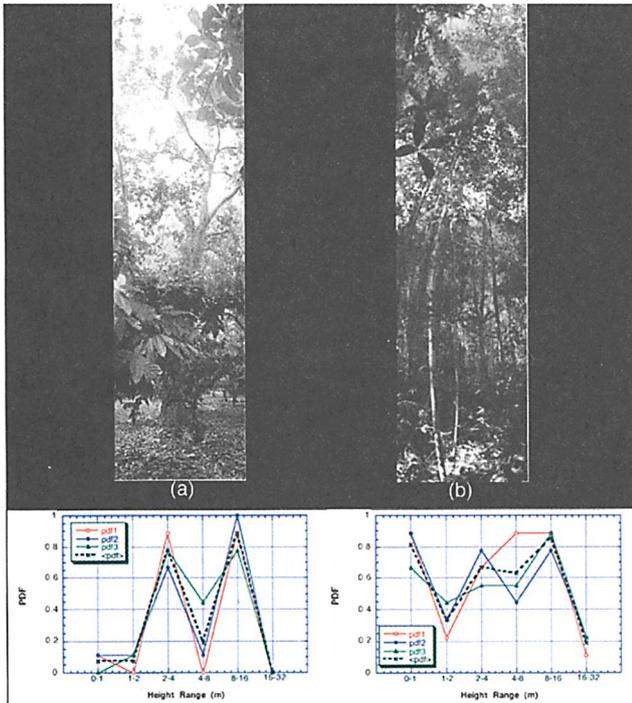
Figure 5. Structural differences of cabruca and primary forests: (a) cabruca forest, (b) primary forest. Probability distribution (PDF) of forest and cabruca height structure derived from point contact measurements are shown under each picture of the forest type.

During the field survey, the structure of vegetation in cabruca and primary forest patches were quantified by measurements of tree density, size, gap fraction, and height distribution. In the field, we examined the vertical stratification (height structure) of cabruca and forest stands by the point-contact method (Fig. 5), which measures the probability of finding plants at different heights within the stand (Catchpole & Wheeler 1992). We used this method and other structural measurements, such as gap fraction and tree density, during fieldwork in 1995 and 1998. At each point, one person counted the contact of any live vegetation with a rod up to 4 m tall, and we estimated the contacts above 4 m up to 32 m of height. The intervals are presented in logarithmic base and cover the heights 0-1, 1-2, 2-4, 4-8, 8-16, 16-32, and above 32 m. At each interval, one and zero were used to indicate contact or no contact respectively. The measurements were repeated at nine locations in the 20 × 20 m grid. To capture some of the structural variability in the forest, we repeated the grids in three to five locations. For heterogeneous forest stands, it is generally recommended to have five grids. In our study, however, we used only three grids to characterize primary and cabruca forest patches but repeated the measurements in different patches. The plots provided quantitative measures of forest structure that we used to interpret the remote-sensing data.

Results

We used a confusion matrix to determine the accuracy of the land-cover classification (Table 2). The elements of the matrix were determined by calculating the number of pixels correctly classified into the class, divided by total number of pixels in that class (number of pixels used for test sites is shown in the last column of Table 2). The results suggest that overall accuracy was about 89%. The main source of error was in separating various types of forests and tree crops. In this case, variability in canopy cover, density, and structure increased the variance in Gaussian distributions assumed for each class type and derived from the training data sets. The increase in the variance increased the confusion in choosing the class label within the maximum-likelihood classifier.

The most important radar channels for separating cabruca from forest were LHH and LHV. The removal of understory in cabruca allowed more penetration of radar energy into the forest and, in turn, permitted a larger return from tree trunks and branches because the energy was bounced back from the soil surface (double-bounce scattering term). The cross-polarized channel LHV was sensitive to the overall aboveground biomass of vegetation and therefore to those disturbed cabruca stands that differed in biomass from intact forest patches. The textures generated from CHV and CVV also contributed to distinguishing cabruca. At C-band channels, the radar energy penetrated into the top portion of the canopy, and hence the backscattering energy received by radar carried information about the roughness and structure of the forest canopy. In general, as the intensity of disturbance in cabruca increased, its distinction from undisturbed forest became easier. We used plots (Fig. 5) from measurements by the point-contact method to understand and validate the response of the radar backscatter to different degrees of disturbance. These measurements corresponded with three different classes of cabruca forests.

The classifier was able to separate mangroves and restinga forests along the coast from primary forest patches. Because of their monospecies structure and underlying water, mangroves show up clearly in CHH and LHH channels. In addition, low-texture measures representing the homogeneous structure of the canopy also contributed to the correct classification of mangroves. Restinga forests, on the other hand, can be confused with evergreen primary forest types further inland. This is because in some areas the density of vegetation in restinga gradually increases as one moves inland. The most distinctive feature of restinga observed in the test sites is the underlying white sandy soil that does not appear in radar images. We also identified a few secondary forest patches further inland that were misclassified as restinga. These secondary forests have a low density of large trees and resemble the training sites used for restinga.

Table 2. Confusion matrix of land-cover classification accuracy defined by percentage of the area of the test sites classified correctly in the final vegetation map.[a]

Class	Primary forest	Cocoa with Erythrina	Cocoa thinly shaded	Cocoa densely shaded	Pasture	Siringa	Restinga	Other[b]	Urban	Mangrove	Flooded vegetation	Secondary forest	Open water	No. of pixels
Primary forest	91	1	7	0	0	0	0	0	0	0	1	0	0	834
Cocoa with Erythrina	5	91	4	0	0	0	0	0	0	0	0	0	0	279
Cocoa thinly shaded	15	5	75	1	0	0	0	0	0	0	0	4	0	471
Cocoa densely shaded	2	1	1	81	0	0	6	0	0	1	0	0	0	576
Pasture	0	0	0	0	95	0	0	0	0	0	0	0	3	379
Siringa	0	0	1	0	0	94	0	0	0	0	0	4	0	961
Restinga	16	0	0	0	0	0	81	0	0	0	0	3	0	1025
Other	0	0	0	0	5	0	0	93	0	1	0	0	0	1689
Urban	0	1	0	0	0	0	0	1	89	0	10	0	0	156
Mangrove	1	2	2	2	0	0	0	0	0	94	0	0	0	784
Flooded vegetation	0	0	0	0	0	0	0	0	0	1	97	0	0	1362
Secondary forest	12	0	0	0	0	0	2	0	0	0	0	86	0	312
Open water	0	0	0	0	2	0	0	0	0	0	0	0	98	3724

[a] Overall accuracy is 89%.
[b] For example, plantation such as dende.

Another source of confusion in radar images was forest biomass. As the vegetation biomass increased, the radar waves attenuated much faster while traveling in the canopy and at some point reached a saturation level. This saturation level is not known for tropical forest types but, according to some studies, stays below 100 tons per ha for L-band systems and below 50 tons per ha for C-band systems (Luckman et al. 1997; Saatchi et al. 1997). The capability of radar images to provide information about forest structure was important in separating the cabruca forests. Optical sensors such as Landsat were not able to provide similar information. The degraded and the young secondary forests often observed by optical images are distinguished by the degree of homogeneity and disturbance on the top of the canopy and not the understory or the overall structure (Saatchi et al. 1997).

Discussion

The results of our land-cover classification, based on SIR-C data from 1994, demonstrate the feasibility of distinguishing natural-forest fragments from secondary forest and agroforestry practices that cannot be differentiated by optical techniques. Identification of natural-forest patches from the surrounding matrix of forest-like vegetation is a prerequisite to conservation planning at the landscape scale in this region. Although natural-forest fragments in the cocoa-producing region of Bahia are still more likely to be adjacent to secondary forest and agroforestry than in other parts of the Atlantic forest, these buffers are being eliminated by conversion to pasture or coffee. Isolation diminishes the probability of species survival and undermines the function of a protected-area system (Soulé & Terborgh 1999). Until recently, cocoa plantations connecting natural-forest fragments served as wildlife "corridors," and these connections overcame the effects of reserve isolation. The decline of the cocoa economy threatens both the natural-forest fragments that function as "stepping stones" and the interstitial medium of cocoa plantation that permitted mobility among populations of species. A radar methodology that can distinguish the spatial relationship of natural-forest patches and cocoa plantations will permit analysis and monitoring of those plantations that are higher conservation priorities because of their role in maintaining connectivity.

Although the natural forests of southern Bahia provide various environmental services to human communities, much of the value of forest conservation lies in global services such as biodiversity conservation and carbon sequestration. Mechanisms are now being constructed, such as the Kyoto Protocol, that may permit compensation of private landholders for these global services (Peters & Lovejoy 1992; Frumhoff et al. 1998; World Resources Institute & World Conservation Union 1998). Planning is now necessary at a regional scale to select

priority areas for private and public reserves and biodiversity-friendly agroforestry plantations. These areas will have a better chance of conserving biodiversity than the existing system of isolated protected areas and will cost less than purchase of extensive agricultural areas for transformation into nature reserves (Dobson et al. 1999; Margules & Pressey 2000). For landowners to be eligible for incentives to maintain these reserves and agricultural systems, the purchasers of environmental services will want frequent, low-cost remote sensing to monitor landowner compliance. The ability of radar sensors to collect data regardless of atmospheric conditions and readily distinguish between "high natural shade" and "low exotic shade" plantations could be key to such a monitoring system.

The SIR-C image we used covered only a 100-km strip from Itabuna to south of Una Biological Reserve, so the results of this study cannot be easily extrapolated to a larger area. Patterns of deforestation and land-cover transformation in southern Bahia are distinct from those observed in the Amazon basin. Forest conversion and fragmentation in this region neither resemble the fishbone patterns along branched road systems of Rondônia, Brazil, nor do they expand from urban centers leading to huge clearcut areas, as is the case in the state of Acre (Skole & Tucker 1993; Saatchi et al. 1997). Clearcut areas in southern Bahia are relatively small, and they appeared all over the region simultaneously after the decline of cocoa commodity prices. Although deforestation of natural forest is illegal in the Atlantic forest region, the legal status of abandoned cocoa plantations or degraded forest is unclear, so the law and its enforcement have not been a significant deterrent to land conversion.

The golden headed lion tamarin (*Leontopithecus chrysomelas*) and the yellow-breasted capuchin (*Cebus xantosthernos*), two of the most endangered primates in the world, use cocoa plantations surrounding natural forest in their home range, but seem to depend on fragments of primary forest for reproduction (Dietz et al. 1996). These tree-dwelling species and predators such as wild cats suffer particularly from fragment isolation. The conservation value of the small fragments in Bahia is also increased by their relatively recent isolation. The slow effect of isolation on the original composition of plants means that Bahian fragments could still be used to rehabilitate the destroyed forest (Gentry 1996; Brooks et al. 1999).

The land-cover map derived from the remote-sensing analysis in our study gives a different picture of the distribution and intensity of forest fragmentation than existing data sets such as those of SOS Mata Atlântica and the Instituto de Pesquisas Espaciais (1993). The smallest mapping unit in SOS Mata Atlântica data is 400 ha, but in our study it is <5 ha. Furthermore, the map generated by SOS Mata Atlântica does not distinguish between forest fragments and tree crops. In our results, the forest and several types of tree plantations are separated. By

successfully identifying the forest fragments and surrounding tree plantations, our results also suggest that the region of southern Bahia is a unique and complex case within the Atlantic coastal forest of Brazil, with suitable preconditions for future conservation actions.

Frequent use of radar remote-sensing data for mapping and monitoring land-use practices in this region may be the most obvious means of evaluating the conservation value of the landscape in the region. In future analysis, the radar data from the Japanese Earth Resources Satellite (JERS-1) and RADARSAT will be used to map forest fragments of the entire coastal region of southern Bahia (Saatchi et al. 2000). With the launch of ALOS, a new Japanese satellite radar and optical platform that should be operational by 2002, monitoring and mapping forest remnants of the entire Atlantic coast of Brazil will become feasible.

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