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CHAPTER 3 Biodiversity

Source: A Perfect Storm in the Amazon Wilderness: Development and Conservation in the Context of the Initiative for the Integration of the Regional Infrastructure of South America (IIRSA): 43

Published By: Conservation International

URL: https://doi.org/10.1896/978-1-934151-07-5.43

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CHAPTER 3

Biodiversity

The Amazon, Andes and Cerrado are among the richest and most diverse regions of the planet. (Top: ©Haroldo Castro/CI; Bottom: ©John Martin/CI)

Collectively and individually, IIRSA projects represent an enormous threat to the conservation of the biodiversity of the South American continent. All but one of the ten IIRSA corridors intersects with a Biodiversity Hotspot (Andes, Cerrado, Atlantic Coastal Rainforest) or Wilderness Area (Amazon, Pantanal, Gran Chaco, Caatinga). The IIRSA highway corridors planned for Bolivia, Ecuador, and Peru, the Arco Norte in the Guayana Shield region, and the PPA investments in the Brazilian Amazon are particularly worrisome because they will radically increase access to wilderness areas with very high levels of biological endemism. IIRSA will expose the western Amazon and the Andean foothills to potent global and regional economic forces, and the region's interconnected ecosystems will be inalterably changed. Climate change and geological history have left their mark on today's ecosystems and their species. The distribution of biodiversity is radically different in each of the region's major biomes due to the distinct physical attributes of mountains versus lowlands, and terrestrial versus aquatic ecosystems. Consequently, IIRSA and other development phenomena will have variable impacts across the Amazon, Andes, and the Cerrado biomes. Designing mitigation programs and conservation strategies must be predicated on a thorough understanding of the regional nature of biodiversity.

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MONTANE FOREST

Montane forests are the most biologically diverse habitats within the Andes Mountains, occupying the terrain between the grasslands of the Andean highlands and the humid forests of the Amazonian lowlands. Landscapes include broad valleys, narrow canyons, slopes of varying steepness, cliff faces, and ridge tops situated between 500 and 3,500 m in elevation. Tropical montane forests are characterized by strong gradients related to topography and manifest as differences in elevation, precipitation, humidity, soil type, slope, aspect, and radiation. Species adapt to these gradients in often contrasting ways, and their distribution depends on the characteristics that define their reproduction and survival (Kessler *et al.* 2001, Young *et al.* 2002). For example, the diversity of epiphytic bromeliads is correlated with elevation, as this functional group is adapted to cool and humid cloud forest habitats, whereas aroids are more abundant in warm and humid forest communities. Terrestrial bromeliads and cacti are most abundant in dry valleys where high levels of incident radiation reach the forest floor; fern richness is correlated with moss cover, because the fern gametophytes depend on the water captured and held by moss (Kessler 2000, 2001, 2002). Trees, the most important functional group in the ecosystem, are most diverse at lower elevations, but species composition changes over multiple gradients. Birds and bats decrease in species richness with elevation, but the diversity of rodents is unrelated to elevation (Patterson *et al.* 1998). Forest communities are subject to periodic disturbances from landslides due to high precipitation and mountainous terrain (Veblen *et al.* 1981). Because of disturbances and multiple gradients, montane forests are extraordinarily complex spatially; thus, habitat diversity and species turnover are prominent attributes of this ecosystem.

Figure 3.1. Cloud forests are unique habitats that vary according to local topography and wind flow; consequently, they are inherently fragmented and spatially complex as shown by this composite image of the Andean foothills in Bolivia. This image is derived from MODIS images taken at approximately 10:30 and 13:30 local time from the NASA Terra and Aqua satellites. White areas are those with frequent cloud cover (© Michael Douglass).

Lower montane forest communities are similar to lowland rain forests; however, with increasing altitude, montane species become more abundant and lowland species more rare (Gentry 1988, 1992a, 1992b). At the top of the montane forest sequence are "cloud forests," where ridge tops in the foothills and the flanks of the eastern cordillera intersect with the cloud layer that forms over the adjacent lowlands. Cloud forests have unique environmental conditions characterized by mist, low temperatures, and limited solar radiation. Because they are surrounded by forest types that are radically different in structure, function, and composition, patches of cloud forest are effectively geographically isolated (Killeen *et al.* 2005). One of the central tenets of conservation biology is that island-like habitats are important in establishing the reproductive isolation that drives allopatric speciation (Stebbins 1950, MacArthur & Wilson 1967). The effective isolation of cloud forests is manifest in the negative relationship between mean range size and mean elevation; essentially, species with the smallest range sizes occur at higher altitudes (Kessler 2002).

Environmental differences among patches of cloud forest are caused by elevation gradients and the frequency of cloud formation (Figure 3.1). The Andean foothills are composed of a series of parallel ridges of increasing altitude situated between the lowland plain and the eastern cordillera. Evaporation over the valleys leads to cloud formation over the adjacent ridges in a diurnal cycle that exaggerates both the humidity on ridges and the evapotranspiration in the valleys (Troll 1968, Kessler *et al.* 2001, Killeen *et al.* 2007a); consequently, cloud-impacted communities occur at elevations as low as 1,000 m and as high as 3,500m. High levels of endemism are particularly pronounced for higher taxa and functional groups such as amphibians (Köhler 2000, Kattan *et al.* 2004) epiphytic orchids (Vasquez *et al.* 2003), aroids (Vargas *et al.* 2004), and mosses (Churchill *et al.* 1995). Taxa that are well represented in other biomes also have experienced a radiation of species in montane forests: Ericaceae (Luteyn 2002), *Inga* (Pennington 1997), Solanaceae (Knapp 2002), and the Podocarpaceae (Killeen *et al.* 1993). Animal species such as hummingbirds have coevolved with plant taxa (Ericaceae and Bromeliaceae) that are both abundant and speciose in montane forests (Stotz *et al.* 1996). Many species are known to exist at a single locality, making them extremely vulnerable to extinction (Figure 3.2).

Mid-level and lower montane forest communities provide additional complexity. Some of the valleys of the eastern Andes experience annual precipitation greater than 6,000 mm (Hijmans *et al.* 2004), but rain shadow and the diurnal cycles in deep canyons create semiarid habitats with precipitation less than 1,000 mm (Troll 1968, Killeen *et al.* 2007a). Montane dry forests occur as isolated habitats from Argentina to Venezuela. Although they share a common biogeographic history, they have experienced thousands of years of divergent evolution. Andean dry forests contain numerous endemic species or infraspecific regional variants (Pennington *et al.* 2005); many have been heavily affected by human populations.

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The magnitude of IIRSA-related impacts on montane forests is impossible to map with any level of precision because the environmental gradients and the resulting habitat mosaic of these forests is complex. Nonetheless, the consequences of road improvement and expansion in the humid montane regions of Bolivia, Ecuador, and Peru are very predictable. Due to the extremely high levels of endemism associated with cloud forests, there is a high probability that any highway construction will directly lead to species extinction (Ricketts *et al*. 2005). Deforestation on the adjacent piedmont may reduce cloud cover and raise the height of the cloud base during the dry season (Lawton *et al*. 2001, Nair *et al*. In press), possibly altering the environmental conditions of the cloud forest during a critical time of the year. If such a trend develops, then cloud forest species will have to shift their distribution upward or be exposed to environmental conditions different than those to which they are adapted. Many will not be able to migrate upward in response to a rapidly changing altitudinal gradient or adapt to the changing conditions at their current elevation distribution. If so, these species will become extinct.

In lower montane forests the largest impacts will be indirect because they are associated with increased deforestation and forest fragmentation (see discussion on lowland tropical rainforests below). Fortunately, montane forests of the central Andes Mountains are still largely intact; a dozen highway corridors connect the Andean highlands and the Amazon lowlands, but large forest blocks remain unsettled and wild. IIRSA threatens to change this rare wilderness area, permanently degrading a global biodiversity hotspot. Several of the planned transportation corridors will transect areas that have been inhabited for decades (Yungas and Chapare in Bolivia, Huallaga Valley in Peru, Napo in Ecuador), but road improvement will accelerate the expansion of secondary roads into the intact forest blocks, degrading forest remnants. The construction of the Interoceanic Corridor in southern Peru[53] will produce even greater impacts because it will improve a road that is closed during several months of the year and that is sparsely settled where it transects montane forests. The situation is even more critical in Colombia, Ecuador, and Venezuela, where montane forest ecosystems have been occupied by human civilizations for centuries. The montane forests of the northern Andes are already highly fragmented, and the cloud forest habitats have been encroached upon from above and below the cloud zone.[54] The potential impact from IIRSA investments in the northern Amazon basin will take place on landscapes that have already been substantially altered by human activities. Consequently, special care needs to be taken so that the few remaining patches of native habitat are identified and provided maximum protection.

[53] The Interoceanic Corridor is a project in the Peru–Brazil–Bolivia Hub rather than a component of the Central Interocenic Hub that spans Bolivia and Brazil to the south (see Figure 1.1 and Figure A.2).

[54] In Colombia, potatoes are cultivated near the ecotone between cloud forest and high altitude paramo grasslands.

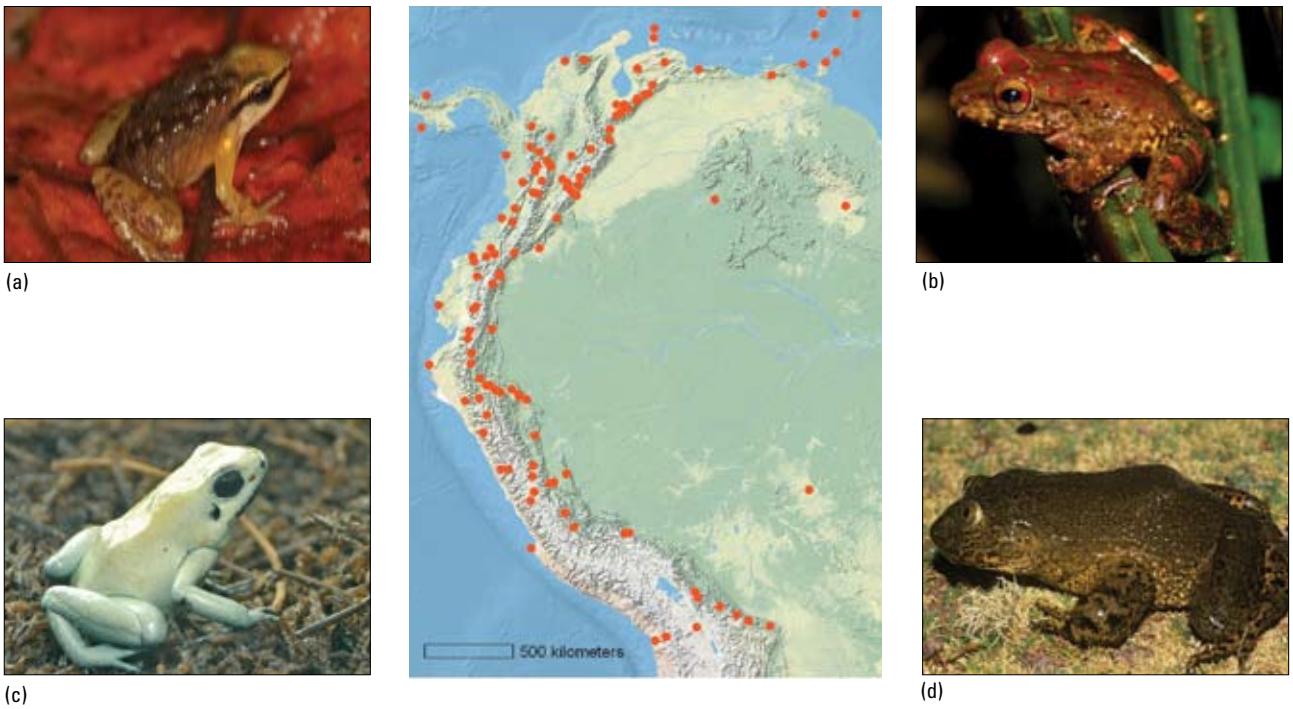

Figure 3.2 The Alliance for Zero Extinction (AZE) identified locations that contain the only known populations of one or more endangered species. Amphibians top the list and include these South American species: (a) *Colostethus ruthveni* and (b) *Cryptobatrachus boulengeri*, both from Sierra Nevada de Santa Marta National Park in Colombia (© ProAves), (c) *Phyllobates terribilis* from Río Saija in Colombia (© John White), and (d) *Telmatobius gigas* from Bolivia (© Ignacio de la Riva).

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LOWLAND TROPICAL RAINFOREST

The Amazon region is sometimes described as a monotonous expanse of tall forest that covers more than half of the continent; however, this apparent uniformity is deceiving: the variability in species composition is manifest at the basin, the regional, and the local scale. Botanical research has shown that the floras have strong regional differentiation (Prance 1972, 1989, Mori & Prance 1990, Baker *et al.* 2004) and that plant communities vary over latitudinal and longitudinal gradients (ter Steege *et al.* 2000). The distribution of vertebrates is constrained by rivers, leading to many endemic species and subspecies (Wallace 1852, Emmons 1997, Patton & da Silva 1998, da Silva *et al.* 2005). Scientists with different taxonomic and disciplinary perspectives have fiercely debated the origin and evolution of biodiversity in the Amazon (Haffer 1969, Colinvaux 1993, Nelson *et al.* 1993, Irion *et al.* 1995, Marriog & Cerqueira 1997, Lovejoy *et al.* 1998, Burnham & Graham 1999, Maslin 2005, Mayle & Bush 2005). There is no argument, however, over the distinctiveness of the regional biota and that IIRSA projects will impact some regions more than others.

Studies of vertebrate taxa have identified eight subregions of the Amazon separated by rivers and differentiated according to the distribution of endemic frog, lizard, bird, and primate species (see review in da Silva *et al.* 2005). The most commonly accepted hypothesis is that the largest Amazonia tributaries and the main trunk of the Amazon River are situated in very old valleys that have acted as barriers to the distribution of forest species over millions of years. Given this geographic isolation, a characteristic suite of endemic species or subspecies has emerged within each subregion. Each one of these biogeographic subregions (Figure 3.3) represents a basic unit of conservation planning because the species in it cannot be affected by conservation measures in the other subregions. One of the central tenets of conservation planning is the need to protect large blocks of forest (Tarabelli & Gascon 2005); however, if a large block is composed of two or more separate subregions that are differentiated by endemism, then the effective size of that forest block is proportionally reduced. Consequently, the large forest remnants in the southern and eastern Amazon are not as effective conservation units as they may seem. Regional endemism should be the primary consideration in designing conservation corridors (da Silva *et al.* 2005). Unfortunately, IIRSA corridors have been designed without consideration of their potential impact on regional endemics. Regional endemism is less important in defining geographic stratification on the Andean piedmont, where landscapes are younger and there is little evidence that rivers have acted as barriers to the distribution of species (Aleixo 2004); nonetheless, there are still regions of high endemism that must be considered in development planning. Botanical studies show a gradual change in forest composition between Bolivia and Ecuador (Smith &

Figure 3.3. The Amazon has different biogeographic regions, each characterized by endemic vertebrates: (a) Equatorial saki (*Pithecia aequatorialis*) is endemic to the Napo region in Ecuador and northern Peru; (b) White-faced saki (*Pithecia pithecia*) is endemic to the Guiana region; (c) Emperor tamarin (*Saguinus imperator*), is endemic to the Inambari region and (d) Prince Bernhard's titi monkey (*Callicebus bernhardi*) is endemic to a restricted area in the Rondônia region. Deforestation has already severely affected the eastern and southern regions, while IIRSA investments will impact the Inambari and Napo regions.

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Killeen 1998, Terborgh & Andresen 1998, Pitman *et al*. 2001). However, the latitudinal gradient does not correspond simply with the precipitation gradient that is responsible for a concomitant reduction in biodiversity. There are three regions that experience anomalously high rainfall at some distance from the equator (Hijmans *at al*. 2004); each of these regions is floristically distinct and contains high levels of species richness and endemism (Killeen *et al*. 2007a). They have been hypothesized to be climatically stable and probably remained wet during the Pleistocene, when the distribution of humid forest species was reduced.[55] Habitat conversion in these regions is particularly unfortunate, especially because these areas are prime candidates for biological reserves that are resistant to future climate change (Killeen *et al*. 2007a).

The structure and composition of Amazon forest communities make them particularly susceptible to deforestation and fragmentation because they are characterized by a small number of oligodominant tree species (usually ten to twenty) that are more or less abundant, constituting up to 50 percent of all stems (Pitman *et al*. 2001, 2002). Oligodominants tend to have very wide distributions and can be viewed as successful species in terms of their ability to reproduce, disperse seeds, and recruit adult individuals into the forest canopy. However, the rest of the tree community is composed of hundreds of species that are represented by only one to a few individuals per hectare. Rare species represent the bulk of tree diversity in tropical forest communities (Pitman *et al*. 2001, 2002, Condit *et al*. 2002). Detailed studies on the range distribution of rare species have not been undertaken, but it is reasonable to hypothesize that most are regional endemics. Because of their low population densities, they are particularly susceptible to forest fragmentation and deforestation, which will tend to homogenize the Amazon forest as these rare regional endemics are eliminated, leaving the widespread oligodominants.

The deleterious effects of forest fragmentation are well documented (Laurance *et al*. 2002, Tabarelli & Gascon 2005). Most deforested landscapes retain patches of natural forest surrounded by a matrix of human modified landscapes that include crops, pastures, and secondary forest. Forest fragments are relatively small and have a large edge-to-interior ratio that exposes the fragment to further degradation. Edge effects include greater penetration of light and wind, which leads to drier conditions in the understory, impedes the regeneration of native species, and exposes adult trees to increased mortality from wind sheer (Laurance & Wiliamson 2001). In addition, fire is an increased threat because forest fragments are often surrounded by pasture that is periodically burned for weed control; fire invades forest remnants, increasing adult mortality and further degrading the forest structure (Cochrane & Laurance 2002). Because forest remnants are located in areas with relatively high population density and reduced regional fores cover, logging is also more intensive to meet the local population's ongoing need for timber and firewood. Similarly, intensive hunting quickly leads to the local extinction of the vertebrate fauna, which limits the dispersal of seeds and genetically degrades tree populations. Edge effect has been shown to penetrate up to 300 m into forests, and because remnants are often quite small, there is often no place free from some sort of edge effect (Laurance *et al*. 2002). Disturbance from adult mortality, logging, and fire promote the regeneration of pioneer species that are both invasive and widely distributed; all of these processes lead to further homogenization of the forest flora (Tabarelli & Gascon 2005).

Lowland forests will be degraded over an extensive area due largely to the economic and social forces unleashed by the IIRSA projects (Fearnside & Graça 2006). Highway construction in remote areas stimulates human migration, which leads to accelerated land use change and increased habitat fragmentation. Because the land on the piedmont and adjacent plains is essentially flat, secondary roads will proliferate, bringing extensive deforestation, forest fragmentation, and forest degradation (Laurance *et al*. 2001). It is not unreasonable to predict that at least 250,000 km^2 will be deforested in the Amazon over the next decade, with a total of at least 50,000 km^2 in Bolivia, Colombia, Ecuador, and Peru combined.[56] If the proposed highways are constructed, forest habitats on the eastern slope of the Andes and the adjacent piedmont will be fragmented into at least eight distinct blocks with several highways transecting proposed biodiversity conservation corridors. Even larger areas will be subject to forest degradation caused by logging and fire.

GRASSLANDS, CERRADOS, AND DRY FORESTS

The regions adjacent to the Amazon support a variety of ecosystems adapted to the seasonal climates of the dry tropics (Daly & Mitchell 2000). The largest and the most biologically diverse of them is the Cerrado Biodiversity Hotspot, a complex of savannas and shrublands that stretches across the southern Amazon from Maranhão to eastern Bolivia (Machado *et al*. 2007). Structurally similar but floristically distinct are the grasslands in Colombia and Venezuela (*Llanos de Orinoco*); Bolivia (*Llanos del Moxos*); and on the border of Bolivia, Brazil, and Paraguay (*Gran Pantanal*), which are recognized as wilderness areas because the greatest part of their surface area remains essentially intact. Natural grasslands also occur in the Guayana Shield region of Venezuela (*Gran Sabana*), Guayana (*Rupinini*), and Brazil (*Roraima*), as well as on isolated patches associated with poor soils or seasonally inundated landscapes in the Brazilian Amazon, such as the Araguaia River (*Ilha do Bananal*) and white sand *caatingas* of the central Amazon. Savannas and scrublands predominate on these landscapes due to environmental factors such as seasonal drought, poor soils, and impeded drainage, with fire almost always playing an important role in modulating the density of the woody cover. Savannas almost always occur within a landscape mosaic with a seasonal forest habitat

[55] The presence of humid forest refugia in the Pleistocene does not imply that Amazonian speciation occurred during that period (e.g., Refugium Hypothesis), which is generally believed to be a Tertiary phenomenon (see Maslin 2005), but only that several disjunctive or loosely connected areas on the Andean piedmont would have provided appropriate conditions for humid forest species (Killeen *et al.* 2007a).

[56] Annual land use change in the Brazilian Amazon is approximately 20,000 km^2 yr−1 (Laurence *et al*. 2004); in Bolivia it is 2,400 km2 yr−1 (Killeen *et al.* 2007b). Studies are underway in Colombia, Ecuador, Peru, Venezuela, and the Guayanas, with a sum of 3,000 km2 yr−1 being a conservative estimate for these countries (see Table A.2).

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where the edaphic constraints that limit forest formation are less severe. Dry or seasonal forest formations exist on landscapes with relatively fertile soils, such as in eastern Bolivia (*Chiquitano, Gran Chaco*), northeastern Brazil (*Caatinga*), and Venezuela (Pennington *et al*. 2005).

The Cerrado biome is renowned for its high levels of diversity and endemism, with an estimated 40 percent of its woody plants and 38 percent of its reptiles occurring only in this biogeographic region (Colli 2005, Ratter *et al*. 2006). One of the key ecological attributes of the Cerrado ecosystem is its habitat diversity, which ranges from open grasslands to dense scrubland and gallery forests along water courses; specialized species are often most abundant or even restricted to a specific habitat type (Figure 3.4). Habitat diversity leads to complex landscape mosaics with multiple ecotones. Gallery forests are particularly important for providing cover for wildlife, and most savanna fauna depend on this habitat type within the savanna ecosystem. The biodiversity of the Cerrado Hotspot has not been adequately mapped, but the distribution of woody plant species reveals that there is strong regional differentiation (Ratter *et al*. 2006), and a gap analysis performed for 244 threatened and endemic amphibians, reptiles, birds, mammals, and plants demonstrated that almost 30 percent of the Cerrado biodiversity is not represented in the existing protected areas (Machado *et al*. 2007).

Modern development in the Cerrado region began in the 1950s and 1960s with the expansion of cattle ranching on the Planalto de Mato Grosso. However, because most native grasses are coarse and unpalatable, landowners cleared them to plant cultivated grasses that allowed them to increase their livestock herds and improve animal management. Beginning in the late 1980s, agronomists learned that the application of lime ($CaCO_2$) to Cerrado soils could dramatically improve soil fertility. Landhold-

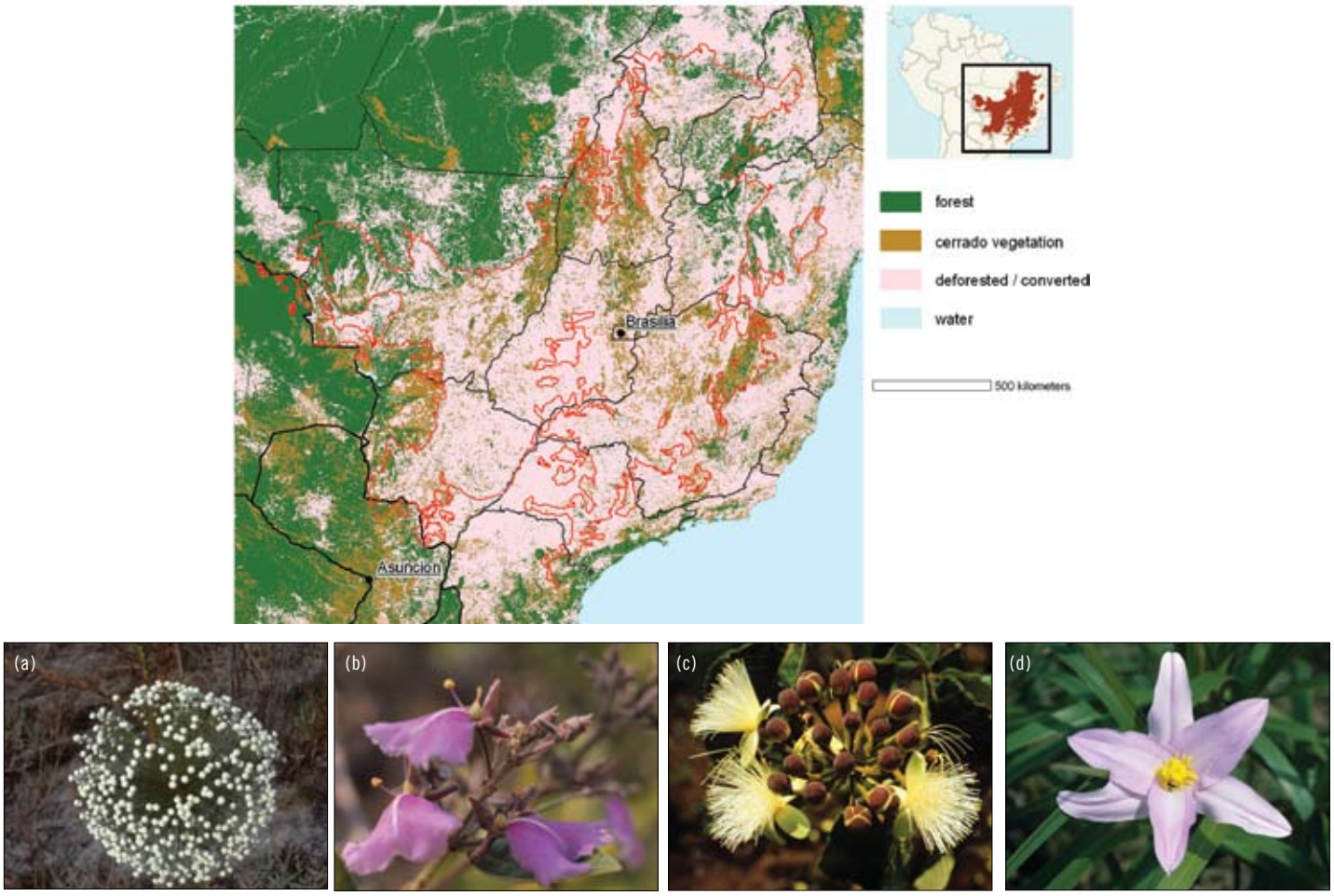

Figure 3.4. The Cerrado Biodiversity Hotspot is well known for its endemic plant species: (a) *Actinocephalus bongardii* (A. St. Hil.) Sano (© Haroldo Castro/CI); (b) *Quarea parviflora* Mart.; (c) *Caryocar brasilensis* Camb., and (d) *Vellozia squamata* Mart. ex Schult. (© Dr. Jimmy Ratter, Royal Botanical Garden of Edinburgh). The Cerrado has already lost much of its natural habitat to agricultural production; an improved transportation infrastructure will increase the competitiveness of Cerrado agriculture, leading to an intensification of land use.

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ers then began to convert ranches into cropland, and the Cerrado has since become the largest soybean producing region, making Brazil the largest exporter of soy in the world. The original extent of the Cerrado habitat has been estimated at 2.2 million km^2, but approximately 55 percent has been converted to either pasture or cropland. The rate of habitat conversion was estimated at 1.36 to 2.2 million ha per year between 1985 and 2002, and some models predict that what remains of the Cerrado will disappear by 2030 (Machado *et al*. 2004, 2007). Unfortunately, only 2.2 percent of the original Cerrado area has been set aside as protected areas (Klink & Machado 2005, Rylands *et al*. 2005).

Rapid land use change and habitat degradation are similarly occurring in seasonally dry forest formations, where climates and soils have long favored human settlement and agriculture (Olson & Dinerstein 1998). These geographically separate forests share a common biogeographic history (Prado & Gibbs 1993, Pennington *et al*. 2005). Apparently, they coalesced near the equator during the last glacial maximum surrounding a much reduced rainforest ecosystem in the central and western Amazon (Mayle *et al*. 2004); nonetheless, today, each subregion of seasonally dry forest has its own group of endemic species or subspecies (Pennington *et al*. 2005). Nonsustainable logging practices are particularly damaging in these ecosystems because of the inherently slow growth rates of species adapted to these climatic regimes (Dauber 2003). The Caatinga region is the most degraded of the seasonal forest regions due to the long history of human settlement and colonization in northeastern Brazil. Recent deforestation has impacted dry forest regions in Bolivia, Venezuela, and southern Brazil.

Fortunately, the savannas of the Llanos de Orinoco, Moxos, and the Gran Pantanal are still relatively intact due largely to the seasonally inundated landscapes, which inherently limit cultivation. Nonetheless, cattle ranchers do graze livestock on the native grasses of these regions, which are more palatable than the native grasses on the upland savannas, and some areas are locally impacted by overgrazing. In addition, there are recent experiments to convert seasonally inundated habitats to paddy rice cultivation in Bolivia, and there is clearing of woody plants in the Gran Pantanal.

IIRSA and PPA investments will accelerate habitat degradation in most, if not all, of the extra-Amazonian ecosystems. The Cerrado Biodiversity Hotspot is the most endangered due largely to its suitability for mechanized agriculture. Although the Federal Government of Brazil makes repeated commitments to conserve the Amazon, similar actions to conserve in the Cerrado region are weighed against national priorities to expand agricultural production (Figure 3.5). Thus, although the Amazon ecosystem faces extensive degradation and fragmentation due to IIRSA investments over the medium term, the Cerrado faces virtual annihilation over the next half century (Machado *et al*. 2007). Considering the advanced state of the destruction of this biome, protected area creation should be part of any strategy that seeks to mitigate the effects of the PPA's investments in modern highways. The Brazilian forest code requires that 20 percent of private properties be left as native habitat within the Cerrado biome. These efforts to conserve gallery forests within private lands could significantly

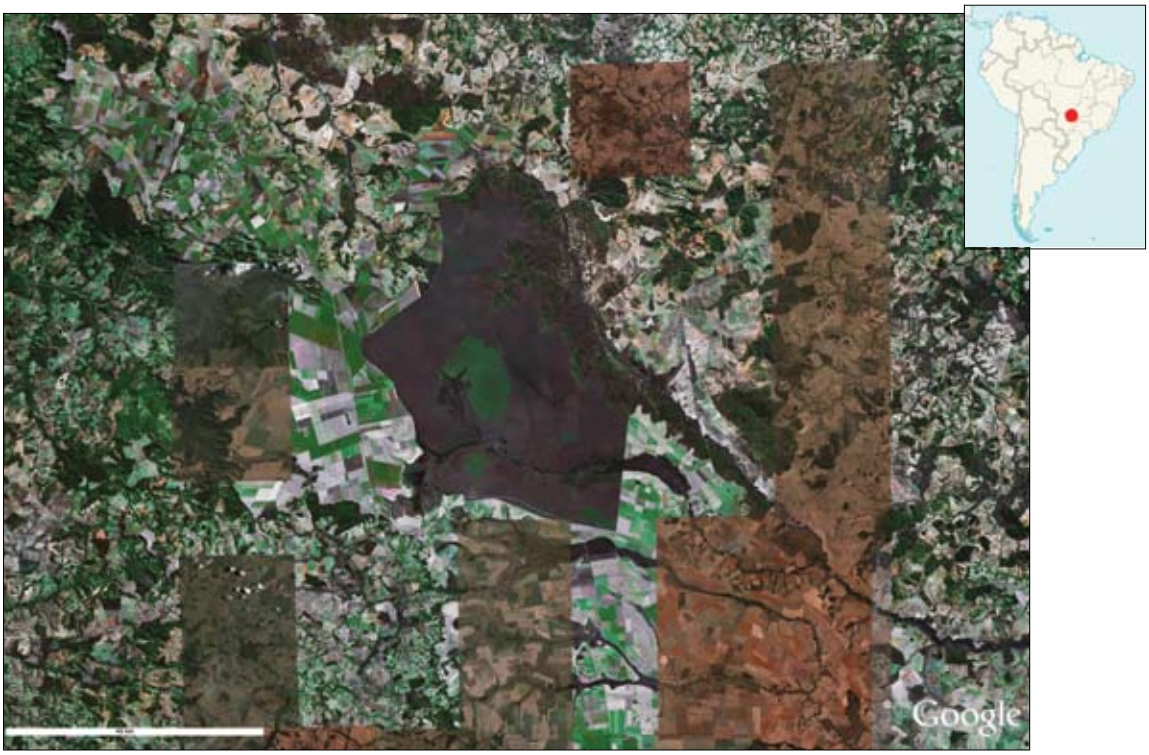

Figure 3.5. Emas National Park is an island of native habitat surrounded by farmland in the Cerrado. Gallery forests along rivers and scattered remnants of native habitat provide opportunities for a regional conservation strategy (Google Earth ™ Mapping Services).

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reduce the effect of habitat conversion within savanna ecosystems.[57]

AQUATIC ECOSYSTEMS

The Amazon River system is the world's largest freshwater ecosystem, with nearly 20 percent of the Earth's freshwater discharge (Goulding 1980). The aquatic biodiversity of the Amazon is the consequence of geological history, the sheer size of the basin, the contrasting nature of the constituent sub-basins, and the extraordinary habitat heterogeneity of each individual floodplain. The Amazon's sub-basins have been traditionally classed into three broad categories on the basis of turbidity, color, and pH of the water: 1) white water rivers originating in the Andes are characterized by high sediment loads and approximately neutral pH; 2) black water rivers drain lowland landscapes with white sand soils dominated by plants with very high tannin[58] levels, so their runoff is very dark and acidic; 3) clear water rivers arise in moderate terrain, particularly the Brazilian and Guayana Shield, and have relatively clear water of nearly neutral pH (Sioli 1968, Junk 1983). Recent studies have emphasized the diversity of aquatic habitats associated with the morphological variability of channels, lakes, and wetlands, as well as distinct hydrological regimes in upstream, midstream, and downstream sections of the river (Mertes *et al*. 1996, Goulding *et al*. 2003). Like their terrestrial counterparts, aquatic ecosystems are characterized by high levels of biodiversity and species endemism (Figure 3.6). Estimates of the number of Amazonian fish species vary between 1,300 and 3,000, but the true number may be much higher as systematists revise the status of headwater populations of widespread but poorly studied taxonomic groups (Ruffino 2001).

Migration is a behavioral trait characteristic of many Amazonian fish. Some of the most economically important commercial species such as the piramutaba (*Brachyplatystoma vaillantii*) and the dourada (*B. flavicans*) migrate long distances between the estuary and upstream sections of the basin. Other species are less pelagic in their migration, moving within certain sectors of the basin, such as the tambaqui (*Colossoma macropomum)*, pacú (*Mylossoma* spp.), jaraqui (*Semaprochilodus* spp.), and curimatã (*Prochilodus nigricans),* among others (Barthem & Goulding 1997, Ruffino 2001). One of the most salient features of the Amazon River system is the importance of the floodplain in providing multiple niches for aquatic organisms, and many fish species migrate locally between the channel and flood plain habitats in accord with annual fluctuations in river levels (Goulding 1980, Goulding & Ferreira 1996). Along white water rivers, floodplain forests known as *varzea* are particularly productive because the sediments washed down from the Andes bring essential chemical nutrients. Frugivorous fish migrate into *varzea* during periods of high water to spawn and feed on a rich assortment of fruits, then return to the river channels during low-water periods (Barthem & Goulding 1997).

Modifications to the Amazon's aquatic systems through the construction of dams and reservoirs will bring obvious direct impacts in the immediate area of each project. The most serious are those relating to fish populations. At the Tucuruí dam on the Tocantins River in Brazil, a program to monitor fish populations before and after the flooding of the reservoir showed declines in species diversity upstream (25 percent) and downstream (19 percent); in addition, species diversity was down 27 percent compared with the preexisting riverine habitat (LaRovere & Mendes,

57 Conservation International–Brazil is working with farmers and ranchers to restore areas cleared beyond the legally allowed amount; voluntary certification schemes are being promoted to reward farmers in compliance by providing secured access to European markets.

58 Tannins are chemical compounds that plants have evolved as defense mechanisms against herbivores. They are particularly common in plants from areas with very sterile soils where the leaf nutrients are difficult to replace.

Figure 3.6. The inundated forests of the Amazon are strategically important for biodiversity conservation: (a) Igapo forest near Manaus is home to plant and animal species adapted to the acidic conditions of black water rivers; (b) Varzea forests have muddy, nutrient-laden waters and are among the most productive wetlands in the world (©CI and Tim Killeen/CI).

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2000). Another recent study of mercury contamination in the Caroni River in Venezuela revealed that mercury levels in fish populations were several-fold higher within the reservoir than in populations below the reservoir. Apparently the high organic content of lake bed sediments (the result of flooding tens of thousands of kilometers of forest vegetation) creates anoxic conditions that enable mercury-methylate to form, a type of mercury that is rapidly absorbed by biological organisms (Veiga 1997, Fearnside 2001a, 2005a).

Aquatic systems are particularly susceptible to secondary long-term impacts: upstream effluents and sediments are conveyed downstream, while downstream obstacles impede the migration of species to headwater regions. Consequently, the impacts of IIRSA investments on aquatic systems will be apparent both locally and regionally. Deforestation of upland forest in lowland landscape will bring about a pulse of nutrients associated with ash and increased sedimentation, as well as long-term changes in temperature and chemistry (Bojsen & Barrigo 2002). Muddy streams that meander through cattle pasture bear little resemblance to the cool, shaded, clear water habitats that existed prior to deforestation. Paddy rice cultivation is not common in the Amazon, but recent experiments in Bolivia are encouraging new migrants to adopt this production system in the accessible areas of the Llanos de Moxos of the Beni. The conversion of savanna wetlands for paddy rice cultivation will also have important, if poorly understood, impacts on fish populations. Savanna fishes are known to be diverse, although they represent the most poorly studied segment of freshwater fishes in tropical America (Schaefer 2000). Deforestation of inundated forests is particularly devastating because it directly affects the prime feeding and spawning ground of the most economically important fish species. Road-building in mountainous regions will have severe short-term impacts. Because roads typically are built on slopes above rivers, earth-moving equipment can dump tens of thousands of tons of soil and rock into watercourses during construction. Highways and rivers usually run parallel for dozens of kilometers; thus, the riparian environment will be permanently altered.

A major emphasis of IIRSA is the renovation and improvement of hydrovias. This promotion of river transport will have fewer negative impacts than highway construction, and the creation of river ports will pose moderate impacts. Nonetheless, a revitalized Amazonian hydrovia will potentially lead to increased population density along major and minor rivers. This would almost certainly lead to increased fishing pressure, and may also foster increased deforestation in both upland and flooded forests. IIRSA investments to construct dams for energy production would constitute a long-term, permanent impact on dozens if not hundreds of migratory fish species. Damming the major tributaries of the Amazon River may have catastrophic effects on fish migration and fish populations and bring about huge economic consequences.

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