Online Supplement to T. Dietz, E. Ostrom, & P. C. Stern, *Science* 302 (2003): 1907-12.

Since the publication of Hardin's "Tragedy of the Commons" in 1968, substantial academic and policy interest has been devoted to the question of how diverse forms of ownership—government, private, or common property—affect the extent and condition of common-pool resources. This research has been conducted in many areas of the world and has examined many kinds of commons, including forests, lakes, pasture lands, irrigation systems, and fisheries. As discussed in the text of the article to which this is a supplement, it is always a *struggle* to govern the commons so as to achieve sustainable resource flows over time. Research cited in the text demonstrates how systems of rules operating under each of these forms of ownership have succeeded in achieving sustainable use. The requirements for sustainable commons include (i) providing trustworthy information about the resource and its users, (ii) dealing with conflict, (iii) inducing rule compliance, (iv) providing appropriate physical and institutional infrastructure, and (v) encouraging adaptation and change. If resource users contest the legitimacy of the boundaries and do not comply with rules, however, major deterioration is likely to occur.

The analysis of remotely sensed images over time is a particularly useful technique to illustrate the importance of establishing legitimate boundaries and achieving rule compliance in order to manage forests sustainably. In Figures S1–S5, we present multi-temporal color composites from Madagascar, Uganda, Brazil, Nepal, and Guatemala, each generated from three dates of Landsat satellite images (*1*). Each composite is constructed by overlaying Landsat satellite images of each area taken at three different points in time. The colors in the composites show change over time in forested areas (*2*). All of the composites can be interpreted using the following color scheme:

- Red: Forest was stable between first and second satellite image dates but cleared by date of last image.
- Yellow: Forest was cut between the earliest and middle image dates and did not regenerate by the last date.
- Green: Forest existed in the earliest image date, was cleared before the middle date, and regrew prior to the last date.
- Blue: Forest regrew before the date of the middle image and remained in forest at the time of the last image date.
- Black or dark grey: Forest is stable.
- Bright grey or white: Cleared land, riverbanks, roads and other non-forest land that does not change across the three image dates.

Figures S1–S5 illustrate that the extent of deforestation is *not* dependent on the form of ownership (*e.g.*, whether a forest is owned by an individual, a community, or a government) in any simple way (*3*). The figures illustrate that under each form of ownership stable forest boundaries or substantial deforestation may result. A key factor associated with stable forests is that they all have well-demarcated and legitimate boundaries and effective rule enforcement. When these requirements are not present we see major deforestation. We will discuss each composite to examine what has happened.

Figure S1 from Madagascar shows a large number of small, sacred forests on the southeastern coast of Madagascar, based on Landsat images from 1973, 1985, and 1999. Much of the southern portion of this area was cleared of forest prior to 1973. The red and yellow areas reveal active clearing to the north. The many small dark circular patches present in the southern portion of this figure are "islands" of forest vegetation surrounded by cleared land now in agricultural production. This multi-temporal composite shows that many of these stands have not experienced substantial change since 1973. According to maps based on aerial photographs taken around 1950, the boundaries of these remnant patches also have remained virtually unchanged over the past 50 years (*4*).

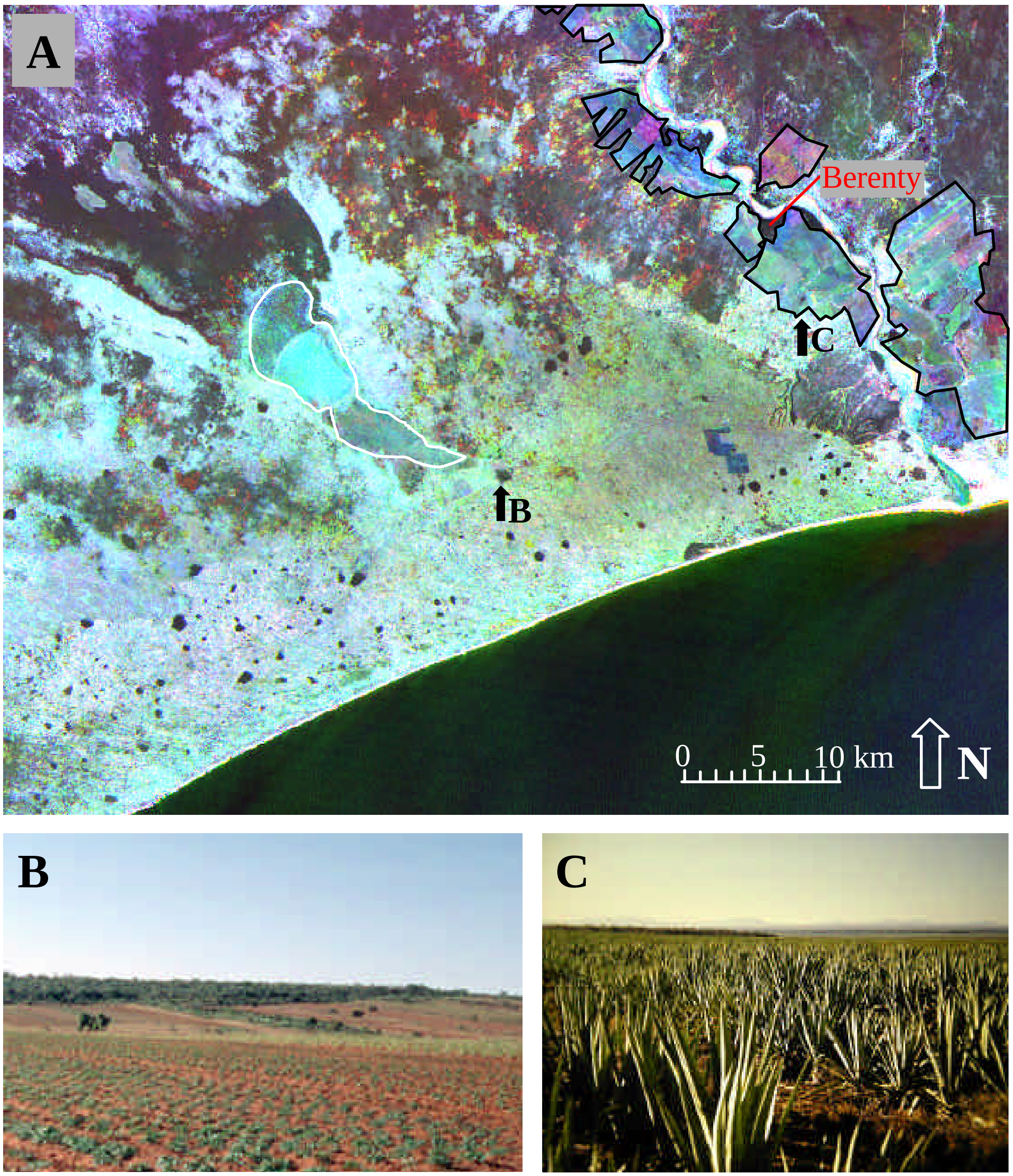

Figure S1. Sacred forests in Madagascar

The numerous small dark circular areas located in the lower portion of A are sacred forests surrounded by agricultural lands on the southeastern coast of Madagascar, just west of Amboasary. B is a photograph of one of these sacred forests (viewed as shown by the black arrow in A). Privately owned sisal plantations (outlined in black in the upper right corner of A; photograph shown in C) are located in areas that, prior to 1950, were partially covered with gallery forests along the banks of the Mandrare River (depicted by the white meandering line). A remnant of these gallery forests is now the private Berenty Reserve. The area outlined in white is seasonally inundated wetland. The multi-temporal color composite is produced from Landsat images from 1973, 1985, and 1999: band 2 from a 1973 MultiSpectral Scanner (MSS) scene, band 3 from a 1985 Thematic Mapper (TM) scene, and band 3 from a 1999 Enhanced Thematic Mapper Plus (ETM+) scene. The area in the composite is approximately 65 km by 53 km and extends from 85,300 m to 137,900 m Northing and from 336,900 m to 402,000 m Easting (Laborde grid/ International 1924 spheroid/Tananarive observatory1925 datum). This composite and the Malagasy landscape are more fully described in Sussman *et al*. (*4*). (Composite constructed in 2003 and photographs taken in 2001 by Glen Green.)

Local Antandroy peoples have maintained these forest remnants as sacred areas that protect tomb sites, often referred to as *fady* or taboo forests (*5*). The forests are generally circular and 300–400 m in diameter (*6*). Engström (*7*) found more than 1,400 of these forest patches evenly distributed throughout the area but covered only 4% of total area in the author's analysis.

An English boy, shipwrecked on this coast in 1701, mentions the sacred tomb sites of this region in his journal (*8*). Thus, these sacred forests have been respected by the local people and protected by communal institutions for more than 300 years. Lemurs are reported in these protected forests but are generally absent from the surrounding agricultural terrain (*4*).

Figure S1 also shows how large, privately owned, sisal plantations (multi-color rectangular areas outlined in black) now dominate the borders of the Mandrare River in the northeast, an area that once supported large stretches of dense, closed-canopy gallery forest. However, a number of small yet stable patches of gallery forest still remain, protected in private reserves established by the plantation owners after they had cleared the rest of the forest. The best known of these private reserves is Berenty, a favorite location for tourists to view the local ring-tailed lemurs.

Figure S2 from Uganda illustrates the long-term stability of government ownership when boundaries have long been recognized and enforced. The government-owned, gazetted (*9*) forest reserves (outlined in white), located in the West Mengo (Mpigi) region of Uganda, have been remarkably stable since the first, cloud-free Landsat image taken in 1986. Aerial photographs taken in June/July 1955 also show deforestation on private land occurring right up to the boundaries of the gazetted forest reserves but few incursions.

Agreements between the British government and the Regents of the Buganda Kingdom in 1900 and 1907 established a process to register private land parcels, referred to as *mailo* land, as well as the gazetted forests. Private *mailo* land was demarcated first, beginning in 1904 and ending in 1936. *Mailo* boundaries were demarcated with earth cairns and *Dracaena sp.* shrubs planted at each cairn. *Ficus natalensis* and *Ficus brachypoda* were also used in boundary demarcation. These species were used to demarcate land in pre-colonial Buganda and served to aid in managing boundary conflicts (*10*), and are still used today. The *mailo* land surrounding the government forests is today farmed both by owners and tenants, who have a long history of traditional rights (*bibanja*) and who are slowly gaining permanent rights to their *bibanja* plots.

After completion of *mailo* boundary demarcation, delineation of the gazetted forests began. Agriculture was typically not practiced within the gazetted forests because they lay mostly on poor, seasonally inundated soils of wide valleys (the dendritic pattern is readily observed in the satellite images). Water, construction poles, fuel wood, and plants used for basket making were, and still are, the main products extracted from these forests. Local forest users maintained the rights to extract these products, so the use patterns in the new forest reserves (declared in 1932) were not altered under the agreement with the Regents of the Kingdom.

In the 1930s and 1940s, the gazetted forest reserve boundaries were demarcated with earth cairns covered by stones, and the traditional boundary tree or shrub was planted at each cairn. Boundaries were marked at each turning point and at center points of unusually long straight lines (*11*). Relevant *mailo* owners and traditional administrators were present during the process of forest reserve boundary demarcation to ensure agreement on the location of the gazetted reserve boundary.

Since the 1930s, the Ugandan Forest Department has periodically remarked these boundaries. Community members are always hired to aid in this effort, which serves to maintain awareness of the precise location of the boundaries across generations. Conversion of gazetted forest reserves to other purposes is consistently prosecuted even though some small-scale harvesting of charcoal may be tolerated by government officials (*12*). A study comparing on-the-ground measures obtained from nine forests in the Mpigi district in 1995 with measures obtained in 2000 after a major

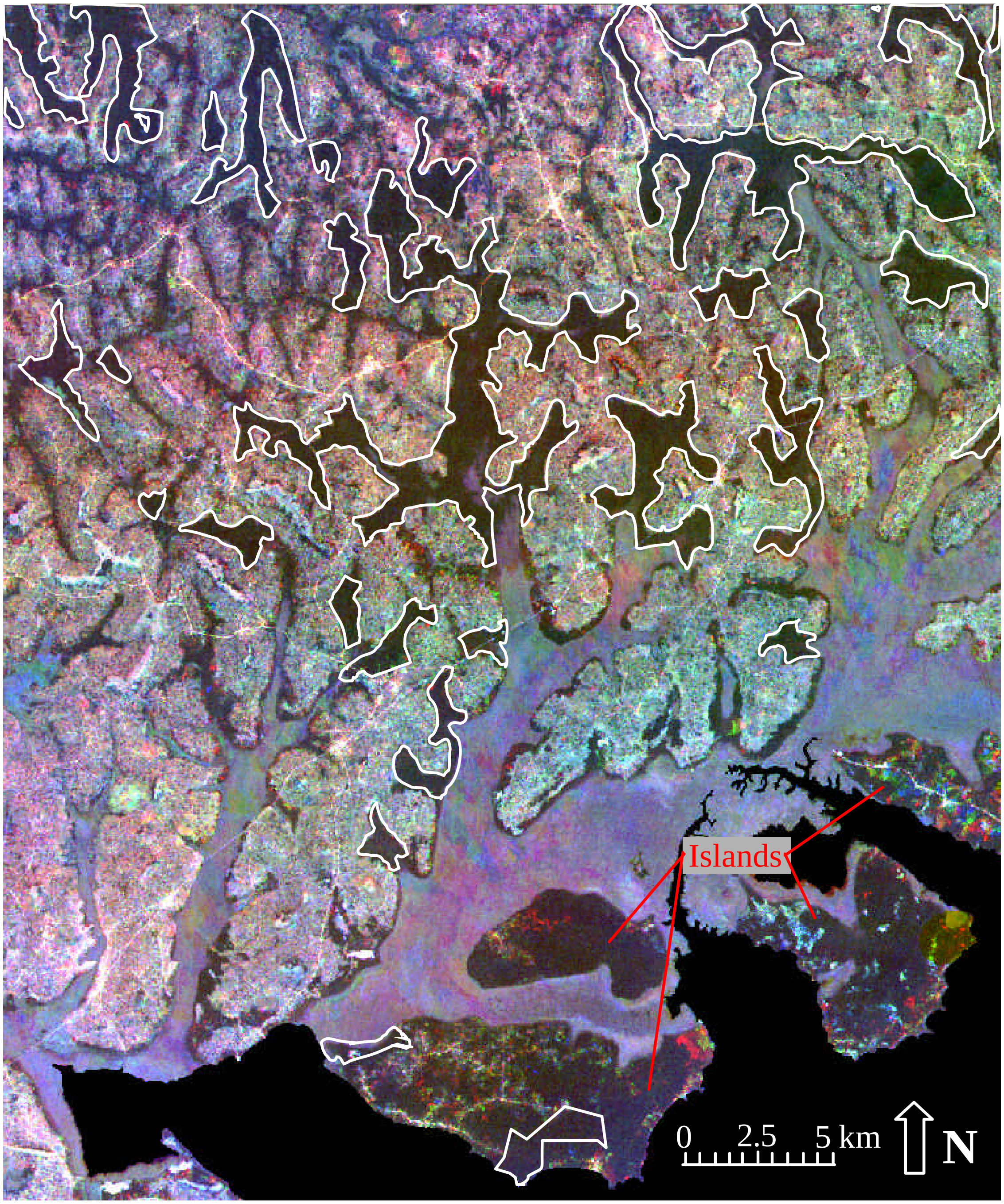

Figure S2. Government forest reserves in Uganda

The highly stable gazetted forest reserves (outlined in white) are located less than 50 km west of Kampala, within the traditional boundaries of the Buganda Kingdom in central Uganda. The waters of Lake Victoria appear in the lower portion of the figure. The four islands in Lake Victoria are isolated from the mainland by wetlands (shown in purple) and, thus, are more forested than the mainland. In this instance, biophysical conditions, not institutional enforcement, have protected the forest. The multi-temporal color composite is produced from Landsat images from 1986, 1995, and 2002: band 3 from 1986 and 1995 Thematic Mapper (TM) scenes, and band 3 from a 2002 Enhanced Thematic Mapper Plus (ETM+) scene. The area in the composite is approximately 44 km by 35 km and extends from 189,400 m to 233,200 m Northing and from 388,700 m to 423, 600 m Easting. Because the country is bisected by the equator, the Ugandan National Biomass Survey (NBS) uses a 200,000 m shift in geographic coordinates so the entire country falls within UTM zone 36N/Clarke 1880 spheroid/Arc 1960 datum. (Composite constructed in 2003 by Glen Green and Sean Sweeney.)

reduction in the local staff of the Forest Department, however, did reveal deterioration in biomass, basal area, and stem density due to increased levels of tree harvesting (*13*).

The long-term stability of forest boundaries and cover in the central forest reserves, obvious in the satellite images, is explained primarily by the persistence of well-demarcated and enforced boundaries over time, continued government intolerance of conversion to agriculture, assignment of local forest rangers to enforce and implement central Forest Department management goals (practices maintained by the post-colonial government), and the rapid canopy closure after stem removal. The poor drainage of the soils in the forest reserve also helps to discourage conversion to agricultural land without major technological investments, which would be noticed immediately. Recent increases in illegal harvesting, however, may undercut this long-term stability.

Figure S3 from Brazil illustrates the dramatic difference that the design of colonization projects in the State of Rondônia can make in the level and pattern of deforestation. Most of the colonization projects in the Brazilian Amazon were undertaken to accommodate landless migrants from southern Brazil. They were designed around an orthogonal road network that has resulted in a fishbone pattern of deforestation (*14*). Two Rondonian settlements with substantially different architectural and institutional designs, Vale do Anari and Machadinho d'Oeste, were established adjacent to each other in the 1980s by Brazil's Institute of Colonization and Agricultural Reform. The initial similarities in terrain, soils, types of settlers, and original forest cover created an opportunity for a careful study comparing deforestation rates over time in these two settlements (*15*).

Vale do Anari (located in the lower part of Figure S3) was laid out in the traditional manner. Each farmer was assigned 50 ha of land, of which 50% (located anywhere within the property) was to be preserved as forested land. The rest of the property legally could be used for agriculture, homestead, or other purposes determined by the settler. Although the 50% restriction existed, there were economic and subsistence incentives for settlers to cut down more forest than allowed on their parcels.

Machadinho d'Oeste (located in the upper part of Figure S3) was laid out with a distinct architectural and institutional design. Instead of a rigid rectangular layout, the roads and property lots were laid out to accommodate the topography. At the same time, 16 forest reserves of different sizes encompassing 33% of the total settlement area were also created. The original intent of these reserves was to preserve larger forest areas with lower fragmentation. Because of the forest reserves, under the original agreement settlers in Machadinho d'Oeste could use the full extent of their properties with no legal constraint. Rubber tappers had long lived in this area and were assigned use rights to the reserves. They became the unofficial, but very active, monitors of the forest reserves.

The reserves in Machadinho d'Oeste were decreed as official State Reserves in 1994 and 1995, and the use rights of the rubber tappers were formally legalized (*16*). In 1996 and 1997, governmental and non-governmental organizations established management plans for the reserves (*17*). The plans were approved by the local rubber tappers association. Thus, while the forest reserves are officially government-owned land, local rubber tappers have been allowed to use these reserves in line with the forest plans they helped to devise. Most important, the rubber tappers have a strong, positive incentive to protect the reserves from incursion by others.

As shown in Figure S3, differences in land-use change occurred in the two settlements. In 1988, during the early stage of implementation, both settlements had similar percentages of forest and pasture. Ten years later forest cover dropped to 51% in Vale do Anari in contrast to 66% in Machadinho d'Oeste. In Anari, pasture land increased threefold, while in Machadinho it increased less than twofold. For the ten-year period of analysis between 1988 and 1998, the rates of deforestation on private lands were very similar in Anari and Machadinho; however, because the reserved forests in Machadinho were successfully protected, the overall rate of deforestation in Anari was consistently higher than that in Machadinho (*15*, *18*).

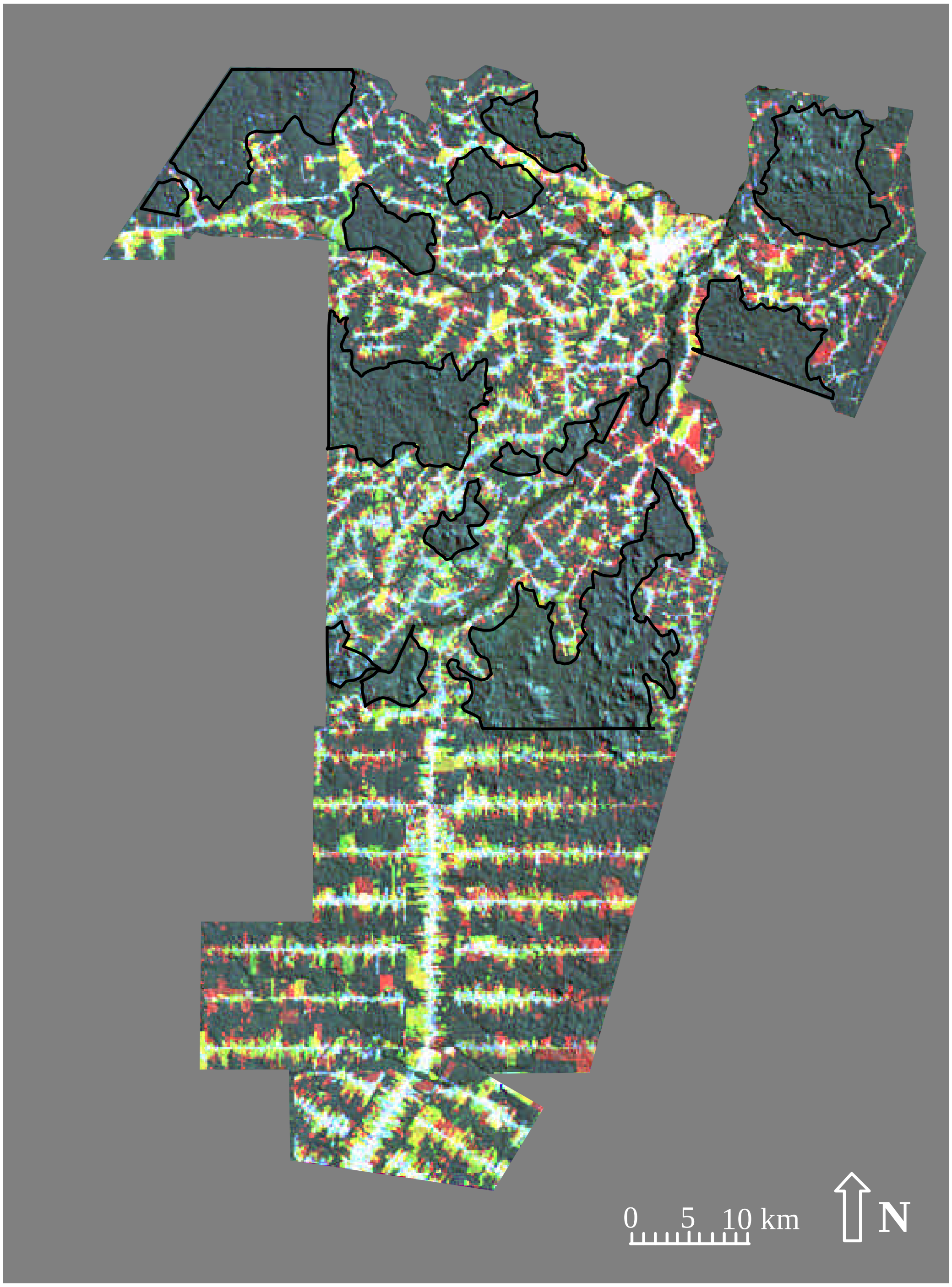

Figure S3. Two contrasting colonization projects in Rondônia, Brazil

Colonization projects Vale do Anari (bottom) and Machadinho d'Oeste (top) are located in northeastern Rondônia and illustrate two distinct community layout designs: orthogonal (fishbone) and topographic, respectively. These two communities, established in the 1980s, have different road, infrastructure, and property systems that have had different effects on forest cover. The analysis of the satellite images shows not only that the percentage of forest cover was higher in Machadinho, but also that the design based on topography and including state reserves managed by rubber tappers produced a less fragmented landscape, with greater shape complexity, and more interior habitat than Anari (*18*). The multi-temporal color composite was produced from Landsat images from 1988, 1994, and 1998: band 5 from 1988, 1994, and 1998 Thematic Mapper (TM) scenes. The area in the composite is approximately 79 km by 105 km and extends from 8,874,000 m to 8,978,500 m Northing and from 555,000 m to 634,100 m Easting (UTM zone 20S/South American 1969 spheroid/SAD 69 datum). (Composite was constructed in 2003 by Glen Green and Mateus Batistella.)

The establishment of the forest reserves did produce positive ecological outcomes in Machadinho d'Oeste. It is clear in the composite that the reserves helped to maintain larger forest patches spread throughout the landscape in contrast to smaller and fragmented forest remnants within the fishbone-like settlements. The boundaries of the reserves were common knowledge, and the presence of the rubber tappers to enforce them made a substantial difference over time.

Figure S4 from the Chitwan valley of Nepal presents a mosaic of ownership forms as well as diverse patterns of reforestation and deforestation (*19*, *20*, *21*, *22*). The Chitwan valley is located in the Terai of Nepal, all of which was heavily forested until the successful campaign to eradicate malaria during the 1950s. Soon thereafter a major settlement program was undertaken by the government of Nepal to relieve population pressures and land fragmentation in other regions of the country and to open the Terai for agricultural development. Unfortunately, the original inhabitants were pushed to the periphery of development (the lower hills of the Himalayan Mountains) as heterogeneous groups of settlers from multiple regions moved to this timber- and agriculturally rich area.

The oldest protected area in Nepal, the Royal Chitwan National Park (labeled RCNP), is located south of the Rapti River. The park was converted from a hunting reserve for the royal family in 1973 to a protected area that is strictly enforced by the Royal Nepal Army. The park has been a major tourist attraction for the past three decades. Little deforestation has occurred inside the park, but the presence of more than three million people in the adjacent valley has been a source of continuous conflict. In an effort to reduce the high levels of tension between the dense population of the Chitwan valley and government officials, local residents recently have been allowed to harvest building materials from the park during one ten-day period every year (*23*).

In 1995, the Department of National Parks and Wildlife Conservation began to implement a Parks and People program in the buffer zones of the RCNP and other protected areas that were used by local settlers. Buffer zone boundaries were delineated by park wardens and handed over to user-group committees who were given limited authority to manage these forests in accordance with the Buffer Zone Management Guidelines (*24*). In essence, the user group committees exercise a form of *co-management* since the buffer zone is still owned by the government. The warden retains the authority to stop projects and acts as the secretary of the user-group committee, but the communities do have considerable authority to harvest some products, fix the price on them, and sell and distribute them (*25*). The efforts of the user groups co-managing the Buffer Zone Forests (outlined in black) appear to have led to modest regrowth (shown in photograph B and by the green color within many of these areas on the composite in Figure S4). Until the recent violent outbreaks in Nepal, some of these user groups were able to earn substantial funds from major tourism in this region and have used 30–50% of the income for local community development.

Community forests (a form of common property), located north of the Chitwan valley in the middle hills of Nepal, have had a long history and have frequently been evaluated as significantly contributing to forest conservation (*26*, *27*, *28*, *29*). Given the initial focus on agricultural settlement in the Chitwan valley in the last half of the 20th century, little effort had been devoted by the government of Nepal to enabling community forests there. That changed with the passage of the Community Forestry Act in 1993, but it is still the case that only 17% of all community forests in Nepal are located in the Terai (*30*). Eight community forests in the area are outlined in white in A of Figure S4. A recent study comparing the performance of formally registered Buffer Zone Forests with that of the formally registered community forests in the Chitwan valley found a net decrease in forest cover over time for the community forests as contrasted to the Buffer Zone Forests that demonstrated a net increase in forest cover (*25*). Thus, common property, like all other broad forms of ownership, can sometimes fail to conserve natural resources.

At other locations in the composite, public ownership has been unsuccessful in controlling the use of forest resources, in part because the

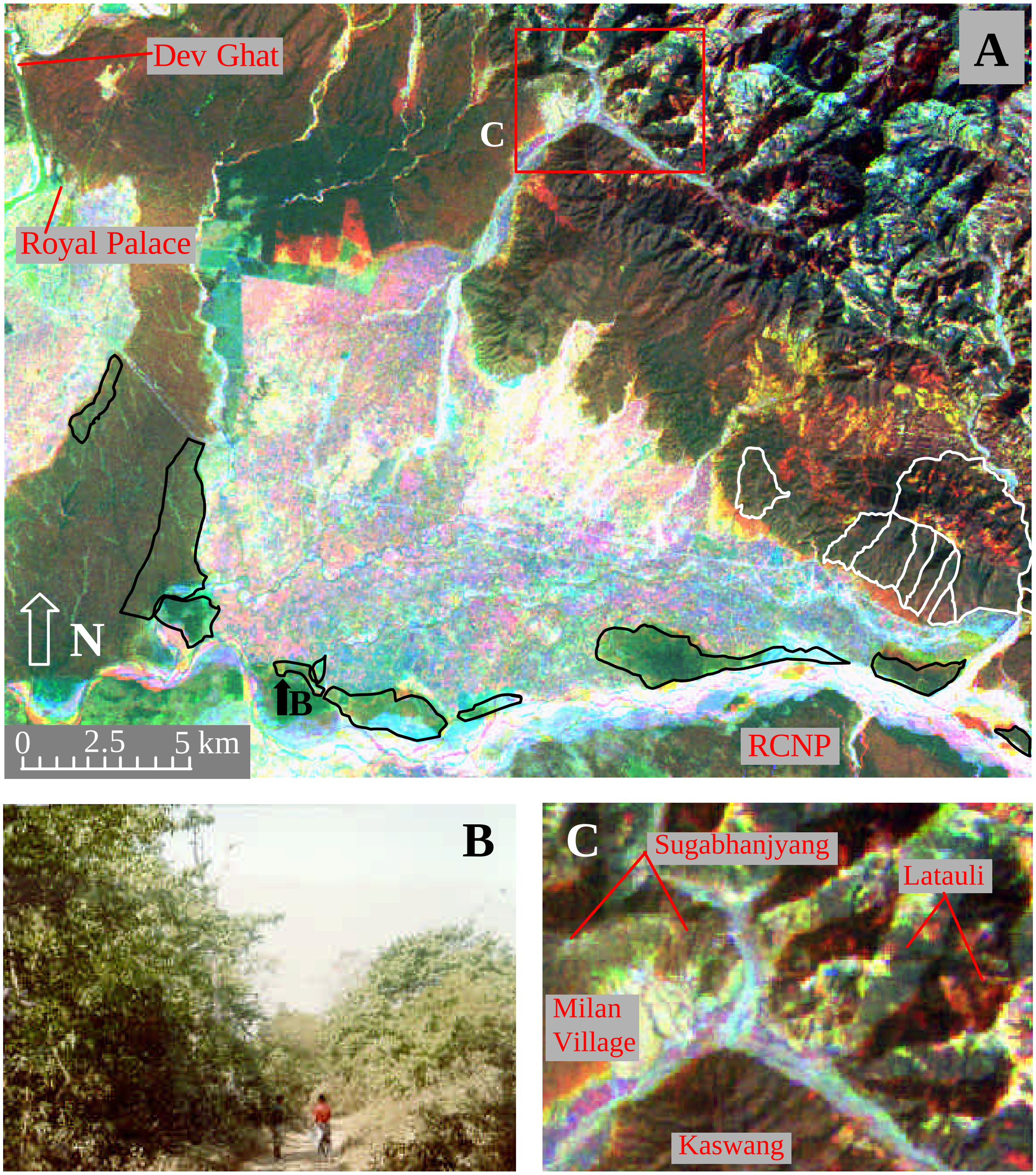

Figure S4. A mosaic of ownership forms in Nepal

The Chitwan District of south-central Nepal provides an example of a landscape containing a mosaic of ownership forms, including a religious forest (Dev Ghat), a government-owned and -managed national park (marked RCNP), co-managed Buffer Zone Forests located adjacent to the park boundary (outlined in black; photograph shown in B), and community forests (outlined in white). The Rapti River separates the large Royal Chitwan National Park, which extends farther south and west below the composite, from the rest of the valley. The multi-temporal color composite was produced from Landsat images from 1976, 1989 and 2000: band 2 from a 1976 MultiSpectral Scanner (MSS) scene, band 3 from a 1989 Thematic Mapper (TM) scene, and band 3 from a 2000 Enhanced Thematic Mapper Plus (ETM+) scene. The area in the composite is approximately 31 km by 23 km and extends from 3,048,100 m to 3,071,300 m Northing and from 542,200 m to 573,000 m Easting (Transverse Mercator/Everest spheroid/Indian datum). This landscape is more fully described in Schweik et al. (*19*), Nagendra (*21*), and Schweik (*31*). (Composite was constructed in 2003 by Glen Green and Harini Nagendra; photograph B was taken in March 2001 by Harini Nagendra.)

areas covered are huge and in rugged terrain and an insufficient number of forest guards is available to monitor the region. In these cases, government ownership has been much closer to a *de facto* open-access situation. For example, Schweik (*31*) found that District Forest Office (DFO) guards for the area shown in C were located in two posts at substantial distances from the three government-owned forests located in this region (Sugabhanjyang, Latauli, and Kaswang). Kaswang has a natural "protective" boundary in that two rivers converge to the north of it, and the "backwater" effect has deposited massive quantities of boulders and rocks in the riverbeds. Crossing these rivers is difficult throughout the year. There is a motorable road into Milan Village, and DFO guards are occasionally known to visit the village and enforce the government rules against harvesting timber and agricultural incursions nearby. Schweik reports that the quantity of an important species for timber, *Shorea robusta*, declined as one moved from the forest near Milan Village (Sugabhanjyang) to a more remote forest (Latauli), where guards would have to travel long distances on foot to observe illegal activities (see the red patches in this forest). Higher-caste users from neighboring villages also tended to harvest from Latauli forest.

Figure S4 also illustrates the stability of sacred sites. Dev Ghat, a highly respected Hindu pilgrimage spot, is located at the confluence of the Kali Gandaki and Trishuli rivers in the northwest corner of A. It is surrounded by relatively dense forest that has been protected because of its proximity to a religious site and a royal palace. In 1996, the government attempted to lease 28 ha of this forested land to the International Medical Study Center for construction of a teaching hospital. There was a popular protest, and the decision was challenged in the courts. The court ruled that the government's decision was arbitrary and that a forested area having archeological and religious significance could not be leased out to a private party (*32*).

Figure S5 from the Maya Biosphere Reserve (MBR) in Guatemala shows the largest and most important conservation area in that country. This reserve was created in 1990 by a decree from the government of Guatemala to protect the remaining areas of pristine ecosystems in the northern parts of the country (*33*). The region saw a dramatic advance of the agricultural frontier in the 1980s resulting from an aggressive policy of immigration established by the central government to provide land to farmers from the southern parts of the country (*34*). In total, the MBR occupies an area of over 21,000 km^2, equivalent to 19% of the Guatemalan territory. It borders to the north and east with reserves in Mexico and Belize, and all together, this system represents the fifth largest reserve for tropical forest in the world and the second largest tract of tropical forest in the western hemisphere, after the Amazon (*35*).

The MBR is divided into different zones to facilitate its management. The core zone, managed for complete conservation is composed of a system of four national parks and three biotopes: Laguna del Tigre Biotope and Laguna del Tigre National Park (jointly known as the Laguna del Tigre Conservation Unit), El Mirador–Rio Azul National Park, Dos Lagunas Biotope, El Zotz Biotope, Tikal National Park, and Sierra del Lacandón National Park. The multiple-use zone allows limited extractive activities by locals under a strict management plan. Finally, the buffer zone is a strip of land 15 km wide in the southern part of the reserve where all human activities are supposed to be sustainable and nature-friendly. As shown in Figure S5, this management scheme for conservation has had mixed results. The areas in yellow in the lower left corner show that the buffer zone of the reserve was heavily deforested between 1986 and 1993, indicating that the mere declaration of a reserve by the central government did little to stop the advancement of the agricultural frontier. The four national parks, designated at the highest official level of protection in Guatemala, tell very different stories in terms of deforestation. The Mirador–Rio Azul National Park in the northeast corner of the figure has remained practically intact, primarily due to its remoteness (*36*). No roads lead into the park and it can only be reached by helicopter or a three-day trip by mule. The opposite story is represented by the Sierra del Lacandón National Park in the southwest corner of the figure. This park has the highest deforestation rate of all the core zones in the Reserve (*36*). This park is bordered by a

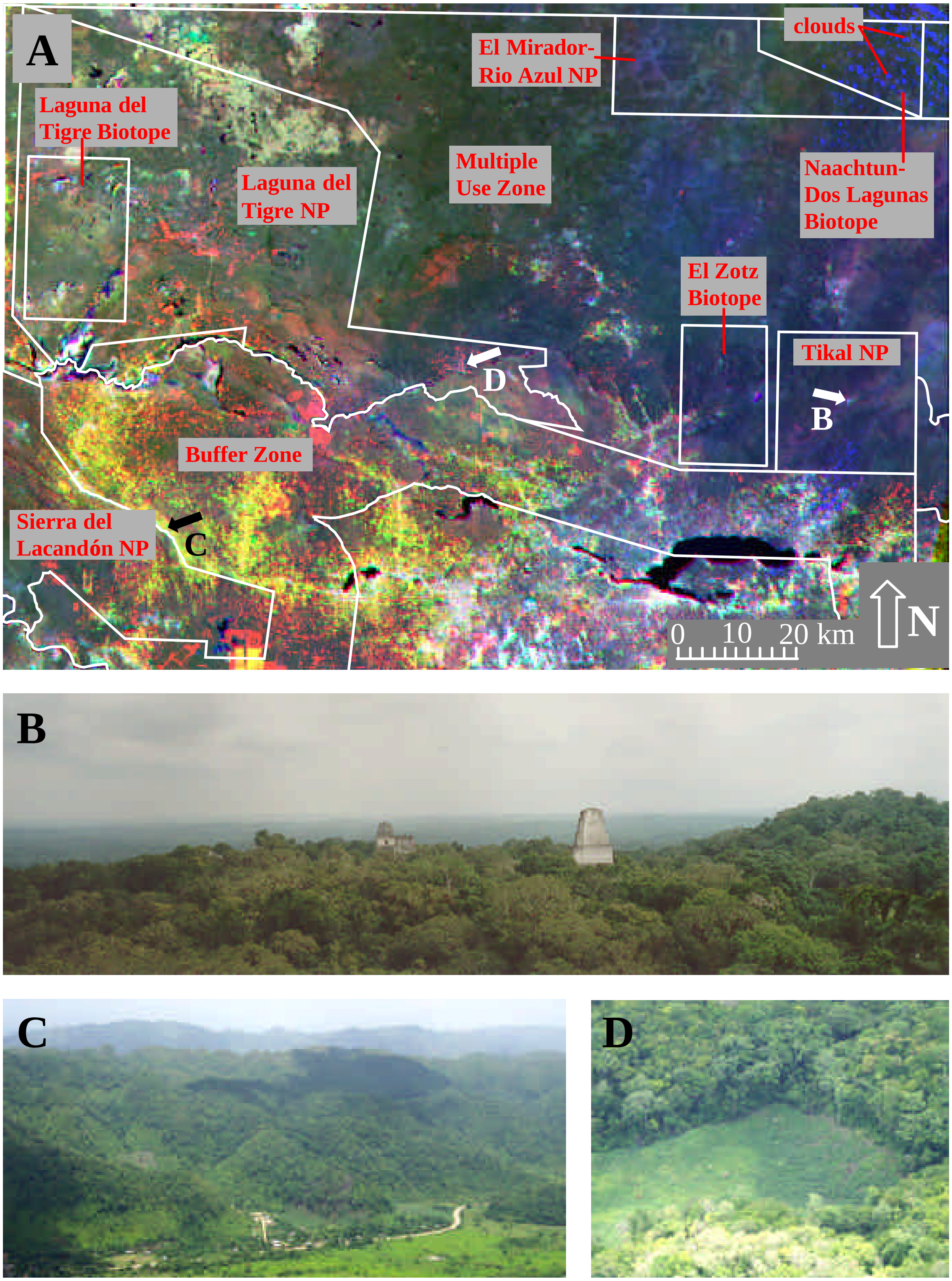

Figure S5. Guatemala

This figure shows land-cover change and the numerous zones of the Maya Biosphere Reserve in the Petén region of northern Guatemala. The composite shows a uniform, black color within Tikal National Park (B is a photograph taken of the park's forests from the top of a Mayan temple) indicative of stable forest cover. While many tourists visit the archeological sites of Tikal by road, El Mirador–Rio Azul National Park and Naachtun–Dos Laguna Biotope to the north are accessible only by foot or horse (clouds in the 1986 image produce the blue spots). Thus, the stable forests of these two areas are related to their isolation and not to institutional protection. The yellow and red areas of A reveal ongoing clearing in the south. This deforestation is concentrated in the Biosphere's buffer zone and within the Sierra del Lacandón National park, the Laguna del Tigre National Park, and the Laguna del Tigre Biotope. C shows recent clearing on hillsides along the northern boundary of Lacandón National Park. More isolated clearings (photographed from the air in D) were cut within the southeastern corner of Laguna del Tigre. Roads to the center of Laguna del Tigre were constructed to access oil fields within the park. The multi-temporal color composite is produced from Landsat images from 1986, 1993, and 2000: band 7 from a 1986 Thematic Mapper (TM) scene, band 5 from a 1993 Thematic Mapper (TM) scene, and band 5 from a 2000 Enhanced Thematic Mapper Plus (ETM+) scene. The area in the composite is approximately 163 km by 114 km and extends from 1,860,000 m to 1,974,400 m Northing and from 76,500 m to 239, 800 m Easting (UTM zone 15N/Clarke 1866 spheroid/NAD 27 datum). (Composite constructed in 2003 by Glen Green, Edwin Castellanos, and Victor Hugo Ramos; photograph B taken by Ronaldo Robles, 2002; photographs C and D taken by Victor Hugo Ramos, 27 January 2003.)

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major road that has served as the main channel for deforestation in the area. Photograph C illustrates the incursions that are taking place. The remaining two national parks deserve more attention, as they illustrate interesting institutional differences.

Tikal NP was created in 1955 and is the best known and most visited tourist destination in Guatemala. The park is one of few protected areas in Guatemala to receive the full support of the government. In 1979, Tikal was declared a UNESCO World Heritage Site for its exceptional cultural (archaeology) and biological (rain forest) characteristics (see photograph B in Figure S5). In 1990, it became one of the core zones of the Maya Biosphere Reserve. The park generates substantial revenue from entry fees paid by both international and local tourists. This money covers the entire budget for the park plus a surplus that goes to the Ministry of Culture and Sports and has made the preservation of this resource a high political priority. Directors of the park are held accountable by high-level government officials for the successful protection of this source of government revenue. It is one of the best-staffed protected areas in Guatemala, with permanent administrative and support staff, as well as paid guards. The park also hires local people to prevent forest fires and do other maintenance work. Although Tikal NP is in better shape than many other parks (*36*), it faces multiple threats, especially from bordering communities. Forest fires ignited to transform the land for agricultural and livestock purposes and illegal extraction of forest products are the main causes of forest thinning and loss that the area is experiencing (*37*). The dark grey color of the park in the composite in Figure S4 shows the areas of stable forest.

The Laguna del Tigre Conservation Unit consists of two parks, Laguna del Tigre Biotope and Laguna del Tigre NP, and is managed by two different conservation agencies. The Biotope was created in 1989 and became part of the Maya Biosphere Reserve when the latter was established in 1990, and the National Park was created as part of the Reserve. The area includes important Guatemalan wetlands, where periodic floods help create savannahs and transitional forests. It is the largest protected wetland area in Central America. The Laguna del Tigre Conservation Unit is included in the Ramsar Convention's list of Wetlands of International Importance. The park is also included in the Montreux Register of sites where adverse change in ecological character has occurred. The principal threats to the Conservation Unit are permanent human settlement and immigration, encroaching agriculture and livestock, oil prospecting and drilling, construction of roads and other infrastructures, and lawlessness (inability of officials to control intentional setting of forest fires, drug trafficking and plantations, illegal transients on their way to Mexico, and armed groups ready to contest any action from authorities). Land speculation inside and outside the Conservation Unit, fueled by cattle ranchers, corrupt politicians, and other officials, push illegal settlers deeper into the reserve, where they clear tree cover to establish new agricultural plots and homesteads. Numerous red patches within the Conservation Unit in A of Figure S5 reveal recent forest clearing.

Oversight in the area has been weak. The Conservation Unit has hired a small and underpaid group of park rangers who are unable to enforce the mandates assigned to them: (i) prevent establishment of human settlements, (ii) control illegal harvesting of timber, and (iii) sanction those who set forest fires or extract flora and fauna. It has not been unusual for people accused of violating conservation laws to threaten park officials to the point where the

Table S1. Summary of ownership regimes, boundaries of forested lands, monitoring and enforcement practices, and stability in forested areas in regions depicted in Figures S1–S5. Both stable and unstable forests exist under each type of ownership; a key to forest stability is the presence of legitimate boundaries and the monitoring and enforcement of rules of use.

Location	Type of ownership	Establishment of boundary	Boundary monitoring and enforcement	Stability of forested area (*39*)
		Madagascar		
Sacred Forests	Common property	Antandroy religious custom	Informal social sanctions	Stable
Berenty Reserve	Private property	Registration of land title	Private owner	Stable
Surrounding agricultural land	Mixture of private and communal property	Registration of land title	Private or communal owners	Deforested for agriculture
		Uganda		
Gazetted forest reserves	Government property	Buganda Treaty initially confirmed existing tenure, reserve boundaries regularly updated with local people	Boundaries well marked, enforced by government officials backed by informal local enforcement	Stable
Surrounding agricultural land	Private property	Registration of *mailo* land title and evolving *bibanja* tenant rights	Private owners and their tenants	Deforested for agriculture
		Brazil		
Vale do Anari	Private with restricted uses on 50%	Government agency – laid out in rectangular grid	Private owners with little oversight	Some settlers have deforested more than allowed
Machadinho d'Oeste	Separate private land and state-owned forest reserves	Government agency – laid out in grid based on topography	State reserves monitored intensely by rubber tappers, who have use rights	State forest reserves are stable
		Nepal		
Royal Chitwan National Park	Government property	National government	Heavily policed	Stable
Park Buffer Zone Forests	Government property – co-managed by user group	National government	Local user groups enforce boundaries	Regrowing
Community forests in Chitwan valley	Common property	National government turned forest over to Forest User Group	Weak enforcement	Deforesting
Sugabhanjyang	Government property	National government	Guard station located relatively near forest	Relatively stable
Latauli	Government property	National government	Weak enforcement by government guards	Substantial deforestation
Dev Ghat pilgrimage site	Government property	Religious custom	Informal social customs plus litigation to prevent conversion	Stable
		Guatemala		
Tikal National Park	Government property	National government plus UNESCO as World Heritage Site	Large paid staff and armed guards	Relatively stable
Laguna del Tigre National Park	Government property	National government plus UNESCO as World Heritage Site	Small staff and unarmed guards	Substantial deforestation

latter are afraid to enforce the law. ParksWatch calculates that the budget allocated for the protection of Laguna del Tigre is the lowest per hectare of all national parks in the Maya Biosphere Reserve (*38*).

The data compiled in this supplement and summarized in Table S1 challenge the notion held by many policy analysts and scientists that simple solutions exist for the problems of the commons. The analysis of remotely sensed images combined with extensive fieldwork provides data to examine the stability of forests over time. We have shown that all broad forms of ownership have led, in some locations, to highly stable forests while the same form of ownership has led to deforestation in other locations. Establishing a favored form of ownership is not sufficient by itself to counteract incentives to overharvest valuable forested land. Substantial efforts have to be devoted to creating effective institutions that deal with conflict and induce rule compliance before it is possible to begin to address the other requirements of sustainable use: obtaining trustworthy information about the resource and its users, providing appropriate physical infrastructure, and encouraging adaptation and change.

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References and Notes

1. Dr. Glen M. Green of the Center for the Study of Institutions, Population, and Environmental Change (CIPEC) at Indiana University has supervised the preparation of the multi-temporal color composites presented in Figures S1–S5, using the same procedures for all composites so they can be easily interpreted. The description of Figure S1 is based on Green's own research in Madagascar. We are deeply appreciative of his unstinting efforts to bring this group of figures together to highlight the diversity of ownership forms associated with long-term, stable boundaries of forests as contrasted to major incursions of deforestation.

2. The multi-temporal color composites were constructed using the red or mid-infrared wavelength bands from each image. In the composites, brightness of the earliest image was set to the color blue, brightness of the middle image was set to green, and brightness of the most recent image was set to red. Constructed in this way, the resulting colors of the composite can be used to detect land-cover change between the three dates. In these multi-temporal products, land cover that does not change appreciably between the three dates appears black, white, or a shade of gray, depending on its inherent brightness at red wavelengths (0.6 to 0.7 μm) for Madagascar, Uganda, and Nepal or mid-infrared wavelengths for Brazil and Guatemala (1.55 to 1.75 μm and 2.08 to 2.35 μm, respectively). At these wavelengths, forests generally appear dark, while savannah, cleared land, cities, roads, and riverbank sands generally appear bright. Thus, stable forest is depicted as black or dark gray in the multi-temporal composites, while unchanging non-forested land is generally bright gray or white.

In contrast, areas that experience land-cover *change* between the three dates, exhibit differences in image brightness across the three dates, imparting color to the multi-temporal composite. Thus, areas that experience land-cover change can be identified in the figures by their colors. The color gives the particular sequence of those changes. For example, if forested land was stable between the earliest and middle dates and was subsequently cleared before the last date, it results in a red color in the multi-temporal color composite. Forests that were cut between the earliest and middle dates and did not regenerate by the last date are depicted as yellow. Areas that were forest in the earliest date, cleared before the middle date, and regrew prior to the last date appear green. If cleared areas regrew before the middle date and remained in forest, they appear blue. These simple color rules may be complicated by the fact that processes other than land-cover change, such as seasonal changes and year-to-year climatic variability, also can alter the reflectance of land cover and impart color to the multi-temporal composite. These climatic differences generally affect an entire region and impart an overall color tone to the composite, which can easily be ignored. In mountainous regions, such as Nepal, seasonal or yearly differences may impart bright color to mountain ridges. Climatic effects generally conform to broad, ecological gradients and vary continuously, such as a moisture gradient across topography, while human-induced changes tend to be locally

patchy and have sharp edges. These composite products are more fully explained in Sussman *et al.* (*4*).

3. The figures in this supplement have been produced as part of an ongoing research effort to understand how a variety of biophysical and institutional factors affect land use and land change, particularly related to forested lands, in tropical dry, tropical wet, and mid-latitude deciduous forests. We present this set of figures to illustrate a major point of the article rather than as a full sample of the variety of institutional rules we have found within these broad types of ownership regimes. We wish to illustrate that the relationship between institutions and sustainable resource use is far more complex than presented in the many policy prescriptions. Too frequently simple prescriptions are recommended, such as the creation of national parks or the privatization of forested land, rather than recognizing the complex set of rules needed to meet the multiple requirements laid out in the article. For more details about ongoing studies of the relationship of biophysical and institutional factors of forests, see the CIPEC webpage (http://www.cipec.org).

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41. The image processing and many drafts of paragraphs reported in this supplement were contributed by colleagues associated with the Center for the Study of Institutions, Population, and Environmental Change (CIPEC) at Indiana University with the support of the National Science Foundation (SBR 9521918). The technical input of Glen Green, Sean Sweeney, Nathan Vogt, Harini Nagendra, Charles Schweik (University of Massachusetts), Mateus Batistella (Empresa Brasileira de Pesquisa Agropecuária, Brazil), Edwin Castellanos (Universidad del Valle de Guatemala), Victor Hugo Ramos (Consejo Nacional de Areas Protegidas de Guatemala), and Ronaldo Robles (United Nations Development Fund, Guatemala), and editing inputs of Joanna Broderick, Célia Futemma (University of Sao Paulo, Brazil), Lilian Marquez-Barrientos, and Ashok Regmi are gratefully acknowledged.