Demographic Change, Land Use, and Conservation in and Around Calakmul Biosphere Reserve, Mexico

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November 2003

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Abstract

Covering about 723,000 hectares, Calakmul Biosphere Reserve comprises the largest tract of protected tropical forest in Mexico. Despite its geographic isolation, the reserve and its immediate surroundings experienced considerable population growth during the 1980s and 1990s, placing increasing pressure on resources in the region in general and on the biosphere reserve in particular. The following study examines data from 1980, 1990, and 2000 censuses of population and housing in Mexico to document geographic patterns of demographic change in the region, to identify the main causes of recent population change over time, and to explore relationships between human population and land use patterns in this part of Mexico at the end of the 20th century. Results of the study indicate that rapid population growth continued in the region through the 1990s, affecting most localities in or near Calakmul, in large part due to continued migration (likely) from other parts of Mexico. Census data reveal the presence of economic activities in or near Calakmul incompatible with conservation, and satellite imagery indicates agriculture in several parts of the biosphere, including the nuclear zone. Statistical analysis of the former indicates a significant relationship between population and agriculture, while an evaluation of agricultural suitability in and around Calakmul indicates mixed though often limited potential. As a result, continued population growth in this area will expand the agricultural footprint, likely straining Calakmul management to maintain the conservation function of the biosphere reserve.

Introduction

Calakmul Biosphere Reserve encompasses slightly more than 723,000 ha in the southern part of Mexico's Yucatan Peninsula. Comprising the largest protected tract of tropical forest remaining in Mexico, Calakmul is one component of the *Maya Forest*, a large expanse of tropical forest extending over several states in Mexico, western Belize, and northern Guatemala (Figure 1). The reserve consists of a tropical humid forest ecosystem that includes evergreen tropical humid forest, semi-deciduous forest with temporally flooded forest, thorn forest, and tropical deciduous forest (UNESCO 2003). This ecosystem contains considerable biodiversity, including about 250 tree species, 500 butterfly species, 30 amphibian species, 100 reptile species, 280 bird species, and 100 mammal species (Galinda-Leal 1996; see also Instituto Nacional de Ecología [INE] 2000). Calakmul also is home to a rich collection of (predominantly) Classic Maya archaeological sites, not only increasing the importance of conserving this part of southern Mexico but also providing evidence of substantial prehistoric human occupation in an area that in the late 20th century would experience considerable settlement once again.

Following an historic period of relative seclusion and obscurity, in the 1970s human population began to grow in and around what would become Calakmul Biosphere Reserve. In large part this is due to programs promoted by the Mexican government to foster development in this region, resulting in population growth in the vicinity of Calakmul. This surge in human population began attracting attention from conservationists who were concerned that the increase

in human presence would negatively affect biodiversity in the reserve (Ericson 1996; Ericson et al. 1999; Stedman-Edwards 1999; INE 2000). Examinations of data from the 1990 census of population and housing and the 1995 nation-wide population count showed that population growth had continued at a rapid rate for selected communities in and near the reserve (Ericson et al. 1999). However, those studies did not explore connections between demographic change and impacts on Calakmul. There remains a need to assess how population growth possibly led to expanding agricultural activities, resource extraction, and other shifts in land use that have important implications for the conservation integrity of this key protected area.

Using selected community-level data from the 2000 census of population and housing in Mexico, this study seeks to provide an increased understanding recent human demography in and around Calakmul Biosphere Reserve. In the process, it explores evidence that the influx of humans in the area has introduced certain impacts on the biosphere reserve. The study begins by examining evidence for population growth in the Calakmul region over the past two decades, providing an explicit geographic context for the demographic analysis and examining possible causes of population change. The study then examines both statistical and remotely sensed data to help understand better the relationship between population change in the region and possible impacts in and around the reserve. Statistical evaluations of demographic and both land use and economic data help illuminate possible relationships between population change and impacts on Calakmul. It closes by exploring implications for further population growth in and around the reserve, and development and management options to explore in attempting to conserve the remaining biodiversity in this irreplaceable portion of southern Mexico.

Competing Concerns: Biodiversity Conservation and Human Population

Biodiversity, the diversity of life on earth, currently is declining at rates rarely seen previously in the history of the world—with extinction by some estimates reaching 1,000 species annually (Tuxill and Bright 1998). At the same time, the number of people on earth has grown to unprecedented levels, with global population reaching 6.3 billion in late 2003 (U.S. Bureau of the Census 2003). The precipitous decline of biodiversity in a period of enormous human numbers led many to equate a large human population with biodiversity decline (Cincotta et al. 2000)—with the loss of vast areas of natural habitat and the rapid extraction of resources, helping to explain the widespread loss of plants and animals. With humans living throughout most of the terrestrial world, conservationists have sought varying solutions to protect remaining biodiversity. One possible solution proposed by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) was the *biosphere reserve*, a protected area that incorporates biodiversity conservation, economic development, and research and monitoring associated with the first two functions (UNESCO 2002). Calakmul was designated as a protected area by the Mexican government in 1989 and was named a biosphere reserve in 1993 (Stedman-Edwards 1999).

The biosphere reserve concept is an attempt to conserve biodiversity in areas that also contain people. Central to the biosphere concept is the division of each reserve into a series of three types of *zones*: core areas secured for biodiversity protection in minimally disturbed ecosystems; buffer zones, generally surrounding the core and allowing human activities compatible with

biodiversity conservation; and transition zones, containing human settlements, agricultural fields, and other activities in which residents, government agencies, researchers, and others attempt to develop resources sustainably (UNESCO 2002).

Although historically a remote, sparsely populated area until the 1970s, the region of southern Mexico containing Calakmul contained large numbers of people more than 1,000 years ago. With evidence of habitation and public building construction as early as 300 BC, the prehistoric Maya capital of Calakmul came to occupy 70 km^2 and contain 50,000 people at its apex during a period of occupation called Late Classic (AD 500-775) (Folan 1992; Folan et al. 1995; Folan et al. 2001). The population of Calakmul survived through intensive agriculture (primarily maize). Classic period residents addressed the key limiting factor of water addressed through an elaborate hydraulic system based on water catchments and canals. A combination of factors, including political, economic, and environmental (a prolonged drought), likely contributed to the demise of Calakmul during the ninth century AD. Human habitation in the region would not even begin to approach prehistoric levels until the late 20th century.

Available data from the 1980, 1990, and 2000 censuses of population and housing reveal a pattern of considerable population growth over the past two decades in and near Calakmul Biosphere Reserve (Instituto Nacional de Estadística, Geografía, e Informática [INEGI] 1982, 1992, 2002). These trends emerge both in the changing number of separate communities at various distances from the reserve, and in changing population (Table 1). In 1980, the census of population and housing recorded only 14 communities within 20 km of the reserve. By 1990, the total number of communities within 20 km of the reserve had increased to 58, and by 2000 to 203—the totals varying with placement within the reserve or within one of two 10-km bands around the reserve. Population statistics for these same years and geographic areas support the trends observed among communities. In 1980, slightly more than 3,300 persons lived within 20 km of Calakmul, the total increasing to more than 10,700 in 1990 and nearly 26,700 in 2000 (see Table 1). As with the number of communities, the growth in population between years was remarkably rapid for the three geographic regions in and around Calakmul, in one case averaging more than 30 percent annually. Much of the population added in 1990 and (especially) 2000 resided in small settlements, as indicated by the decline in the number of persons per community for some of the groups of communities near the reserve.

One can develop an appreciation of the distribution of population across space through considering population densities in áreas geoestadísticas básicas (AGEBs). AGEBs represent the smallest geographic units (apart from communities) used by the Mexican 1990 and 2000 censuses of population and housing, as well as the 1991 census of agriculture—providing a more precise picture of spatial distributions than is possible with larger geographic units. The distribution of population density in 1990 indicates generally sparse human habitation across AGEBs (see INEGI 1998b). This is consistent with evidence of people living in small communities scattered along roads throughout the region and likely equates with geographic localization of human impacts as well. By 2000, AGEB population and population densities had increased throughout much of southern Mexico, including the area in and around Calakmul Biosphere Reserve. Despite the population growth mentioned in the preceding paragraph none of the AGEBs within 20 km of the reserve contained population densities in excess of 20

persons/km^2 (Figure 2).[1] An examination of population change between 1990 and 2000 shows that the majority experienced rapid population growth in excess of 4 percent annually, although several AGEBs lying at least partially inside the reserve boundaries lost population during this decade (Figure 3). Population increase particularly occurred along the eastern edge of Calakmul and across the constricted area that effectively defines a northern and southern component of the reserve.

What demographic mechanisms caused the rapid population growth during the 1990s in the vicinity of Calakmul? Because all data from the 2000 census of Mexico are not yet available, we have to piece clues together to arrive at a likely answer. During the 1980s and early 1990s, the general picture offered was one of high in-migration and high fertility (Ericson et al. 1999; Stedman-Edwards 1999). The 1990 census eventually published information on mobility as well as fertility at the level of AGEBs (INEGI 1998b). Examining those data provides evidence of both lifetime migration and short-term migration. The former emerges in the form of people living in a particular area who were born elsewhere. The resulting analysis presents a striking picture of long-term in-migration: more than half of the AGEBs within 10 km of the reserve contain populations composed in excess of 50 percent in-migrants. Geographic concentrations of these lifetime migrants tend to occur along the eastern edge of the reserve, and in a band running east-west across its center. Evidence for short-term migration appears as individuals living in a particular area who lived elsewhere five years earlier. Nineteen of the 53 AGEBs within 10 km of the reserve contained populations composed in excess of 20 percent in-migrants over the five years preceding the census.

Comparable data on mobility from the 2000 census are not yet available. At present, the best we can do is examine data for Calakmul Municipio, an administrative area defined in 1997. Data for the municipio indicate that nearly 49 percent of the total population of 23,115 living there in 2000 was born elsewhere—in another municipio, state, or country (INEGI 2001). Of the nearly 20,000 residents aged 5 years or more in 2000, about 9.8 percent lived elsewhere in 1995, providing a sense of the continuing importance of recent migration—suggesting that both processes continued through the 1990s at least at the municipio level.

Decennial censuses also provide information on fertility. Available data indicate that in 38 of the 53 AGEBs within 10 km of Calakmul Biosphere Reserve, average children per mother exceeded the replacement rate of 2.1, with 25 AGEBs showing averages in excess of 3.0 children per mother**.** Once again, the geographic distribution of highest fertility levels tends to emphasize the eastern edge of the reserve and a band across the constricted area separating the northern and southern portions. Fertility data from the 2000 census are only available at the level of Calakmul Municipio. The average number of live births to mothers aged 12 years and beyond is 3.4, over a range of 0 to 13 (or more) live births (INEGI 2001). Although this is not extremely high for many developing countries, fertility in Mexico has been declining for the past two decades. The

[1] INEGI had not released AGEB data from the 2000 census of population and housing when this paper was written. To approximate these data, AGEB boundaries from the 1990 census were used to assign 2000 populations based on community-specific population data (INEGI 2002a). Although some errors are possible through incorrect assignments of populations because of errors in locations of communities or AGEB boundaries, the results of this process are likely quite accurate.

results of our analysis indicate that relatively high fertility has persisted in the vicinity of the reserve despite national trends.

Population in both individual communities and AGEBs grew considerably in and around Calakmul Biosphere Reserve during the 1990s. From available evidence, it appears that the demographic increase observed in the vicinity of the reserve between 1990 and 2000 is a result primarily of continued in-migration, coupled with reasonably high fertility characteristic of rural, largely agrarian populations. The persisting migration likely represents a continuation of the pattern initiated in the 1970s and 1980s through a combination of government programs, infrastructure development, and a social process where personal and familial establishes a connection with a possible migration destination. When they are released, the 2000 census data will confirm the causes of population change, as well as provide evidence to determine if the main mechanisms underlying demographic growth in the Calakmul area show any evidence of slowing down. These data also will provide a basis for designing strategies to stem the growth of population, in some AGEBs or communities focusing on family planning education and in others emphasizing migration and the socioeconomic conditions leading to relocation.

Implications of Human Population Growth in and Near the Calakmul Biosphere Reserve

Conventional wisdom has it that human population generally is incompatible with the conservation of biodiversity (Cincotta et al. 2000; McKee 2003). Indeed, others have made the case for population growth in the Calakmul region being a concern for conservation within the reserve (Ericson et al. 1999; INE 2000; Stedman-Edwards 1999). However, when people are not present in such high densities that their mere presence compromises habitat—such as urban settings—the *activities* of humans are as important as their presence for determining impacts (Gorenflo 2002, 2003). Let us turn our attention to indications of possible impacts from human habitation in the Calakmul region, to examine the relationship between population and environmental impacts.

Focusing on the particularly rich AGEB-level data from the 1990 census of population and housing and the 1991 census of agriculture and livestock enables evaluations establishing geographic relationships between people and activities, and potential impacts to the biosphere reserve. In particular, one can examine population with respect to three different variables indicating economic activity in each AGEB: percentage of land use for agriculture, cubic meters of timber harvested, and percent of employed persons engaged in selected extractive activities (*Sector 1* of the economy equating with agriculture and forestry; INEGI 1998a, 1998b). Visual inspections provide an informal means of associating population and impacts—for example the relationship between population and level of agricultural activity (Figure 4)—that seem to indicate correlation between the distribution of people and activities incompatible with conservation.

With the data available for 1990-91, we examined the statistical relationship between population and certain extractive activities using a simple functional relationship of the form

$$a = f(P),$$

or the activity occurring at a particular locality is determined by the population at that same locality. One can evaluate this function through a simple linear regression, beginning with agriculture. Plotting hectares of land cultivated in 1991 by population in 1990 for those AGEBs lying 10 km or closer to Calakmul indicates a fairly strong linear relationship between these variables (Figure 5). Regressing cultivated area on population produces a highly significant relationship (.01) with an r^2 of 0.4. Such a close relationship should not be surprising in an area where many people rely on subsistence or small-scale agriculture, though measuring association between these variables provides more certain evidence as well as a basis for concern with growing population.

We considered a second possible relationship between population and timber harvest, another human activity of great concern in the Calakmul region. Using data reported at the AGEB level once again (for AGEBs lying at least in part within 10 km of Calakmul), the linear relationship between these two variables is much weaker than the agricultural case (Figure 6). Regression results support these observations, producing a significant (.05) r^2 of only 0.08. Potential complications, including underreporting timber harvests and the use of certain tracts of communal land (*ejidos*) where people do not live for timber harvest, quite likely weaken the utility of the data and any relationship that one can measure between these key variables (see INE 2000; Stedman-Edwards 1999). Moreover, much of the more valuable timber in the Calakmul region was harvested during the second half of the 20th century. Modern harvest patterns focus more on locating remaining resources than on the presence of potential harvesters.

Examining the relationship between population and land use in 2000 requires a different approach due to the availability of different data than those organized by AGEB. Geographic information system coverages based on interpreted satellite imagery reveals the presence of agricultural activities in and near the biosphere reserve in 2000 (Universidad Nacional Autónoma de México [UNAM] n.d.; Figure 7). Much of this development appears outside the biosphere itself, in areas experiencing rapid population growth (see Figure 3). There is a close correspondence of agricultural activities with population, both along the eastern part of the reserve (southern portion) and across the constricted middle of the reserve.

Subsistence agriculture is the main economic activity throughout much of the Calakmul region. Yet the region is not particularly well suited for agriculture. Crop yields are low, labor is difficult, and there is a need to shift crop production as the soil becomes exhausted. An assessment of the agricultural suitability for the area within the biosphere indicates considerable variability, though mean suitability for subsistence production of cereals (including maize) falls in the moderate range (Fischer et al. 2002; Figure 8).

Available data enable us to evaluate the association between human population, population growth, and certain activities associated with habitat loss in and around Calakmul Biosphere Reserve—notably agriculture and timber harvest. However, we cannot examine the relationship between population and other activities that represent threats to the reserve, notably hunting (see INE 2000). Nevertheless, the growth of population in and near Calakmul, many of them relying largely on subsistence agriculture supplemented by whatever activity is available (Stedman-Edwards 1999), suggests that these other activities indeed do place pressure on the reserve.

Conclusions

Many researchers interested in biodiversity conservation recognize the importance of human population in their inquiries. Although sheer numbers of people may signify habitat loss that destroys biodiversity, in other cases the numbers of people and their densities are much less obvious in their potential impacts on biodiversity. In these more subtle situations, one must make efforts not only to understand the amount and causes of population change, but also the potential impacts of population in terms of affects on biodiversity. Depending on the activities pursued, relatively few people can generate large impacts while a larger number of people may produce fewer negative consequences for conservation. It is important to understand such issues before offering solutions to problems that may not be as serious as thought, and missing solutions to problems that are more central to the biodiversity challenges at hand.

Despite being hampered by a lack of detailed data from the 2000 census of population and housing, the study presented above succeeded in reaching some useful conclusions about human demography, demographic change, and conservation in and around the Calakmul Biosphere Reserve. Earlier research had identified recent periods of population growth and suggested that such an increase in the human presence would have a deleterious effect on conservation. In this study we documented precisely the localities and amounts of population change in and around Calakmul as well as the likely demographic mechanisms underlying this change. We also established a connection between population and agricultural activity, a major concern in an area whose ecosystem health rests on maintaining forest cover, providing a means of projecting additional land cultivated if population continues to grow. Finally, we showed the absence of a strong relationship between timber harvests and population in and around the reserve, results not surprising given that most commercially valuable trees were removed during the last half of the 20th century and remaining timber tends to exist in the absence of resident population.

The government of Mexico designated Calakmul as a protected area in the late 1980s, about the same time that it was promoting policies that would promote development in this historically isolated part of the country. What emerged were competing interests in conservation and development that the biosphere concept by design attempts to integrate. But the situation that has evolved in the Calakmul region since 1980 may make integration difficult. One inherent difficulty is the geographic design of the reserve, in particular the elongated layout placing both core areas close to the boundary and hence increasing potential impacts in these most important subsections for biodiversity conservation. As we have seen, population in the region continues to grow rapidly, both within the reserve and along much of its border, with peasant agriculturalists involved in subsistence cultivation still the main contributors to this growth. Because of the relationship between agriculture and population, an increase in the number of people means an increase in land cultivated. Because of the limited agricultural capacity of much of the region, larger areas will have to be cultivated, and cultivation moved frequently as soil fertility declines, exacerbating the need to expand the agricultural frontier. Biosphere management will be able to accommodate such pressure only to a point, before solutions are sought to the situation. It is only through long-term solutions that the integrity of Calakmul will survive, though effective strategies to reversing demographic growth in the area or developing viable alternatives to subsistence agriculture, remain to be identified.

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Table 1. Population in and Near Calakmul Biosphere Reserve

	Number of Communities			Avg. Annual Change (%)	
Geographic Area	**1980**	**1990**	**2000**	**1980-90**	**1990-2000**
Within Reserve	2	15	42	22.3	10.8
< 10 km of Reserve	7	30	85	15.7	11.0
10-20 km of Reserve	5	13	76	10.0	19.3
	Total Population			**Avg. Annual Change (%)**	
Geographic Area	**1980**	**1990**	**2000**	**1980-90**	**1990-2000**
Within Reserve	82	1,158	3,015	30.3	10.0
< 10 km of Reserve	2,104	6,413	11,419	11.8	5.9
10-20 km of Reserve	1,139	3,149	12,244	10.7	14.5
	Persons per Community			**Avg. Annual Change (%)**	
Geographic Area	**1980**	**1990**	**2000**	**1980-90**	**1990-2000**
Within Reserve	41.0	77.2	71.8	NA	NA
< 10 km of Reserve	300.6	213.8	134.3	NA	NA
10-20 km of Reserve	227.8	242.2	161.1	NA	NA

Data sources: INEGI 1982, 1991, 2002.

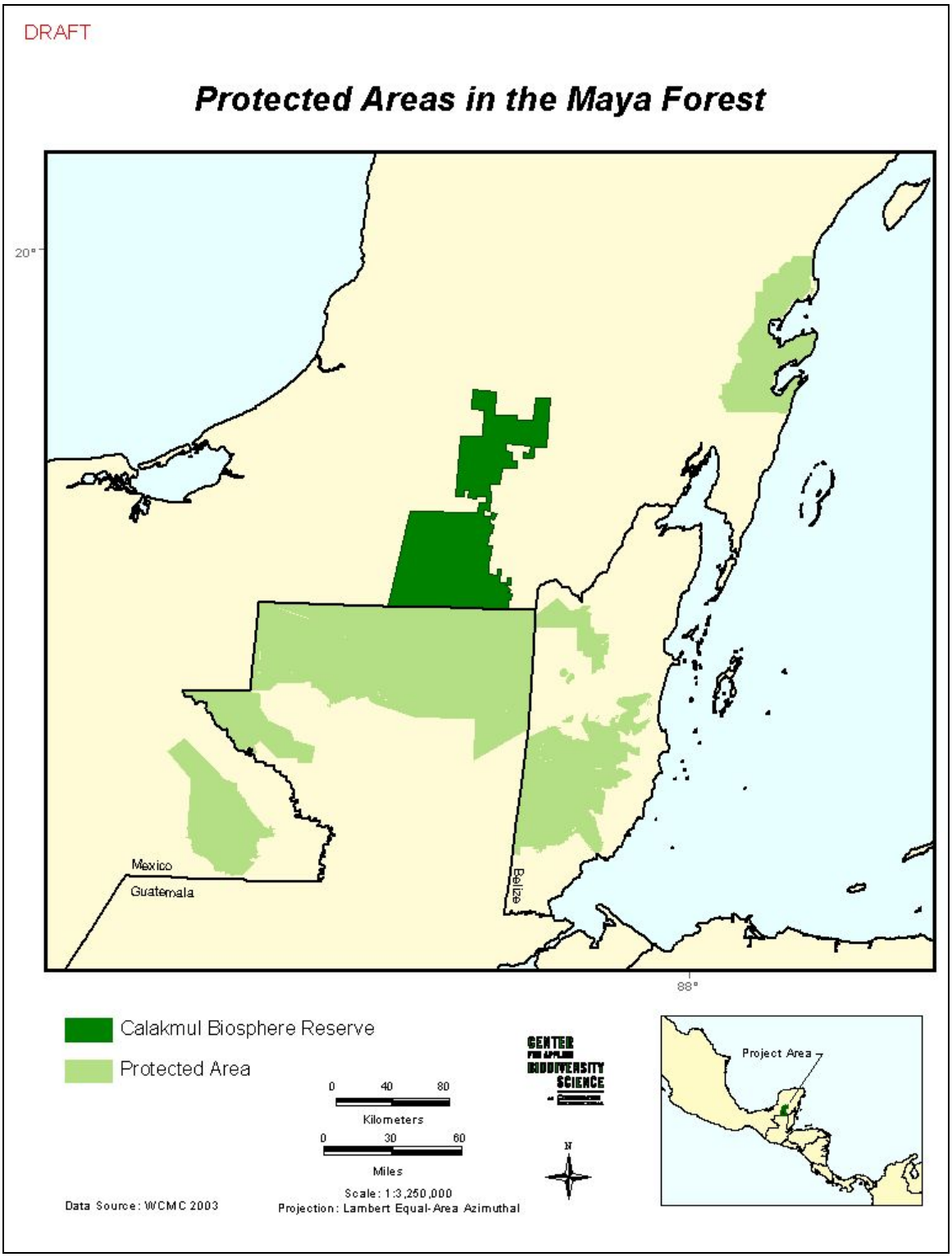

Figure 1. Protected Areas in the Maya Forest

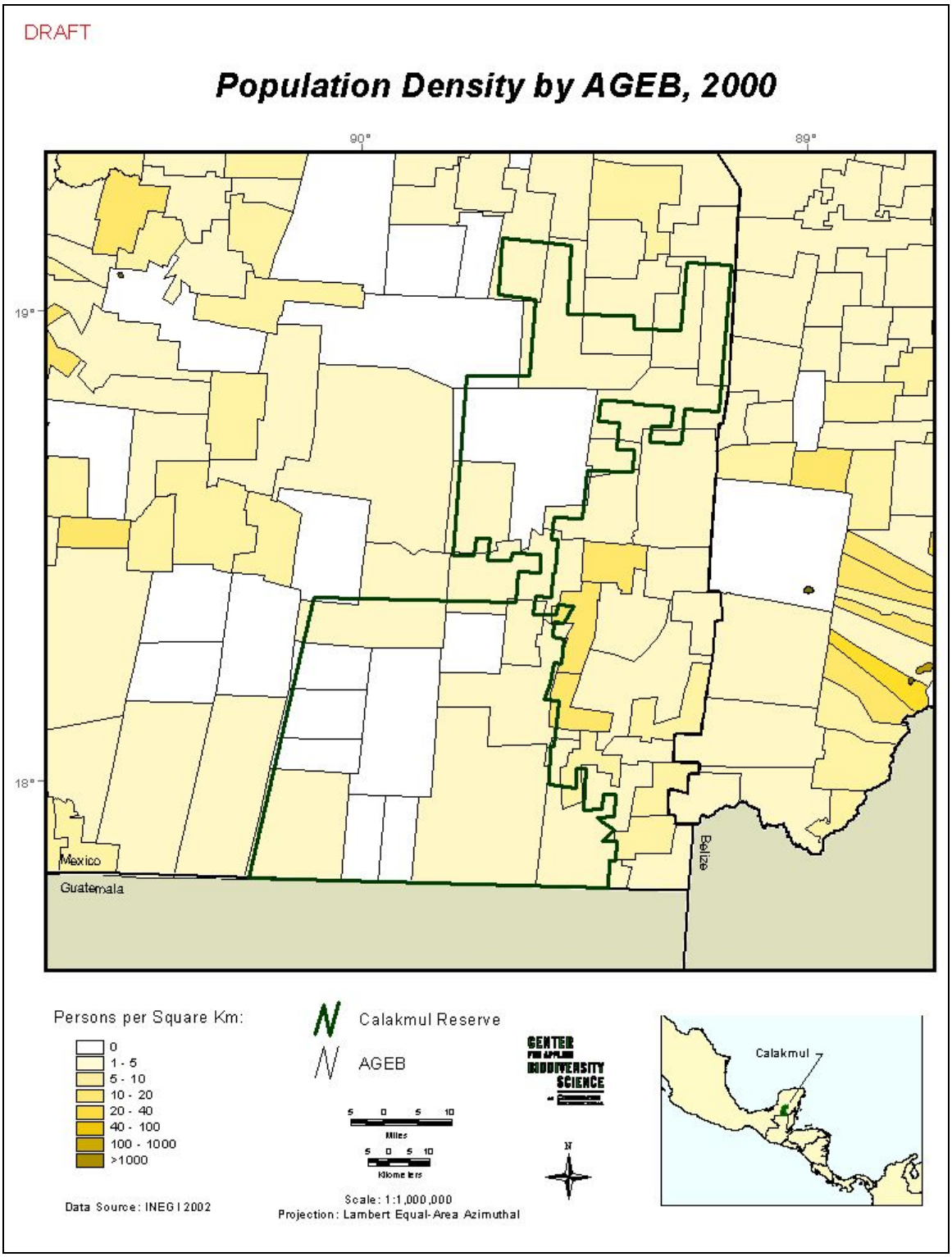

Figure 2. Population Density in and Around Calakmul Biosphere Reserve, by AGEB, 2000

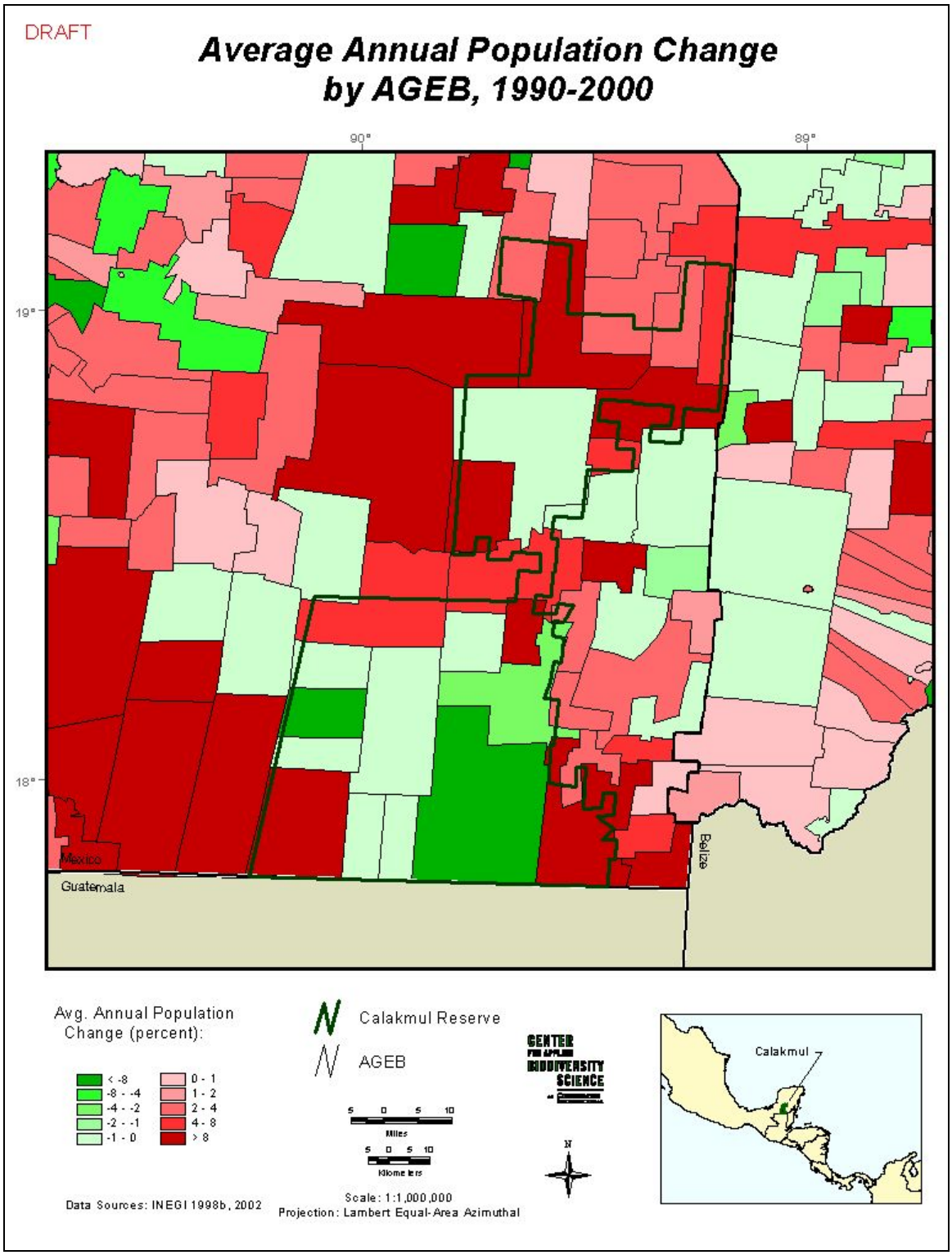

Figure 3. Average Annual Population Change Rate in and Around Calakmul Biosphere Reserve, by AGEB, 1990-2000

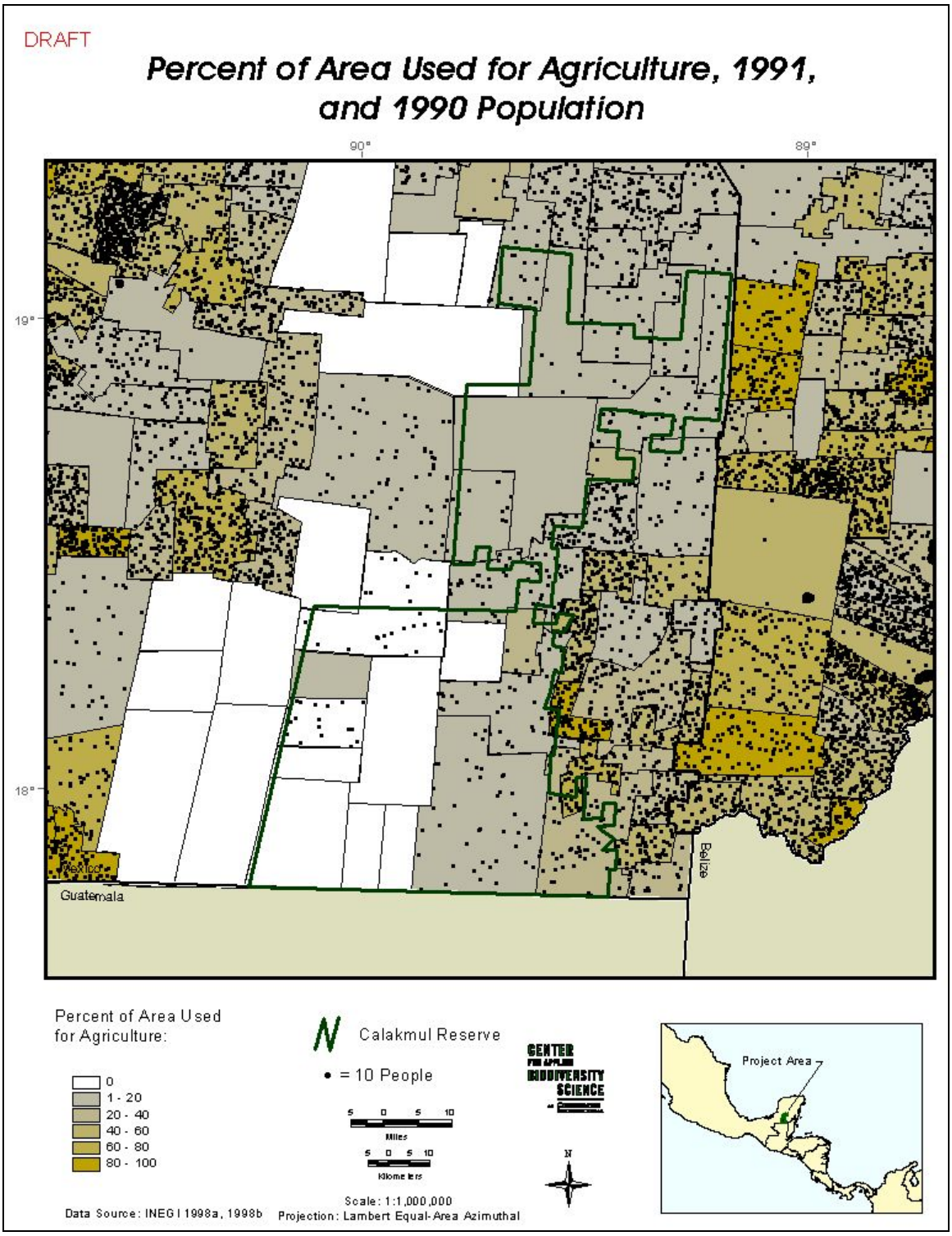

Figure 4. Population (1990) and Percent of AGEB Under Cultivation (1991), by AGEB

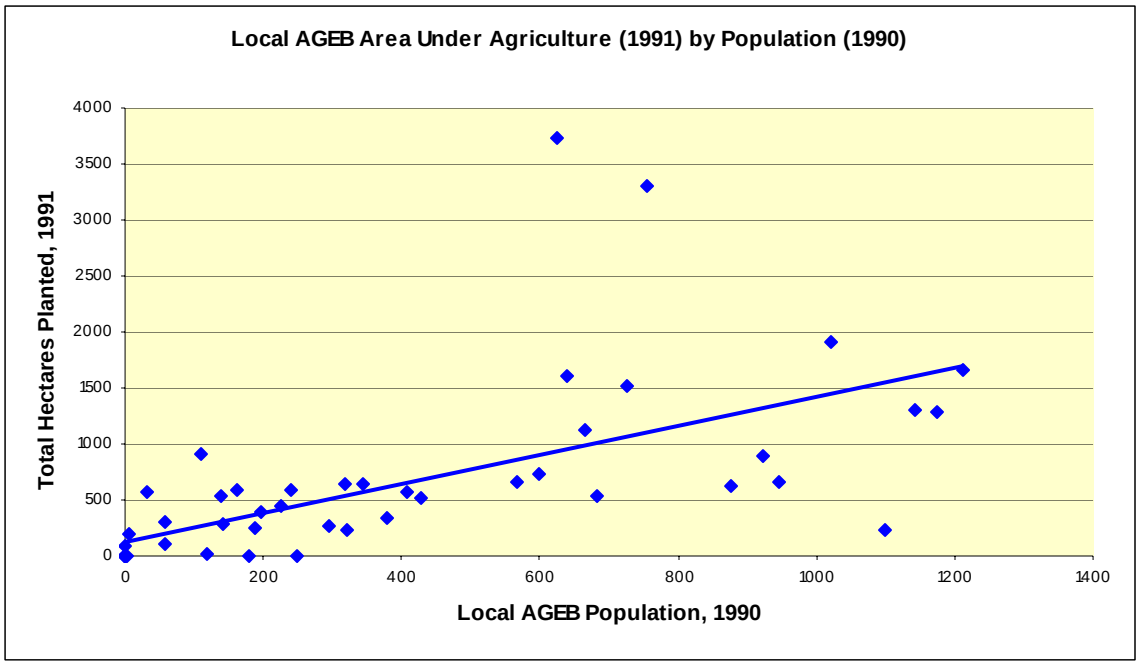

Figure 5. Graph of Population (1990) by Total Hectares Planted (1991) for AGEBs Within 10 km of Calakmul Biosphere Reserve

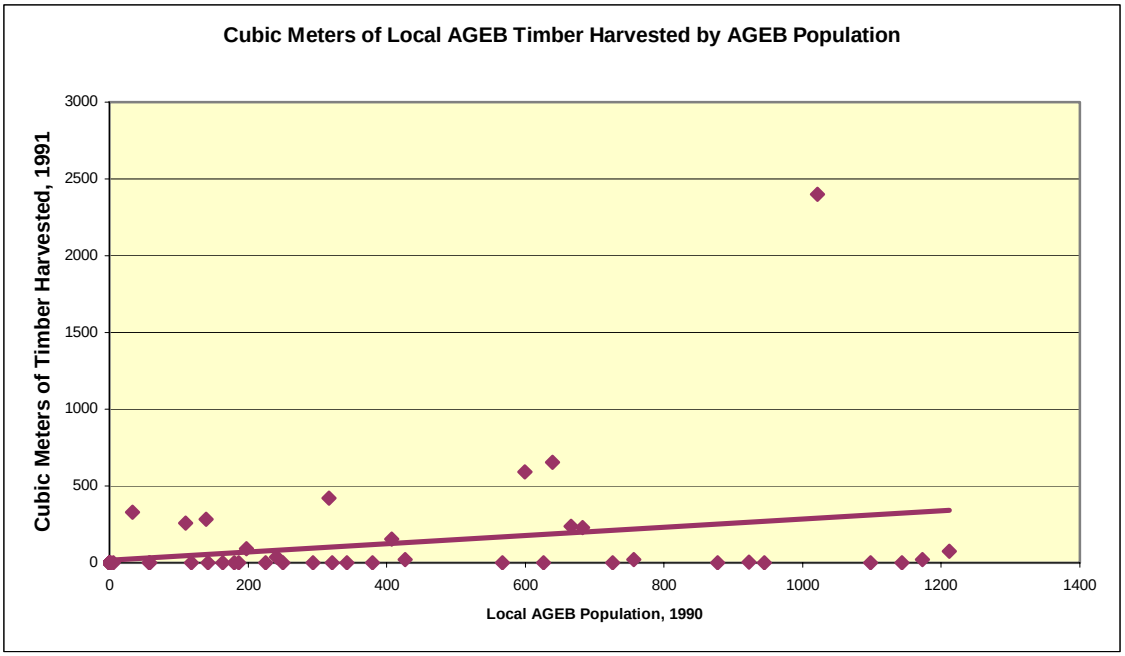

Figure 6. Graph of Population (1990) by Cubic Meters of Timber Harvested (1991) for AGEBs Within 10 km of Calakmul Biosphere Reserve

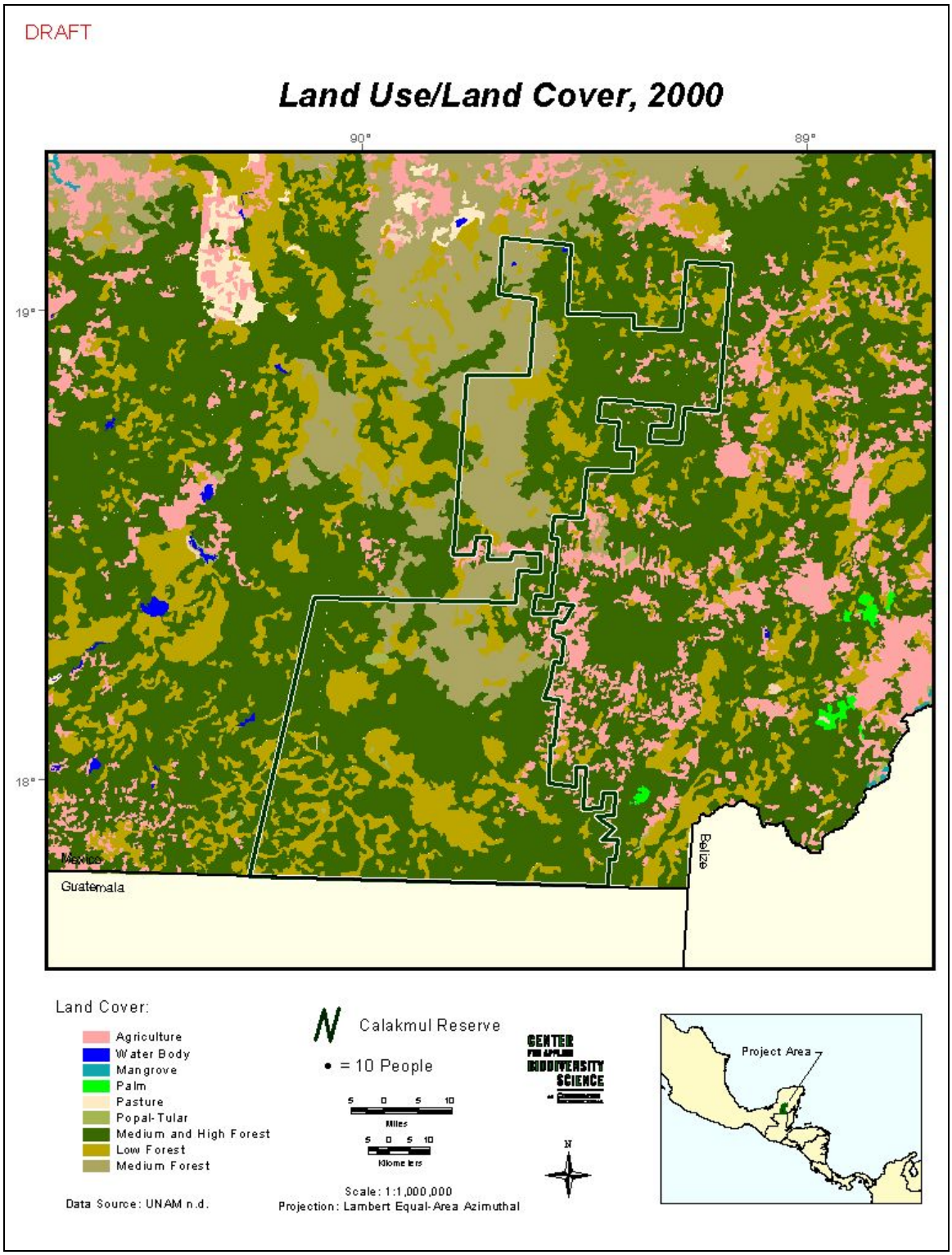

Figure 7. Land Use/Land Cover in the Vicinity of Calakmul Biosphere Reserve, 2000

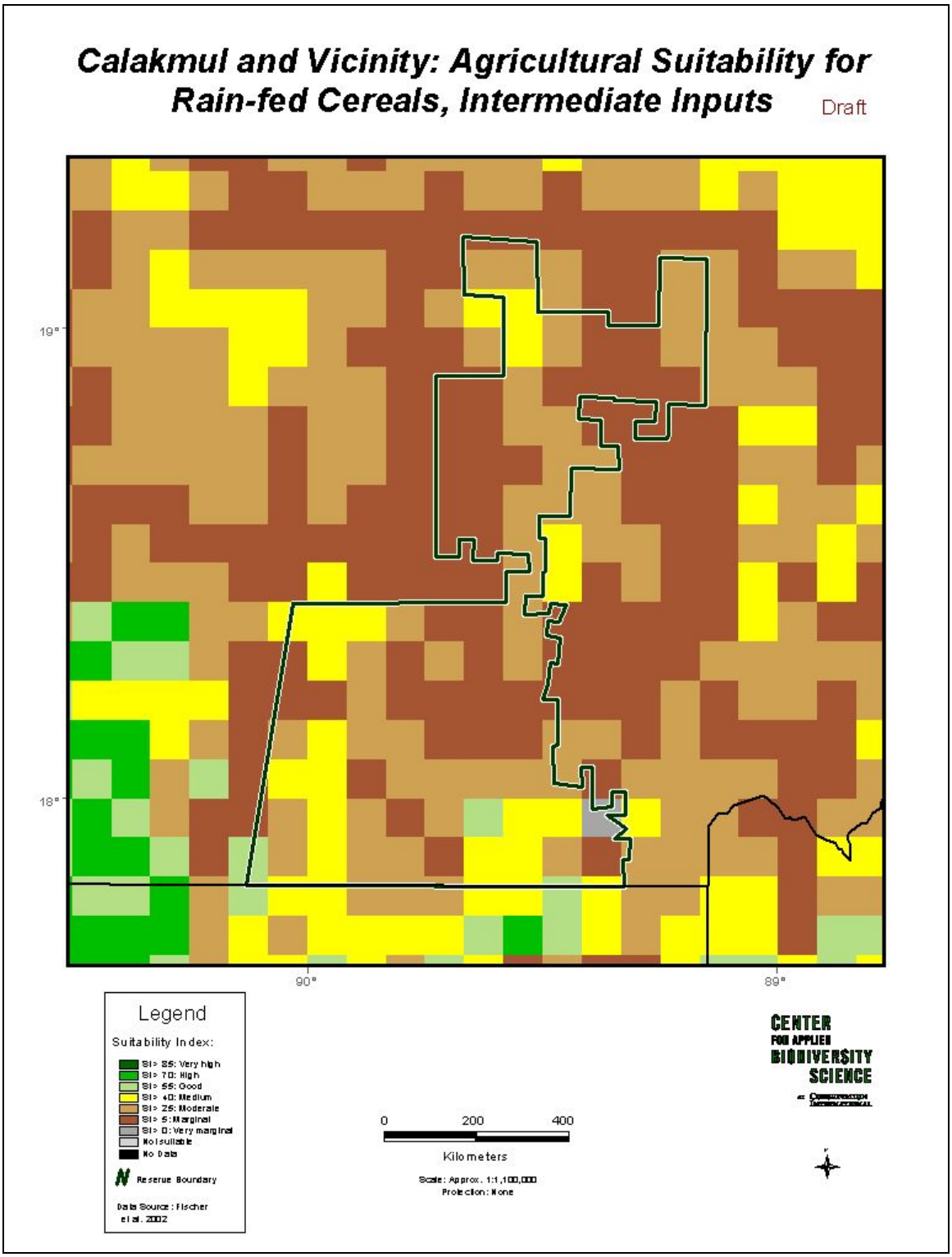

Figure 8. Agricultural Suitability for Subsistence Cereals in the Vicinity of Calakmul Biosphere Reserve