Chapter 20

Three Millennia in the Southern Yucatán Peninsula: Implications for Occupancy, Use, and Carrying Capacity

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INTRODUCTION

The southern Yucatán peninsular region lies within the upland terrain of southern Campeche and Quintana Roo, Mexico, and abuts northern Petén, Guatemala, and northwestern Belize (Figure 20.1). In regard to ancient Maya occupancy, it corresponds to the "central Maya lowlands," defined by Turner (1983:7-9; 1990a), and to the central hills and Petén karst plateau of the lowland Maya "adaptive" regions, defined by Dunning and Beach (2000:182).

The lands demarcated are environmentally similar and share a common human-environment history. They constitute the uplifted, karstic spine of the southern part of the peninsular shelf, rising as high as 300 m above the mean sea level between the Caribbean and Gulf Coast litorals. Well-drained slopelands, dominated by shallow rendzinas (molisols) and seasonal tropical forests, cover about 20 percent of the region (Figure...
20.2).1 Interspersed among them are seasonally inundated polies or bajos (karstic sinks), characterized by clay-rich vertisols and less deciduous forests of similar but smaller-sized tree species that occur on the slopes (Turner et al. 2001).

The ancient Maya entered these lands sometime before 3000 B.P. (ca. 1000 B.C.) and subsequently transformed them into the "beartland" of the Classic Period lowland civilization, as measured by the sheer volume of architecture, population, and land change, especially deforestation (Adams 1981; Dunning and Beach 2000; Turner 1990a), that is known to have occurred there. By 1000 B.P. (A.D. 950), however, the Maya civilization collapsed and the region depopulated by 90 percent or more (Turner 1990a; 1990b). The forest reverted, albeit altered in species composition, and the region remained a refuge until recently. By the middle of the twentieth century, the region witnessed significant logging of its hardwoods (Spanish cedar and mahogany), followed by extensive colonization from various parts of Mexico. Today, the southern Yucatán peninsular region finds itself struggling to strike a balance between the agricultural needs of re-emerging set-
elements (Figure 20.1) and the broader aims of preserving and conserving the region as biotic reserves and corridors, as well as part of El Mundo Maya, perhaps the largest archeo-eco-tourist scheme in the world. The Calakmul Biosphere Reserve is anchored in the middle of the region (Figure 20.1) which is also fully covered by *ejidos* ("communal" peasant or smallholder lands; Figure 20.2), although some of the *ejidos* in the western part are designated only for forest extraction uses.

The population history of the southern Yucatán peninsula region is somewhat unique because it involves only one long wave of growth and decline (Whitmore et al. 1990). Despite reasonably good soils for nonriverine tropical environments, the region remains today sparsely occupied. At its apex in the Late Classic Period (about 1500-1000 B.P. [A.D. 450-950]), the region held millions of people with subregional population densities ascending well above 100 people/km² (Culbert and Rice 1990). The subsequent collapse and depopulation was rapid and dramatic; by 500 B.P. (A.D. 1450), if not before, the region was, for all practical purposes, vacated, save for outposts along its edges. Even the rapid population growth throughout much of the region over the past 30 years, leading to its designation as a "hot
spot" of tropical deforestation (Achard et al., 1998), has generated regional population densities far below those in ancient times (Dunning and Beach 2000:198; Turner et al. 2001).

Given its tropical location and history, the southern Yucatán peninsula region succumbs to various interpretations concerning occupational or use limits that have been subsumed—explicitly and implicitly—under the concept of "carrying capacity." Thus, some have argued that most tropical environments are not suited for intensive human occupation and use, that the Maya exceeded their technological capacity to sustain their civilization in this environment, or that they reached a critical human-environment threshold that was tipped because of climate or some other major change, and that low environmental capacity has been registered in various failed modern-day agricultural projects (Lowe 1985; Tainter 1988; Turner 1990b). In the remainder of this chapter, the logic of the carrying capacity concept, its use in regard to the southern Yucatán peninsula region, and its implications for understanding human-environment relationships there, focusing on four environmental issues will be explored. From this exercise, several lessons of which two are paramount will be examined: (1) carrying capacity is determined as much, if not more so, by the technologies and strategies of use than by the base environmental conditions; and (2) the critical thresholds or tipping points that exist in all environmental use systems are largely underexplored for the region in question.

THE CONCEPT OF CARRYING CAPACITY

Carrying capacity refers to the maximum population (or production) that can be sustained indefinitely within a specified environment without major degradation to that environment. This concept held major currency in the human-environment sciences in the 1960s and 1970s when systems and ecosystems permeated environmental issues. Given this association, it is not surprising that carrying capacity is commonly thought to have its origins in the ecological sciences and that it was borrowed and modified by human-environment subfields to address their own concerns. In reality, the roots of this concept cannot only be traced back to the works of Thomas Malthus (eighteenth-century British political economist-demographer who addressed food ceiling-population dynamics), but can also be found in various guises thereafter, including John Wesley Powell's (nineteenth-century American geologist-explorer) critique of the United States Homestead Act of 1862 for lands west of the 100th meridian (Darragh 1951).

Full development and labeling of the concept for human-environment systems, however, lay in British colonial planning administrations, which sought to orchestrate systematic strategies for optimal land uses, especially
in Africa (Allan 1967; Brush 1975; Street 1969). In this use, carrying capacity identified different land capacities to sustain different levels of occupation under a given use strategy, or land responses to different techno-managerial strategies employed on them. The higher the land capacity, the more people that could be supported on it, and the greater the response to added inputs.

The appeal of carrying capacity, in retrospect, is understandable. It offered a simple measure for planning, and its robustness seemed to be confirmed by the long-term adjustments of indigenous farmers to follow different techno-managerial strategies and the concomitant intensities of cultivation on different lands. The more intensively used and highly productive lands invariably coincided with attributes that made them superior for this purpose than their counterparts elsewhere. Uncritical or careless use of carrying capacity, therefore, de-emphasized techno-managerial considerations that transformed “unfriendly” environments to prime cultivation lands (e.g., tidal land to polders in the Netherlands, steep slopes to terraces along the Andes, and desert to irrigation in the Middle East), and implicitly granted “cause” to the environment. High-quality physical conditions for cultivation were not made so by human ingenuity, they simply existed. The reality, of course, is that environmental opportunities for land use vary widely, as do environmental responses to different land uses, but techno-managerial strategies change these capacities and shift consideration to the socioeconomic need and capacity to improve environmental conditions and maintain them through techno-managerial inputs.

Given this reality, carrying capacity involves at least two critical elements in its measure: (1) E, the physical attributes of the environment used (e.g., soil, climate, vegetation), and (2) S, the techno-managerial strategies applied to use this environment, including their sensitivity and resilience to perturbations. In this sense, no “native” carrying capacity exists for any environment in terms of land use; rather, a number of potential capacities exist depending on the strategies employed. The synergisms between E and S hold the key to land use in general, and longitudinal and cross-sectional studies reveal several important lessons about them that transcend cultures and locations (Wagner 1961):

1 Environments favoring a given production strategy are developed for that activity before others, and improvements focus on those environments as long as marginal returns remain positive (Turner and Brush 1987). The “prime” agricultural lands of the world, therefore, rarely experience a loss in production intensification over the long term, while more marginal lands made highly productive (e.g., colonial New England, high Andean terracing) are taken in and out of produc-
tion in concert with economic conditions (Cronon 1983; Denman 2001; Doolittle 2000).

2. Cultural preferences (e.g., foods) lead to the search for those environments that favor associated land uses, and commonly bypass highly productive environments that support alternative strategies. For example, the Spaniards' search for Mediterranean-like environments is the New World that would enable the cultivation of winter wheat, as well as the introduction of European livestock systems, illustrates this preference (Butzer 1991). In many cases, far more productive Native American systems of production were passed over or destroyed in order to facilitate the conquoror's preference (Turner and Butzer 1992; Whitmore and Turner 1992; 2001).

3. Techno-managerial strategies are linked to land pressures; as these pressures increase, so do the human inputs required to control the environment and substitute for its drawdown (e.g., soil nutrients, water shortfalls) as do the investments for new strategies and technologies to meet the rising demands (Boserup 1965, 1981; Hayami and Ruttan 1971; Turner and Ali 1996). Low land pressures, therefore, tend to be linked to extensive production systems, and the reverse to intensive ones (Turner and Brush 1987).

4. Every land-use system ultimately approaches marginal returns and then stagnates, unless new techno-managerial strategies are used to overcome the critical factor in production (i.e., insufficient water, soil nitrogen) (Hayami and Ruttan 1971; Turner and Ali 1996).

5. Should production pressures mount absent these new strategies (or adequate investment in known strategies), the environment may "bite back" in ways that make human adjustments difficult, or even insurmountable (Kasperson et al. 1995). The salinization of ancient irrigation systems in the Tigris-Euphrates region (Adams 1965) and the recent death of the Aral Sea (Micklin 1988) are illustrative of this problem. This last lesson—bite back—has received the least attention in regard to carrying capacity, save as environmentally improper or highly stressed production systems have encountered large-scale climatic perturbation, such as the dust bowl on the American Great Plains during the 1930s (Glantz 1994; Worster 1979) as well as "desertification" in the Sahel (Glantz 1994; Thomas and Middleton 1994).

6. The kind and significance of the "bite back" observed is strongly affected by the scale of analysis (temporal, spatial, and hierarchical); increasing the scale of analysis usually mutes the role of carrying capacity.
Given the dynamic nature of the E-S relationship, it is difficult and often inappropriate to apply an inflexible view of carrying capacity, or to assume that the extant production system represents the maximum sustainable over the longer term. Whatever that maximum may be, is, in large part, determined by technological and social capacities to employ and maintain the use system in question. In this sense, carrying capacity serves primarily as a heuristic guide to a more inclusive E-S relationship (Brush 1975). The danger here is to allow the human component of the relationship to overshadow the environmental component to such an extent that the latter is relegated to insignificance.

CARRYING CAPACITY AND THE SOUTHERN YUCATÁN PENINSULAR REGION

Nondynamic interpretations of carrying capacity commonly arise for those E-S relationships that stagnate and/or (approach) collapse. In such cases, problems of land degradation and food shortages, among others, are visibly heightened, focusing attention on the environment's sensitivity to use and impacts (bite back) on production. Various interpretations of the Classic Maya collapse and modern land uses in the southern Yucatán peninsular region follow this logic.

The collapse of the Classic Lowland Maya civilization, especially within the heartland zone, remains an enigma: simple causes do not stand the scrutiny of the evidence, and complex explanations are too difficult to demonstrate with any authority (Culbert 1973; Lowe 1985). A long-standing theme or hypothesis points to Malinvisian "overshoot"—that is, population demands exceeded the environmental carrying capacity and/or the technological capacities of the Maya to enlarge this capacity sufficiently (Turner 1990b).

More often than not, interpretations of this kind use carrying capacity as a heuristic, and do not employ measures and metrics regarding land and resource uses (e.g., Cook 1921). Cooke (1931), for example, proposed a "mass wasting" of the landscape by an overtaxing population, presumably pushing the limits of swidden (slash-and-burn) cultivation. Sanders (1973) made a somewhat similar case, although he recognized subregional variations and practices other than swidden. This variation is recognized by Fedick (1995), although he does not make explicit statements about overshoot. Others have made statements, however, most recently in regard to one of the most productive and resilient environments in the lowlands, the Copán Valley of Honduras. Webster and Pretzer (1990) and Lentz (1991), for example, refer to an overshoot in this valley based on the "calculated carrying capacity" of swidden. Wingard (1996) subsequently provided the metrics (see Ta-
Swidden Carrying Capacity

Actual estimates of carrying capacity—of population limits related to specific land uses—for the Maya lowlands are less common and almost always related to swidden or milpa cultivation as currently practiced in various parts of the region (Table 20.1). Swidden is not practiced because of environmental limitations per se, but for its energy and labor efficiency, relying as it does on nature to replenish most of the critical biophysical elements usurped or lost in crop production. It is the system of choice, where land pressures are relatively low in nonfossil fuel and nonmarket agriculture (Boserup 1965; Turner and Brush 1987).

In the southern Yucatán peninsular region and throughout the Maya lowlands, milpas (or maize fields) refers to follow-based cultivation employing slash-and-burn or swidden techniques. The early Spanish chroniclers described versions of it; subsequently, this kind of swidden practice dominated subsistence production throughout the entire lowlands (Whitmore and Turner 1992). Milpas is an extensive production system in that more land than is cultivated must be in various stages of fallow. Crop-fallow cycles vary by the time and location in question, but 2-3:7-15 systems (2-3 years of cultivation; 7-15 years of fallow) were historically typical and remain so today, resulting in the need for about two to seven times more land in fallow than in cultivation (Reina 1967; Reina and Hill 1980). Related carrying capacity estimates range from about 20 to 80 people/km²; the lower figure tends toward the high side globally (Turner 1983:7-9) and the higher figure stresses credibility (but heed notes to Table 20.1). Estimates of the global average population density associated with swidden systems is less than 6 people/km² (e.g., Watters 1960). According to Harris (1972), exceptional swidden systems (read “optimal” environments not taken over by more intensive systems, for whatever reason) may support up to 60 people/km². These last cases invariably are short fallow (1:1) and require substantial technico-managerial investments that move the system in question away from...
<table>
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<tr>
<th>Location</th>
<th>Production System*</th>
<th>Density (people/km²)</th>
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<tr>
<td>Northern Yucatán</td>
<td>Swidden/milpa</td>
<td>19</td>
<td>Cook (1972: 31)</td>
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<td>Northern Yucatán</td>
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<td>Greater Yucatán</td>
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<td>57</td>
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<td>Central Petén</td>
<td>Swidden/milpa</td>
<td>77⁶</td>
<td>Cowgill (1981)</td>
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Source: From Turner 1983.

a. Swidden/milpa = maize-based systems in which fallow exceeds cultivation (1:4 plus); intensive swidden = maize-based system in which length of fallow and cultivation are equal (1:1).

b. The lower figure for longer fallow (10 yr); the higher figure for shorter fallow.

c. Figure or "available land" or cropped land, not total area of some bounded unit noncropped land eliminated from estimate.

d. Figure assumes that virtually all land is high quality and suitable for maize cultivation. It is very high by world standards for swidden systems.

The public meaning of swidden (literally, to bum) of low-input, rotational practices.

The swidden carrying capacity estimates for the Maya Lowlands, therefore, are several orders of magnitude below the population estimates derived from settlement studies of the ancient Maya. These figures vary for the southern Yucatán peninsular region, of course, but exceed 1,000 people/km² for "urban" areas, 800 to 500 people/km² for some peri-urban areas, and range up to 150 people/km² for large rural areas replete with evidence of significant landscape transformation (Culbert and Rice 1990). Assuming that the settlement evidence is not grossly inaccurate, the ancient Maya surely incurred very high levels of land pressures that would have required the use of multiple techno-managerial strategies—many of which would have had to have been far more intensive in scope than swidden.

Research from the 1970s onward reveals that the Maya had begun to employ techno-managerial strategies quite different from swidden perhaps as early as 3000 B.P. (ca. 1000 B.C.) (Pope, Phol, and Jacob 1996). Although debate has focused on the specifics of each major strategy employed (i.e., date of origin, distribution, and production implications), the broader picture emerging for the Maya lowlands and the region examined here is the use of multiple systems of cultivation, some more common to specific subregions.
than to others (Dunning 1992; Dunning and Beach 2000; Fedick 1996; Harrison 1990; Turner 1993). House and orchard gardens appear to have been present almost everywhere (Turner and Miksic 1984; Whitemore and Turner 2001), and in some cases may have taken the form of small-scale agroforestry (Gómez-Pompa 1987; Gómez-Pompa, Flores, and Sosa 1987; McKillop 1994). Presumably such systems were relatively sustainable, given their more-or-less benign impacts on soil, but were subject to damage from hurricanes, fires, and crop disease.

Despite their importance, orchard gardens and agroforestry did not dominate the landscape during the peak population times as registered by the pollen record (see as follows). More open cultivation dominated, which included short-fallow or near-permanent cultivation of the uplands. The southern Yucatán peninsula region is replete with stone-walled landscapes littered with cutting and cultivation tools (Turner 1983). Some of the walls are clearly the remnants of ancient terraces (Turner 1974). Similarly, bajos or seasonally inundated wetlands on the edges (coastal littorals) of the region were taken in wetland cultivation (Dunning et al. 1999; Pohl et al. 1996; Turner and Harrison 1981). Their use in higher perched upland bajos (ca. +100-m asal) remains in question (Adams, Brown, and Cubert 1981; Adams et al. 1990; Pope and Dahlin 1989; 1993).

Logically, the intensively used and settled uplands seem ripe for wetland use (bajos constituting about 19 percent of the region), and recent work indicates the complexity of water works on occupation sites that drained toward bajos (Dunning and Beach 2000; Scarborough et al. 1995). The only established patterns indicating ancient fields in upland bajos, however, are in the huge Nicolas Bravo–Morocoy wetlands situated at 70 m asal (Turner 1974). Some of the patterns there had small stone structures on them with sherds apparently Late Classic in origin (Gliessman et al. 1985). Whether or not these systems were used year-round, or during the dry season only—akin to highly managed recessional cultivation (Siemens 1983; Siemens et al. 1988)—is unknown.

**Multiple-System Carrying Capacity**

Estimating carrying capacities for these practices is fraught with problems, given the unknowns involved. Current swidden yields can be pressed upon assumptions that the previous systems were harvested annually (and only periodically fallowed), yielding extremely large carrying capacities (e.g., Turner 1976). How meaningful these exercises are, however, is not clear. The consensus, at least as evidenced in the literature, is that the mixes of systems used by the Maya were sufficient to meet the high levels of demands and land pressures present during the Late Classic Period.\(^5\)
Paleopathology research dealing with the region has indicated dietary stress in some locales as the Maya collapse approached, but the overall picture is varied and complex, and no evidence exists yet that dietary stress was any worse than that in comparable human-environmental conditions elsewhere in Mesoamerica (White 1999). Virtually no experts call for a lowering of the settlement-based population estimates to densities commensurate with known levels of swidden production. Thus, pan-regional densities approaching (or exceeding) 100 people/km²—and with many subregions, or large areas, far exceeding that figure—are believed to have been sustained hundreds of years or longer. This assumption is consistent with the settlement and landscape evidence, and is informed by analogues of other indigenous mixed-intensive systems.

To be sure, large labor investments and sophisticated techno-managerial strategies were required to sustain the requisite production level, especially for soil upkeep (e.g., mulch, night soil, muck, blue-green algae applications). In turn, the total system was undoubtedly under considerable stress and subject to repeated production shortfalls, especially in the face of nature’s vagaries (e.g., hurricanes, drought, crop diseases). It is noteworthy, however, that pre-Hispanic populations in the Basin of Mexico also experienced these same stresses and shortfalls, but were able to sustain large populations and powerful states over the long haul (Whitmore and Turner 2001).

ENVIRONMENTAL IMPACTS

The human imprint on the environment is ancient and large (Redman 1999; Thomas 1956; Turner et al. 1990), and paleoecological studies invariably register it commensurate with the size and duration of occupation and use of an area. The imprint of Maya land use and occupation on their tropical lowland environment was no exception. Binford and colleagues (1987) capture the broad stroke of these impacts in two powerful figures (combined here in Figure 20.3, following Rice 1993) that illustrates distinctly the significant deforestation, soil erosion, rates of sedimentation, and phosphorus (P) loading (phosphorus mobilized by Maya activities and removed by erosion), in the central Petén lakes region during ancient Maya settlement. There is every reason to suspect that these broad trajectories of change were present throughout the southern Yucatán peninsular region, and thus constitute problems for modern redevelopment of the region.

It must be remembered, however, that the Maya confronted environmental problems for several thousand years, albeit with temporarily localized failures. For this reason alone, interpretations must heed not only those techno-managerial strategies that worked, but also the socioeconomic con-
diions that supported them over the long run. The inherent danger of the use of carrying capacity, illustrated in its application to African development (Turner, Hyden, and Kates 1993), is to privilege the environment (E), or environmental problems or consequences, as the “determinant” of land-use failures and relegate the role of socioeconomic determinants (S) that affect the capacity and incentive to employ and sustain appropriate strategies of use. The E-S relationship, of course, may reach some critical threshold in which a perturbation (environmental or human) reduces carrying capacity, or makes the costs of sustaining carrying capacity unrewarding and unacceptable (Lee 1986; Lowe 1985). Unfortunately, to demonstrate this kind of synergism for the southern Yucatán peninsula region is well beyond capacities at this time because of limitations in data.

Consideration of various kinds of environmental bite backs that are central to the E-S relationship, however, is possible. Such bite backs do not specifically involve global climate change or rise in sea level because they are not exogenous to the use-occupation system. Rather, they include those local-to-regional environmental impacts that followed Maya land and resource uses.

Several bite backs are apparent in the previous discussion; others involve subset and other problems not so apparent or common in the literature. They involve (1) upland soil and soil nutrient loss; (2) weed and pest invasion, including “detrimental invasive species”; (3) wetland sedimentation; and (4) regional climate change and water stress. These possible sources of environmental feedbacks are registered in the paleoenvironmental evidence and suggested in studies of contemporary human-environmental relationships in the region. For example, various studies of swidden or milpa in Maya lowlands demonstrate declining second- and third-year yields (for maize) owing to soil nutrient losses, weed invasion, and pest infestation (Reina 1967; Wingard 1996). The assumption is that these base problems were magnified with the more-or-less permanent cropping that characterized the peak periods of occupation in the region.

**Soil and Soil Nutrient Loss**

The southern Yucatán peninsula region was significantly deforested (see Figure 20.3), despite substantial use of house and orchard gardens (Turner and Miksicek 1984; Rex, Jones, and Dunning 1995), the apparent need for wood-fuel lots, and the possibility that some patches of forests were managed (Dunning and Beach 2000; Gómez-Pompa, Flores, and Sosa 1987). Although the regionwide pattern of deforestation follows that outlined in Figure 20.3, subregional or local variations undoubtedly existed.
Certain large sites were abandoned, presumably contributing to reforesta-
tion, and subsequently reoccupied in some way.¹⁰ Deforestation everywhere in the region (and the Maya lowlands) has been associated with accelerated soil erosion (Dunning and Beach 2000; Rice 1993; Rue 1987; Wingard 1996), as it is today under swidden systems on slopes (Beach 1998). With this physical erosion, soil nutrients were lost as well, perhaps signified in the phosphorous loadings in the central Petén lakes region (Rice 1996).⁹ As slopelandos were increasingly cleared, soil erosion and loss of soil nutrients increased until measures were taken to im-
pede the rates of loss. By the Classic Period, terraces of various kinds were employed across the southern Yucatán peninsula region (Dunning and Beach 2000; Turner 1983); where intact, these features hold 2.7 to 3.6 times more soil than adjacent cultivated slopes (Dunning and Beach 2000). Deeper soils on slopelandos tend to retain more moisture and maintain a superior ca-
pacity to respond to cropping inputs (e.g., mulch, manure) than do thinner, nonterraced slope soils.

The cropping impacts of these losses are not clear. Dunning and Beach (2000) suggest that Preclassic slope clearing was followed by substantial erosion, land degradation, and perhaps abandonment of certain locales (see the section on Wetland Sedimentation that follows). By the Classic Period, however, slope management increased significantly, reducing per-unit land degradation and contributing to more sustainable slope uses. Beach (1998), in fact, argues that there were surprisingly low losses of soil in Late Classic times where terraces were used. Terracing involved significant labor and management costs, however, especially in regard to various constructional and surface-drainage measures required to combat hydrostatic pressure on the terraced walls, which resulted from the thickened soils that developed there. Loss of this management, for whatever reason, would have degraded the terrace system.

Weed and Pest Invasion

Pest damage to crops is large in the tropics, and at least one thesis specu-
lates that the Maya collapsed because of the spread of the maize mosaic virus by *Peregrinus maidis*, as insect that could have been carried by hurri-
canes from the Caribbean Islands to Yucatán (Brewbaker 1979). Swidden addresses pest disease problems by moving the plot and escaping the point source of the problem. Presumably, the intensively used landscape of the Maya could not afford this luxury. Intercropping and use of species that re-
pel certain crop predators were undoubtedly employed. Similarly, the use of many species varieties and intercropping were the principal combatants
against crop diseases as well (Thurston et al. 1994). Unfortunately, little is known about the strategies used to combat crop pests and diseases. In contrast, one of the few methods to combat weeds (absent herbicides) is to remove them manually, and the paleo record is replete with indications that increased occupancy and use of the lowlands tracks with significant losses in arable as well as increases in maize, grass, and weed pollea (see review, Rice 1996). Milpa cultivation practiced with steed macheas largely involves cutting weeds at the surface, and is not an appropriate analog for intensive cultivation. Frequent cropping would have required hoeing (digging up weeds) or preparing earthen hillocks (montones) or ridges for planting (pauperizing soil and reworking its shape).

These labor-intensive strategies, if not employed thoroughly and in conjunction with soil nutrient upkeep, may have triggered another environmental bite back that has been little considered for the region. Work on contemporary land-use/cover practices in southern Campeche and Quintana Roo has revealed that three invasive species pose considerable problems to overgrown plots: (1) bracken fern or techecho (Pteridium aquinunum L.), (2) tajin (Vigaria dentata [Cav.] Spreng), and (3) Cecropia peltata L. (Turner et al. 2001). Of these, bracken fern poses almost insurmountable problems because it impedes (and even arrests) successional growth; it fails to produce quality biomass necessary for agriculture (biomass is produced, but it has low nutrient composition); and it regenerates rapidly after burning (for Amazonia see Uhl et al. 1982; Suazo 1998).

If bracken invades sufficiently large areas (continuous plots), farmers today virtually give up attempts to control or defeat it. If the species invades small, isolated plots, farmers attempt to control it by regular cutting—possibly permitting surrounding regrowth to increasingly shade the plot and reduce the bracken. There is no evidence that regular cutting will completely remove plots of bracken, although it may be effective in minimizing its spread. Unfortunately, virtually no work has been undertaken to date on the causes of bracken invasion; thus, possible causes are subject to various interpretation. One view suggests that bracken invasion is related to long-term swiddea cultivation and/or reduced crop-fallow cycles. Another view suggests that out-of-control fires burning through large areas give rise to large areas of bracken that farmers are unable or unwilling to control. Regardless of the cause, the problem is a growing one. For example, of the nearly 18,000 km² area examined in southern Campeche and Quintana Roo during 1987, about 1 percent of the land that had been disturbed for cultivation (mostly to medium-fallow milpa) during a period of 20 to 30 years was covered by bracken fern; ten years later (and under mounting land pressures), almost 5 percent of the disturbed land cover was in bracken (Figure 20.4; Turner et al. 1990).
As noted, the role of bracken fern and other such invasive species on ancient Maya cultivation is not known. The paleo record indicates fern spores and maize pollen are inversely related for the lowlands at large. Rue (1987) demonstrates, however, the increased presence of fern in the Late Classic based on cores taken from Aguada Peapilla (Copán Valley peat bog) and Lago Yojoa, Honduras. It is unlikely that bracken is a recent arrival to the region, which suggests that the Maya found some means to deal with the species or that it proliferates when crop fallows are shortened, without requisite inputs to account for nutrient and other soil losses. Nevertheless, bracken deserves far more attention than it has received in terms of its bite back impacts.

**Wetland Sedimentation**

Commensurate with Preclassic soil erosion, the evidence indicates substantial sedimentation in wetlands, especially those on the Caribbean littoral (Dunning and Beach 2000; Dunning et al. 1999; Jacob 1995; Pope, Pohl, and Jacob 1996). These sediments covered peaty wetlands, some of which were apparently in use by the Maya (Pohl et al. 1996). The duration and pace of this process remain debated, but impact on Maya cultivation would have been substantial, especially on the littoral. The suggestion that sedi-

Figure 20.4. Area increase and location of bracken fern from 1987 to 1997: 19 km² to 92 km². (See Figure 20.2 for location of this area within the region.)
ensation arrested Maya use of wetlands on the littoral appears doubtful, given settlement gravitation toward wetlands in some places during the Classic Period, as well as the apparent Late Classic ceramic evidence from the Nicolas Bravo-Morocoy wetland. It would appear that by the Middle to Late Classic, the Maya had recovered wetland cultivation.

The implications for the southern Yucatán peninsula region are problematic. With the exception of the Bajo Nicolas Bravo-Morocoy, no other wetland patterning associated with possible cultivation has been reported with confidence, or even confirmed. Human manipulation of small wetlands has been reported in the northeastern Petén (Culbert, Levi, and Cruz 1990), and the adjacent area indicates upland hydraulic works engineered to move surface water from settlement areas to reservoirs and, ultimately, to wetlands (Scarborough et al. 1995). Although this engineering has numerous implications, it raises issues about the possible role of bajos in the maintenance of the southern Yucatán peninsula region—if not for food production, perhaps for some other purpose.

**Regional Climate Change and Water Stress**

The southern Yucatán peninsula region experiences a pronounced dry season. Its karst geology is not favorable for surface water, and elevations ranging between 100 to 300 m asl promotes deep water tables, commonly 200 m or more below the surface. The paucity of dry season surface water hampers cattle projects in the region today, as well as various tourist-based development schemes (e.g., El Mundo Maya). Given demands in the Late Classic, the provisioning of water during the late dry season must have posed a significant problem and required substantial attention.

Interestingly, the very landscape changes triggered by large-scale Maya occupation in the past may have aggravated water stresses. One of the more intriguing findings from earth system science research is the profound effect that a region's land-cover change may have on local climate, especially on rainfall (IGBP 1999). If the southern Yucatán peninsula region was long denuded at a sufficient spatial scale, as the pollen records hint, significant decreases in average annual precipitation or increases in the length and severity of the dry season may have followed. It is not surprising, therefore, that Maya-made reservoirs of various sizes abound throughout the region, especially large ones concentrated at major sites. Scarborough (et al. 1995) has demonstrated the engineering feats employed by the Maya to control water flow from settlements to reservoirs (clay lined) and, ultimately, wetlands (clay lens). Either feature retained surface water, although the area and volume of bajos far exceed that of reservoirs.10

Critical questions remain unresolved, such as why runoff was directed to bajos, as well as to what purpose bajo water was put. Bajos were, of course,
the natural drainage features; engineering feats related to them may have served only to alleviate excessive upland water during the height of the rainy season. Alternatively, bajos may have provided critical water resources and biomass (wood fuel); the hydraulic works would thus have ensured that more water would be delivered to them than percolated through the upland limestone to the deep aquifers below (see Scarborough et al. 1995; Scarborough 1996). Of course, if these wetlands were used for cultivation, the runoff features would help to supply water for dry season cultivation (Siemens 1983; Siemens et al. 1988).

Some, if not many, wetlands may have resembled shallow lakes more than seasonal wetlands when the Maya entered the region (e.g., Dunning and Beach 2000)—an idea offered previously by Ricketson and Ricketson (1937) and Harrison (1977). The subsequent infill by Maya-made sediments dispersed surface water and made them more shallow and subject to evaporation. Engineering works, therefore, may have served to deliver more water to bajos over a longer period of the year, for whatever purposes bajos were put. Unlike former hypotheses, however, sedimentation of wetlands did not coincide with the Maya collapse; rather, the carrying capacity of the southern Yucatan peninsula region increased subsequently, as indicated by the huge rise in regional populations.

THREE MILLENNIA CLUES

Three thousand years of human-environment relationships in the southern Yucatan peninsula region, as exhaustively studied as they have been, provide support for only the most general lessons regarding occupancy, carrying capacity, and use. The evidence strongly supports the well-known understanding (if often understated) that the capacity of the lowlands to support large populations over long periods has been intimately tied to techno-managerial strategies used to manipulate the environments there; thus, carrying capacity is a dynamic outcome of the human-environment condition. Use of contemporary analogs to explain the region's past are largely valid only if they are applicable to the human-environment conditions of the past. In this case, current swidden cultivation and landscape configurations are a far cry from those present at the apex of Maya occupancy.

The same evidence also supports the case that the Maya, as with all other peoples, could not sustain themselves without a large human impress on the "native" conditions they encountered upon entering the region. They changed these conditions considerably—transforming a tropical forest land into an open, managed complex of integrated landscapes. This conclusion appears
little disputed, although the specifics of the individual practices and landscapes are still in contention.

Transformation, however, does not come without costs; for most environmental changes, sustaining the substitutes for nature’s losses dominates these costs. If these costs become impractical, for whatever reason, the transformations degrade as part of nature’s bite back. Recent attention has refocused on the bite back to Maya land and resource systems, with several individual problems elevated in attention—especially upland soil loss and wetland sedimentation—to which water stress and critical invasive species also can be added. Comparative studies of environmental degradation reveal, however, that few, if any, individual bite back create collapses akin to that experienced in the southern Yucatán peninsular region (Kasprow, Kasprow, and Turner 1995). Rather, multiple synergistic stresses must be active and sufficient in their damage to make social choices to combat them difficult.

It is precisely such human-environment conditions that are especially vulnerable to exogenous perturbations (e.g., invasion, climate change) that can tip the production systems. The role of climate change as a perturbation of this kind has long been proposed. Based on observations in the Copán Valley Huntington (1917), proposed that the collapse was associated with increased precipitation. Recently, new evidence indicates that, in fact, the north-central lowlands experienced a shift to drier climatic conditions (Hodell, Curtis, and Brenner 1995; Hodell, Brenner, and Curtis 2000). If this shift was pan-lowland geographically (an assumption questioned by Dunning and Beach (2000)), coupled with the extant water stresses as well as possible land-change induced rainfall reductions, the bite back on the southern Yucatán peninsular region would have been significant.

Unlike the northern Maya lowlands and the coastal littorals, subterranean water was not accessible in the uplands, and captured surface water would have been in short supply. This scenario is dangerously simplistic, however. Although may may serve to explain a reduced carrying capacity and the collapse of the Maya heartland, it fails to account for the resulting catastrophic depopulation—the virtual abandonment of the southern Yucatán peninsular region and the resulting forest regrowth that almost swallowed the Cortés expedition.

Finally, the human-environment history of the region demonstrates the resilience of terrestrial systems, at least in regard to land cover over the long term. The tropical forests did return, if altered in species abundance owing to past land uses or the subsequent impacts of these uses (Gómez-Pompa, Flores, and Sosa 1987; Miksic et al. 1981; Lambert and Amason 1981). Interestingly, species abundance in the region is one of the few modern impacts matching those of the Maya. Selective logging in the middle of the twentieth century significantly reduced the presence of mahogany and Span-
ish cedar on the uplands proper. Ironically, the “humanized” forests of the southern Yucatán peninsula region are those now central to various biological preservation and carbon sequestering programs.

NOTES

1. The percentage of the Maya lowlands covered by slopeland or upland and bajos (depressions or poljes) varies by location and size of area examined. The figures provided here are based on TM (LandSat 7) image analysis for a 22,000 km² portion of southern Quintana Roo and Campeche, Mexico (Figures 20.1 and 20.2; Turner et al. 2001). Absent of agriculture, uplands are dominated by mediana (upland forest) and bajos by bajo forest in areas covered by the imagery (Figure 20.2).

2. In 1524, Hernando Cortés led an ill-fated expedition across the region that struggled through dense forest—largely absent trails and settlements of any kind—until they reached Maya settlements on the central lakes of Petén (Whitmore and Turner 2001, Chapter 8). From colonial times until the early twenty-first century, the “forest frontier” of the study region served as a refuge for Maya and others who sought to escape state control, for whatever reasons (Jones 1989).

3. Sidrys and Berger (1979) speculated that the Classic Maya collapse may not have involved a massive depopulation. Although it is true that some lowland areas, especially in northern Yucatán and on the coastal litorals, retained substantial populations, research on the southern Yucatán peninsula region strongly supports substantial depopulation there after about 1000 B.P. (ca. A.D. 950).

4. Sanders noted (during the question and answer session of the symposium in which this chapter was delivered) a definitional issue that may create confusion among those using the term swidden or its various counterparts in the study of the Maya. Some researchers use the term (or that of “super-milpas”) to refer to near-permanent cropping (1.1-2 crop-fallow cycle), especially if major landuse capital is not employed. Others, including the authors, do not employ the term in this way because of the public meaning that swidden has taken in a large, interdisciplinary literature. This public meaning is not consistent with near-permanent or predomi- nately permanent cultivation that requires substantial labor and techno-managerial investments to overcome the limitations and vagaries of nature. Although we refer to techno-labeled systems of cultivation (e.g., swidden, terracing), the critical analytical issue is the level of inputs or costs of production. We infer a loose connection between these labels and the input issue. Those using the term super-swidden, or others with similar implications, are, in fact, consistent in meaning, if not labels, with our use here. Insufficiently explained labels, however, can lead to confusion.

5. Although remnants of wetland fields occur in these low-lying coastal zones is not disputed, their age and principal period of use are in contention. Condensing the various arguments, one viewpoint sees the fields as Preclassic in origin—largely peat-based systems that subsequently were abandoned, or only ephemeronally used once major sediments from Maya land uses elsewhere began to cover them (Pohl et al. 1996; Pope and Dahlin 1989). Alternative views suggest that early experiments in wetland cultivation culminated in major wetland systems in the Late Classic Period, apparently in concert with, or after, major sedimentation (Harrison 1990; 1996; Turner 1993).
6. Our reading of the literature indicates that the expert community does not take seriously statements akin to the following: "One doubts that intensive methods were ever responsible for more than 10 percent of the subsistence base [of the Maya]" (Gryuk and Harrison 1975:125).

7. The evidence also mounts in regard to large-scale, pre-Hispanic soil erosion and sedimentation in the "altiplano" of Mexico mountains (O'Hara, Street-Perrott, and Timothy 1993; Whitmore and Turner 2001). The evidence suggests that graphics akin to those in Figure 20.3 are applicable for the highlands, although massive abandonment of large regions did not follow.

8. Deep within the Rio de la Pasión region of Guatemala, bi-model deforestation evidence has been found corresponding to the Late Preclassic and Classic periods. The second deforestation period, however, appears to have been less extensive and suggests agroforestry, given the apparent loss of certain species as well as the increase in fruit-bearing species (Dunning and Beach 2000:190).

9. Turner has long suspected that the phosphorus loadings found in the lake cores in question reflect increased human waste and nitrogen soils used within the lake drainages.

10. Bajos typically release water through surface drainage during high-water periods. They connect to one another by way of ephemeral waterways that remain dry and/or nonrunning for most of the year. At high water, and especially during hurricanes, these waterways not only flow, but they also flood adjacent, lower-elevated lands.

**LITERATURE CITED**


Wagner, H. O. 1968. Subsistence potential and population density of the Maya on the Yucatan Peninsula and causes for the decline on population in the fifteenth cen-


