Population, Development, and Environment on the Yucatán Peninsula:

From Ancient Maya to 2030

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Editors

RR-00-14
July 2000

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International Standard Book Number 3-7045-0138-7

Cover design by Anka James.

Printed by **Rema***print*, Vienna.

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Introduction: Understanding Complex Population–Environment Interactions

Wolfgang Lutz

Gaining a better understanding of how human populations depend on fragile environmental conditions and limited natural resources and at the same time change the environment on which they depend is a great scientific challenge of our time. There is no simple formula for adequately describing these interdependencies. Whether a given ecosystem can support a certain human population is not simply a question of the size of the population – as is the case for the carrying capacity of animal populations. It also depends on the behavior, the stage of economic development, the technology, and even the culture and social institutions of the specific population under consideration. This is why one cannot make a universal statement about the maximum or even the ideal number of people that should live in a given territory. Similarly, the impact of the human population on the environment through deforestation, water and air pollution, destruction of marine ecosystems, etc., depends not only on the sheer number of people, but on the production and consumption patterns of these people and, of course, on the frailty of the specific ecosystem as well.

Does the high complexity of population–development–environment (PDE) interactions mean that nothing can be said about this issue and that it must be left entirely to the randomness of future evolutions that we do not understand and cannot influence? Such a conclusion seems unreasonable. Although we may not be able to find a global formula, we may well be able to document and analyze these PDE interactions in specific settings for which we have reasonably reliable empirical information. Such an understanding can be achieved through traditional descriptive analysis of past trends as well as through more formal computer-based modeling. Both approaches are applied in this report, taking the Yucatán peninsula as a specific case study.

The International Institute for Applied Systems Analysis (IIASA) has long been a leading international center in the field of global and intersectoral modeling. Founded in 1972, at the height of the Cold War, by an American–Soviet initiative to enable scientists to work together on issues of truly global relevance using the new tools of systems analysis, IIASA soon became a center of what is usually described as global modeling. During the 1980s, global modeling went out of fashion because of strong and mostly well-justified criticisms that too-strong assumptions were being made without a good empirical basis and that different parts of the world were simply too different to be covered by rather simple uniform equations. This change in the research paradigms was also reflected in IIASA's scientific research agenda during the 1980s. Research groups returned to sectoral modeling in the fields of demography, energy, forestry, water, air pollution, etc. Within these sectors, much more meaningful and reliable models were developed that found much greater acceptance by scientists around the world. In a way, IIASA's research agenda became more like those of most academic institutions, in which science is compartmentalized by discipline.

The only problem with traditional research along disciplinary boundaries is that the real world is not compartmentalized into disciplines. For example, in the real world water systems depend on the consumption of water by people and on the water pollution caused by them. The health status of the population depends on changes in the natural disease environment and on food availability, among other things. Food availability in turn depends on the provision of clean water and a host of factors that depend on changes in the human population size, settlement patterns, and consumption preferences. How can we understand the processes of the real world if we always stop our analysis at disciplinary boundaries?

During the late 1980s, we at IIASA became increasingly aware of these problems, especially when we were asked to prepare some new crosscutting analyses in preparation for the 1992 Earth Summit on environment and development, held in Rio de Janeiro. But how could we do crosscutting research without falling into the traps of earlier global modeling? One promising option that we decided to pursue was to broaden the disciplinary focus while at the same time narrowing the geographic focus. We decided to do a truly comprehensive study of one specific microcosm with excellent data and high population density – the island of Mauritius.

Together with colleagues from the University of Mauritius and funding from the United Nations Population Fund (UNFPA), we studied this highly interesting island from all possible angles. The book documenting this study (Lutz, 1994) combines more traditional multidisciplinary analysis with interdisciplinary modeling and alternative scenarios to 2030. The second part of the book, Understanding through History, includes chapters on topics ranging from the environmental to the demographic and political history of this small island in the Indian Ocean. The third part, Understanding through Modeling, tries to pull the different aspects together by defining some of their interactions. Under both these perspectives, which together make up the PDE approach, the primary goal is to understand what has happened in the past and what is likely to happen in the future under alternative development paths. This kind of analysis is highly relevant for policymakers because it can help to indicate the longer-term consequences of short-term political decisions while taking account of some of the most important interactions between population trends, economic development, and environmental change.

This Mauritius study not only provided a comprehensive picture of the island's history and alternative future trends, it also taught us many important lessons about how to use the new generation of intersectoral models to avoid some of the pitfalls of traditional global models. However, the very nature of this case study approach means that the findings cannot be applied directly to other parts of the world. To gain a better understanding of more general features of population–environment interactions, additional case studies have to be conducted in different parts of the world. For this reason, after the Mauritius study, IIASA chose to go to the Yucatán peninsula, and from there we have now gone on to Namibia, Botswana, and Mozambique.

Of course, IIASA is not alone in conducting case studies on population–environment interactions. In the process of organizing a session on population and environment at the 1997 International Population Conference (organized by the International Union for the Scientific Study of Population and held in Beijing), I identified more than 250 recent small-scale studies concerning population and the environment, most of which used an anthropological approach. After looking through this large number of studies on all kinds of population–environment issues in different parts of the world, I felt that I had not really gained a much better understanding of the more general nature of these interactions. Of course, there were very interesting specific cases and lots of intriguing and thought-provoking empirical evidence, but because every study used somewhat different variables, different definitions of relationships, and different scientific paradigms, I found it extremely difficult to summarize the collective findings of these studies in any meaningful way. Will another 250 case studies conducted by individual initiatives in a completely uncoordinated manner improve the situation?

Clearly, in every new field of study we initially need many exploratory studies using all kinds of data and approaches if we are to avoid having too narrow a focus or specific disciplinary biases. These specific case studies usually serve other purposes in addition to helping us gain a better understanding of the study area: they help to build capacity in local research, and they often have important policy implications at the local level. But with respect to the general understanding of the nature of the interactions, the value added by many additional case studies using different variables and approaches, even when studying similar phenomena, tends to decline. For this reason, IIASA chose to use isomorphic approaches and some important common elements (such as multistate population projections by at least three dimensions – age, sex, and educational status) in its different case studies. Also, its PDE case studies tend to be more comprehensive and more in-depth than most other case studies. Each of these case studies will be documented in a substantial scientific volume.

Why focus on the Yucatán peninsula? This peninsula in southeast Mexico has always interested scientists. Approximately 60 million years ago, a huge meteorite crashed off its coast, blowing so many particles into the air that the sky was dark for many years, a condition now assumed to be the reason for the end of the dinosaur era. The mammals that survived those years of darkness due to their size and robustness subsequently found new ecological niches in which to evolve and multiply. Without this meteorite on Yucatán, there probably would be no human species of the kind we know. In a way, this is a most fundamental population–environment dependency, because global environmental forces originating from Yucatán facilitated the very existence of a human population on Earth.

Moving to much more recent times, the astonishing culture and infrastructure of Maya civilization still present many puzzles for scientific research. Interactions between population size, agricultural techniques, infrastructure, and the natural environment likely played important roles both in the rapid population growth during the classic Maya period that resulted in a population density on the peninsula that was higher than today's – even given the massive recent migration to the Cancún area – and in the collapse of Maya civilization with its precipitous decline in population. The nature of these interactions, however, is still a mystery.

Structure of the Report

This report is divided into two parts: the first part provides historical and sectoral analyses; the second part presents intersectoral models on specific issues. Chapter 1, on social and environmental factors of the Classic Maya collapse, is co-written by an archaeologist, an anthropologist, a demographer, and a climatologist. These four disciplines together can help to shed more light on the highly controversial issue of what kind of population–environment interactions caused the Maya collapse. Many environmentalists concerned about the rapid growth of world population repeatedly cite the Maya collapse as an example of what happens if a region's population growth exceeds its population carrying capacity. This chapter, which synthesizes some of the most recent evidence from different fields, suggests, however, that the Maya collapse was most likely triggered by exogenous climate change rather than purely endogenous factors. However, this is not to say that population density was irrelevant. High population density together with rigid social structures probably made the Maya population less robust. Because of these factors, it could not manage the consequences of the extended droughts triggered by exogenous climate change.

Chapter 2 introduces the concept of socioecological regions (SERs), which has become very important in PDE analysis and is an important new aspect of the Yucatán study. In the earlier PDE study on Mauritius, the entire island was considered to be one region. The Yucatán peninsula is clearly too heterogeneous for this. First, it consists of three states (Campeche, Yucatán, and Quintana Roo) with different governments; thus any analysis that is to be politically useful needs to make reference to these political entities. Also, all of the demographic and social information is organized according to state and municipal boundaries. Unfortunately, however, the ecosystem does not coincide with these political boundaries. For analysis of the water system, soil, and vegetation patterns, it makes no sense to look at political units instead of, say, watersheds. An additional problem is that even within given political and ecological regions there are significant urban/rural differences, which in Yucatán also largely correspond to ethnic differences. This incompatibility of geographical disaggregation by socioeconomic and political criteria, on the one hand, and physical aspects, on the other hand, is a problem common to all population–environment studies for which no completely satisfactory solution has yet been developed.

One approach, especially in the context of the analysis of satellite images, has been to structure all information according to small grid cells and then recompose the political units by aggregating the appropriate cells. This approach makes data compatible for descriptive analysis but still does not solve the problem for cases where the unit of analysis must go beyond a specific administrative zone, such as in modeling water dynamics. For this reason, we have tried to go in a different direction. Chapter 2 describes the criteria and the process of defining the SERs by reaching some sort of compromise between political, socioeconomic, and physical criteria. Although it is relatively difficult to generate the data at the SER level (all the sociodemographic information has to be reaggregated starting at the municipal level) and it still only presents approximations with respect to ecological aspects, it seems to be a viable solution and possibly the only one for dealing with the problem. The fact that this chapter has seven authors from widely varying fields of study underlines the multidisciplinary nature of this approach.

Chapter 3 applies the concept of SERs to the field of demographic and educational trends. It gives a comprehensive analysis of significant recent changes in the different regions of the peninsula and at the same time provides the groundwork for the population and education projections documented in the second part of the report.

Chapter 4, on Maya culture, population, and environment on the Yucatán peninsula, looks at contemporary Maya culture, which still predominates in large parts of rural Yucatán, Quintana Roo, and Campeche. An anthropologist with many years of field experience on the peninsula and a social demographer with considerable experience in other parts of Latin America merge their expertise in assessing the viability of traditional Maya modes of agricultural production for modern sustainable agriculture. Not surprisingly, they conclude that much is to be learned from the indigenous knowledge that has evolved over the centuries from an intimate understanding of the peninsula's ecosystem. This chapter is also remarkable insofar as it synthesizes a large number of area-specific anthropological studies conducted over recent years and tries to assess the macrolevel implications for future sustainable development on the peninsula. In this respect, the Yucatán study goes an important step beyond the Mauritius case study, which was only based on aggregate statistical information.

The dramatic changes in the economic structure that have taken place in recent decades are discussed in Chapter 5. Early in the 20th century the economy, especially in the state of Yucatán and its capital Mérida, was dominated by the production of henequen. After the development of synthetic fiber, however, the henequen industry and the regional economy experienced a severe depression until the rise of tourism around Cancún in the 1980s and the increase of assembly plants resulting from the establishment of the North American free trade zone. These recent changes have altered not only the structure of the economy, but also its geography.

Chapter 6 on the peninsula's water system was produced by two local experts who for years have been actively involved in water analysis and water management. Due to its karstic soil, there is essentially no surface water (lakes or rivers) on most of the peninsula. There is access to the groundwater only in places where the rock has broken and water holes, or cenotes, have opened. In the past, human settlements on the peninsula were only possible because of these cenotes. As the chapter also indicates, the geomorphology of the groundwater system is dominated by a semicircle of cenotes resulting from the crater of the huge meteorite explosion discussed above.

The second part of the report defines and calibrates intersectoral models on specific relevant issues. It has been edited and greatly inspired by Warren Sanderson, who leads the modeling components of all IIASA PDE projects. For reasons outside the influence of IIASA and its primary partner on the Yucatán (CINVESTAV, Universidad Mérida), funding for this project ended before the actual modeling phase could begin. Thus, this part of the report was produced under especially difficult conditions. For this reason, we did not have the opportunity to produce the full and comprehensive model, in which, according to our plan, the different components could be run at different levels of aggregation and which also would have had a stronger policy component than is currently the case. Instead, individual participants in the project (essentially working with no budget) produced different compatible subcomponents of the planned larger model that use the same software and address four key issues for the future of the Yucatán peninsula.

Chapter 7 operates at the level of the SERs defined in Chapter 2. Using the multistate population projection methods developed at IIASA during the 1970s, alternative future population projections by age, sex, and educational attainment have been produced for all the regions. This in itself is of great interest and goes far beyond what has been produced so far in terms of population or social structure projections for the peninsula. But these population projections also are essential input variables for the other models, which look at the peninsula's environmental and economic dynamics.

Chapters 8 and 9 single out two specific but highly interactive and dynamic issues, namely, tourism and fisheries. The chapters illustrate how population–environment modeling can go beyond traditional, more descriptive analysis and teach us some interesting new lessons.

Chapter 10 models past and future land-use changes on the peninsula. These changes, which are driven by demographic, economic, and political factors, have implications for many agricultural and environmental issues. Because land-use change tends to happen very slowly and in many instances is considered irreversible, it represents a major factor in the assessment of the future sustainable development options of the Yucatán peninsula.

Conducting this multidisciplinary, multi-approach project with a very long time horizon has been an exciting and rewarding experience. It has been good to see how well a heterogeneous group of people with very different national and disciplinary backgrounds can work together on one project. The constructive collaboration between scientists at CINVESTAV and at IIASA continued throughout, despite various financial and other hurdles. This project received partial funding from the UNFPA.

We hope that the reader will find the interactions between the peoples and environments of Yucatán, both over the past centuries and into the future, as interesting as we found them over the course of our studies.

Reference

Lutz, W., ed., 1994, *Population–Development–Environment: Understanding their Interactions in Mauritius*, Springer-Verlag, Berlin, Germany.

Part I

The Evolution of Yucatán

1

Social and Environmental Factors in the Classic Maya Collapse

William J. Folan, Betty Faust, Wolfgang Lutz, and Joel D. Gunn

1.1 Introduction

Human habitation of the Maya area dates to the Pleistocene. At that time, mastodon, bison, felines, deer, and horses were hunted or trapped by populations living in areas near the Cave of Loltun in the northern Yucatán peninsula (Velázquez Valdéz, 1980). When large Pleistocene mammals disappeared as a result of climate change and overexploitation, these pre-ceramic hunting and gathering societies settled in riverine and coastal areas where large quantities of food were available. Possibly as far back as 3500 B.C. or more, these populations began supplementing their diet with domesticated edible plants, including corn, (Pohl *et al*., 1998; A. Siemens, personal communication, April 1999). These and other plants later became the mainstays of the traditional Maya diet, augmented by birds, fish, mollusks, and smaller mammals, by tubers and fruit including ramon (*Brosimum alicastrum*), zapote (*Manilkara zapota*), nance (*Byrsonima bucidaefolia*), plums (*Cordia sebestena*), and by other items where and when available (Folan, 1979). This settled lifestyle combined with a population increase that necessitated new concepts of territorialism as well as religious and scientific advances associated with more complex forms of sociopolitical organization.

During the Early Preclassic (2000–1000 B.C.), complex societies like the Maya and Olmec were still in the process of establishing urban infrastructures. These groups of ceramic-producing, village-dwelling horticulturists fished, hunted, and collected seafood and other consumables along the Pacific Coast (Coe, 1961; Clark and Blake, 1989) and near the central coastal lowlands at Colha in present-day Belize (Hester *et al*., 1996). The appearance of early, settled forms of human culture is not surprising given recent discoveries of earthen mounds across the Gulf

The authors are grateful to Betty J. Meggers for helpful comments and to the International Institute for Applied Systems Analysis for financial support.

of Mexico in Louisiana dating from some 5,000–6,000 years ago (Saunders *et al*., 1997).

By the Middle Preclassic (1000–600 B.C.) large, early manifestations of chieftainships appeared among the Olmec of Tabasco, Mexico, as well as among what may have been Maya-speaking people inhabiting the middle Grijalva River of Chiapas (Lowe, 1989). Middle Preclassic sites in the Central Peten in places such as Calakmul in Campeche (Domínguez Carrasco, 1994; Folan *et al*., 1995) and Nakbe and Tintal in Guatemala (Hansen, 1996) indicate large civic and ceremonial communities grouped together in what appears to have been an early form of urban organization headed by powerful civic and religious leaders, as has been suggested for Preclassic San Lorenzo in the Mexican state of Vera Cruz (J. Clark, personal communication, 8 February 2000).

Evidence from the Late Preclassic (600 B.C.–A.D. 250) is most abundant at Calakmul and El Mirador, where some of the largest structures in the Maya area and in Mesoamerica were raised. Around the beginning of the Common Era, these civic and religious manifestations developed a triadic architectural form that reflects the origins and development of the population's sociopolitical organization, including a royal court that endured until the early part of the 20th century with the Chan Santa Cruz Maya (Dumond, 1997; Folan *et al*., 2000). This triadic organization included dynastic societies with some form of divine king (*ahau*), a governor (*halach uinic*), and a principal military commander (*yaxbatab*) that favored the civic, military, religious, and productive factions of the society. The concept of the *ahau*'s speaker or *ahaucan* apparently came later (Folan *et al*., 2000; Gunn *et al*., 2000a).

There is considerable evidence that large regional centers dating from the Early Classic (A.D. 250–600) still existed in Calakmul and Tikal after the fall of El Mirador. These centers included a large number of early sculptured stone monuments (stelae) accompanied by hieroglyphic texts focusing on leadership, family, warfare, and calendrics (Marcus, 1987; Pincemin Deliberos *et al*., 1998). Evidence of more complex social organization can be found in the contents of these dynastic texts, in the elaborate stucco-decorated palaces, and in the construction of large religious structures, at times taking on a quadrilateral architectural form. There is now more evidence of a state organized into four levels including its regional center (Marcus, 1974, 1976), associated not only with demographic growth but also with the expansion of major tributary centers and related hamlets founded during the later part of the Late Preclassic (Domínguez Carrasco *et al*., 1999; Folan *et al*., 1999).

An increase in the number of hamlets during the Early Classic and major urban centers during the Late Classic (A.D. 600–900) provides evidence of a rise in population levels, apparently associated with improved climate conditions, especially during the latter period. This population increase was reflected in great building projects at Caracol in Belize, at Tikal in Guatemala, and at the more northern sites in Mexico such as Calakmul, Coba, Chichén Itzá, Uxmal, Izamal, and Ichcansiho (present-day Merida). During this period there was a profusion of hieroglyphic texts in Calakmul, with over 118 stelae, as well as in Piedras Negras on the Usumacinta River in Guatemala and in Palenque, Chiapas, Mexico. Around A.D. 800, however, there was a decrease in development, including a decline of dynastic texts, probably due to the onset of adverse climate and accompanying demographic shifts (Folan, 1981; Gunn and Adams, 1981; Gunn *et al*., 1994, 1995). Some recent lake cores appear to confirm a deteriorating climate (Hodell *et al*., 1995), although conflicting core trajectories need to be resolved. Demographically, populations began to abandon the interior of both the Maya Lowlands (Folan *et al*., 2000) and Kaminaljuyu in the Maya Highlands (Valdés and Popenoe de Hatch, 1995). In Calakmul (Domínguez Carrasco *et al*., 1999; Folan *et al*., 2000) and Copan, Honduras (Braswell, 1997), populations retreated into the urban centers before finally abandoning these sites and moving toward the coasts, interior lagoons, rivers, and in some cases cenotes and wells. The latter two are adequate for daily water consumption but apparently not for horticultural activities. In the north, the majority of the Maya population encountered by the Spanish was concentrated along the coast in Tulum, the trading center of Chauaca on the northeast coast of Yucatán, in present-day Campeche (known then as Ah Kin Pech) and Champoton, as well as up the Candelaria River at El Tigre (Pincemin Deliberos, 1994; Vargas Pacheco, 1999). Only small populations were encountered in large centers like Chichén Itzá, Ichcansiho, and Izamal. The Itzá, formerly of Chichén, were encountered by Hernan Cortes on an island in Lake Tayasal in 1525, but were not conquered until 1697.

Since the Conquest, the Maya area has experienced periods of growth and decline, often related to changing climate conditions affecting large parts of the indigenous population through famine and associated disease (Farriss, 1984; Gunn *et al*., 2000b). In spite of these difficulties, it would appear that Maya culture, including its sociopolitical, military, economic, and religious organization, was still present in Noh Cah Chan Santa Cruz and Tulum up to the beginning of the 20th century (Folan *et al*., 2000). As we enter the 21st century, these sociocultural concepts still form the cultural memory of many Maya of Quintana Roo and elsewhere, acting as a unifying force for their well-being and continued development.

As concern increases over potential negative impacts of global environmental change and the rapidly expanding world population, scholars have started to look back into history for possible cases in which highly developed urban civilizations have collapsed (Thomas, 1956; Tainter, 1988; Bates and Plog, 1991; Crumley, 1994). These efforts are partly driven by the hope that understanding past collapses may help to prevent the future collapse of our own society. It is not surprising that the literature on possible impacts of global change often refers to

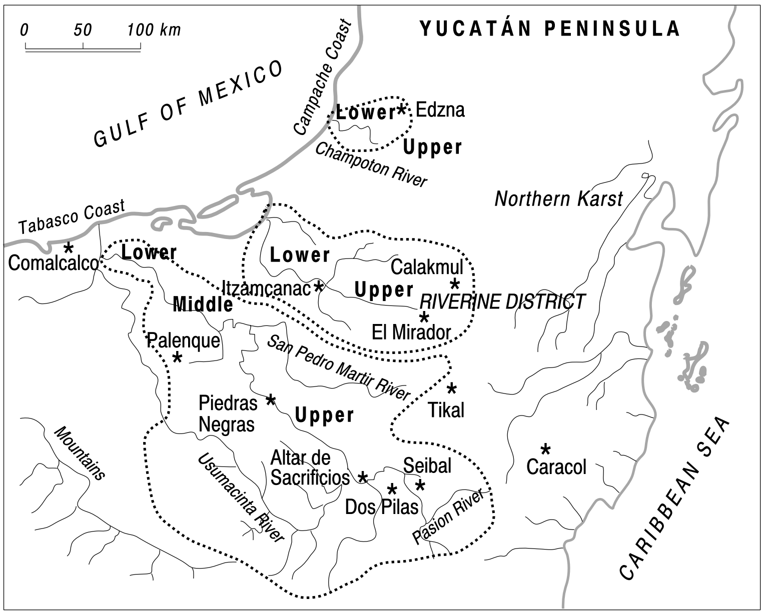


Figure 1.1. Sites and pertinent river basins of the Maya area. Source: Gunn and Folan, 1996.

past collapses, most frequently to those of the Roman Empire and Classic Maya Civilization (Adams and Smith, 1977; Antonio, 1979; Lowe, 1985).

Any comparative analysis requires a definition of "collapse." Large civilizations have risen and declined throughout human history. For many, however, military conflicts ending in defeat and gradual infiltration by new cultures can be identified as the proximate reasons for decline, but not necessarily collapse. The southern Maya lowlands (the southern Yucatán peninsula plus neighboring areas, see *Figure 1.1*) suffered the simultaneous abandonment of almost all cities and regional states and the failure of the population to rebound. The rare exceptions were near the few natural lakes and rivers, where Europeans encountered indigenous populations during the 16th, 17th, and 18th centuries in places such as Tayasal and the Petén region of Guatemala (Rice, 1987). Estimates for the southern Maya lowlands suggest that by A.D. 1000, the population was only about 20% of its A.D. 700–800 peak in cities such as Calakmul in Campeche (Fletcher *et al.*, 1987; Santley, 1990; Folan *et al.*, 1995).

As the south was collapsing, the north was undergoing a cultural florescence, reaching its apogee around the 10th century. After that time, construction was reduced in Chichén Itzá, which had partially overlapped Terminal Classic Puuc period sites such as Uxmal (Folan, 1977:18; Folan, 1998). The center of power shifted to the walled city of Mayapán with an urban population estimated at 12,000. These northern centers participated in a complex system of political alliances (with intermittent warfare) and long-distance trade until the mid-1400s, when the area fractionated into a number of independent political regions (Okoshi Harada, 1999; Quezada, 1997, summarizing reports by the Spanish). Despite political differences, long-distance canoe trade continued until the Spanish Conquest. It extended from the coast of what is now the Mexican state of Tabasco in the west, around the Yucatán peninsula to Cozumel Island off the east coast, and south at least as far as Honduras (Sabloff, 1990). It probably also extended north along the east coast of Mexico, although detailed investigations remain to be made in that area.

The Spanish explorers and conquerors arrived with previously unknown diseases and various species of plants and animals new to the Americas. Some of these introductions caused massive epidemics, serious degradation of many ecosystems, and loss of many endemic species that could not compete with the exotic species introduced from the Old World (Crosby, 1972, 1986). The Maya population again suffered a precipitous decline, this time to only about 2% of its Classic period peak (Santley, 1990).

The mystique of ancient cities discovered abandoned in the jungle – Copán, Palenque, and Tikal being the most famous – has aroused speculation since scientific studies of the Maya began. The public's impressions of the Maya were first formed by John Lloyd Stephens (1841, 1843), whose travel books included excellent illustrations of the ruins by Frederick Catherwood. Connections between the people who created these cities, those encountered by the first Spanish explorers, and even those of today's small villages on the Yucatán peninsula were not initially understood – and still are not, despite decades of documentation by anthropologists of continuities in Maya culture for highland Guatemala, Chiapas, Belize, northern and coastal regions of the Yucatán peninsula, the lake region in the Guatemalan Petén, and parts of San Salvador and Honduras. The visual impact of ruins of ancient cities in the middle of an uninhabited jungle continues to impress tourists and producers of mass media and their audiences.

Although some archaeologists now consider the Maya collapse to have been confined to parts of the region, the very large population declines and nearly complete abandonment of some centers continue to intrigue and puzzle scholars. The list of potential internal and external factors contributing to the collapse is long. Sharer (1994:343–348) singles out the most important ones, namely, volcanism, earthquakes, hurricanes, epidemic diseases, overplanting, overshooting carrying capacity, climatic change, internal revolt, economic collapse associated with trade, competition among polities, reduction of soil fertility, and, finally, beliefs in predetermined cycles (or "suns"). None of these explanations has been substantiated to the exclusion of others.

During the 1970s, the hypothesis that the Maya collapse resulted from overshooting carrying capacity due to excessive population growth (Wissler, 1923; Culbert, 1974:116) attracted the attention of ecologists stressing Earth's limited carrying capacity and looking for historical examples of their point (see Catton, 1982). Under this view, the collapse of various ancient civilizations is evidence that human populations can grow beyond the limits of what can be sustained in the long term, in which case their collapse would be inevitable. This view implies that technological innovation cannot be depended upon to rescue a population that has grown beyond the limits of its resources. Other examples include Hay Hollow Valley (Zubrow, 1972), Easter Island (Young, 1993), and the Viking colonies in Greenland and Iceland (McGovern, 1994). Antonio (1979) has attributed the fall of Rome to overuse of soils associated with population growth. Meggers (1954) analyzed the relationship between environmental factors affecting agriculture and cultural processes of development and decline, concluding that there is a "Law of Environmental Limitation on Culture ... (such that) the level to which a culture can develop is dependent upon the agricultural potentiality of the environment it occupies." Analyzing the existing archaeological data, she concluded that attempts to expand dense human populations (required for the support of full-time specialists and complex social organization) into areas unsuited for intensive agriculture resulted in a gradual degradation of agricultural capacity, necessarily producing a decline in population size and cultural complexity (Meggers, 1954:817–821). Whether this decline occurs rapidly or over centuries depends on both the environmental factors sustaining agriculture (soils, heat, humidity, rainfall, slope, soil moisture, remaining forest, etc.) and the cultural factors affecting both population growth and selection of known technologies (Meggers, 1954:820–822). An apparent exception is modern civilization, in which dense populations live in marginal areas supplied with food by modern transportation and storage systems (Meggers, 1954:814).

The counter-hypothesis to internally produced overshooting of carrying capacity is that external factors triggered the collapse. Rapid climate change on a continental scale (not just changes in the microclimate that could be induced by deforestation) is the most obvious external factor. This chapter examines the evidence that significant climatic change provoked the Maya collapse. If such evidence can be found, it will substantially increase the complexity of the carrying-capacity argument. Carrying capacity is always dependent on the interaction between given techniques of procurement/production and the set of raw materials selected by a species to fulfill its survival needs. In the case of human beings, neither techniques nor raw materials are selected by genetically programmed behavior; therefore, the carrying capacity depends on cultural priorities as well as available subsistence resources, many of which in turn require certain environmental conditions for their productivity. Thus, if a change in climate reduces the availability of those items culturally selected to provide survival needs, then in stratified societies the struggle for status can inhibit the adoption of techniques and resources that would solve survival problems. As McGovern has pointed out, this can provoke a demographic collapse:

> [I]t is clear that Norse Greenland did not perish . . . devastated by the Little Ice Age. Instead, they starved in the midst of unexploited resources, with a working model for maritime-adapted northern survival camped on their doorsteps (that of the indigenous Innuit). The death of Norse Greenland was not caused by Nature, but by culture. After all there is no lasting advantage to managing your own society so you have the privilege of starving last. We may assume that the managers of Norse Greenland did not intend the outcome that resulted from their self-serving, short-term choices. [McGovern, 1994:148]

1.2 What Do We Know About Maya Population Trends in the First Millennium A.D.?

Much has been written by archaeologists on population patterns during the Classic Maya period. A book entirely dedicated to this topic was published in 1990 (Culbert and Rice, 1990). The population information is not, however, the kind that demographers expect. First of all, the studies tend to be specific to certain archaeological sites; second, they are based on the number of structures assigned to specific periods.[1] The proportion of structures actually occupied by households at a given point in time and the average number of persons living in a household have to be derived in another way. The standard procedure for estimating rural population densities is the so-called house-count method (see Turner, 1990:304). The equation used to estimate the total population size (POP) in a defined area at any point in time (t) requires an informed guess concerning the number of structures occupied at a specific point in time [OcStruct(t)] and the average number of occupants per structure, that is, household size for the same period of time [HHS(t)]:

$$\mathrm{POP}(t) = \mathrm{OcStruct}(t) * \mathrm{HHS}(t)\ , \tag{1.1}$$

where

$$\mathrm{OcStruct}(t) = \mathrm{Struct} * \mathrm{Prop}(t) * \mathrm{OcRate}(t) * \mathrm{DwellRate}(t)\ , \tag{1.2}$$

where “Struct” refers to the total number of independent structures counted at a specific archaeological site, Prop(t) represents the number of structures that date to a certain chronological phase of occupation, “OcRate” indicates phase occupancy rate (i.e., the proportion of time that structures were occupied during that phase), and "DwellRate" is the proportion of all occupied structures that were actually used.

Archaeologists and demographers use this equation to estimate changes in population size and density for specific areas by assuming parameter values that cannot be directly inferred from the evidence. Most problematic seem to be the determination of which structures were dwellings (versus storage buildings or kitchens), the average household size, and both the chronology and seasonality of occupation. Most estimates use the figure of 5.6 persons per nuclear residence, derived from ethnohistoric (Santley, 1990:331) and ethnographic documents (Folan, 1969; Folan *et al.*, 1983b). However, there are examples where the modal estimate per house is much higher (Ringle and Andrews, 1990; McAnany, 1990). Another problem is the number of mounds that functioned as habitation structures. Some research suggests that at least 40–50% had functions other than residence (Folan, 1975; Folan *et al.*, 1983b; McAnany, 1990; Ford, 1995; Fletcher *et al.*, 1987; Fletcher and Gann, 1992), which is higher than traditionally assumed. The methodology developed by Folan (1975), based on the demographics of the modern village of Cobá, in Quintana Roo (including public buildings and abandoned houses as well as those dedicated mainly to culinary activities and storage), rectifies some of the problems.

Faust has found indications in oral histories of cyclically reused hamlets (*rancherías*) associated with swidden fields owned by patrilineages and located near natural sources of groundwater, which were sometimes modified to enlarge their capacity.[2] These hamlets ranged in size from 2 or 3 families to 10 families, depending on the availability of cultivable land and the size of the patrilinage. The average size is said to have been around 5 families (some nuclear, some extended). Before government schools, clinics, electricity, and household water supply systems were provided to the towns, whole families lived in these hamlets during the agricultural season, returning to town in December for the beginning of the six-month dry season. Thus, housemounds in sustaining areas of pre-Columbian cities could represent seasonal hamlets occupied only during the agricultural season, with their residents returning to urban homes for the remainder of the year. The swidden cycle described by the village elders of Pich has a long fallow: 20 years, following two years of use. Each farmer would reuse the same swidden field only twice in his adult life (over 60 years) and would require 20 different fields of 2 hectares (ha) each, as each year 2 ha would be planted in low areas and 2 ha in high areas. Thus one has to use four different 4-ha plots for two years each during a total of eight years or 16 ha for eight years. Multiplying 16 ha times the average total of five families in a *ranchería* gives a total of 80 ha of land used during an eight-year period. As areas that are too rocky or water-logged for agriculture constitute approximately one-fifth to one-third of all land, each *ranchería* would need 100–120 ha to supply

80 ha of cultivable land. Thus this system would require 1–1.2 square kilometers (km^2) to sustain a typical hamlet of five households, averaging 5.6 persons each for a total of 28 persons, giving an average density of about 25 persons/km^2. After eight years, the first plots used would have been fallow only 6 years and would require another 14 before replanting. Therefore, the community would find it necessary to move to a new *ranchería* site. Thus the number of such *ranchería* sites that a single nuclear family would use during the domestic cycle of 35 years would have been roughly 35 divided by 8 years on each site, or about 4.5 sites per family. The number of years of residence at each site would depend on the quality of surrounding land (the proportion of cultivable land) and the size and number of the *ranchería* households, the latter in turn related to the available water supply for domestic use. In the area surrounding Pich, Campeche, there are many *aguadas*, ponds with clay bottoms typically found at the foot of ridges (some of which were enlarged and lined with stone and lime mortar by the ancient Maya; see Faust, 1998:77–87, for a review of the literature). In contrast, the *rancherías* of Sahcaba, Yucatán, were typically limited to two or three families by the very restricted water supply in nearby *sartenejas* (shallow concavities in the surface limestone that hold water for a few days at a time during the rainy season).[3]

If each family occupied a dry season home in town plus four different *ranchería* sites during its domestic cycle (the adult lifetime of the parents), then each family owned five homes during its domestic cycle. According to village elders in Pich, Campeche, and Sahcaba, Yucatán, ceramics and furniture were never carried to the agricultural hamlets; people lived more "rustically," using *jicaras* (gourds) for food containers, tortillas for spoons, stones for chairs, and hammocks for beds – most of which are rapidly biodegradable. Thus, *rancherías* could easily escape the notice of Spanish authorities insistent on permanent residence in supervised towns, while archaeologists may have mistakenly identified relics of earlier *rancherías* as permanent residences of a rural population that sustained Classic-period cities. If Faust's ethnohistory of seasonal and cyclical *ranchería* use is substantiated for the Classic period, then a large proportion of dwellings must be discounted for the purposes of estimating population density (in addition to the discounting of those buildings considered kitchens and storage houses; Folan *et al*., 1983b).

Abrams' (1994:106) analysis of labor needs in the construction of ceremonial buildings indicates that the populations may not have been as large as previously thought. A population of 25,000, including both the urban area and the periphery, would have supplied enough labor to build the ceremonial buildings at Copán, with each adult male required to contribute only 180 days to the state during his lifetime, or three dry seasons' labor at 60 days per season. Abrams compares this with estimates of 900 days of tribute labor provided by the average Chinese in the Han dynasty (206 B.C.–A.D. 220). Faust suggests that limits on the use of Maya labor may not have resulted solely from the culturally preferred forms of political organization, but also from transportation costs. Maya city size may have been limited by the need to use humans for the transport of basic grains. Aztec canoe transport on the lakes of Tenochtitlán would have been more efficient than foot transport on the Maya *sacbeo'ob* (as roads made of stuccoed-over limestone rock beds) in the interior of the peninsula. The radius of a supporting hinterland from which food could have been efficiently transported (so that the caloric costs of transport did not exceed the calories transported) would have limited the size of the city being supported. Cities near the coast would be less limited due to the facility of coastal canoe transport. Coastal cities, however, never reached the size and importance of the largest interior cities.

An additional problem with population estimates in actual archaeological work is that it is very difficult to date a structure to a specific period of time shorter than, for example, the Early or Late Classic, Terminal Classic, or Postclassic. Visibility of structures is related to the thickness of the earth overburden.[4] For example, in a place like Dzibilchaltún, Yucatán, where bedrock is more visible than at Calakmul or Cobá, there is the possibility of recognizing more stone habitation foundations, which are often only 20–30 cm high (or less), than in other sites to the south and east.

The results of these population reconstruction efforts are typically presented in the form of a chronological chart that gives current population size as a fraction of the maximum population calculated for any period. *Figure 1.2* shows that in all Maya regions a population peak was reached around A.D. 700–800 and was followed by a precipitous decline. Since these estimates are site- or at least region-specific and there are marked regional differences, it is very difficult to derive estimates for the whole Yucatán peninsula. Some of the best data are for the south-central Maya lowlands, including Tikal and other sites in the Guatemalan Petén, neighboring parts of Belize, and the Mexican sites of Calakmul and Cobá.

In overview, population reconstructions for the Maya lowlands show that the Maya could have been a full-blown agricultural society by about 3000–2000 B.C. (Hammond, 1986). However, most published house counts provide an inception no earlier than 1000–300 B.C. (Turner, 1990). Estimated population density around 300 B.C. is 15 persons/km^2, falling to about 4 persons/km^2 at the end of the pre-Columbian period, A.D. 1500 (Turner, 1990). Between these two points, there was at least one dramatic wave of population growth and decline during which rural population density may have approached 150–200 persons/km^2 (Culbert, 1988). In the Rio Bec region, it may even have reached 280 persons/km^2, supported by terraced fields (Turner, 1990). Adams *et al*. (1997) suggest a still higher figure of 510 persons/km^2 for the Three Rivers region in what is now the frontier between Belize and Guatemala. Most site centers are estimated to have had population

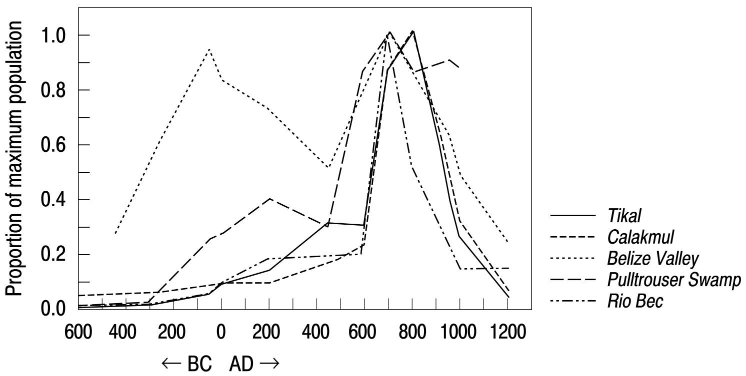


Figure 1.2. Demographic history of various southern Maya sites (estimates interpolated from raw data). Source: Santley, 1990:342.

densities of between 500 and 800 persons/km^2 [see also Adams and Jones (1981), more or less in agreement with figures from Fletcher *et al*. (1987), Fletcher and Gann (1992), and Folan *et al*. (1995) for the Late Classic period in Calakmul].

These are incredibly high population densities by any standard, but especially for a rural, preindustrial subsistence economy operating on variably fertile soils. They imply greater population size and density on the Yucatán peninsula in the Classic period than today, despite the recent "population explosion" due to declining mortality and still very high fertility plus immigration from other parts of Mexico into new tourist areas in Quintana Roo.

Figure 1.3 gives the estimated population growth rates for the south-central Maya lowlands (taken from Santley, 1990), which show an explosion between A.D. 600 and 700, the middle of the Classic period. Average annual growth rates were on the order of 1.5% throughout that century. All other regions in the Maya lowlands seem to have followed this trend, although with somewhat moderated growth rates (Turner, 1990). It is unclear what caused this prehistoric "population explosion." Santley (1990) suggests that it may have been the adoption of new systems of wetland agriculture, something for which there is little or no proof. In contrast, there is solid evidence for intensive Preclassic (1500 B.C.–A.D. 250) wetland agriculture from sites in both Campeche (Siemens and Puleston, 1972; Matheny *et al.*, 1983) and Belize (McAnany, 1989; Pohl *et al.*, 1996), indicating that such systems were well known in the Maya world centuries before the population explosion. Recent analyses of climate fluctuations indicate that optimal conditions for upland horticulture may have precipitated that growth (Gunn *et al*., 1994, 1995; Hodell *et al*., 1995; Fialko-Coxeman, 1997).

The famed regional depopulation (and civilization collapse) began after A.D. 750. For the period A.D. 750–1000, depopulation rates of more than 0.6% per year

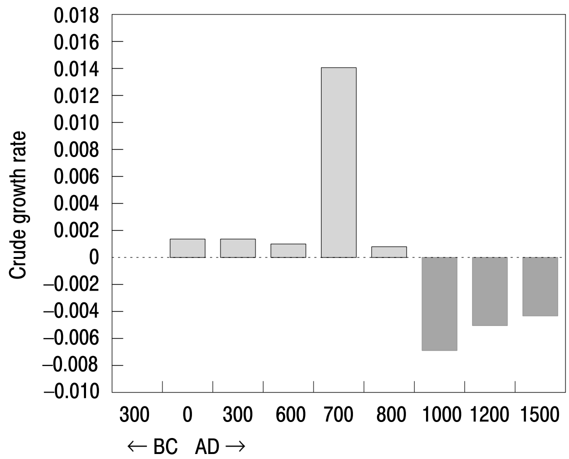


Figure 1.3. Crude population growth rate for the south-central Maya lowlands. Source: Santley, 1990:343.

were estimated by Santley (1990; see *Figure 1.3*). Archaeologists have not discovered mass graves that might reflect epidemics or warfare. Marked site-specific differences in the timing of the decline may indicate that migration flows were elevated during that period. There is no empirical evidence regarding possible changes in fertility. However, skeletal remains show pathology attributable to progressive nutritional disease (Folan and Hyde, 1985; Sharer, 1994:344), which could be expected to reduce both fertility and the viability of offspring. Wilkinson (1995) has suggested that the Maya collapse could have resulted from a yellow fever epidemic migrating north from Brazil, where there is some evidence for an endemic variety of the disease. His conjecture is based on a Maya pattern of demographic decline similar to those reported where yellow fever spread to other populations with no previous exposure; however, there is no direct archaeological evidence for the Maya area.

1.3 What Do We Know About Changing Climatic Conditions During the Classic Maya Period?

As there is strong evidence that climatic change has played a major role in the collapse of other cultures, for example, the collapse of the Pueblo cultures in the American Southwest around A.D. 1150 (Euler *et al.*, 1979), it has been a prime candidate among the hypotheses offered to explain the Maya collapse (Folan, 1981; Gunn and Adams, 1981; Folan *et al.*, 1983a, 1983b). The rationale has been that high population density made Maya civilization vulnerable to a decline in rainfall.

Counterarguments, mostly based on indirect evidence, assert that one would expect a decrease to most seriously affect the relatively arid north, whereas it was first felt in the more humid southern margin (Lowe, 1985). Hence Huntington (1913) concluded that the opposite must have occurred, that is, that rainfall increased during the Terminal Classic period, bringing prosperity to the North, while the South suffered from the luxuriating vegetation. This hypothesis fails to explain the differential distribution of the collapse in the southern zone (Rice, 1987), where population densities remained highest around lakes and rivers – precisely where rain forest would have been thickest. Analysis of regional wind patterns associated with rainfall suggests that a climatic band favorable for corn agriculture moved from south to north in response to global temperature shifts (Gunn and Adams, 1981; Messenger, 1990; Gunn and Folan, 1996).

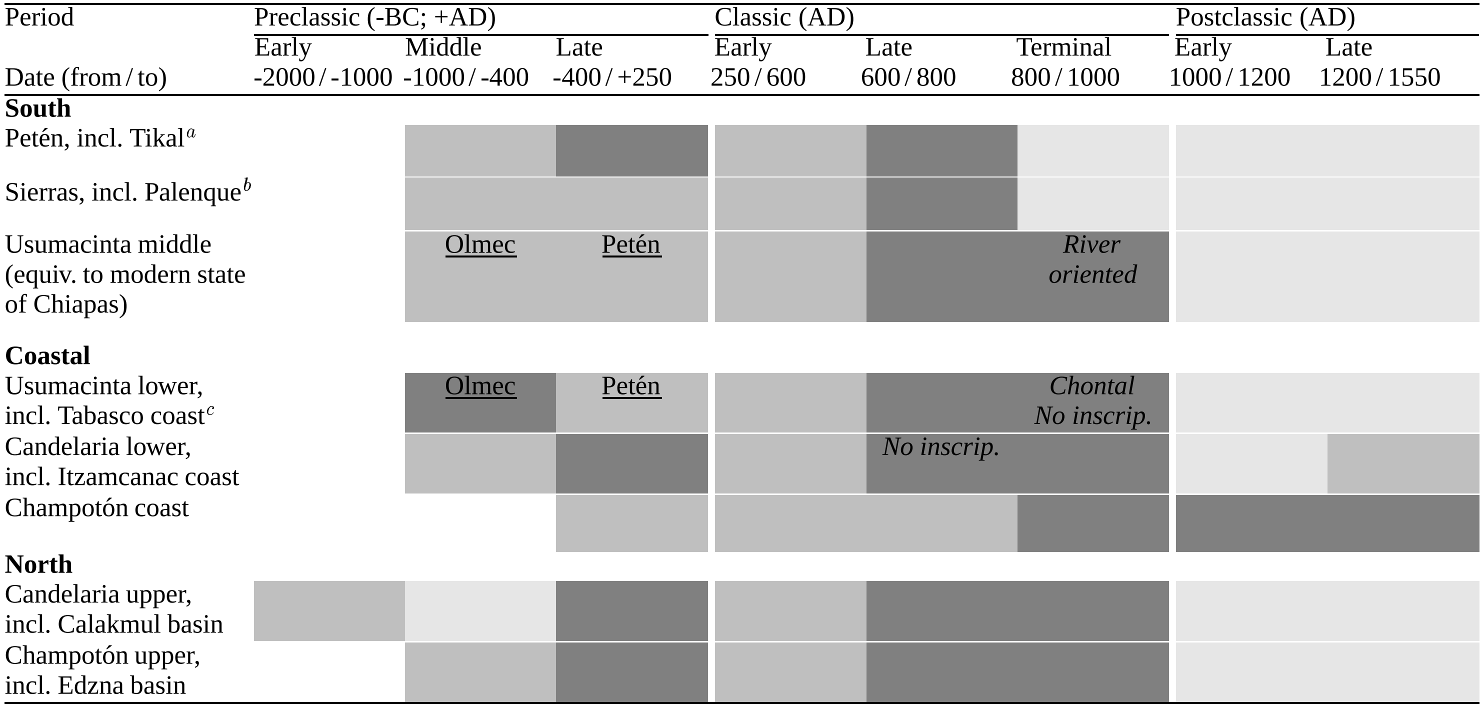
Attempts by Gunn and Folan (1996) to identify a possible climatic cause from the geographic patterns of the Classic Maya collapse have been encouraging (*Figure 1.4*). Further corroboration

> has already begun in the Yucatán peninsula with Fialko *et al.*'s (1998) study of the central Petén, which shows that elements of the Gunn *et al*. (1994, 1995) model are applicable there, and [research] is currently being extended into the Guatemalan Highlands. Eventually intra-regional studies should yield variations and serendipitous elaborations of the original models. [Gunn, forthcoming:22]

Other recent studies have provided direct evidence of climate change. One indicator is the age analysis of sediment cores from Lake Chichancanab on the central Yucatán peninsula (Hodell *et al*., 1995); another is extrapolated analysis of covariance between the discharge of the Candelaria watershed in southern Campeche and the Global Energy Budget (Gunn *et al*., 1994, 1995).

Hodell *et al*. (1995) used temporal variations in oxygen isotope and sediment composition in a 4.9-m sediment core from Lake Chichancanab to reconstruct a continuous record of Holocene climate change for the central Yucatán peninsula. This record shows that the interval between 1,300 and 1,100 years B.P. (A.D. 800–1000) was the driest period of the middle to late Holocene. This evidence is compatible with low lake stands in Central Mexico and increased fires in Costa Rica. The data plotted in *Figure 1.5* also show that the driest climate conditions reached a maximum value at 1,140$\pm$35 years B.P. Since the dating of peak aridity is based on radiocarbon analysis of a single seed taken from 65 cm deep in the core, it must be interpreted with caution.

Gunn *et al*. (1994, 1995) previously used a different method for reconstructing humidity in Yucatán during the Late Holocene. Monthly measurements of water discharge from the Candelaria River were compared with the annual mean temperature of the Northern Hemisphere between 1958 and 1990. A significant correlation



[a] Also includes Dos Pilas, Aguateca, Altar de los Sacrificios, and Seibal (the Petexbatun). [b] Also includes Sierra del Norte de Chiapas. [c] Also includes San Pablo and San Pedro, and Palizada Rivers, Xicalanco pen., Comalcalco, El Pájaro, Allende, El Encanto, Oaxaca, and Jonuta.

Low / Decline: No evidence or little evidence of construction or aggregated populations.

Active: Substantial evidence of construction and population aggregation.

Heavy: Very substantial evidence of construction and / or population aggregation.

No Information.

Note: Influences from other subregions are underlined; other observations on influences are italicized.

Figure 1.4. Chronology of southwestern Maya lowland subregional cultural activity. Adapted from Gunn and Folan (2000).

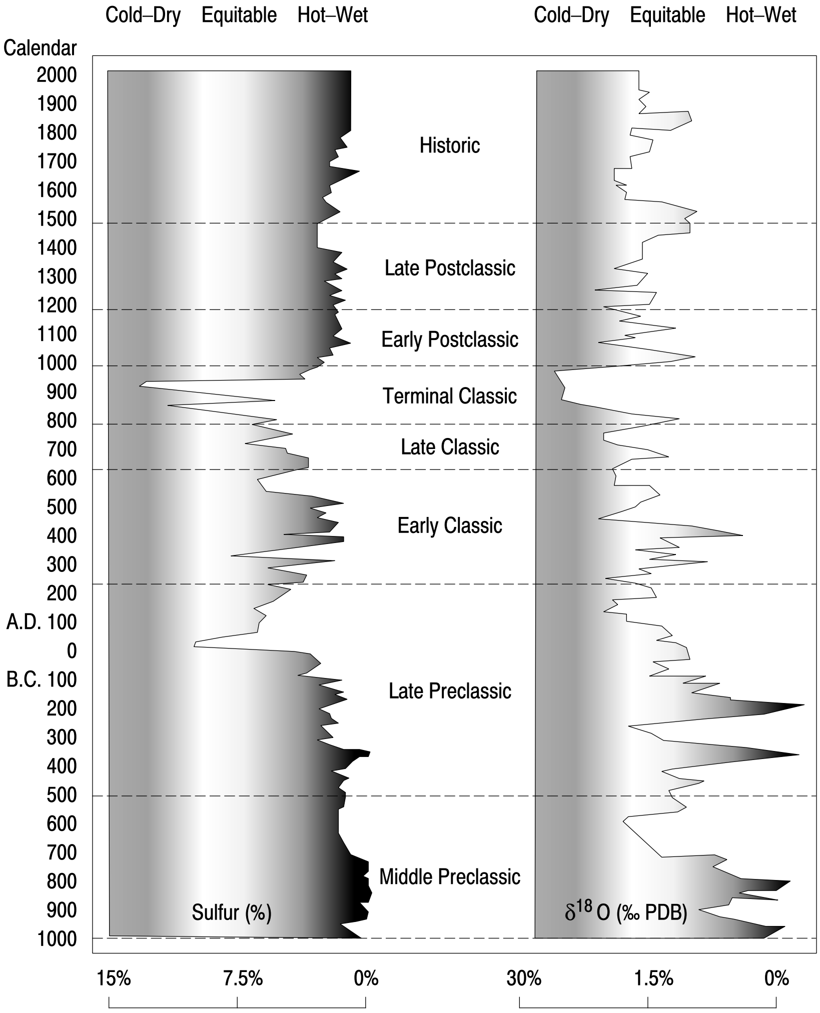


Figure 1.5. Climate conditions during the last 3,000 years as measured by sediment core chemistry from Lake Chichancanab, northeastern Yucatán peninsula. High sulfur (left) and ostracod oxygen 18 isotope (right) during the Terminal Classic and other periods indicate extreme evaporation or drought. Maya civilization appears to have flourished during equitable (center of each profile) episodes, and periodically retracted during periods of extreme drought (left of each profile) or moisture (right of each profile). Source: Gunn *et al*., 1994, 1995; Chichancanab chemistry adapted from Hodell *et al*., 1995:393.

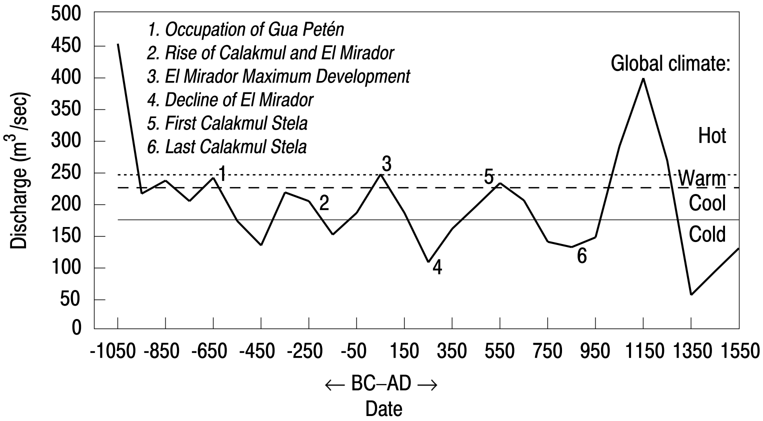


Figure 1.6. Estimated Candelaria River discharge (m^3/sec) for the Late Holocene. Source: Gunn *et al*., 1995:30.

was established between the duration of the dry season in the Candelaria basin and the Global Energy Budget. The highest growing-season discharge correlates with hot conditions. During warm and cool conditions, less discharge occurs. Cold conditions provide the least growing-season discharge. Intermediate global temperature correlates with optimal wet/dry season combinations. Hence, agricultural productivity is related to global climate through the intervening mechanisms affecting seasonality of moisture. A regression model reflecting these findings can be used to retrodict paleohydrology for the past 3,000 years (see *Figure 1.6*). The model indicates that favorable agricultural conditions occur with an optimal balance between wet- and dry-season durations, and that catastrophes develop during extended wet or dry periods, or periods of climatic instability. The authors conclude that the southern Maya lowlands have had a record of precipitous urban development and collapse in part because of complex interactions between global climate and upland horticulture of the type described above. The timing of our estimated climatic changes (*Figure 1.6*) fits the archaeological chronology of the rise and decline of Maya settlements and has been corroborated in subsequent empirical analysis by Hodell *et al*. (1995), although they did not detect an otherwise well-documented period of considerable drought around A.D. 250.

1.4 By What Mechanisms Could Climate Change Affect the Population and Trigger the Collapse?

Climatic change would have affected the population in various ways in different regions. In the northern Petén, no adequate quantities of groundwater exist except lagoons and *aguadas*, which would have gone dry without sufficient rainfall (Domínguez and Folan, 1996; Folan *et al*., 1995), forcing the population to move elsewhere.[5] In a hilly region of northern Campeche named for its wells (the *Chenes* in Maya), a lower water table would have dried up shallow wells. The deeper cenotes farther north and the *ojos de agua* (freshwater springs) along the coasts would not have been capable of supporting a state-level or urban population of even moderate size, given the humidity requirements of an adequate agricultural or horticultural base.

In the case of the Classic collapse, what happened probably varied from place to place. In the Petén, decreased rainfall may have provoked an increase in the amount of land planted from year to year, perhaps in the form of larger *milpas* in an attempt to harvest sufficient grain for survival at a lower per hectare yield. According to the pre-Columbian and colonial Chilam Balams (histories written in the Maya language by the priest Balam [Jaguar] using Spanish script; Folan and Hyde, 1985), during times of need urban dwellers would leave the city, possibly for field habitations around a major population center or even for a hamlet next to a permanent water source, probably preferring areas where relatives lived (as Faust, 1988, found in oral histories). If malnutrition resulted from reductions in food supplies, health problems would have increased (also referred to in the Chilam Balams) and fertility would have decreased. Finally, the remaining urban populations would decline through other means, perhaps also affected by warfare of one type or another, leading to final abandonment of cities [see Braswell (1997) and Freter (1994), for documentation of this process in Copán].[6] By the early colonial period, de Landa ([orig. 1566], 1982) considered the Petén to be inhabitable only during the rainy season.[7]

The temporal and spatial pattern of the Maya rise and collapse closely fits the data on climatic change of Gunn *et al*. (1994, 1995). The dated monuments and the occupation of Classic Maya centers from the 4th century to the 9th century, as quantified by Erickson (1973, in Tainter, 1988), indicate a fairly steady population increase after the A.D. 250 drought [one detected by the analysis of Gunn *et al.* (1994, 1995), but not by Hodell *et al*. (1995)], with a plateau occurring around A.D. 475–550 (or a little later), the period known to Maya archaeologists as "the hiatus." Subsequently, monument construction increased and occupation sites expanded until around A.D. 750–775, when they declined rapidly in conjunction with a major drought. This rapid decline was accompanied by a shift toward coastal and surface water areas in the Petén and the surrounding region (Folan *et al.*, 1983a; Rice, 1987).

As the climatic conditions needed for upland horticulture worsened in the south, they may have initially improved in the north (Gunn and Adams, 1981; Messenger, 1990), making possible Puuc cultural development until around A.D. 900–1000, when the drought spread north. The 10th-century abandonment of the large Puuc center at Uxmal (and its tributary centers) somewhat overlapped that of a still active Chichén Itzá, a site associated with the highland cultures of the Valley of Mexico (Folan, 1977:18). Chichén fell during what seems to have been a period of excessive drought. Mayapán rose probably due to more favorable climatic and hydraulic conditions including multiple cenotes (Gunn and Adams, 1981; Folan *et al.*, 1983a; Messenger, 1990; Gunn *et al*., 1994, 1995).

It is important to note that on the Yucatán peninsula, water is not only needed for agriculture, but is a crucial factor on a number of other fronts as well. Because of the Yucatán peninsula's porous karstic topography, water limitations are probably more severe than limitations imposed by food availability. Water has to be available to wash bodies and clothing on a daily basis or one soon acquires skin diseases and parasites that can be debilitating. There must be enough precipitation to flush the surface and subsurface karst basins or the water supplies become contaminated; distribution of fecal coliform bacteria is widespread in the water table, contributing to gastrointestinal illnesses (Doehring and Butler, 1974; Faust, 1998). The transition period between the dry and rainy seasons is known locally as "the time when babies die," or "the time of sickness," because the waste accumulated during the dry season is mobilized on the surface and enters the water table. This is one of several situations in the Maya lowlands that make a little rain worse than none at all. Unless the earliest rains are followed by enough precipitation to flush the karst, the entire population is subject to dysentery and other maladies, a situation that recurs at the end of the *canícula*, or dog days of summer (see Faust, 1988:251–252).

It follows from the above discussion that maintaining city water supplies is of particular concern to large urban concentrations in the interior of the peninsula. In fact, it has been suggested that the plastered surfaces of the temples and plazas were water-collecting systems that fed cisterns capable of supporting the cities (see Faust, 1998:84, for a review of the literature) – a view supported by the temples' great emphasis on invoking the rain gods (Sharp, 1981). The Gunn–Folan model shows correlations between the largest urban concentrations in the interior and medium-range climate (warm-cool times with precipitation evenly distributed), implying that even the cities, with their complex water systems, were only able to function when precipitation variation was not too extreme, thus enhancing horticultural production. Hansen (1996) has found that the urban centers of El Mirador, Tintal, and Nakbé, among the earliest in the Maya lowlands, were occupied almost exclusively during the Late Preclassic, a period of optimal climate similar to the Late Classic. These early cities used their forests for fuel, investing in the manufacture of plaster surfaces that could be used to collect water. The soil of the uplands, denuded of forest, eroded into the *bajos* (seasonal swamps; Martínez *et al*., 1996).

Contemporary Maya farmers report that in addition to planting in the uplands and on the edge of *bajos*, they have traditionally planted small raised areas called *cuyitos* (*culenculo'ob* in Maya) in the flooded *bajos* during the rainy season and again during the *tornamil* (second planting), when planting is also done on and between these natural features. This second planting occurs during a drier season, when the *bajos* are drying but still retain more moisture than other areas. This planting of *bajo cuyitos* has the form of primitive *chinampas* (artificially raised fields associated mainly with lagoons and some riverine systems), while that at the *bajo* edge resembles a floodplain form of horticulture. Together, the Maya have a five-step strategy using three different environments during two different plantings: the first planting is (1) in the uplands, (2) at the *bajo* edge, and (3) on *cuyitos* in the *bajo*; and the second planting is (4) on the *cuyitos* and (5) in the area between them on the floor of the *bajo* (Folan and Gallegos Osuno, 1992, 1996, 1998). Far from being unusable soils, the *bajos* (in at least some areas) provide for two crops a year, and depending on weather conditions, in some years a third planting may even be possible (T.P. Culbert, 1997, personal communication; Folan and Gallegos Osuno, 1998). The surface area of the *cuyitos* averages 25 cm $\times$ 25 cm, or .0625 m^2, with 45 *cuyitos*, or a total of 25 m^2 per *mecate* (of 400 m^2) that is planted together with the edge of the *bajo* and the uplands during the first planting. The *cuyitos* are planted again together with the bottom of the *bajo* during the second planting. Archaeological research indicates similar practices in the Guatemalan Petén (Martínez *et al*., 1996; Hansen *et al*., forthcoming). For a discussion of hummock use on the Belizean coast, see Pohl *et al.* (1996).

Throughout the southern and central lowlands, use of *bajos* was complemented in the Preclassic and Classic periods by other forms of intensive agriculture, which have been documented in increasing numbers of ground surveys and excavations since the 1970s, when Siemens and Puleston (1972) first published their findings concerning relict raised fields in the area of the upper Candelaria River. In the period immediately following their seminal publication, misinterpretation of some forms of radar imagery produced estimates of extremely large areas covered with raised fields (Adams *et al*., 1982). Subsequent ground surveys and excavations have confirmed Maya modification of natural water-drainage systems for agricultural or domestic purposes, including raised fields in the El Laberinto *bajo* of Calakmul and other areas (see Turner, 1979; Matheny *et al.*, 1983; Fedick, 1995a, 1995b; Culbert, 1996; Domínguez and Folan, 1996; Martínez *et al*., 1996; Siemens *et al*., 1996; Fialko-Coxeman, 1997; May Hau, 1997, field notes from Calakmul; Vargas Pacheco, 1997). In some cases these modifications could have made possible two or three harvests per year and would have reduced the time for fallowing, thereby increasing the harvest per hectare over a multiyear period and supplying the large urban populations estimated for both the Preclassic and the Classic periods. Reduced population densities following the collapse in the southern and central lowlands would have obviated the need for, and reduced the feasibility of, some intensive practices. Under pre-collapse technology, fallow was minimized and irrigated and drained fields required more labor per unit of output, but yields per unit of land were increased. These techniques were therefore only appropriate for dense populations (Culbert, 1977:518).

Pohl *et al.* (1996) have reported the results of pollen analysis and excavation of raised fields along the Hondo and New Rivers in Belize, an area where groundwater levels are directly affected by changes in sea level. Their research indicates that intensive wetland agriculture emerged very early (1500–1000 B.C.) in the Preclassic period, taking advantage of hydromorphic soils as groundwater levels fell in response to global climate change. These topographic modifications were later abandoned when water levels rose again in the Late Preclassic period (400 B.C.–A.D. 250). Pohl *et al.* (1996) comment on the relevance of their findings for the central southern lowlands. They state:

> [Our] explanation of the origin and evolution of wetland agriculture does not apply to the cultivation of seasonal wetlands at higher elevations removed from the influence of sea level. Nevertheless, we question whether these interior wetlands, most notably the bajos of the central Maya region, were ever intensively cultivated. [Pope and Dahlin, 1989, 1993]

Contrary to the above statements, work by Folan and Gallegos Osuno (1992, 1996, 1998), Hansen (1996), Culbert (1996), Fialko-Coxeman (1997), and Fialko *et al.* (1998) indicates that *bajos* cultivated today were also cultivated in the pre-Hispanic past. Final evaluation of the existence of intensive agriculture in the interior of the peninsula will have to await the results of excavations and pollen and phytolith analysis in that area. Pohl *et al.* (1996) did research on pollen samples and lake cores indicating serious soil erosion problems postdating the Late Classic period, possibly from overuse of swidden on hillsides (see Jacob, 1995, for Cobweb Swamp, Belize; Pohl *et al*., 1990, for Albion Island, Belize). This suggests the possibility that, following abandonment of raised fields in the Preclassic period (at least in areas affected by rising sea levels), population pressures caused shortening of the fallow period, resulting in accelerated rates of soil erosion. An alternative explanation for soil erosion is the abandonment of terrace maintenance (due to climate change, warfare, or internal rebellion). Terraces are artificial constructions on deforested slopes subject to degradation by heavy rain and gravity; without continual repair, the soil washes downhill, accumulating in wetlands and lakes.

In Tabasco, there exists today a form of horticulture called *cultivo de marceño* wherein low areas referred to as *popales* (named for a resident species, *Thalia geniculata*) are slashed, burned, and planted during the dry season, in March (hence the term *marceño*). The moist earth produces between 4 and 5 tons of corn per hectare, and may reach levels of 10 tons per hectare. The corn is harvested from canoes at the beginning of the rainy season, in June. If rains are delayed, a second harvest is possible (Mariaca Mendez, 1999; Exhibit, Museo de Historia Natural, Villahermosa, Tabasco, Mexico, 1997). This form of horticulture may be related to the *milpa* of San José planted in March in the Petén, according to Messenger (1997) and V. Fialko (1998, personal communication).

1.5 Discussion

Monocausal explanations can never comprehensively describe human behavior, although social scientists have sought them repeatedly. In the case of the rise and fall of the Classic Maya, Lowe (1985) reviewed the simple causal models and the systematic multifactor models that have become prominent. After computer analysis of 12 different systemic models that give different weights to social, economic, agricultural, and political factors, he built his own dynamic model of the Maya collapse that incorporates many aspects of the most prominent explanations, including

> Cowgill's emphasis on warfare; Adams's, Sabloff's and Willey's notion that the Maya collapse was not purely internal process, that external pressure played a non-negligible and perhaps decisive role; Thompson's and Sharer's formulations emphasizing the destruction of the elite class as a consequence of degenerating material/subsistence conditions; Bateson's and Holling's discussion of the effects of decreased flexibility/resilience; and, finally, Willey's and Shimkin's view that the collapse was basically due to managerial failure, that a shock administered to Maya polities created administrative overload and thus societal breakdown, or to put it another way, that the special conditions that resulted in the collapse were consequences both of the importance of elite administrative apparatus to the whole, and of its relative fragility ... ecological degradation may also have operated in parallel ... to induce increasing levels of stress in Late Classic times ... [Lowe, 1985:201–202]

He identifies two thresholds:

> One, an impact threshold, describes the magnitude of a shortfall in food supply at the local level, below which negative feedback and a return to equilibrium prevails and above which positive feedback and collapse occur. The other, the collapse diffusion threshold, identifies the point at which the entire system of states comprising the Southern Maya Lowlands becomes unstable. [Lowe, 1985:206]

An important point relative to the Classic collapse is that it was not the only time that there were droughts and not the only time of urban collapse in the lowlands. Similar processes and interactions appear to have occurred in A.D. 250 and near the middle of the Postclassic, circa A.D. 1350. The virtual abandonment of the interior except along lakes and rivers appears to be the unique mark of the Classic collapse in the southern Maya lowlands. A number of accompanying circumstances probably sealed the fate of the interior area. One was the irreversible, at least on the scale of centuries, degradation of parts of the agricultural environment. This degradation was compounded by a social system that became deeply embroiled in internal warfare, according to Marcus's (1992, 1997) analysis of hieroglyphic texts. Cities and their tributary populations, organized as regional states (see Folan *et al.*, 1995, for the case of Calakmul), occasionally waged war against each other in the decades before and during the collapse. This warfare at times interrupted traditional trade routes across the southern Maya lowlands. New forces emerged in the north whose interests lay with seaborne trade with Chichén Itzá and other regional states; they may have sent armies to the south, which may have further disrupted trade and social commerce (D. Rents-Budet, 1995, personal communication). After the fall of Chichén Itzá and its successor Mayapán, incessant warfare among Maya polities was commonplace in the 15th century, continuing into the contact period and later. The conflicts and their outcomes were recorded both in the Chilam Balams of the Maya elite and in Spanish colonial documents (Roys, 1943, 1957; Jones, 1977; Marcus, 1992; Dumond, 1997). Identifying food and water supply as critical problems in the Classic period still leaves open the question of whether these supplies per capita declined due to a homemade overshoot of carrying capacity and/or an external change in climatic conditions. The evidence for climate change and its timing strongly support the argument that an alteration in the macroclimate put unusual stress on supplies of food and water, which triggered social, political, and military problems resulting in the Maya collapse.

Accumulating information concerning the effects of El Niño events on present-day regional economies makes the climatic causation more comprehensible. We have little control over climatic shifts and their very costly impacts, even with our industrialized agriculture, storage facilities, and distribution networks. Planning for the future economic development of the peninsula should include the preservation of those risk-reduction procedures that are incorporated in the traditional practices of living Maya communities (Faust, 1998), the reintroduction of ancient intensive technologies in areas where they are feasible, and the provision of new technologies appropriate for the prediction of and adaptation to shifts in climate (see Chapter 4). The extended El Niño condition of the 1990s suggests the possibility of fundamental changes to global climate such as mega–El Niños experienced during past episodes of global warming (Meggers, 1994). The last one occurred at the beginning of the 16th century, and earlier ones correlate with periods of cultural collapse in the Amazon River basin (Meggers, 1994). The duration of these episodes is unknown, but an informed guess is that they must have lasted for decades to have resulted in such extensive cultural catastrophes (B.J. Meggers, 1998, personal communication). We may currently be at the beginning of a massive test of our contemporary beliefs in the capacity of modern technology to overcome such a challenge to the economic and political structures maintaining contemporary civilization.

Notes

[1] Dating in Maya archaeology has traditionally been stratigraphic and stylistic, based on analysis of the strata uncovered in excavations and the style of architecture, associated ceramics, and hieroglyphic calculations. More recently, carbon-14 and obsidian hydration methods have been used on appropriate materials. Unanswered questions remain concerning the duration of various periods, including the Late Classic and Postclassic (particularly in Chichén Itzá and Copan).

[2] Much of the following discussion is based on personal observations and field notes by B. Faust, based on field work in Pich, Campeche; the Biosphere Reserve of Río Lagartos, Yucatán; and Sahcabá, Yucatán.

[3] Cenotes do occur in the area around Sahcaba and in the town itself but are much scarcer than *sartenejas*. This area is too flat and the soils too thin for the creation of natural *aguadas* found in Campeche.

[4] This results in large part from vegetation growth, which is in turn related to rainfall and soils.

[5] The bottoms of some of these lagoons and *aguadas* have structures similar to those reported earlier in other areas of the peninsula (Stephens, 1988 [1843]:2:148; Faust and Morales López, 1993; Domínguez Carrasco and Folan, 1995; Faust, 1998). According to Faust (1998), these include stone linings sealed with a lime mortar to prevent loss through seepage, *chultuno'ob*, and wells in the lowest areas of *aguadas* that were replenished by seepage.

[6] In some cases, abandonment was followed by the arrival of pilgrims and travelers during subsequent periods.

[7] The date given for Landa's observation (1566) is the approximate date according to Tozzer (1941).

References

Abrams, E.M., 1994, *How the Maya Built Their World: Energetics and Ancient Architecture*, University of Texas Press, Austin, TX, USA.

Adams, R.E.W., and Jones, R.C., 1981, Spatial patterns and regional growth among Classic Maya cities, *American Antiquity*, **46**:301–332.

Adams, R.E.W., and Smith, W.D, 1977, Apocalyptic visions: The Maya collapse and Mediaeval Europe, *Archaeology*, **30**:292–301.

Adams, R.E.W., Brown, W., Jr., and Culbert, T.P., 1982, Radar mapping, archaeology, and ancient Maya land use, *Science*, **213**:1457–1463.

Adams, R.E.W., Robichaux, H.R., and Mathews, R., 1997, Urban Centers, Construction Episodes and Population Histories in the Three Rivers Region, Paper presented at the 62nd Annual Meeting of the Society for American Archaeology in Nashville, TN, USA.

Antonio, R.J., 1979, The contradiction of domination and production in bureaucracy: The contribution of organizational efficiency to the decline of the Roman Empire, *American Sociological Review*, **44**:895–912.

Bates, D.G., and Plog, F., 1991, *Human Adaptive Strategies*, McGraw Hill, New York, NY, USA.

Braswell, G., 1997, La cronología y la estructura del colapso en Copan, Honduras, *Los Investigadores de la Cultura Maya*, **5**:262–273, Universidad Autónoma de Campeche, Campeche, Mexico.

Catton, W.R., Jr., 1982, *Overshoot: The Ecological Basis of Revolutionary Change*, University of Illinois Press, Urbana, IL, USA.

Clark, J., and Blake, M., 1989, El origin de la civilización en mesoamerica: Los olmeca y mokaya de Soconusco de Chiapas, México, *El Preclásico o Formativo: Avances y Perspectivas. Seminario de Arqueología. Dr. Román Piña Chan*, pp. 385–404, Instituto Nacional de Antropología e Historia (INAH), Mexico.

Coe, M.D., 1961, *La Victoria: An Early Site on the Pacific Coast of Guatemala*, Peabody Museum of Archaeology and Ethnology, Harvard University, Cambridge, MA, USA.

Crosby, A.W., Jr., 1972, *The Columbian Exchange: Biological and Cultural Consequences of 1492*, Greenwood Press, Westport, CT, USA.

Crosby, A.W., 1986, *Ecological Imperialism*, Cambridge University Press, Cambridge, UK.

Crumley, C.L., ed., 1994, *Historical Ecology: Cultural Knowledge and Changing Landscapes*, School of American Research, Advanced Seminar Series, Santa Fe, NM, USA.

Culbert, T.P., 1974, *The Lost Civilization: The Story of the Classic Maya*, Harper and Row, New York, NY, USA.

Culbert, T.P., 1977, Maya development and collapse: An economic perspective, in N. Hammond, ed., *Social Process and Maya Prehistory: Studies in Honor of Sir Eric Thompson*, Academic Press, London, UK.

Culbert, T.P., 1988, The collapse of Classic Maya civilization, in N. Yoffee and G. Cowgill, eds, *The Collapse of Ancient States and Civilizations*, University of Arizona Press, Tucson, AZ, USA, pp. 69–101.

Culbert, T.P., 1996, Agricultura Maya en los humedales de las tierras bajas Mayas: Primera conferencia magistral, *VI Encuentro de Los Investigadores de la Cultura Maya*, (5):14–19, Universidad Autónoma de Campeche, Campeche, Mexico.

Culbert, T.P., and Rice, D.S., eds, 1990, *Pre-Columbian Population History in the Maya Lowlands*, University of New Mexico Press, Albuquerque, NM, USA.

Doehring, D.O., and Butler, J.H., 1974, Hydrogeologic constraints on Yucatán's development, *Science*, 186:591–595.

Domínguez Carrasco, María del Rosario, 1994, Calakmul, Campeche: Un análisis de la cerámica, *Colección Arqueología*, No. 4. Universidad Autónoma de Campeche, Campeche, Mexico.

Domínguez Carrasco, María del Rosario, and Folan, W.J., 1996, Calakmul, México: Aguadas, bajos, precipitación y asentamíento en el Petén Campechano, *IX Simposio de Investigaciones Arqueológicos en Guatemala*, pp. 171–193, Museo Nacional de Arqueología y Etnología, Guatemala.

Domínguez Carrasco, María del Rosario, Folan, W.J., Morales López, A., Gonzalez Heredia, R., and Florey Folan, L.M., 1999, An approximation of rural demographics in the Northern Calakmul Regional State, *III Mesa Redonda de Palenque, Segunda Epoca*, Instituto Nacional de Antropología e Historia (INAH), June/July, Palenque, Mexico (forthcoming).

Dumond, D.E., 1997, *The Machete and the Cross*, University of Nebraska, Lincoln, NE, USA.

Erickson, E.E., 1973, The life cycle of life styles: Projecting the course of local evolutionary sequences, *Behavioral Science Notes*, **8**:135–165.

Euler, R.C., Gumerman, G.J., Karlstrom, T.N.V., Dean, J.S., and Hevly, R.H., 1979, The Colorado Plateaus: Cultural dynamics and paleoenvironment, *Science*, **205**:1089–1101.

Farriss, N.M., 1984, *Maya Society Under Colonial Rule: The Collective Enterprise of Survival*, Princeton University Press, Princeton, NJ, USA.

Faust, B.B., 1988, Cosmology and Changing Technology of the Campeche-Maya, Ph.D. dissertation, Syracuse University, Anthropology Department, New York, NY, USA.

Faust, B.B., 1998, *Mexican Rural Development and the Plumed Serpent: Technology and Maya Cosmology in the Tropical Forest of Campeche, Mexico*, Greenwood (Bergin and Garvey), Westport, CT, USA.

Faust, B.B., and Morales López, A., 1993, La aguada en la historia oral de Pich, Campeche: Adapciones a variaciones de clima en un pueblo Maya, paper presented in Session 341, *XIII International Congress of Anthropological and Ethnological Sciences: The Cultural and Biological Dimensions of Global Change*, 4 August 1993, Mexico City, Mexico.

Fedick, S., 1995a, Ancient Maya Use of Wetlands in Northern Quintana Roo, Mexico, Paper presented at the Conference Hidden Dimensions: The Cultural Significance of Wetland Archaeology, University of British Columbia, Vancouver, BC, Canada.

Fedick, S., 1995b, Observations on Archaeological Features Within a Wetland of the El Eden Ecological Reserve, Northern Quintana Roo, Mexico, Report submitted to the Instituto Nacional de Antropología e Historia, Mexico.

Fialko-Coxeman, V., 1997, Organización territorial y de asentamientos Mayas en los intersitios de Yaxha y Nakum, *Los Investigadores de la Cultura Maya*, **5**:249–261, Universidad Autónoma de Campeche, Campeche, Mexico.

Fialko, V., Folan, W.J., Gunn, J.D., and Domínguez Carrasco, María del Rosario, 1998, Investigations in the Intersite Areas Between Yaxha-Nakum-Tikal, Paper presented at the 63rd Annual Meeting of the Society for American Archaeology, Seattle, WA, USA.

Fletcher, L.A., and Gann, J.A., 1992, Calakmul, Campeche: Patron de asentamiento y demografia, *Antropológicas*, **11A**, Nueva Epoca, No. 2, UNAM, Mexico City, Mexico.

Fletcher, L.A., May Hau, J., Florey Folan, L.M., and Folan, W.J., 1987, *Un analysis estadistico preliminar del patron de asentamiento de Calakmul, Campeche*, Universidad Autónoma del Sudeste, Campeche, Mexico.

Folan, W.J., 1969, Dzibilchaltún, Yucatán, México: Structures 384, 385, and 386: A preliminary interpretation, *American Antiquity*, **34**(4):434–461.

Folan, W.J., 1975, Cobá Archaeological Mapping Project, Interim Report, No. 2, Cobá, Quintana Roo, Mexico, 6 August 1975, photocopy, also in *Boletín de la Escuela de Ciencias Antropologicas de la Universidad de Yucatán*, January–April 1977 (22/23):52–71.

Folan, W.J., 1977, *Chichén Itzá*, Orto Press, Mexico.

Folan, W.J., 1979, La organizacion sociopólitico de los habitantes de la peninsula de Yucatán a través del tiempo, *Boletín de la Escuela de Ciencias Antropólogicas de la Universidad de Yucatán*, **6**(34):34–45.

Folan, W.J., 1981, CA* comment, the late Postclassic eastern frontier of Mesoamerica, cultural innovations along the periphery by John W. Fox, *Current Anthropology*, **22**(4):321–346.

Folan, W.J., 1998, La peninsula de Yucatán en visperas de la conquista: Un modelo diacronico de desarrollo y decaimiento, *Gaceta Universitaria Año VIII*, **41–42**:25–38.

Folan, W.J., and Gallegos Osuno, S., 1992, Uso prehispanico del suelo, in W.J. Folan, J.M. Garcia Ortega, and M.C. Sánchez Gonzalez, eds, *Programa de Manejo, Reserva de la Biósfera Calakmul, Campeche*, Centro de Investigaciones Historicas y Sociales, Universidad Autónoma de Campeche, Campeche, Mexico.

Folan, W.J., and Gallegos Osuno, S., 1996, El Uso del Suelo del Sitio Arqueológico de Calakmul, Campeche, *Yum Kax*, Boletín de Información Ecológica de la Universidad Autónoma de Campeche, **2**(3):7–8, January–February.

Folan, W.J., and Gallegos Osuno, S., 1998, Uso del Suelo en el Estado de Campeche, México y Alrededores, Paper presented at the Symposium "La eliminación de la quema en la milpa de roza, tumba y quema," 6–8 November 1997 in CINVESTAV, Mérida, Yucatán, Mexico (version revised for publication in the Universidad Autónoma de Campeche).

Folan, W.J., and Hyde, B.H., 1985, Climatic forecasting and recording among the ancient and historic Maya: An ethnohistoric approach to epistemological and paleoclimatological patterning, in W.J. Folan, ed. *Contributions to the Archaeology and Ethnohistory of Greater Mesoamerica*, Southern Illinois University, Carbondale, IL, USA, pp. 15–48.

Folan, W.J., Gunn, J.D., Eaton, J.D., and Patch, R.W., 1983a, Paleoclimatological patterning in southern Mesoamerica, *Journal of Field Archaeology*, **10**:453–468.

Folan, W.J., Kintz, E.R., and Fletcher, L.A., 1983b, *Cobá, A Classic Maya Metropolis*, Academic Press, New York, NY, USA.

Folan, W.J., Marcus, J., Pincemin Deliberos, S., Domínguez Carrasco, María del Rosario, Fletcher, L.A., and Morales López, A., 1995, Calakmul: New data from an ancient Maya capital in Campeche, Mexico, *Latin American Antiquity*, **6**(4):310–334.

Folan, W.J., Morales López, A., Domínguez Carrasco, María del Rosario, Gonzalez Heredia, R., and Florey Folan, L.M., 1999, Una aproximación demográfica rural al norte del Estado Regional de Calakmul, *XIII Simposio de Investigaciones Arqueologicas en Guatemala*, Museo Nacional de Arqueología y Etnología, 19–23 July, Ciudad de Guatemala (forthcoming).

Folan, W.J., Gunn, J.D., and Domínguez Carrasco, María del Rosario, 2000, Triadic temples, central plazas and dynastic palaces: A diachronic analysis of the Royal Court Complex: Calakmul, Campeche, Mexico, in T. Inomata and S. Houston (eds), *Royal Courts of the Ancient Maya*, Westview Press, Boulder, Co, USA (forthcoming).

Ford, A., 1995, Arqueología en acción, reserva arqueológica El Pilar para fauna y flora Maya, *Los Investigadores de la Cultura Maya*, **4**:291–306, Universidad Autónoma de Campeche, Campeche, Mexico.

Freter, A., 1994, The Classic Maya collapse at Copán, Honduras: An analysis of Maya rural settlement trends, in G.M. Schwartz and S.E. Falconer, eds, *Archeological Views from the Countryside: Village Communities in Early Compex Societies*, Smithsonian Institution Press, Washington, DC, USA, pp. 160–176.

Gunn, J.D., A.D. 536 and Its 300-year Aftermath (forthcoming).

Gunn, J.D., and Adams, R.E.W., 1981, Climatic change, culture, and civilization in North America, *World Archaeology*, **13**:87–100.

Gunn, J.D., and Folan, W.J., 1996, Tres ríos: Una superficie de impacto climático global para las tierras bajas de los Mayas del suroeste (la cuenca de los Rios Candelaria, Usumacinta y Champotón), *Memorias del V Encuentro: Los Investigadores del Area Maya*, pp. 57–79, Universidad Autónoma de Campeche, Campeche, Mexico.

Gunn, J.D., and Folan, W.J., 2000, Three rivers: Subregion global climate response surface for the southwestern Maya lowlands (Candelaria, Usumacinta, and Champotón watersheds), in R. McIntosh, S. McIntosh, and J. Tainter, eds, *Global Climate Change and Cultural Memory*, Columbia University Press, New York, NY, USA.

Gunn, J.D., Folan, W.J., and Robichaux, H.R., 1994, Un análisis informativo sobre la descarga del sistema del Rio Candelaria en Campeche, México: Reflexiones acerca de los paleoclimas que afectaron los antiguos sistemas Mayas en los sitios de Calakmul y el Mirador, in W.J. Folan Higgins, ed., *Campeche Maya Colonial*, Collection Arqueología, Universidad Autónoma de Campeche, Campeche, Mexico.

Gunn, J.D., Folan, W.J., and Robichaux, H.R., 1995, A landscape analysis of the Candelaria watershed in Mexico: Insights into paleoclimates affecting upland horticulture in the southern Yucatán peninsula semi-karst, *Geoarchaeology*, **10**(1):3–42.

Gunn, J.D., Domínguez Carrasco, María del Rosario, and Folan, W.J., 2000a, *Lithics Among the Maya Elite at Calakmul, Campeche, Mexico* (forthcoming).

Gunn, J.D., Foss, J., Folan, W.J., and Domínguez Carrasco, María del Rosario, 2000b, *Environments of Elevated Cities in the Interior Yucatán Peninsula*, paper written for the 65th Annual Reunion of the Society for American Arqueology in Philadelphia, PA, USA, 5–9 April 2000.

Hammond, N., 1986, The emergence of Maya civilization, *Scientific American*, **255**: 106–115.

Hansen, R.D., 1996, New Perspectives on the Origin and Collapse of the Maya Civilization, Paper presented at the VI Encuentro de Los Investigadores de la Cultura Maya, Universidad Autónoma de Campeche, 11–15 November 1996, Campeche, Mexico.

Hansen, R., Culbert, T.P., and Folan, W.J., *Bajo Horticulture on the Peninsula of Yucatán* (forthcoming).

Hester, T.R., Iceland, H.B., Hudler, D.B., and Shafer, H.J., 1996, The Colha Preceramic Project: Preliminary results from the 1993–1995 field seasons, *Mexicon*, **XVIII**(3): 45–50.

Hodell, D.A., Curtis, J.H., and Brenner, M., 1995, Possible role of climate in the collapse of Classic Maya civilization, *Nature*, **375**:391–394.

Huntington, E., 1913, Guatemala and the highest native American civilization, *Proceedings of the American Philosophical Society*, **52**:467–487.

Jacob, J.S., 1995, Ancient Maya wetland agricultural fields in Cobweb Swamp, Belize: Construction, chronology and function, *Journal of Field Archeology*, **22**:175–190.

Jones, G.D., 1977, *Anthropology and History in Yucatán*, University of Texas Press, Austin, TX, USA.

de Landa, F.D., 1982 [orig. 1574–1575], *Relación de las Cosas de Yucatán*, Ed. Porrúa, Mexico City, Mexico.

Lowe, J.W.G., 1985, *The Dynamics of Apocalypse*, University of New Mexico Press, Albuquerque, NM, USA.

Lowe, J.W.G., 1989, La presencia olmeca y maya en el preclasico de Chiapas, *El Preclásico o Formativo: Avances y Perspectivas Seminario de Arqueología. Dr. Román Piña Chan*, Martha Carmona (ed.), pp. 363–384. Instituto Nacional de Antropología e Historia (INAH), Mexico.

Marcus, J., 1974, *An Epigraphic Approach to the Territorial Organization of Lowland Classic Maya*, Doctoral Thesis, Harvard, Anthropology.

Marcus, J., 1976, *Emblem and State in the Classic Maya Lowlands*, Dumbarton Oaks, Washington, DC, USA.

Marcus, J., 1987, *The Inscriptions of Calakmul: Royal Marriage at a Maya City in Campeche, Mexico*, University of Michigan Museum of Anthropology Technical Report 21, Ann Arbor, MI, USA.

Marcus, J., 1992, *Mesoamerican Writing Systems*, Princeton University Press, Princeton, NJ, USA.

Marcus, J., 1997, New Hieroglyphic Data Showing Calakmul's Role in the Affairs of Other Maya Cities, 62nd Encuentro Anual de la Sociedad Americana de Arqueología, Nashville, TN, USA.

Mariaca Mendez, R., 1999, Aprovechamiento del sistema popal por una comunidad agricola tradicional en Tabasco, Mexico, in J.J. Jimenez-Osorio and V.M. Rorive, eds, *Los Camellones y Chinampas Tradicionales,* Universidad Autónoma de Yucatán, Merida, Mexico, pp. 211–220.

Martínez, G., Hansen, R.D., and Howell, W.K., 1996, Cultivos Intensivos: Sistemas Agrícolas de Nakbé, X Simposio de Investigaciónes Arqueológicos en Guatemala, Museo Nacional de Arqueología, Etnología, 22–26 July 1996, Guatemala.

Matheny, R.T., Gurr, D.L., Forsyth, D.W., and Hauck, F.R., 1983, *Investigations at Edzn á, Campeche, Mexico: The Hydraulic System,* Papers of the New World Archaeological Foundation, No. 46, Brigham Young University Press, Provo, UT, USA.

McAnany, P.A., 1989, Economic foundations: Paradigms and concepts, in P.A. McAnany and B.L. Isaac, eds, *Research in Economic Anthropology*, Supplement 4: *Prehistoric Maya Economies of Belize*, JAI Press, Greenwich, CT, USA, pp. 347–372.

McAnany, P.A., 1990, Water storage in the Puuc region of the northern Maya lowlands: A key to population estimates and architectural variability, in T.P. Culbert and D.S. Rice, eds, *Pre-Columbian Population History in the Maya Lowlands*, University of New Mexico Press, Albuquerque, NM, USA, pp. 263–284.

McGovern, T.H., 1994, Management for extinction in Norse Greenland, in C.L. Crumley, ed., *Historical Ecology: Cultural Knowledge and Changing Landscapes*, School of American Research Press, Sante Fe, NM, USA, pp. 127–154.

Meggers, B.J., 1954, Environmental limitation on the development of culture, *American Anthropologist*, **56**:801–824.

Meggers, B.J., 1994, Archeological evidence for the impact of mega–Niño events on Amazonia during the past two millennia, *Climatic Change*, **28**:321–338.

Messenger, L.C., Jr., 1990, Ancient winds of change: Climatic setting and prehistoric social complexity in Mesoamerica, *Ancient Mesoamerica*, **1**:21–40.

Messenger, L.C., 1997, “El Paleo – Evaluación del impacto ambiental”: Algunas perspectivas sobre paleoliatología con respecto a estudios de los Mayas antiguos, *Memoria VI Encuentro: Los Investigadores de la Cultura Maya*, **5**:328–347.

Okoshi Harada, T., 1999, Analisis de la organizacion politico-territorial de los mayas peninsulares del Postclasico Tardio: Una nueva perspectiva, IX Encuentro, Los Investigadores de la Cultura Maya, Ciudad y Puerto de Campeche, Mexico, 9–12 November 1999.

Pincemin Deliberos, S., 1994, Remontando el río: Exploraciones arqueológicas en el Río Candelaria, Campeche, *Colección Arqueología*, **2**, Universidad Autónoma de Campeche, Campeche, Mexico.

Pincemin Deliberos, S., Marcus, J., Florey Folan, L.M., Folan, W.J., Morales López, A., Domínguez Carrasco, María del Rosario, 1998, Extending the Calakmul Dynasty Back in Time: The Discovery of a Fifth-Century Stela from a Maya Capital in Campeche, Mexico, *Latin American Antiquity*, **9**(4):310–327.

Pohl, M.D., Bloom, P., and Pope, K., 1990, Interpretation of wetland farming in northern Belize: Excavations at San Antonio Río Hondo, in M. Pohl, ed., *Ancient Maya Wetland Agriculture: Excavations on Albion Island, Northern Belize*, University of Minnesota Publication in Anthropology and Westview Press, Boulder, CO, USA, pp. 187–278.

Pohl, M.D., Pope, K.O., Jones, J.G., Jacob, J.S., Piperno, D.R., de France, S.D., Lantz, D.L., Gifford, J.A., Danforth, M.E., and Josserand, J.K., 1996, Early agriculture in the Maya lowlands, *Latin American Antiquity*, **7**(4):355–372.

Pohl, M., Pope, K., and Jones, J., 1998, Agricultura y civilización prehistoricas en las planicies mayas orientales, *Los Investigadores de la Cultura Maya*, **6**(1):108–119, Universidad Autónoma de Campeche, Campeche, Mexico.

Pope, K.O., and Dahlin, B.H., 1989, Ancient Maya wetland agriculture: New insights from ecological and remote sensing research, *Journal of Field Archaeology*, **16**:87–106.

Pope, K.O., and Dahlin, B.H., 1993, Radar detection and ecology of ancient Maya canal systems: Reply to Adams *et al.*, *Journal of Field Archaeology*, **20**:379–383.

Quezada, S., 1997, Revision de la Organización Politica Territorial de los Mayas Yucatecos al Tiempo de la Invasion Española, Paper presented at the 62nd Encuentro Anual de la Sociedad Americana de Arqueología, 2–6 April 1997, Nashville, TN, USA.

Rice, P.M., 1987, *Macanché Island, El Petén, Guatemala: Excavations, Pottery and Artifacts*, University Presses of Florida, Gainesville, FL, USA.

Ringle, W.M., and Andrews, E.W., V., 1990, The demography of Komchén: An early Maya town in northern Yucatán, in T.P. Culbert and D.S. Rice, eds, *Pre-Columbian Population History in the Maya Lowlands*, University of New Mexico Press, Albuquerque, NM, USA, pp. 215–244.

Roys, R., 1943, *The Indian Background of Colonial Yucat án*, Carnegie Institution of Washington, Publication 548, Washington, DC, USA.

Roys, R., 1957, *The Political Geography of the Yucatec Maya*, Carnegie Institution of Washington, Publication 613, Washington, DC, USA.

Sabloff, J.H., 1990, *The New Archaeology and the Ancient Maya*, Scientific American Library, New York, NY, USA.

Santley, R.S., 1990, Demographic archaeology in the Maya lowlands, in T.P. Culbert and D.S. Rice, eds, *Pre-Columbian Population History in the Maya Lowlands*, University of New Mexico Press, Albuquerque, NM, USA, pp. 325–344.

Saunders, J.W., Mandel, R.D., Saucier, R.T., Allen, E.T., Hallmark, C.T., Johnson, J.K., Jackson, E.H., Allen, C.M., Stringer, G.L., Frink, D.S., Feathers, J.K., Williams, S., Gremillion, K.J., Vidrine, M.F., and Jones, R., 1997, A mound complex in Louisiana at 5400–5000 years before the present, *Science*, **277**:1796–1799.

Sharer, R.J., 1994, *The Ancient Maya*, Stanford University Press, Stanford, CA, USA.

Sharp, R., 1981, Chacs and chiefs: The iconology of mosaic stone sculptures in pre-conquest Yucatán, Mexico, *Studies in Pre-Columbian Art and Archaeoology*, No. 24, Dumarton Oaks, Washington, DC, USA.

Siemens, A.H., and Puleston, D.E., 1972, Ridged fields and associated features in southern Campeche: New perspectives in the lowland Maya, *American Antiquity*, **37**(2): 228–239.

Siemens, A.H., Hebda, R.J., and Heimo, M.I., 1996, Remontando el río, de nuevo: Nuevos hallazgos en las zonas inundables a lo largo del Río Candelaria en Campeche, *Los Investigaciones de la Cultura Maya*, **4**:32–56.

Stephens, J.L. [1841], 1949, *Incidents of Travel in Central America, Chiapas, and Yucatán*, Vols. 1 and 2 (illust. F. Catherwood, ed. R.L. Predmore), Rutgers University Press, New Brunswick, NJ, USA.

Stephens, J.L. [1843], 1988, *Incidents of Travel in Yucatán*, Vols. 1 and 2 (illust. F. Catherwood), Panorama Editorial, Mexico City, Mexico.

Tainter, J.A., 1988, *The Collapse of Complex Societies: New Studies in Archaeology*, Cambridge University Press, Cambridge, UK.

Thomas, W.L., Jr., ed., 1956, *Man's Role in Changing the Face of the Earth*, International Symposium of Wenner-Gren Foundation for Anthropological Research, Vol. 1, University of Chicago Press, Chicago, IL, USA.

Tozzer, A.M., 1941, Introduction to *Landa's Relación de las Cosas de Yucatán*, Papers in the Peabody Museum of Archaeology and Ethnology, Harvard University, Vol. XVIII, Translation and notes by A.M. Tozzer, Peabody Museum Publications, Cambridge, MA, USA.

Turner, B.L., II., 1979, Prehispanic terracing in the central Maya Lowlands: Problems of agricultural intensification, in N. Hammond and G.R. Willey, eds, *Maya Archaeology and Ethnohistory*, University of Texas Press, Austin, TX, USA.

Turner, B.L., II., 1990, Population reconstruction for the central Maya lowlands: 1000 B.C. to A.D. 1500, in T.P. Culbert and D.S. Rice, eds, *Pre-Columbian Population History in the Maya Lowlands*, University of New Mexico Press, Albuquerque, NM, USA, pp. 301–325.

Valdés, J.A., and Popenoe de Hatch, M., 1995, Evidencias de poder y control social en Kaminaljuyu: Proyecto Arqueológico Miraflores II, *IX Simposio de Investigaciones Arqueológicas en Guatemala*, pp. 377–396, J.P. Laporte and H.L. Escobedo (eds.), Museo Nacional de Arqueología y Etnología, Ciudad de Guatemala.

Vargas Pacheco, E., 1997, Uso, manejo y dominio de los recursos fluviales: El caso del Rio Candelaria, *Los Investigadores de la Cultura Maya*, **5**:432–440.

Vargas Pacheco, E., 1999, *Itzamkanak y Acalan: Tiempos de Crisis, Anticipando el Futuro*, Doctoral Thesis, Instituto Nacional de Antropología e Historia (INAH), Mexico.

Velázquez Valdéz, R., 1980, Recent discoveries in the caves of Loltun, Yucatán, Mexico, *Mexicon*, **2**:53–55.

Young, L.B., 1993 [orig. 1991], Easter Island: Scary parable, in A. Angeloni, ed., *Anthropology 93/94*, pp. 236–240 (original in *World Monitor*, pp. 40–41).

Wilkinson, R.L., 1995, Yellow fever: Ecology, epidemiology, and role in the collapse of the Classic lowland Maya civilization, *Medical Anthropology*, **16**:269–294.

Wissler, C., 1923, *Man and Culture*, Thomas Y. Crowell, New York, NY, USA.

Zubrow, E.B.W., 1972, Carrying capacity and dynamic equilibrium in the prehistoric southwest, in M.P. Leone, ed., *Contemporary Archaeology: A Guide to Theory and Contributions*, Southern Illinois University Press, Carbondale, IL, USA, pp. 268–279.

2

Socioecological Regions of the Yucatán Peninsula

Eduardo Batllori, Federico Dickinson, Ana García, Manuel Martín, Ivan González, Miguel Villasuso, and Jose Luis Febles

2.1 Regions of the Yucatán Peninsula

Virtually all population–development–environment-type studies require some choice of regional boundaries. The main difficulty in determining an appropriate regionalization is the mismatch between indices based on political entities such as counties, states, and countries, and those based on natural units such as landscapes, climatic zones, and soil types. The aim of this chapter is to propose and describe a new set of regions appropriate for socioecological analyses.

In defining the socioecological regions (SERs), superficial hydrological basins or geohydrological units on the peninsula were considered in conjunction with the different socioeconomic and demographic processes taking place in such units or subunits.[1] Based on its karstic characteristics and on the main hydrological flows, the Yucatán peninsula was divided into four geohydrological units and one superficial hydrological basin: (I) the ring of cenotes; (II) the interior flatlands; (III) the hills and valleys region; (IV) the hydrological basin of the Candelaria River, located in the state of Campeche; and (V) the block-fault basins region.[2] Taking into consideration the relationships between the regions' historical economic evolution (as defined by the type of agricultural specialization) and the geohydrological units referred to above, eight rural and three urban regions were elaborated (see *Figure 2.1* and *Table 2.1*).[3]

The three largest cities on the Yucatán peninsula (Mérida, Cancún, and Campeche), each with more than 100,000 inhabitants, account for more than 44% of the peninsula's total population as well as a sizable proportion of the population of the states of Yucatán, Quintana Roo, and Campeche (45.5%, 34%, and 28.12%, respectively; INEGI, 1991). The most important regional economic processes are

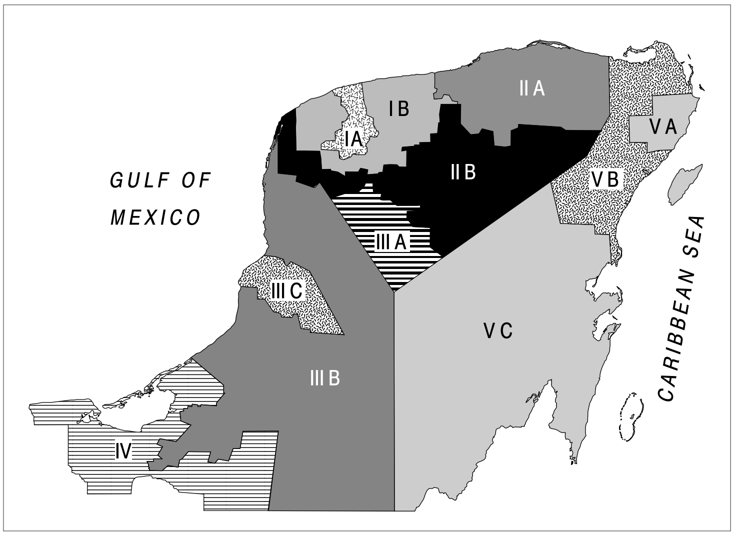


Figure 2.1. The socioecological regions of the Yucatán peninsula. See *Table 2.1* for region names.

carried out in these three cities. For these reasons, the *municipios* (counties) constituting these urban centers were categorized as urban regions. (For additional information on the peninsula's economy, see Chapter 5.)

Using the pattern of human settlements along the coast, the nature of the economic activities, the administrative characteristics of some of the harbors, and the format of the available socioeconomic information, each of the *municipios* located in the coastal region – from Isla del Carmen and the city of Campeche on the Gulf of Mexico up to the Bahía de Chetumal on the Caribbean Sea – was incorporated into one of the urban or rural regions previously alluded to. Thus, the peninsula was divided into the 11 regions shown in *Table 2.1*. The geographical distribution of the SERs of the Yucatán peninsula is shown in *Figure 2.1*. The main geohydrological units of the Yucatán peninsula may encompass more than one SER.

2.1.1 Ring of cenotes geohydrological unit (I)

This geohydrological unit comprises most of the *municipios* of the former henequen-producing region, including the coastal *municipios*, Telchac Puerto, Dzidzantúm, and Hunucmá, and the *municipios* of Kanasín, Mérida, and Umán, which together with the *municipio* of Progreso, located in the coastal region, constitute the metropolitan region of Mérida.

Table 2.1. Area and population of the socioecological regions of the Yucatán peninsula.

Code	Region	State	Area (km^2)	Population (1990)	Population density (persons/km^2)
IA	Metropolitan region of Mérida	Yucatán	1,636.32	658,458	402.4
IB	Former henequen-producing region	Yucatán	6,807.20	250,077	36.7
IIA	Cattle-producing region	Yucatán	8,712.39	101,491	11.6
IIB	Maize-producing region	Yucatán	19,451.32	250,833	12.9
IIIA	Fruit-producing region	Yucatán	6,576.01	102,087	15.5
IIIB	Hills and valleys region	Campeche	38,239.00	218,344	5.7
IIIC	Campeche region	Campeche	3,411.00	173,645	51.0
IV	Candelaria region	Campeche	15,206.00	143,196	9.4
VA	Tourist–urban region	Quintana Roo	2,311.00	221,668	95.9
VB	Northern block-fault basin region	Quintana Roo	9,227.00	26,633	2.9
VC	Southern block-fault basin region	Quintana Roo	39,305.00	244,976	6.2
State of Yucatán			43,183.24	1,362,940	31.5
State of Campeche			56,856.00	535,185	9.4
State of Quintana Roo			50,843.00	493,277	9.7
Yucatán peninsula			150,882.20	2,391,402	15.8

Source: INEGI, 1991.

The Yucatán peninsula has two main types of climate (hot and subhumid, and hot and dry) and 12 subtypes of climate. The ring of cenotes geohydrological unit has the following climate subtypes:

- Semiarid, hot (average temperature of the coldest month above 18°C) with summer rains and a high percentage of winter rainfall. This climate type is found in both a narrow zone between Sisal and Santa Clara, and the Alacranes reef.
- Semiarid, but not as dry as the climate subtype above, with a more marked dry spell in the middle of the summer rainy season. This type of climate is characteristic of the northern part of the state of Yucatán, between Celestún and Las Coloradas up to El Remate in the state of Campeche.

- Hot, the driest of the subhumid climate type, with summer rains and a sizable dry spell in the middle of the main rainy season. This type of climate characterizes a large zone in the northern and central part of the state of Yucatán and the northern part of Campeche, the city of Mérida, the Puuc hills, and the Chenes zone in Campeche (García, 1978; Duch, 1988).

This area has generally flat terrain. Landscape slopes increase toward the south, particularly in the Sierrita de Ticul. Geologically, it presents strata from the Quaternary (Holocene and Pleistocene) and from the Carrillo Puerto Formation (Miocene–Pliocene) with intermingled materials from the Oligocene limiting, with rocks of the Chumbec Member (Eocene) to the southeast, and with geological materials from the Pisté Member (Eocene) to the south. For details on the geological materials of the peninsula, see Villasuso and Mendez (1997).

The ring of cenotes is an important feature of the hydrogeology of this unit (Velázquez, 1986). Marín (1990) hypothesized that the semicircle of cenotes is a high-permeability duct that transports underground water toward the coast.[4]

The main soil types of this region are rendzinas and lithosols. Calcareous regosols are characteristic of the coastal area. The main vegetation type is low (8–15 m) or medium (15–20 m) deciduous forest and low (8–15 m) forest with cactuses and *Beaucarnea pliabilis*. Savannas and mangroves predominate in the coastal zone.[5]

This geohydrological unit encompasses the metropolitan region of Mérida and the former henequen-producing region.

Metropolitan Region of Mérida (IA)

The city of Mérida changed from being a small town in the middle of the 19th century to being the capital city of one Mexico's richest states at the beginning of the 20th century. During the early 20th century, Mérida was a booming city. Its expansion originated from economic activities related to henequen production and processing. From such developments, several industrial, commercial, and service activities evolved in the city that have helped it to partly overcome the effects of the henequen crisis.

At the beginning of the henequen boom, the port of Progreso, around 30 km from Mérida, was established for henequen export. Thus, the economy of Progreso was integrated into Mérida's economic dynamics.

If the Yucatán peninsula is viewed as a network, the metropolitan region of Mérida is its main node. At the peninsula level, the region generates about 52% of the mining gross domestic product (GDP), 72% of the manufacturing GDP, 48% of the commercial GDP, and 27% of the services GDP. In 1990, about 50% of the population of the state of Yucatán and 33% of that of the Yucatán peninsula were concentrated in this region (INEGI, 1991, 1996).

Due to the effects of the henequen crisis, the close proximity of Mérida, and that city's sprawl, the *municipios* of Kanasín and Umán and their main human settlements are becoming increasingly integrated with the city of Mérida. The decline of the agricultural sector has resulted in a recent increase in rural–urban migration, which has contributed to Mérida's population growth.

Geomorphologically and hydrologically, three *municipios* of this region (Mérida, Kanasín, and Umán) are located in the semicircle of cenotes, and one (Progreso) is located in the coastal zone.

Water use is distributed approximately as follows: agriculture, 42%; services, 19%; public entities, 15%; industry, 15%; and livestock production, 5%; with other uses accounting for the remainder. Most wells are located in the *municipio* of Mérida (65%) and in Umán (25%). Kanasín and Progreso each have about 5% of the wells in the region.[6] Management of wastewater is a very serious health issue, particularly, but not exclusively, in urban centers. This situation is partly illustrated by results from Cabrera *et al.* (n.d.), who found nitrates in underground water in the city of Mérida at levels between 10.3 and 39.6 mg/l, higher than the allowed threshold value of 5 mg/l.

Former Henequen-producing Region (IB)

The invention and widespread use of agricultural machinery in the United States during the second half of the 19th century increased the demand for henequen (or sisal) fiber, which was used to bind agricultural products. The area where henequen was cultivated expanded up to a radius of approximately 80 km from Mérida and became known as the henequen-producing region.

In 1937, agrarian reform led to changes in the structure of henequen production and a dismantling of its main organizational unit, the *hacienda*. Thereafter, the state intervened, taking over henequen production.[7] The government's intervention deepened in the following decades as it acquired henequen manufacturing plants, thereby exercising total control over henequen agricultural, industrial, and commercial activities. Despite this governmental control, vertical integration between fiber production and its processing/marketing was not established. Henequen production was controlled by development banks, whereas the other activities were directed by the Ministry of Industry and Commerce.[8] As a result, the management of henequen production and its marketing were inefficiently carried out, and the industry was unable to respond properly to the challenges of the international market. Changes in the external environment included more efficient production systems in competing countries, an increasing share of the world market for natural fiber by sisal-producing countries such as Brazil and Tanzania, competition from synthetic fibers, and the emergence of new technologies requiring less natural fiber. Henequen production peaked in the 1950s and started to decline significantly after 1960. In 1992, after more than 50 years of intervention, the state pulled out of henequen-related activities.

The economic problems originating from the henequen production crisis have been partly counterbalanced by a series of development programs. Poultry and pig production programs have been promoted in the western and southern parts of this region. In some *municipios*, horticultural production, particularly citrus production, has been encouraged.[9] Maize production for subsistence has been promoted, primarily in remote *municipios*. At the same time, employment has increased in the construction and service sectors of Mérida and, more recently, in the *maquiladora* sector.

Generally, however, the henequen production crisis led to an increase in unemployment, a decrease in income, and a deterioration of the population's standard of living, resulting in important migratory flows to Mérida and to the tourist regions of Quintana Roo. Henequen production continues to be an important activity in this region; however, it is no longer the main source of income for the region's inhabitants.

Water is chiefly used in crop production (84%), livestock production (12%), and in public services (4%). The highest well concentration is found in the following *municipios*: Samahil, 15%; Hunucma, 13%; Kinchil, 6%; and Abala, 6%.

2.1.2 Interior flatlands geohydrological unit (II)

The most predominant climate is the driest of the subhumid type and is typified by a high proportion of winter rainfall. It is the dominant climate in northern Campeche and Quintana Roo and in northeastern Yucatán. Geologically, this area is characterized by rocks from the Quaternary (Holocene and Pleistocene), the Carrillo Puerto Formation, the Chumbec Member, and the Pisté Member (Eocene). In these vast flatlands, the water table depth ranges between 15 m and 30 m. The underground water has substantial levels of calcium, carbonates, and sulfates.

The main soil types are rendzinas and lithosols in the north, rendzinas with chromic luvisols and vertisols in the south, and calcareous regosols in the coastal zone. The major vegetation types are low (8–15 m) or medium (15–20 m) deciduous forest, medium transitional forest (25–35 m) between rain forest and medium (25–30 m) subdeciduous forest with abundant *Vitex gaumeri*, and low (8–15 m) or medium (15–20 m) deciduous and high (35 m) or medium (25 m) subdeciduous forest with abundant *V. gaumeri*. Savannas and mangroves are the dominant vegetation in the coastal zone.

This geohydrological unit comprises the cattle-producing region and the maize-producing region.

Cattle-producing Region (IIA)

The cattle-producing region is located in the eastern part of the state of Yucatán. From the 19th century until the middle of the 20th century, the region's economy was based on timber and traditional maize production, as well as on some cattle production. In the 1960s, calf production and cattle fattening became major economic activities.[10] This change originated in part from the investment shift from henequen production to cattle production. This change was partly the result of agrarian reform and the succession of land use from forest production to *milpa* production and finally to grass and cattle production.

Approximately 50% of the economically active population of this region is engaged in agriculture-related activities. The area's population density is low (see *Table 2.1*). The main urban center is the city of Tizimín, which supplies the goods and services required for cattle production. The coastal *municipios* of Dzilam de Bravo, San Felipe, and Río Lagartos, where fishing and salt production activities are carried out, were incorporated into this region because of their economic and cultural integration.

Agriculture-related activities consume approximately 78% of the total water used in this region. The *municipios* with the highest concentration of wells are Tizimín (34%) and Dzilám González (20%).

Maize-producing Region (IIB)

The maize-producing region has undergone relatively few changes during the past five centuries. Its area has diminished with the expansion of fruit and cattle production. The majority of its inhabitants are of Maya ancestry. The maize-producing region is the least developed zone in the state of Yucatán in terms of income, education, and health care.

As the name indicates, the region's main economic activity is maize production, which is the main component of the system known as the *milpa*.[11] Generally, each family crops about 6 hectares (ha), but only a minority obtain enough maize yield to fulfill their subsistence needs. Still fewer families obtain yields in excess of their food needs. For these reasons, the region's inhabitants engage in paid work outside their production unit and carry out additional economic activities such as poultry, honey, handicraft, and small ruminant production.

The region's economy is based on family work in agriculture for subsistence and the sale of surplus agricultural production and labor, with employment outside the family production unit providing additional income. Cattle production has recently increased in this area. There have been large migratory flows from this region to the tourism corridor of Quintana Roo. Approximately 58% of the economically active population is engaged in agriculture-related activities. The main urban center is the city of Valladolid, where some manufacturing and service activities are carried out.

Agricultural uses account for approximately 87% of total water volume consumed in the region. The *municipios* with the highest water extraction volumes are Maxcanú (47%) and Halachó (22%).

2.1.3 Hills and valleys geohydrological unit (III)

The climate of this region is similar to the climate subtypes described for region IIB in the state of Yucatán. The predominant climate is the hot subhumid type with summer rains and a low proportion of winter precipitation. This climate type characterizes a narrow zone along the western coast of the state of Campeche located between southern Seybaplaya and northern Sabancuy (Duch, 1988).

This geohydrological unit is located in Yucatán and Campeche. In the former, its topographical features are diverse. It comprises isolated zones with low slopes and some karstic hills about 40 m in height. The main chain of hills, the Sierrita de Ticul, has a northwest to southeast orientation approximately 160 km long and 50 km wide and is characterized by carbonates from the Eocene. The hills range between 100 m and 110 m in height, measured from the ground, and are about 150 m above sea level. The Sierrita de Ticul are the only hills found in the flat landscape of the northern part of the peninsula.

This area is geologically diverse, with rocks from the Carrillo Puerto Formation in the northeastern zone; from the Pisté Member in the northern and northeastern zones (Eocene); from the Xbacal Member in the southeastern zone (Eocene); from the Icaiché Formation; and from nondifferentiated rocks in the central and southern zones (Paleocene). It also has some geological components from the Cretaceous in the south. The carbonates from the Eocene predominate and include limestones, dolomitic limestones, and dolomites. Some rocks are slightly silicified. The high permeability of these carbonates is reflected in the low gradients of the water table. The water table is located at a depth ranging between 50 m and 100 m. Therefore, the exploitation of underground water is both costly and difficult.

The predominant water type contains high levels of calcium, magnesium, and bicarbonates. The first two elements result from the dissolution of carbonates from the calcareous rocks. There is also water with substantial levels of magnesium and sulfur. The levels of sulphates are generally below 250 parts per million (ppm). However, at some points in this hilly region, sulphate levels ranging between 250 ppm and 450 ppm can be found. Such levels are associated with the presence of gypsum. Sulphate levels around 450 ppm, found in some wells near the coast, are probably associated with the extraction of seawater. Near the shoreline the water tends to have higher sodium and chloride contents because of the greater magnitude of the mixing zone between the fresh water and the seawater. Extraction of this type of water is increasing because instances where water extraction surpasses the supply capacity of the freshwater layer are not uncommon.

The main soil types of this region are the rendzinas with chromic rubisols, vertisols, and lithosols. The main vegetation types include low (8–15 m) or medium (15–20 m) deciduous forest with abundant *V. gaumeri*. There is rain forest with *Manilkara sapota* but without *Bucida buceras* and *Thrinax radiata* in the southern part. In the coastal zone, mangroves and savannas predominate.

In the state of Campeche, the northern and northeastern areas have limestones from the Miocene and Eocene and a hilly landscape. In the south, there are calcareous rocks from the Eocene and Paleocene. Sedimentary rocks from the Quaternary predominate in the coastal area. In the southeastern zone, the Icaiché Formation extends up to the western part of the Conguas *ejido*.

In the southern part of this geohydrological unit, some hills reach up to 250 m above sea level, whereas in the northwest the flatlands extend up to the coast. The geological materials of this area present vertical fractures through which water infiltrates, dissolving the rocks and forming sizable cavities. This water circulates underground, in an east–west direction, reaching the sea. In the central–southern part, there is a platform driven by the canal of the Candelaria River, whose basin has a southeast–northwest direction. The Candelaria River is a tributary of the peninsula's aquifer system. The southeastern zone presents a hilly landscape with low slopes. The depth of the water table varies from 1 m near the coast to 165 m around the Chencoh *ejido*, in the northern part of the *municipio* of Hopelchen. In the central part of the region, the water table ranges between 3 m and 90 m, following the coast in a west–east direction up to Escárcega. The water table level decreases from the central part toward the south, where it reaches values ranging between 10 m and 20 m.

Taking into account the region's geological characteristics, it can be inferred that it supplies significant water inflows to the peninsula's underground water system. However, the chemical composition of the geological materials is an important constraint. If rocks dissolve in water, high sulfate concentrations may result. In the coastal zone, the water available for human, industrial, and agricultural consumption is of medium quality. In the Nuevo Pital area and in some scattered locations, bicarbonated water with high calcium or magnesium levels prevails. In the central part, porous and soluble sedimentary rocks, if dissolved in water, generate salts. Water in contact with limestones and dolomites may be saturated with carbonates, calcium, magnesium, and sodium. This type of water is of medium quality and is suitable for both irrigation and human consumption. In the southeastern region, the water is of unsatisfactory quality because it has a high sulfate concentration originating from gypsum and anhydrides.

This geohydrological unit comprises the fruit-producing region, located in the state of Yucatán, and the hills and valleys and Campeche regions, in the state of Campeche.

Fruit-producing Region (IIIA)

The fertile and deep soils of this region have allowed the development of more diversified agriculture than in other regions of the peninsula. Agricultural production has included horticultural production as well as sugarcane production during the colonial era. Sugarcane production ended during the Caste War. The current agricultural configuration started during the 1960s with a government program called "Plan Chaac" aimed at establishing 2,500 irrigated hectares for citrus production, especially oranges.[12] An industrial plant for obtaining concentrated orange juice was constructed in 1980. Orange production has increased substantially during the past three decades, and the region now accounts for about 75% of the total orange production of the state of Yucatán. Most production is obtained from small production units averaging about 3 ha. Although the region's main product is oranges, there is also production of mandarins, avocadoes, mangoes, and maize.

The main urban centers of this region are the cities of Ticul, Oxkutzcab, and Tekax, which supply the goods and services demanded regionally. Oxkutzcab is the main market for agricultural products. Approximately 48% of the economically active population is engaged in agricultural activities. This proportion is lower here than in the cattle- and maize-producing regions because of the development of industrial activities such as production of shoes, handicrafts, and other products in the city of Ticul.

Water is mainly used for agriculture-related activities. The *municipios* with the highest well concentrations are Tekax (20%), Oxkutzcab (17%), Ticul (12%), and Tzucacab (11%).

Hills and Valleys Region (IIIB)

This region has characteristics similar to those of the fruit- and maize-producing regions in Yucatán. The area's human settlements are ancient. A high proportion of the population is of Maya ancestry, particularly those living near the border with Yucatán. Approximately 56% of the economically active population is engaged in agricultural activities. The main crop is maize, although there is also fruit production (e.g., mangoes, oranges, *chicozapote*, tomatoes, and watermelon). This region generates about 85% of the timber production value of the state of Campeche. Sugarcane production is an important economic activity in the *municipio* of Champotón, located in the southern part of the region. The *municipio* of Escárcega accounts for approximately 30% of Campeche's cattle production. Forest-related activities have decreased sharply since the 1970s.

Approximately 55% of the water consumed is used for public services and 45%, for agricultural activities. Deep wells are required because of the depth of the water table. The highest concentration of wells is found in the *municipio* of Champotón (41%).

Campeche Region (IIIC)

Because of the economic and demographic importance of the city of Campeche, the *municipio* of Campeche was considered an urban region. The city of Campeche has had considerable physical and demographic growth during the past two decades. Although growth of the Campeche region has recently accelerated, its growth has not yet reached the pace of other urban centers such as Cancún and Mérida. Approximately 80% of the economically active population is engaged in service and manufacturing activities. However, manufacturing activities are still incipient. The city of Campeche is the commercial and service center of the state of Campeche. Because of its size, the *municipio* of Campeche is also an important producer of maize, fruit, and other horticultural products such as mangoes, *chicozapote*, oranges, tomatoes, and watermelon. This region also produces about 77% of the state's poultry.

Agricultural activities account for approximately two-thirds of total water consumption and public services account for one-third. As in the hills and valleys region, the great majority of wells are deep wells.

2.1.4 Hydrological basin of the Candelaria River (IV)

The hydrological basin of the Candelaria River is characterized by the climate subtypes described for region IIIB in Campeche. The prevailing climate types for this region are a hot climate, the most humid of the subhumid type, with a high proportion of winter rainfall, and the humid and hot climate, with summer rains and an intersummer dry season.

There are geological strata of the Quaternary (Holocene and Pleistocene) near the coast, which lie above rocks from the Pisté Member and the Xbacal Member (Eocene), and undifferentiated rocks from the Paleocene. This region is geologically simple because it is dominated by alluvial deposits. These deposits lie above lutites and sandstones from the Upper Miocene and may reach depths of 200 m to 300 m. Some red sandstones are also found in this zone. In the central part of the region, underground water can be found near the surface.

Geomorphologically, this region has two areas. The first is characterized by large flatlands that are flooded during some periods of the year. In the second area, pluvial erosion of alluvial deposits has formed a series of short, round hills. The main rivers of this region are the Candelaria, the Champotón, the Mamantel, and the Palizada Rivers. The water flow of these rivers is approximately 8,740 million cubic meters per year (CNA, 1995a). The main soils of the region are alluvial soils. The main vegetation types are subperennial rain forest with *Manilkara sapota* (*zapote*), *Bucida buceras* (*pukté*), *Lysiloma latisiliquum*, *Brosimum alicastrum*, and *Ceiba pentandra*. There is a transitional forest between this vegetation type and evergreen rain forest with *Tabebuia pentaphylla* and *Vochysia* spp. Vast savannas and mangroves are typical of the southern part of this region.

Candelaria Region (IV)

This region has undergone the most accelerated change in Campeche. It encompasses the rapid growth of Ciudad del Carmen, a city located on the island of the same name. Ciudad del Carmen was a small fishing village until the 1970s. The regional demand for goods and services has grown owing to the increase of oil production activities along Campeche's coast during the past decade. As a result, Ciudad del Carmen has become a city of approximately 100,000 inhabitants. However, it is little integrated with either the region or the state. Oil production has had a negligible impact on Campeche's development, and the state economy has had a slow growth rate during the past 10 years.

Approximately 42% of the economically active population of Ciudad del Carmen is engaged in the service sector and about 36%, in agriculture-related activities. At the state level, this region provides 60% of cattle production, 75% of rice production, and 90% of coconut production.

Roughly 80% of the water used is for public services and 20%, for agricultural activities. Most wells are deep wells. The highest well density is found in the *municipio* of Carmen (86%).

2.1.5 Block-fault basins geohydrological unit (V)

The block-fault basins geohydrologic unit extends from Cabo Catoche in Quintana Roo to southern Belize. In this region, the carbonated rocks represent geological accidents resulting from a series of normal faults with a northern and northeastern orientation. These faults – known as "fractures of Holbox" in the north, and as "faults of the Río Hondo" in the south – have variable dimensions and drifts, some of which can be seen on the surface. For our purposes, these basins are called the northern block-fault and the southern block-fault. Their major biophysical features are described below.

Northern block-fault. The prevailing climate types of the northern block-fault region are the hot subtype, the driest of the subhumid type with a high percentage of winter rainfall, and the hot subhumid type with a summer rainy season with a marked intersummer dry spell and sizable winter precipitation (García, 1989; Duch, 1988).

Cozumel has two types of climate, the hot and humid type with a summer rainy season with a short intersummer dry spell and a high percentage of winter precipitation, and the hot and most humid of the subhumid type with a summer rainy season with a marked intersummer dry spell and a high percentage of winter rainfall. The last climate subtype is also typical of a narrow zone near the shoreline in the state of Quintana Roo (Duch, 1988).

In the northern part of this region, rocks from the Quaternary (Holocene and Pleistocene) lie above rocks from the Carrillo Puerto Formation (Miocene–Pliocene). Geologically, the area presents rocks of marine origin with calcareous composition. In some small areas, such rocks are covered by lateritic soils ranging in depth between 5 cm and 20 cm. Lithologically, this unit can be classified as a clay limestone changing from a cream to red color with some spots of brown limestone resulting from water, wind, and temperature effects. These rocks have a hard, thin, deep brown layer. They belong to the Carrillo Puerto Formation. The main emergent points of these geological materials are located in the northern part of the state and encompass Cozumel Island and Isla Mujeres. These islands are from the Upper Miocene–Pliocene (CNA, 1995b).

There is strong evidence that continuous dissolution takes place at a certain depth below the water table where water salinity increases rapidly (Stoessell *et al.*, 1989). Active dissolution of limestone takes place at this level. In these high-permeability zones, a thin layer of fresh water is underlain by seawater and both water types establish an equilibrium. However, at some specific points, such as in the area of Kantunilkin, this equilibrium has been broken and intrusion of seawater is increasing rapidly.

The most important soils are highly permeable rendzinas and lithosols. The main vegetation type is subperennial rain forest with *M. sapota* (*zapote*). There is also medium subdeciduous (25–35 m) rain forest with abundant *V. gaumeri*. Savannas and mangroves are typical of the coastal zone.

The northern block-fault basin has two regions: the tourist–urban region of Cancún and Cozumel Island, and the northern block-fault basin region. The southern block-fault basin encompasses only one region.

Southern block-fault. The southern block-fault has climate subtypes similar to those described for the northern block-fault. The geology of this region is a mosaic comprising rocks from the Carrillo Puerto Formation in the northern and eastern zones (Pliocene), rocks from the Estero Franco Formation and the Bacalar Formation in the southern zone (Pliocene–Miocene), and rocks from the Pisté Member (Eocene) and undifferentiated rocks (Paleocene) in the western zone. The wetlands' sediments from the Quaternary are, by and large, located in the eastern part of the state of Quintana Roo, which in turn is aligned with the Río Hondo and the Laguna de Bacalar. The region also has flooded areas with some sandbanks and a series of small and shallow bays and deposits of sand, clays, and mollusks.

This region is the most complex of this geohydrological unit because of its higher elevations and topographic landscape. It has highly fractured dolomitic limestones, which also form part of the geology of the Petén region in neighboring Guatemala. These rocks form round structures that reach heights of up to 200 m above sea level. In the *municipio* of Othón P. Blanco there is a zone bordering the state of Campeche to the west with limestones, loamy materials, and gypsum. These geological materials belong to the Icaiché Formation. Due to their chemical composition (e.g., gypsum and anhydrites), such rocks react with the water, reducing the quality to unsatisfactory levels. As yet, none of the well explorations directed to obtain good-quality water has been successful. The major soil types are highly permeable lithosols and rendzinas.

The main vegetation type is subperennial rain forest with *M. sapota* (*zapote*), *B. buceras*, *B. alicastrum*, and *C. pentandra*. Savannas and mangroves predominate in the coastal zone.

Tourist–urban Region (VA)

The development of this region has greatly modified the economy of the Yucatán peninsula. Development in the city of Cancún began in the 1970s. Prior to this development, there was only a small fishing settlement in the northeastern part of the peninsula and some tourism on Cozumel Island. The construction in Cancún began in the 1970s as part of a national policy aimed at developing several centers of tourism in the country. Because of the supply of jobs, Cancún very rapidly became attractive to migrants from elsewhere on the peninsula and around the country. Construction in Cancún accelerated the development of tourism on Cozumel Island. This newly developed region displaced the city of Chetumal, the capital of Quintana Roo, as the state's main economic center. Likewise, the development of this region has been a central factor in the movement of the main destination of investment from the state of Yucatán to the state of Quintana Roo.

Tourism and related services are the region's main economic activities. It is estimated that tourism in this region produces approximately 30% of the total foreign currency generated from tourism activities in Mexico (Anonymous, 1993). Approximately 50% of Quintana Roo's limited manufacturing activities are concentrated in this region (Peña *et al.*, 1997).

The region comprises the Benito Juarez *municipio*, where the city of Cancún is located, and the recently founded Cozumel *municipio*, which includes the island of the same name and two tourism centers along the Caribbean coast of mainland Quintana Roo, both located to the south of Cancún. This region is a nationally important tourism center because of the large foreign and domestic investments in the area.

Approximately 90% of the water used is for the provision of services. In general, fresh water floats on top of salty water, and water salinity increases with depth. On Cozumel Island, as on the peninsula as a whole, the water salinity is equal to that of seawater at about 20 m deep. Tourism activities in Cancún have had negative impact on the ecological conditions of the Nichupte lagoon.

Northern Block-fault Basin Region (VB)

Traditionally, the population of this region has engaged in agricultural and fishing activities. Its population density in 1970 was very low (less than 1 person/km^2). Its growth has accelerated during the past 5–10 years and is highly dependent on the development of Cancún. Its population density rose from 2.9 to 6 persons/km^2 between 1990 and 1995. Approximately 38% of the economically active population is engaged in agricultural activities, including maize, cattle, pig, and poultry production, and to a lesser extent forestry-related activities. Nearly half (48%) of the economically active population is engaged in the service sector, primarily in tourism-related activities.

Human consumption accounts for approximately 55% of water use in this region. Agricultural uses account for about 30% of the total water used. José María Morelos is the *municipio* with the highest well density in this region (59%).

Southern Block-fault Basin Region (VC)

For centuries Quintana Roo was scarcely populated. In 1950, there were only 27,000 inhabitants and 80% of the population was located in the southern block-fault basin region, with the remainder on Cozumel Island, Isla Mujeres, and in other small fishing towns.[13] The only urban settlement in Quintana Roo was Chetumal, which at the time had only 7,000 inhabitants.

Chicle production was an important economic activity during the first decades of this century.[14] Thereafter, logging and timber production of tropical hard- and softwoods became important economic activities. Because of its isolation, the city of Chetumal had duty-free port status, which from the 1960s permitted increased commercial activity based on the sale of imported products. The population of Chetumal increased twofold from 1960 to 1970. Currently, there is limited regional industrial activity concentrated in wood and sugarcane production.

Approximately 39% of the economically active population is engaged in agricultural activities. Traditionally, these activities include the *milpa* system and honey production. However, since the 1960s and 1970s new crops and cattle production have been introduced as a result of governmental policies promoting migration to the region. Sugarcane and citrus production are important agricultural activities along the banks of the Río Hondo. Commerce is the main economic activity in the city of Chetumal. Because the liberalization policies enacted during the past decade have seriously eroded the advantages of being a duty-free center previously enjoyed by Chetumal, commercial activities have been redirected from the domestic market to Belize.

This region has two urban centers: Carrillo Puerto, the main center for the population of Maya origin, who are chiefly engaged in traditional agriculture, and Chetumal, Quintana Roo's capital city, where commerce and other services, especially those related to government and education, predominate. Agriculture and human consumption account for approximately 62% and 35% of total water consumption, respectively.

2.2 Final Remarks

Since the temperature regime is fairly constant, both across the peninsula's regions and between years, the main difference from year to year is in rainfall. The occurrence of different vegetation types is the result of the combination of precipitation and soil differences throughout the peninsula.

Accessibility of land and historical development of human activities have substantially contributed to the decline of forest resources. Thus the regions located in the central and southern parts of the peninsula have the least disturbed biotic resources. These regions are also the least integrated into the regional economic system. Regions encompassing coastal areas have been paramount in both commercial and tourism activities. Because of the land–sea interface, these areas are also very important in terms of biodiversity. Therefore, tourism and other human activities, including oil extraction in the coastal area of Campeche and Yucatán, ought to give due attention to the mutual interdependence of natural and human systems.

The urban regions encompass most of the peninsula's economic and social resources. These regions also have the highest population densities. The advantages they offer in the form of positive synergetic effects (e.g., economies of scale, concentration of mutually reinforcing socioeconomic activities resulting in productivity and efficiency gains) contrast with their high consumption of resources and their threat to the stability of ecological systems. This is particularly relevant for preventing a worsening of problems concerning the availability of good-quality fresh water. Undoubtedly, the evolution of the urban regions will, by and large, drive the peninsula's future development.

Development has been regionally uneven. Cancún, Mérida, and the city of Campeche are the most developed areas. The maize- and fruit-producing regions and the former henequen-producing region have relatively high population densities, and their economies rely on agriculture-related activities.

Because of the increasing interdependencies between the rural and urban regions, an integrated planning approach may be helpful in dealing with regional development problems. Consideration of this interrelationship is also relevant for maintaining and enhancing the positive interactions between the regions' coastal and inland areas.

The peninsula's economic dependence on external markets has been important since the Classic Maya period (e.g., in carrying out commercial activities) and has continued more recently in the cases of the henequen- and tourism-based economies. Given the likelihood of an increase in the globalization process, the question of how to effectively steer development of the internal market remains to be answered. Current living conditions in most of the SERs suggest that there is not yet in place a continuous planning and acting process – at the inter- and intra-regional levels, at the peninsula level, and at the global level – that will ensure a certain quality of life for the majority of the peninsula's population. Thus the challenge is to meaningfully link development at different spatial and social levels, integrating natural and human systems.

Notes

[1] The importance of the hydrological basin as a unit for planning and development purposes lies in its condition as a very specific natural geographic unit. The regional framework used in this document attempts to dovetail ecological and social systems.

[2] The categorization of the main hydrological flows was based on information from Butterlin and Bonnet (1963); Wilson (1980); Lesser and Weidie (1988); Duch (1988); CNA (1995a, 1995b); and Perry *et al*. (1995). The description of vegetation types was based on information from Miranda (1958) and Flores and Espejel (1994). The description of population was based on INEGI (1991, 1996).

[3] Translator's note: The *municipios* constituting each of the socioecological regions are listed in Appendix 2.A.

[4] This hypothesis is plausible considering (1) the alignment of the cenotes; (2) the results of measurements of the water table carried out in two north–south sites that cross the semicircle of cenotes and in one east–west site, which indicated that the water level diminishes toward the ring of cenotes; (3) the occurrence of freshwater springs where the ring of cenotes intercepts the coast; (4) the fact that the water flow (e.g., in the estuaries of Celestún and Dzilám) causes these barriers to be opened toward the sea, despite the strong flow of sand toward the Yucatán coast, which forms

barriers; and (5) the high conductivity values found by Steinich and Marín (1997), which indicate high permeability for the ring of cenotes.

[5] Translator's note: References to vegetation types throughout the text designate the original vegetation. However, the original vegetation has suffered diverse degrees of disturbance in different areas of the peninsula.

[6] Translator's note: The proportion or quantity of wells per *municipio* is used implicitly as a proxy for water extraction.

[7] From 1915 to 1918, during the governorship of General Salvador Alvarado, the Mexican state participated only in the distribution and sale of henequen.

[8] Translator's note: In addition to the lack of bureaucratic integration, the *ejidos* did not take over ownership of the physical capital necessary to process the henequen leaves into fiber, nor did they have the financial capital or the management capability needed to significantly add value to henequen activities.

[9] Translator's note: Evidence from elsewhere (e.g., central Mexico and the northern highlands of Guatemala) suggests that agriculture-based socioecological systems with limited or not very attractive migration opportunities have evolved toward small-scale horticultural production, self-employment (e.g., handicrafts or other labor-intensive production), and small-scale commercial activities carried out in regional markets. This set of activities already exists in the Yucatán peninsula; what remains unclear is the future configuration of the rural economy.

[10] In 1960, more than 30% of the total herd of the state of Yucatán, estimated at 500,000 head of cattle, was concentrated in this region. During the first part of the 1990s, approximately 50% of the 900,000 head of cattle in the state of Yucatán were concentrated here. The region's share of the state's herd continued to increase, reaching 70% in 1993; however, the state's total herd has decreased.

[11] During the past four decades, maize production in the state of Yucatán has fluctuated widely. For instance, in 1981 maize production reached 150,000 tons as a result of the governmental program known as SAM (Mexican Alimentary System), whereas in 1988 maize production declined to 10,000 tons due to the devastating effects of Hurricane Gilbert. Average annual maize production in the state of Yucatán amounts to approximately 100,000 tons. The maize production region provides about 50% of this production (INEGI, 1994).

[12] The program was initiated in 1964 using sprinkling irrigation. Prior to this program, 1,400 ha already used surface irrigation. As a result of this program, orange production in the state of Yucatán increased from 20,000 tons per year in the first part of the 1960s to more than 100,000 tons during the last years of that decade.

[13] Population size might have been underestimated because a series of small human settlements dispersed in the jungle were difficult to access, not only because of the lack of roads, but also because a large proportion of these inhabitants were descendants of the Maya who fought in the Caste War and maintained their isolation well into the 1950s.

[14] *Chicle* was produced from the latex of a large tropical forest with *Manilkara zapota*.

Appendix 2.A: Socioecological regions of the Yucatán peninsula and their constituent *municipios*

Metropolitan region of Mérida (IA)			
Kanasín	Mérida	Progreso	Umán
Former henequen-producing region (IB)			
Abala	Hoctun	Tahmek	Ucu
Acanceh	Homun	Tecoh	Xocchel
Baca	Hunucma	Tekat de V.	Yaxkukul
Bokoba	Ixil	Tekanto	Yobain
Cacalchen	Izamal	Telchac Pueblo	
Cansahcab	Kinchil	Telchac Puerto	
Conkal	Mococha	Temax	
Cuzama	Motul	Tepakan	
Chicxulub Pbo.	Muxupip	Tetiz	
Chochola	Samahil	Teya	
Dzemul	Seye	Timucuy	
Dzidzantún	Sinanche	Tixkokob	
Hocabá	Suma	Tixpehaul	
Cattle-producing region (IIA)			
Buctzotz	Dzilám González	San Felipe	
Calotmul	Espita	Sucila	
Cenotillo	Panaba	Tizimín	
Dzilám de Bravo	Río Lagartos		
Maize-producing region (IIB)			
Cantamayec	Dzoncahuich	Opichen	Temozon
Celestún	Halachó	Peto	Tinum
Chacsinkin	Huhi	Quintana Roo	Tixcacalcupul
Chankom	Kantunil	Sacalum	Tixmehual
Chapab	Kaua	Sanahcat	Tunkas
Chemax	Kopoma	Sotuta	Uayma
Chichimila	Mama	Sudzal	Valladolid
Chikindzonot	Mani	Tahdziu	Yaxcabá
Chumayel	Maxcanú	Teabo	
Cuncunul	Mayapan	Tekit	
Dzitas	Muna	Tekom	
Fruit-producing region (IIIA)			
Akil	Santa Elena	Tzucacab	
Dzan	Tekax		
Oxkutzcab	Ticul		
Hills and valleys region (IIIB)			
Calkini	Escárcega	Hopelchen	
Champotón	Hecelchakan	Tenabo	
Campeche region (IIIC)			
Campeche			
Candelaria region (IV)			
Carmen	Palizada		
Tourist–urban region (VA)			
Benito Juarez	Cozumel		
Northern block-fault basin region (VB)			
Isla Mujeres	Lázaro Cárdenas	Solidaridad	
Southern block-fault basin region (VC)			
Othón P. Blanco	Felipe Carrillo Puerto	José María Morelos	

References

Anonymous, 1993, Quintana Roo: Plan Estatal de Desarrollo 1993–1999, Gobierno del Estado de Quintana Roo, Chetumal, Quintana Roo, Mexico.

Butterlin, S., and Bonnet, F., 1963, Mapas geológicos de la península de Yucatán, Bol. A.M.P.G., Vol. X, Nos. 9–10, Mexico, in R. Orellana, *El Clima de la Península de Yucatán: Presente, Pasado y Futuro*, manuscript.

Cabrera, A., Pacheco, J., Coronado, V., and Gómez, A., n.d., Evolución de la Calidad del Agua Subterránea al Norte de Mérida, Yucatán, Facultad de Ingeniería de la Universidad Autónoma de Yucatán, Mexico.

CNA, 1995a, Resumen Técnico de las Condiciones Geohidrológicas del Estado de Campeche, Comisión Nacional del Agua, Subgerencia Técnica, Gerencia Regional del Sureste, Mérida, Yucatán, Mexico.

CNA, 1995b, Resumen Técnico de las Condiciones Geohidrológicas del Estado de Quintana Roo, Comisión Nacional del Agua, Subgerencia Técnica, Gerencia Regional del Sureste, Mérida, Yucatán, Mexico.

Duch, J., 1988, La Conformación Territorial del Estado de Yucatán, Los Componentes del Medio Físico, Universidad Autónoma de Chapingo, Centro Regional de la Península de Yucatán.

Flores, J.S., and Espejel, I., 1994, Etnoflora Yucatanense: Tipos de Vegetación de la Península de Yucatán, Fascículo 3, Universidad Autónoma de Yucatán, Sostenibilidad Maya, Mérida, Yucatán, Mexico.

García, E., 1989, Apuntes de Climatología de Mexico, Sexta edición, Facultad de Ciencias, UNAM, Mexico DF.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1991, Censo General de Población y Vivienda de 1990, Aguascalientes, Mexico.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1994, Censo Agrícola-Ganadero, Aguascalientes, Mexico.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1996, Sistema de Cuentas Nacionales de Mexico, PIB por Entidad Federativa, 1993, Aguascalientes, Mexico.

Lesser, J.M., and Weidie, A.E., 1988, Region 25, Yucatán peninsula, The Geological Society of America, *The Geology of North America*, Vol. 0-2, Hidrogeology Chapter 28, pp. 237–241.

Marín, L., 1990, Field Investigations and Numerical Simulation of the Karstic Aquifer of the Northwest Yucatán, Mexico, Doctoral thesis, Northern Illinois University, De Kalb, IL, USA.

Miranda, F., 1958, La vegetación de la península Yucateca, in E. Beltrán, ed., *Los Recursos Naturales del Sureste y su Aprovechamiento*, Ed. IMERNARAC, **2**:215–271.

Peña, J.L., Martin, M., and González, J.C., 1997, The economy of the Yucatán peninsula: Its performance from 1970 to 1993, Population, Development, Environment Project, Technical Report, CINVESTAV-IPN/IIASA/UNFPA/CONAPO.

Perry, E., Marín, L., McClain, J., and Velázquez, G., 1995, Ring of cenotes (sinkholes) in northwest Yucatán, Mexico: Its hydrogeologic characteristics and possible association with the Chicxulub impact crater, *Geology*, **23**(1):17–20.

Steinich, B., and Marín, L., 1997, Determination of flow characteristics in the aquifer of the Northwestern peninsula of Yucatán, Mexico, *Journal of Hydrology*, **191**(1–4): 315–331.

Stoessell, R.K., Ward, W.C., Ford, B.H., and Schuffert, J.D., 1989, Water chemistry and $CaCO_3$ dissolution in the saline part of an open-flow mixing zone, coastal Yucatán peninsula, Mexico, *Geological Society of America Bulletin*, **101**:159–169.

Velázquez Aguirre, L., 1986, Aplicación de Principios Geoquímicos en la Hidrología Kárstica de la Península de Yucatán, Dirección General de Administración y Control de Sistemas Hidrológicos, Secretaría de Agricultura y Recursos Hidráulicos, Ingeniería Hidráulica en Mexico, pp. 21–29.

Villasuso, M., and Mendez, R., 1998, A conceptual model of the Yucatán peninsula's aquifer, Population, Development, Environment Project, Technical Report, CINVESTAV-IPN/IIASA/UNFPA/CONAPO.

Wilson, E., 1980, Physical geography of the Yucatán peninsula, in E.H. Museley and E.D. Terry, eds, *Yucatán: A World Apart*, University of Alabama Press, Tuscaloosa, AL, USA.

3

Recent Population and Education Trends on the Yucatán Peninsula

Amarella Eastmond, Ana García de Fuentes, and Juan Córdoba y Ordoñez

3.1 Introduction

Many of the changes occurring on the Yucatán peninsula today are intimately related to and influenced by its demographic history and present population characteristics. Describing and understanding these features is therefore an essential first step for successful development planning and management of the area. Here, we outline the principal demographic and educational characteristics of the peninsula, highlighting the urban–rural differences and regional contrasts, and indicating how they have changed over the past 30 years.[1]

The Yucatán peninsula extends over a large territory (constituting 7.5% of Mexico's territory) and is still relatively underpopulated (*Figure 3.1*). The average population density in 1995 was only 19 persons per square kilometer (km^2).[2] Of the three states that make up the peninsula, Yucatán is the smallest, representing only 28.6% of the territory. However, in 1995 it was home to 53.6% of the peninsula's population, its average density being 36 persons/km^2. Campeche has the largest territorial extension – 38.7% of the total – but contributes only 22.1% of the population. It has the lowest average density at 11 persons/km^2. Quintana Roo, with 33.7% of the territory and a small population, has the highest growth rate. The population jumped spectacularly from 88,150 inhabitants in 1970 to 703,442 in 1995 and the average density rose from 1.7 to 13.8 persons/km^2 over the same period, leaving little doubt about the demographic and economic importance of this frontier state for the future of the country.

The most notable demographic contrasts within the peninsula can be observed between the predominantly rural and predominantly urban regions. These contrasts highlight the significance of the urban–rural divide, which remains one of the most evident expressions of the conflict between the traditional Maya culture with its agricultural roots, on the one hand, and modern Western culture, centered in the cities, on the other. Whereas in the urban areas of the metropolitan region

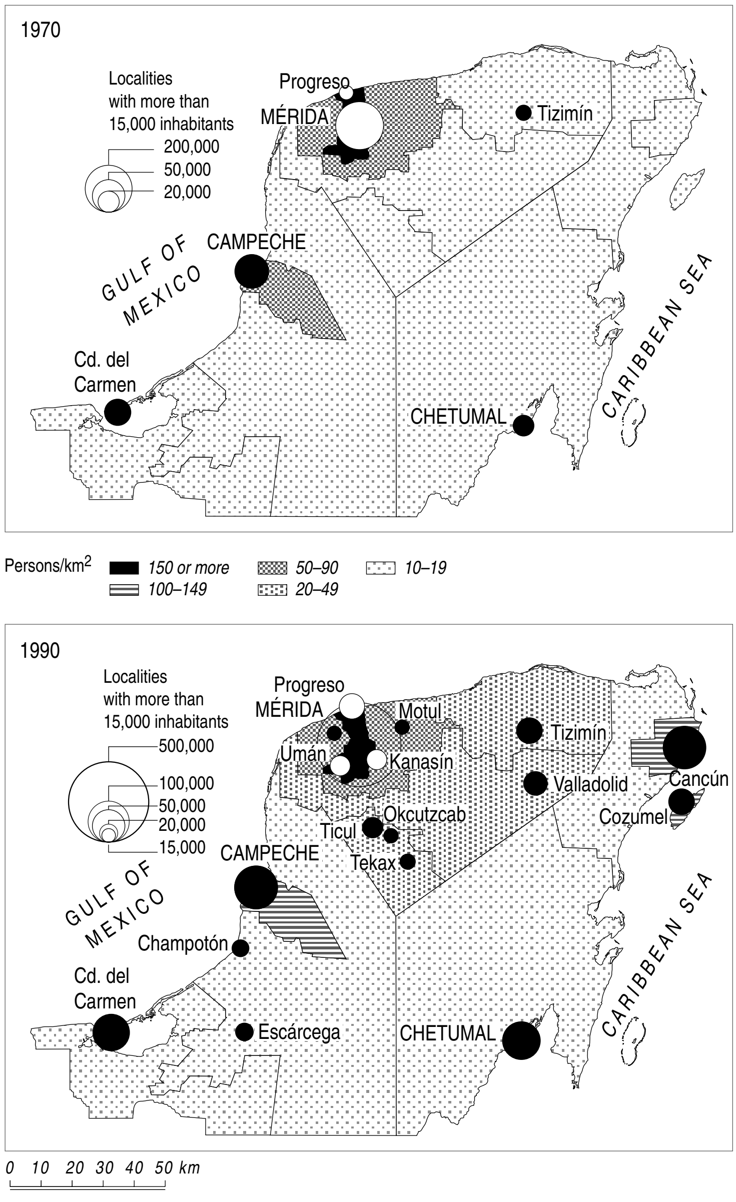


Figure 3.1. Population density and urban structure, 1970 and 1990.

of Mérida, the Campeche region, and the tourist–urban region, the average population density in 1995 was 181.63 persons/km^2, it was only 10.9 persons/km^2 in the rural regions. Resolving the conflicting demands made on resources by these two profoundly different cultures is perhaps the greatest challenge facing sustainable development on the Yucatán peninsula today.

3.2 Historical Background

Through the *encomienda* system and, later, through the establishment of *haciendas*, the Spanish *conquistadores* and their Creole descendants imposed a new economic system on the indigenous people of Yucatán that profoundly influenced the pattern of population distribution. Whereas traditional Maya agriculture, or *milpa*, functioned on the basis of a highly dispersed population, the *encomienda* system required the concentration of the indigenous people into more easily controllable villages (see Bolio Osés, 1983a).

After its original decimation at the time of contact with the *conquistadores* – brought on as much by disease as by warfare (see Cook and Borah, 1978) – the peninsula's population began to recover slowly following two distinct patterns. In the northwest, near the maize and cattle *haciendas* around Mérida, it grew relatively rapidly. From the outset, Mérida was the capital of the colonial province of Yucatán (which included the three present states on the peninsula). It played an important role as the cultural, ecclesiastical, political, and economic center (Brannon and Baklanoff, 1989), attracting population and growing steadily in size. Throughout the rest of the peninsula, population growth occurred at a slower pace, especially among the isolated groups of Maya, who were only very loosely integrated into the new economic system and who continued to live by traditional means.

For a long time, the population of the state of Campeche was limited to the coastal zone and concentrated in the city of Campeche (the state's capital) and in the island town of Ciudad del Carmen. The coastal population's economy grew as a result of the exploitation of dyewood and small-scale fishing activities.[3]

Important population growth and serious competition with Maya *milpa* agriculture for land and labor on the peninsula began with the establishment of sugar plantations around Tekax at the beginning of the 19th century. The Maya who refused to capitulate were deprived of the best lands and pushed farther into the forest to the south and east (Patch, 1991). There they gathered force and later violently counterattacked in what became known as the Caste War, one of the bloodiest Indian revolts in Mexico, in which half of the population of Yucatán was killed (see Reed, 1964). The effect of this rebellion was to temporarily redisperse the Indian population and to mark Quintana Roo as an undesirable region in need of central military control. In the late 19th and early 20th centuries, President Porfirio

Díaz used it as a camp for political prisoners, who perished under the hardships of forced labor (Soto Mora and Soto Mora, 1980). No substantial population increase in Quintana Roo occurred until the recent creation of the Caribbean holiday resort of Cancún around 1970.

After the Caste War, the center of population growth on the peninsula again moved to the arid northwest, where the vertiginous increase in henequen production soon began to transform the landscape and fuel Mexico's most prosperous agro-industry of the time. As the industry grew, so did its insatiable demand for land and labor, so that by the beginning of the 19th century most of the free villagers in the northwestern part of Yucatán had been converted into resident *hacienda* workers and their communal lands incorporated into the *haciendas* (Joseph, 1988:20).

There is no doubt that, since the middle of the 19th century, the henequen industry has been the single most significant factor determining the size and distribution of Yucatán's population. During its rise and peak, the industry pulled people toward its sphere of influence – an area within an 80-kilometer radius around Mérida – tying them ruthlessly to its work demands. In its decline, it has been equally merciless in expelling them, obliging families to leave their homes and land in search of new opportunities (see Bolio Osés, 1983b).

3.3 Population Growth

The most outstanding demographic feature on the Yucatán peninsula between 1970 and 1995 was the speed at which the population grew. In 1970 the peninsula had just over one million inhabitants (1,098,061); by 1995, the number had almost tripled to 2,901,257, indicating an average annual growth rate of 3.97% between 1970 and 1990 (*Table 3.1*). Between 1990 and 1995, this rate declined slightly to 3.94% but still remained above the national average of 2.3% for that period.

Although the fertility rate fell from 4.3 children per woman in 1980 to 3.8 in 1990, considerable population growth will likely continue well into the future. The greatest contrasts in the natural rates of increase of the population within the peninsula can be observed between the predominantly rural regions, where the rates are still high, and the predominantly urban areas, where increased education, more effective family planning schemes, and wider work opportunities for women have generally caused a slowing of the birth rate (*Figure 3.2*).[4] Natural increase alone, however, does not explain the huge increase in population on the peninsula, a large proportion of which has resulted from migratory flows into the region. The highest rates of immigration-based growth have occurred in Quintana Roo, which has exerted a powerful migratory pull from all parts of the country, especially to the tourist–urban (VA) and northern block-fault basin (VB) regions (*Figure 3.3*). Since

Table 3.1. Selected indicators.

Region (code)	Population (thousands of inhabitants) 1970	1990	1995	Growth in population (1970=100) 1995	1990 Age group 0–14 (%)	15–65 (%)	65+ (%)	1990 Number of men per 100 women Total	Aged 15–65	1990 Income (in multiples of min. wage)[a] <1[b] (%)[b]	1–2 (%)	2–5 (%)	>5 (%)
Metropolitan Mérida (IA)	283.7	658.4	772.0	272.09	33.45	60.54	5.83	93.83	91.05	24.89	40.70	24.91	7.36
Former henequen-producing (IB)	186.6	248.0	266.6	142.87	39.68	53.84	6.38	102.47	100.19	58.72	27.96	9.25	1.28
Cattle-producing (IIA)	67.7	101.5	112.5	166.28	41.58	53.13	4.94	101.30	98.71	43.05	37.55	13.31	2.17
Maize-producing (IIB)	161.5	252.9	288.8	178.82	42.92	51.51	4.71	101.45	97.74	60.18	20.88	12.51	1.93
Fruit-producing (IIIA)	58.8	102.1	115.9	197.15	43.59	51.43	4.84	100.56	96.72	43.68	34.98	16.07	2.42
Hills and valleys (IIIB)	86.2	218.3	250.2	290.33	43.36	51.57	3.68	104.49	104.23	44.97	30.75	16.35	2.55
Campeche (IIIC)	81.1	173.6	204.4	251.91	34.79	59.25	4.54	96.50	93.29	27.02	40.22	21.77	5.25
Candelaria (IV)	84.2	143.2	187.4	222.55	39.46	55.99	3.09	100.92	100.50	25.60	32.68	27.28	9.30
Tourist–urban (VA)	12.6	221.7	360.1	2,853.26	35.62	59.36	1.26	109.64	114.48	10.88	25.48	41.34	15.60
Northern block-fault basin (VB)	6.9	26.6	55.7	810.81	41.13	55.47	2.77	110.16	113.87	29.82	30.29	27.14	5.24
Southern block-fault basin (VC)	68.7	245.0	287.6	418.91	43.28	53.67	2.70	104.22	103.34	34.11	28.88	15.79	4.49
State of Yucatán	758.4	1,360.9	1,555.7	205.15	37.70	56.41	5.58	97.80	94.62	38.95	34.66	18.82	4.75
State of Campeche	251.6	535.2	642.1	255.24	39.53	55.25	3.80	100.89	99.30	33.44	34.63	21.17	5.30
State of Quintana Roo	88.1	493.3	703.4	798.01	39.72	56.33	2.06	106.94	109.03	21.97	27.21	33.33	10.23
Yucatán pensinsula	1,098.1	2,391.4	2,901.2	264.22	38.53	56.13	4.46	100.31	98.48	33.95	32.97	22.60	6.10

[a] In 1990 the minimum wage was US$3.30 per day.
[b] Includes workers who do not receive any income.

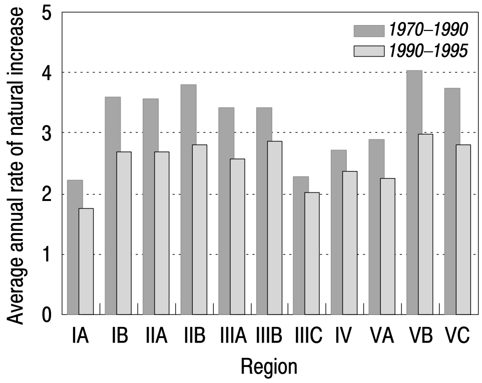


Figure 3.2. Average annual natural increase of the population between 1970–1990 and 1990–1995. See *Table 3.1* for region names.

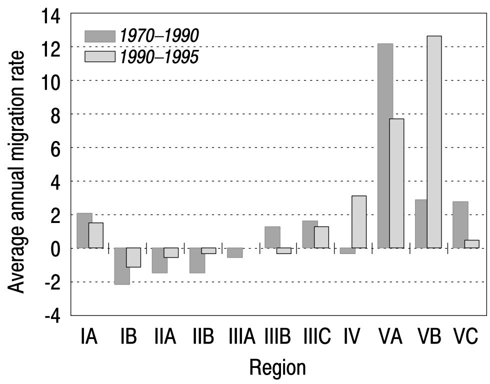


Figure 3.3. Average annual rate of migration between 1970–1990 and 1990–1995. See *Table 3.1* for region names.

the discovery of oil in the 1980s, the state of Campeche has also experienced some immigration-driven population growth. Until 1990, Yucatán was the only state that lost population, especially from the former henequen-producing, cattle-producing, and maize-producing regions. Overall, it is clear that the Yucatán peninsula's socioeconomic characteristics have been a source of attraction for migration, but it is equally clear that the resulting increase in population is making heavy demands on urban infrastructure and services with which the towns and cities are ill-able to cope.

3.4 Age and Sex Composition

A comparison of the 1970 and 1990 age–sex pyramids of the Yucatán peninsula reveals important demographic changes over this period (*Figure 3.4*). In 1970 the general age–sex structure of the peninsula was typical of an underdeveloped area, with a broad base, a marked indentation in the third level indicating high infant mortality, and a constant narrowing of the pyramid's vertex pointing to a small proportion of old people. Although the age–sex pyramids of the states of Campeche and Yucatán indicated a slowing of the birth rate and a deficit of males, in Quintana Roo all the evidence pointed to a continued high birth rate and an important influx of predominantly male migrants. By 1990, all three states showed a small reduction in the proportion of young children (between 0 and 4 years old), which was, however, more marked in Campeche and Yucatán than in Quintana Roo.[5]

A glance at the age–sex pyramids of the different socioecological regions, or SERs (*Figure 3.4*), shows that in 1990 the population under the age of 15 continued to represent a large proportion of the total population throughout the peninsula (averaging 38.5%). Proportionally, the group was less important in the urban areas (less than 36%) than in the rural areas (more than 40% of the population) because of the latter's higher birth rates, shorter life expectancies, and smaller job markets for women. In the case of the tourist–urban region, the relative importance of the young population was reduced (representing 35.6%) because of the large proportion of adult immigrants. In 1990, the adult population (between 15 and 65 years of age) fluctuated as a proportion of the total population between 51.4% and 55.9% in rural areas and between 59.4% and 60.5% in urban areas, the difference being caused by rural–urban migration.

Although the proportion of old people (over 65 years) in 1990 was consistently small (4.5%) over the whole peninsula, the number of old people per 100 young people was above the national average (11.6 on the peninsula versus 10.8 in the country as a whole). Life expectancy was considerably higher in the state of Yucatán than in other parts; it was especially high in the metropolitan region of Mérida and the former henequen-producing region, where people over 65 years old represented 5.8% and 6.4% of the population, respectively, compared with only 1.3% in the tourist–urban region. An unusual, and so far unexplained, characteristic of the population structure on the peninsula as a whole in 1990 was the higher proportion of men than women in the adult groups, generally being above 110 males per 100 females in rural areas and reaching the extreme case of 139.7 men per 100 women in the old-age group in the southern block-fault basin.

The 1990 age–sex pyramids for the majority of the rural areas showed some initial signs of the demographic transition (*Figure 3.4*), although these were weakest in the Candelaria and northern and southern block-fault regions. The maize-producing region showed the most extreme characteristics of underdevelopment.

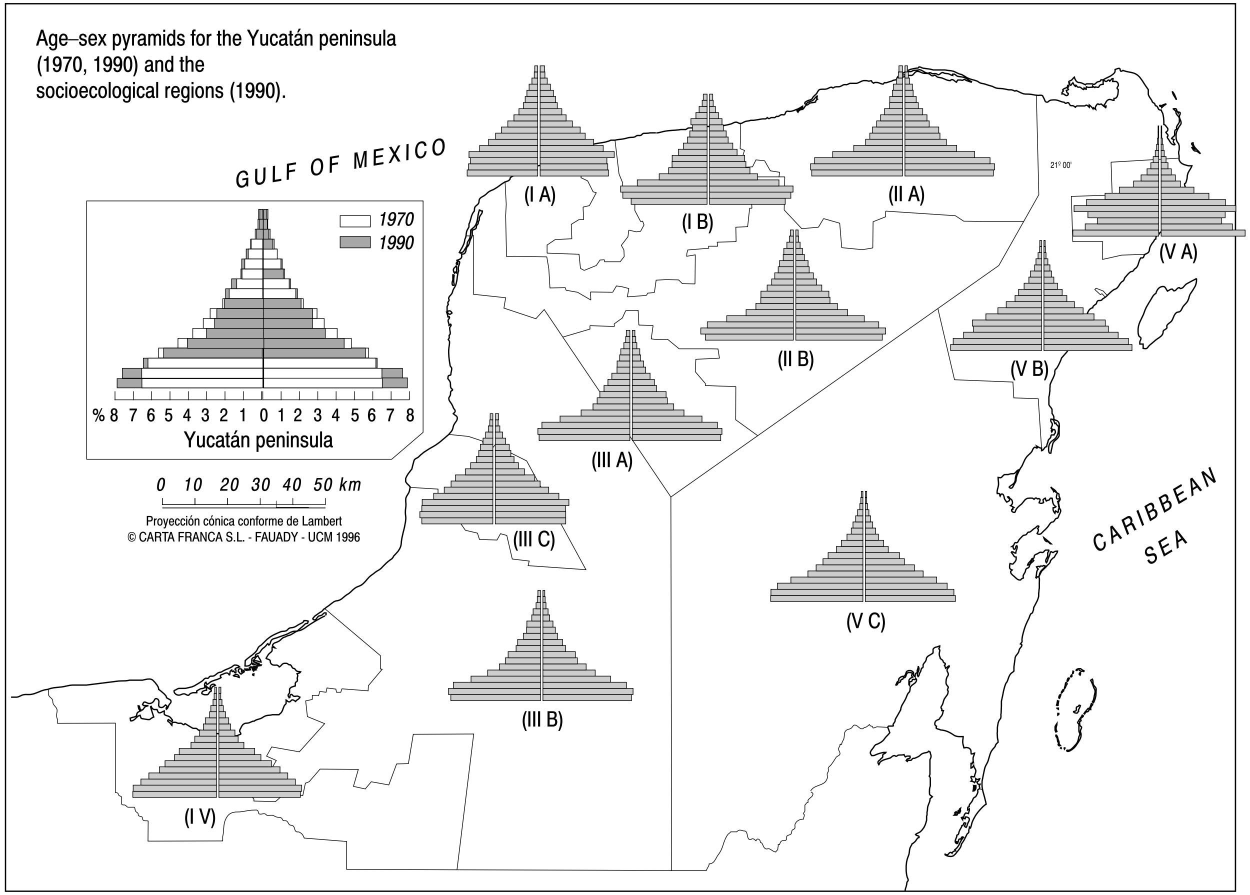


Figure 3.4. Age–sex pyramids for the Yucatán peninsula (1970 and 1990) and the socioecological regions (1990). See *Table 3.1* for region names.

The former henequen-producing region was the most highly distorted by emigration. The tourist–urban region was severely distorted by the effects of immigration. In contrast, the Campeche region and the metropolitan region of Mérida had the most in common with developed-country patterns.

3.5 Urbanization

Compared with industrial countries, the rate of urbanization remains low on the peninsula.[6] Despite having increased from 34% in 1970, it was still only 55.5% in 1990. Moreover, its urban structure is extremely concentrated and badly articulated between its different hierarchical levels (see *Figure 3.1*). The backbone of the structure is represented by Mérida, the dominant center and principal provider of services since colonial times, whose metropolitan area has spread to such an extent that it now includes Progreso on the coast and Kanasín in the southeast. In range and quality of services offered, Mérida surpasses all other urban centers on the peninsula, except Cancún in the case of tourist services.

Even today, the Yucatán peninsula has few cities, defined here as settlements of over 15,000 inhabitants (Unikel *et al*., 1976). In 1970 it had six cities, three of them located in the state of Yucatán; today there are 18, now more evenly distributed over the peninsula. Four of these cities – Campeche, Ciudad del Carmen, Cancún, and Chetumal – have grown very rapidly over the past 30 years, creating a solid structural level below Mérida and somewhat reducing the latter's relative importance. However, the next level down, exemplified by Tizimín in Yucatán, represents an enormous reduction in terms of quantity and quality of services provided. In Campeche and Quintana Roo, the gap is less extreme but sufficient to stimulate the process of outward rural migration and accelerate urban concentration in the top two hierarchical levels. Finally, the smallest urban areas are extremely varied, with some (such as Oxcutzcab and Tekax) having most of the functions of a city despite their small size and others (such as Escárcega) being little more than large villages.

The proportion of the population that still lives in settlements of fewer than 2,500 inhabitants remains high (24.4% in 1990), although there is a clear downward trend. Despite being statistically small, settlements of one or two dwellings are spatially significant in that they characterize the landscape pattern of large areas of southern Campeche and Quintana Roo. Moreover, they are socially important in that they present the development planners with one of their thorniest problems: how to integrate the rural population and provide it with urgently needed infrastructure and services without jeopardizing the survival of Maya culture.

3.6 Migration

Over the past 30 years the Yucatán peninsula has served as a receptor of large migratory flows (see *Figure 3.3*). Two factors can explain its enormous attraction: the spectacular growth of Cancún and policies of directed colonization, which reached a peak during the presidency of Luis Echeverría (1970–1976) and whose effect was to move large numbers of landless people from the north and central parts of the Republic to the sparsely populated interior of the Yucatán peninsula. Quintana Roo represents an extreme case of migration-driven growth, with annual average migration rates of 9% between 1970 and 1990 and 7.4% between 1990 and 1995.

Although Cancún has acted as a magnet attracting people from all over the country, many of the migrants have come from the state of Yucatán. This is partly because historically it has always had a higher concentration of people than the other two states; but more importantly, it is also a result of the protracted economic decline of its rural areas, particularly the former henequen-producing region. In a state of crisis for decades, the contraction of the henequen industry has forced most of the population to leave. The maize- and cattle-producing regions have also actively contributed to this process, as agriculture in general has failed to provide the jobs and economic growth required by the expanding population.[7] Between 1985 and 1990, 74% of the emigrants from Yucatán went to neighboring Quintana Roo, while only 5.7% moved to Campeche.

Within the SERs, migration rates have varied greatly, from a high of more than 12.9% per year in the northern block-fault basin region to a low of –2.16% in the former henequen-producing region (see *Figure 3.3*). The rates of out-migration have, however, begun to slow, especially in the maize- and cattle-producing regions. For some years the former henequen-producing region has experienced a slowing of its out-migration and now forms a “commuter belt” around Mérida, populated by low-paid workers and domestic servants whose economic strategy depends on maintaining their roots in the countryside and traveling on a daily or weekly basis to Mérida (Baños Ramirez, 1992). Although traditionally more men migrated than women because of the urban demand for bricklayers, it is now often easier for women to find work. Low-paying jobs as domestic help, as workers in *maquiladoras*, or in the service sector are still available, and it has been shown that employers frequently prefer women for their greater reliability, their capacity to endure tedious work, and ease of management. Even a cursory glimpse of villages in the henequen zone, however, is sufficient to reveal the extent of the social problems there, such as alcoholism among men, unattended children, and drug addiction, etc., which have increased dramatically with the new pattern of working women and underemployed men.

Migration from the Yucatán peninsula to the United States was relatively common in the 1960s, when the *bracero* programs encouraged Mexican *campesinos* to

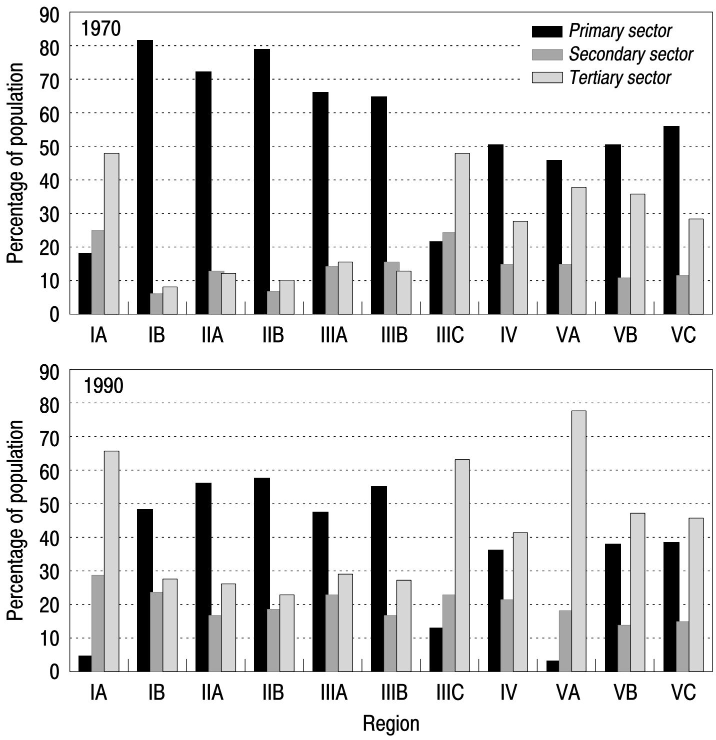


Figure 3.5. Occupation by economic sector in 1970 and 1990. Primary sector: agriculture, fisheries, and forestry; secondary sector: industry; tertiary sector: commerce and services. See *Table 3.1* for region names.

work as farm laborers in the neighboring country. Although some movement toward the United States continues, it has become much less frequent in recent years because of the difficulties encountered at the border.

3.7 Employment

In 1970, the Yucatán peninsula was considered an economically depressed area. Its main economic indicators demonstrated performance well below the national average. While per capita gross domestic product was 3,222 Mexican pesos nationally, in Yucatán it was only 1,906 pesos. At the same time, even though the region was considered basically agricultural, its agricultural capitalization index was only 271 pesos, versus a national average of 768 pesos (García de Fuentes, 1979).

The most notable occupational change over the past 30 years has been the dramatic growth of the tertiary (service) sector of the economy (*Figure 3.5*). Whereas in 1970, 53% of the economically active population was engaged in primary activities (agricultural, forestry, and fishing) and only 26% in the service sector, by 1990 the situation had been completely reversed, so that slightly above 50% was employed in the tertiary sector and only 27.8% in primary activities. This reversal can be seen most spectacularly in the former henequen-producing region, where primary occupation fell from 81% of the economically active population in 1970 to 49% in 1990. Even in the metropolitan region of Mérida, the least agricultural SER in 1970, 18% of the economically active population was still engaged in the primary sector. By 1990, however, this figure was only 4.9%. At the same time there was a corresponding expansion of the tertiary sector, which grew from occupying 47.9% to 66.3% of the economically active population over the same period. Although this rapid growth of the service sector is a result of different factors in the different SERs, it is closely tied to the generally unbalanced structure of the region's economy. While in Cancún it is clearly a consequence of the growth of the tourist industry and in Mérida it can be at least partially explained by the city's status as a regional service supplier, in the rest of the SERs it is more a result of the growth of the informal sector and of the contraction of other economic activities, particularly the henequen industry in Yucatán and forestry activities in Campeche and Quintana Roo.

Whereas crop production dominated Yucatán's agricultural sector in the 1970s, by the 1990s animal production, particularly extensive cattle ranching and intensive pig and poultry production, had taken over as the most economically important activities, causing ever-greater competition for land and other resources with traditional *milpa* while requiring far less labor.[8] Organized around subsistence needs and first developed by the ancient Maya to take maximum advantage of the difficult soil and climatic conditions but great biodiversity in Yucatán (Terán and Rasmussen, 1994; Xolocotzi *et al*., 1995), *milpa* is ill-suited to compete with modern agriculture and has suffered a marked process of decomposition and decline over the past 30 years. This decline has, in turn, resulted in a reduction of the rural population's self-sufficiency, standard of living, and access to resources.

While agriculture has declined, industry (the secondary sector) has expanded very little over the past 30 years: in 1970 it employed 15% of the economically active population on the peninsula, and by 1990 that figure had only grown to 22% (*Figure 3.5*) versus the national average of 28%. Industry's present modest participation in the economy as a whole can largely be explained by the decline of the henequen industry over this period and the conspicuous failure of other industries to replace it as a massive employer and driving force in the regional economy. Apart from the dominant henequen industry, Yucatán's industrial activities in 1970 were limited to the production of food, beer, and soft drinks and the small-scale production of shoes and cloth. By 1990, while the henequen industry had all but disappeared, some new and technologically more advanced industries had emerged (such as food oils and animal feed, plastics, and construction materials) and a small number of *maquiladoras* had been established, but not on the scale necessary to boost economic growth.

Concentrated in the state of Campeche, particularly in Ciudad del Carmen and to a lesser degree all along the peninsula's coast, the fishing industry was an important source of employment and income in 1970. Largely due to fishing, industry as a whole employed 18% of Campeche's economically active population. By 1990, however, despite the discovery of oil in the Gulf of Mexico just off Campeche, this figure had only increased to 22.2%. The oil industry, managed by the parastatal oil company Pemex, has been limited almost exclusively to off-shore drilling in Campeche, leaving very few lasting benefits for the region's economy derived from the growth of only minor oil-related industries (see Chapter 5). Moreover, it has been responsible for causing severe contamination of the once highly productive but fragile marine ecosystems around Campeche. By 1990, Campeche's fishing industry was in marked decline, partly as a result of the pollution but also because of the overexploitation of marine species and the failure of the fishing industry to modernize its fleet.

In the 1970s Quintana Roo's industrial sector basically consisted of two state-run enterprises involving the production of wood and sugar. By the 1980s, both were in crisis. On the one hand, Quintana Roo's tropical forests had been severely depleted, leaving the wood industry without an adequate supply of raw material and forcing it to close down. On the other hand, the state-run sugar industry was in need of complete restructuring and modernization at the national level. In Quintana Roo it was sold to the Coca-Cola Company, which, after investing heavily, has succeeded in revitalizing the industry, converting it into an important source of rural employment in the southern part of the state. Quintana Roo's success also depends on the tertiary sector, in particular tourism, which has taken full advantage of the state's natural beauty, transforming it into a world-class vacation area all along the Caribbean coast.

The labor dependency rate, an indicator of the number of people who do not work in comparison with those who do, is high on the Yucatán peninsula. According to official statistics, for every worker on the peninsula in 1990 there were 2.2 people who did not work. The rural regions, such as the maize-producing and hills and valleys regions, showed considerably higher labor dependency rates (2.8 and 2.7, respectively) than the urban ones, such as the tourist–urban region (1.6). On the whole, women are still very underrepresented in the labor force: for every 100 male workers in 1990 there were only 26.2 female workers. Again, regional differences are quite pronounced, ranging between a high of 41.3 in the metropolitan region of Mérida (and only marginally less in the Campeche and tourist–urban regions) and a low of around 13 in the maize-producing and hills and valleys regions. It should be noted, however, that these indicators are calculated in a way that hides the large work contribution made to households and the community by unpaid members of the family, especially women and children.

3.8 Income

The Yucatán peninsula is characterized by large areas of extreme poverty (concentrated in the rural regions) and a highly skewed pattern of income distribution (see *Table 3.1*). In 1990, 33.95% of the population earned less than the minimum wage (US$3.30 per day at the time). Although the official figures appear to indicate an improvement in the earning capacity of the poorest sections of the population between 1970 and 1990 (60% of the population earned less than the minimum wage in 1970), it should be borne in mind that this may be more apparent than real, because the purchasing power of the minimum wage decreased substantially over the 20-year period.[9] The welfare of people in rural areas deteriorated disproportionately more because of falling yields from traditional agriculture and their decreasing capacity for self-sufficiency, brought on by globalization and the expanding influence of the market.

Over the same period there was a small increase in the proportion of the peninsula's population earning more than five times the minimum wage per day (US$17 in 1990): up from 1.2% in 1970 to 6.1% in 1990. This remains an extremely small percentage, indicating a very low consumer capacity (although it should be noted that the official information gives no indication of the upper range of the top salaries). Although there are marked differences in income distribution within the peninsula, it is clear that the tourist–urban region, where 15.6% of the population earns more than five times the minimum wage per day, represents an exception to the general low income pattern (see *Table 3.1*).

Differentiation between the sexes with regard to income distribution on the peninsula as a whole is not great: surprisingly, slightly more men than women fall into the lowest income range (34.3% men versus 32.7% women earned less than the minimum wage in 1990), whereas, not so surprisingly, more men than women occupied the highest income category (6.6% men versus 4.2% women). The most marked differences were found in Quintana Roo (see *Table 3.1*).

3.9 Education

Historically the Yucatán peninsula – and the state of Yucatán in particular – has played a leading role in spreading education among the lower classes and into rural areas. During the first decades of the 20th century, following the Mexican Revolution, education was given very high priority in government programs.[10] In 1930, Yucatán, Quintana Roo, and Campeche were among the states with the highest school attendance rates for children between 6 and 10 years of age – 58% on the Yucatán peninsula versus a national average of 42%. By 1990, however, the peninsula had lost its leading position and had fallen slightly behind the national average of 85.8%, with only 84% of its young children attending school.[11]

Following the general trend of decreasing illiteracy throughout the country, illiteracy rates on the Yucatán peninsula have fallen enormously over the past 100 years, from 82.1% in 1895 to 27% in 1970 and to 14.3% in 1990.[12] However, as in the case of school attendance, the peninsula has again lost ground in relation to the other states: whereas in 1930 the peninsula's illiteracy was below the national average, in 1990 it was above the national average.[13] In 1990, throughout the peninsula illiteracy rates among women were slightly higher than those among men, indicating a fundamental gap in opportunities between the sexes that is repeated at all educational levels.[14]

The greatest differences in educational attainment within the peninsula are observed between rural and urban regions (*Figure 3.6*). Taking adult illiteracy as an example, it can be seen that in the rural areas, such as the former henequen-producing, maize-producing, fruit-producing, and cattle-producing regions, illiteracy ranged between 22% and 29% of the adult population in 1990, whereas in the urban areas of the metropolitan region of Mérida, the Campeche region, and the tourist–urban region, it varied from a low of 7% to a high of only 10%. Although the rural regions have generally improved more than the urban ones with respect to adult literacy, it is those regions that have experienced the fastest rates of urbanization the (the tourist–urban and hills and valleys regions) that show the highest reductions in their adult illiteracy (see *Figure 3.6*).

Other education-related indicators reflect similar rural–urban differences, highlighting the vastly unequal distribution of educational opportunities between the cities and the countryside. In part, this is responsible for fueling the process of migration to urban areas.

One of the most complex educational problems in Mexico in general (Guevara Niebla, 1992) and on the peninsula in particular is the school drop-out rate: for the academic year finishing in 1995, the drop-out rate was 37% for primary school, 19.7% for secondary school, and 46.8% for high school. The very low primary school finishing rate not only bars a large proportion of the population from any employment other than manual labor, it also represents a barrier to increasing the transition rate from primary to secondary school, which is necessary to achieve a general improvement in the populations' educational attainment. Equally worrisome is the high percentage (79%) of over 20-year-olds who do not have a high

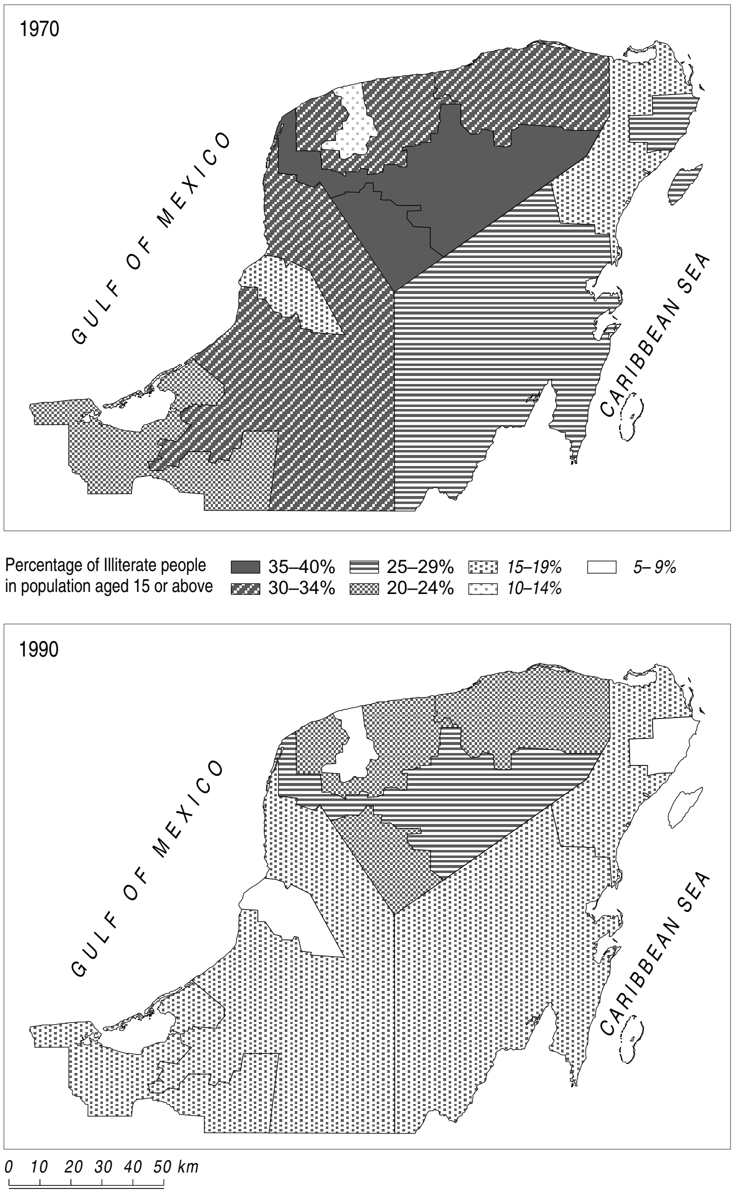


Figure 3.6. Illiteracy rates on the Yucatán peninsula, 1970 and 1990.

school certificate, the entry requirement for higher education courses and professional training. The lack of such a certificate almost automatically excludes people from professional jobs in a system that is highly dependent on paper qualifications for access to above-minimum-wage employment.

Despite these clear deficiencies, the total number of registered school children has increased at all educational levels at a rate slightly faster than the real rate of population increase, especially in the preschool and high school age groups, indicating an awareness of the increasing importance of educational qualifications for social and economic mobility.[14] Whereas private education still plays a very small role in the educational system when analyzed as a whole (more than 80% of registered school children attend free government schools on the peninsula), the participation of women, at all levels, is higher in private schools than public ones.

Given the present restricted economic climate in Mexico and the scope of the challenge that raising its educational level represents, especially in rural areas, it is difficult to forecast a large and generalized improvement in the near future. Current government policies have singled out higher education as a priority for additional federal funding, which can only lead to a reinforcement of the already elitist educational system and a widening of the gap in opportunities between the different social groups.

Notes

[1] Although for the purposes of this study 11 socioecological regions (SERs) were distinguished (as described in Chapter 2), in a preliminary analysis of many of the demographic characteristics it was possible to group these regions into two broad categories with basically similar patterns: the predominantly urban regions, including the metropolitan region of Mérida, the Campeche region, and the tourist–urban region (which includes Cancún and Cozumel); and the predominantly rural ones, including all other regions.

[2] Demographic data for 1995 are taken from INEGI (1996). The data for 1970 and 1990 are derived from Secretaría de Industria y Comercio, Dirección General de Estadística (1972) and INEGI (1992), respectively.

[3] Campeche was famous for its dyewood or *palo de tinte*, which was exploited commercially between the 16th and 19th centuries and was an important source of wealth until it was replaced by synthetic dyes; see Contreras Sanchez (1996).

[4] The rates of natural increase for the socioecological regions of the study were calculated indirectly by Virgilio Partida Bush, Director of Demographic Research for the Mexican National Council of Population (CONAPO). The indirect method is considered to be more accurate than using registered place of birth and death because place of birth/death registration is often faulty.

[5] Because of space limitations it is not possible to show the age–sex pyramids for the three states.

[6] The rate of urbanization refers to the percentage of the population living in settlements of more than 15,000 inhabitants.

[7] Despite falling demand, unsuccessful state reorganization, and poor administration of the henequen industry, accentuated after the 1970s, until very recently henequen production continued to be one of the most important economic activities on the peninsula because of enormous government subsidies. Accumulated losses, however, became unsustainable, and in 1992–1993 the state finally decided to withdraw its support from some 30,000 field workers and sell off Cordemex, the cordage complex, making thousands of workers redundant.

[8] Extensive cattle ranching requires only one cowherd per 300 head of cattle.

[9] Because income data were not collected in terms of minimum wages by INEGI in 1970, some adjustments were necessary to make them comparable with the 1990 information.

[10] Salvador Alvarado introduced coeducation in Yucatán schools and opened government employment to women, see Joseph (1988:105).

[11] Unlike in 1970, in the 1990 census school attendance was calculated for children between 6 and 14 years of age.

[12] Illiteracy has been measured as a percentage of different populations over the years. For the 1895 and 1950 censuses it was taken as a percentage of the over six-year-olds; for the censuses of 1900, 1910, 1921, 1930, 1940, and 1960 it was measured as a percentage of the over 10-year-olds; and for the 1970, 1980, and 1990 censuses the defining population comprised the over 15-year-olds. The data were taken from INEGI (1994).

[13] In 1930 the peninsula had an illiteracy rate of 52% versus the national average of 61.5%. In 1990, the peninsula's illiteracy rate was 14.5% compared with 12.4% for the national average.

[14] The illiteracy rate was 8.8% for women versus 5.7% for men.

[15] According to data obtained from the Ministry of Education offices in Mérida, Campeche, and Chetumal, the total number of enrolled school children on the peninsula increased at 4.13% per annum between 1990 and 1994, compared with the real population growth rate of 3.94% per annum.

References

Baños Ramirez, O., 1992, Crisis Henequenera y Estratégia de Vida, Presentation at the Conferencia Regional sobre el Henequen y la Zona Henequenera, Mérida, Mexico.

Bolio Osés, J., 1983a, *Hacia una Historia del Poblamiento y Urbanización de la Península Yucateca, Primera Parte, Yucatán: Historia y Economía*, **7**(38) July–August:31–48.

Bolio Osés, J., 1983b, *Hacia una Historia del Poblamiento y Urbanización de la Península Yucateca, Segunda Parte, Yucatán: Historia y Economía*, **7**(39) September–October:25–52.

Brannon, J.T., and Baklanoff, E.N., 1989, *Agrarian Reform and Public Enterprise in Mexico*, The University of Alabama Press, Tuscaloosa, AL, USA.

Cook, S.F., and Borah, W., 1978, *Ensayos sobre la Historia de la Población: México y el Caribe*, Vol. II (translated by Clementina Zamora), Siglo XXI, Mexico City, Mexico.

Contreras Sanchez, A., 1996, Capital Comercial y Colorantes en la Nueva España, El Colegio de Michoacan y la Universidad Autónoma de Yucatán, Mérida, Mexico.

García de Fuentes, A., 1979, *Cancún: Turismo y Subdesarrollo Regional*, UNAM, Mexico City, Mexico, pp. 49–50.

Guevara Niebla, G., ed., 1992, *La Catástrofe Silenciosa*, Fondo de Cultura Económica, Mexico City, Mexico.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1992, *XI Censo Censo General de Población y Vivienda, 1990*, Aguascalientes, Mexico.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1994, *Estadísticas Históricas de México*, Vol. 1, Aguascalientes, Mexico.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1996, *Conteo 95*, Aguascalientes, Mexico.

Joseph, G.M., 1988, *Revolution from Without*, Duke University Press, Durham, NC, USA.

Patch, R.W., 1991, Decolonization, agrarian problems and the origins of the caste war, 1912–1847, in J.T. Brannon and G.M. Joseph, eds, *Land Labor and Capital in Modern Yucatán*, The University of Alabama Press, Tuscaloosa, AL, USA.

Reed, N., 1964, *The Caste War of Yucatán*, Stanford University Press, Stanford, CA, USA.

Secretaría de Industria y Comercio, Dirección General de Estadística, 1972, *IX Censo General de Población, 1970*, Mexico City, Mexico.

Soto Mora, C., and Soto Mora, A., 1980, Población y poblamiento de Quintana Roo, in *Memorias del Simposio Quintana Roo: Poblamiento y Perspectivas*, CIQRO–UNAM, pp. 177–185.

Terán, S., and Rasmussen, C., 1994, *La Milpa de los Mayas*, Danida, Mérida, Mexico.

Unikel *et al.*, 1976, *El Desarrollo Urbano de México: Diagnóstico e Implicaciones Futuras*, COLMEX, Mexico City, Mexico.

Xolocotzi, E.H. *et al.*, 1995, *La Milpa en Yucatán*, Vols. 1 and 2, Colegio de Postgraduados, Mexico.

4

Maya Culture, Population, and the Environment on the Yucatán Peninsula

Betty Faust and Richard Bilsborrow

4.1 Introduction

The traditional culture and beliefs of the Maya of the Yucatán peninsula are being affected by recent regional population and economic trends. This chapter describes the contemporary culture, land-use practices, and economic behavior of the Maya as well as implications for the environment. These will be interpreted with reference to historical evidence and in the context of ongoing processes of change associated with external forces.

In the developing world there are several conceptual approaches to explaining recent changes in land use and their impact on the environment. Although earlier explanations exist, Malthusian (Malthus [orig. 1798], 1960) theory is a logical starting place since it continues to dominate (along with anti-Malthusian criticisms) the contemporary debate. A key component is the "law of diminishing returns," which says that average returns to labor must fall with population growth and that this will either result in a voluntary decline in human fertility or in what Malthus called "positive checks": war, famine, and epidemics of disease. Later, the economist Ester Boserup (1965) developed her theory of "agricultural intensification": as population grows in a fixed land area, the resulting pressures on living standards induce people to adopt technologies that increase production by utilizing more (of the relatively higher supply of) labor per unit of land area. In traditional populations this could involve adoption of more labor-intensive methods such as increased weeding, building terraces and raised fields, or directing water flow for irrigation or drainage, all of which have been well documented in many tropical areas with dense populations (see Denevan, 1982, for a review of the literature). In addition, population pressures can induce migration, either through land clearing and deforestation on the agricultural frontier or through rural–urban migration and

The authors are grateful to Betty J. Meggers and William J. Folan for helpful comments, to Sylvia Terán for research assistance, and to IIASA for financial support.

growth of cities (which in turn must be supported by intensified food production). Alternatively, the pressures may result in wars or in demographic responses such as a decline in fertility, or some combination of these adaptations may occur. All of the changes described have occurred to varying degrees in the developing world in recent decades.

4.2 Process of Change Affecting the Traditional Maya Population

The effects of modernization have left the Maya in an impoverished state, both culturally and economically. Levels of poverty on the peninsula are generally higher than the national average, and they are much higher in the traditional Maya areas than in other areas of the peninsula. Thus, extreme poverty was estimated to be 41% for the entire peninsula in 1990, but as high as 80% in the traditional swidden zone and 60% in the former henequen area (both of which have large Maya populations), and only 13% in the urban tourist areas around Cancún. "Alternative technologies" and systems of "sustainable development" are currently being researched, tested in pilot projects, and introduced by government planners, nongovernmental organizations, universities, research centers, and religious groups. However, most of these efforts have not been based on careful examination of the local ecological knowledge remembered by Maya elders (Faust, 1998; Freidel *et al*., 1993).

As elsewhere in Mexico, both fertility rates and natural population growth (due to the difference between fertility and mortality) have been declining recently on the Yucatán peninsula. Thus the peninsula's total fertility rate (total number of births per woman, based on current age-specific fertility rates) fell from 4.3 to 3.8 between 1980 and 1990, which led to a decline in natural population growth from 3.0% to 2.3% per year. Factors influencing these changes are the perceived need to educate children, the availability of contraceptive technology, and an effective government campaign promoting family planning (Elmendorf, 1980). However, the rates of fertility and natural population growth are still higher on the peninsula than in the country as a whole. Unfortunately, campaigns promoting bottle-feeding have contributed to slowing the declines in both fertility and natural population growth, since this supplementation allows for resumption of ovulation otherwise generally suppressed by lactation (Howrigan, 1988).

Contemporary population growth on the Yucatán peninsula is the result not only of the natural population growth of the majority Maya population already residing in the region, but also of a few small government programs begun in the 1970s that have brought colonists from other parts of the country, including Guatemalan refugees from Chiapas. There is also spontaneous migration from other parts of Mexico as well as significant internal migration between the states of the peninsula.

Between 1985 and 1990, Quintana Roo received a total of 93,000 migrants, nearly half (45%) from Yucatán and Campeche. Yucatán had a small net population loss due to migration, while Campeche and Quintana Roo had positive net migration balances that increased their populations by 2.5% and 18%, respectively. In the 1990 census it was found that Quintana Roo migrants (born elsewhere in Mexico) accounted for over half (52%) of its enumerated population, mainly associated with the Cancún tourist boom (figures from García *et al*., 1996, Section 2, Table 9).

Dense rural populations on the peninsula are concentrated in the state of Yucatán, including the former henequen-producing region (39 persons/km^2); the fruit-producing region (17 persons/km^2); the maize-producing region, which traditionally supplied Mérida and other cities with much of their maize (14 persons/km^2); and the cattle-producing region, which includes a coastal area where fishing and salt making are combined with agriculture (13 persons/km^2). In all other rural areas of the peninsula, population density is below 8 persons/km^2 (1995 figures). Note that this excludes the tourist–urban region, the metropolitan region of Mérida, and the cities of Campeche and Ciudad del Carmen (figures from García *et al*., 1996, Section 2, Table 3).

Thus, modest population pressures in rural areas currently are associated with zones where commercial agriculture exists or existed in the recent past. These areas of commercial development have been heavily subsidized by government programs; in other areas population densities remain low. In subsidized areas, population has become more concentrated and introduced commercial production activities have had negative effects on environmental health as a result of soil and water contamination by chemical inputs; destruction of biodiversity as natural predators succumb to biopoisons; clearing of tropical forests for cattle pasture, citrus orchards, cotton plantations, and fields for sugarcane and other monocrops; and reduction of game animals due to both overhunting and loss of habitat.

One response to the reduction of game has been migration to the coast, encouraged by government construction of artificial harbors, docks, and roads, as well as provision of credits for small boats, freezers, and other equipment. In 1957 total catch was only 2,603 tons; by 1987 it was 36,895 tons, an increase of 1,427% in 30 years. This increased local catch has combined with growing competition from international and commercial Mexican vessels, resulting in diminished catches per person for some coastal communities (Faust, 1990, communication from fishermen in Rio Lagartos and Las Coloradas). Hale (1996) has reported that fishing is second only to tourism among the economic activities of the peninsula, but that there are serious problems with overfishing of grouper, spiny lobster, and octopus. Shrimp trawling has damaged other species, particularly marine turtles, and Asian shrimp farming constitutes a threat to the market. Fishing around the reefs is common despite the fact that these marine ecosystems are notoriously fragile and many species found there are extremely vulnerable to overfishing (Hale, 1996). Government agencies have attempted to manage both fishing and hunting, with some success, but they are hampered by a lack of scientific information and resources for enforcement, and by the fact that these activities are not just sports but rather sources of food and income in areas where there are few alternatives.

Government programs to “improve” traditional farming practices have met with little success. Efforts have been made to prohibit burning of swidden plots and encourage green manuring (with leguminous plants) and the use of crop residues to increase organic material in the soil, in conjunction with chemical fertilizer use. The rationale has been that the burning of swidden plots destroys tropical forest, while clearing of extensive areas for mechanized agriculture is seen as “permanent and intensive.” The idea is that intensification through mechanization will allow other areas to stay permanently in forest and thereby protect biodiversity and possibly the Earth’s atmosphere (Schlesinger, 1991). The paradox is that in areas where for thousands of years swidden agriculturalists have cut and burned small patches of *milpa* (corn fields interplanted with beans, squash, and other cultivars), the forest and its fauna appear better conserved than in zones that have received government intervention (B. Faust, personal observation; W.J. Folan, 1996, personal communication).

Along the coast, commercial shrimp trawlers have probably killed far more marine turtles than have artisanal fishermen. Tourist development has probably had a more negative effect on hatchling success for both turtles and waterfowl than has the eating of eggs by Maya communities. This is not to argue that present populations of endangered species can withstand even the former levels of predation by Maya communities, given the restricted habitat left to them, but rather to argue that the highest priority for environmental protection should not be restriction of Maya traditional activities but restriction of commercial activities, which have been encouraged and subsidized by government programs. Analysis of aerial photographs and satellite images combined with terrain-level (and ocean) research should clarify the long-term ecological effects of “sustainable development” projects in comparison with traditional practices (Moran, 1982, 1993; Bodley [1982], 1990).

Government policies and programs directed toward other priorities have also affected farming practices, as have general processes of modernization. Many communities are responding to the 1992 changes in Article 27 of the Agrarian Reform Law, which allow them to divide and sell land originally given as inalienable community property during the reforms of the late 1920s and early 1930s (following the Mexican Revolution). Primary education, medical clinics, electricity, and piped water are available to those who live in towns above a minimum size, increasing population density in those areas. As a consequence, many small hamlets have been abandoned and farm families on the peninsula no longer migrate to relocate around seasonal ponds or cenotes (sinkholes in the limestone geological foundation of the peninsula) during the agricultural season, as was traditionally done (Faust, 1998; Antochiw, 1996). Farmers must either live in small groups away from these services and their families for weeks at a time during the prime planting and harvesting periods or seek fields to work within a few hours of the towns. These modern institutionalized improvements in the quality of life have thus dramatically altered the Maya use of the land and have effectively concentrated population pressures around towns, often resulting in degradation of soils. Many have responded by switching to cattle raising and migrating to urban areas to avoid impoverishment.

4.3 Replacing Traditional Adaptation to the Local Environment with Modern Practices

A number of authors have described conservation aspects of traditional agroforestry practices on communal lands among the Maya (Faust, 1988, 1998; Kintz, 1990; Gómez-Pompa *et al.*, 1993; Terán and Rasmussen, 1994, 1995; Hernández-X. *et al.*, 1995; Anderson, 1996). Unfortunately, these practices are being rapidly eroded by new market factors, government policies encouraging private ownership and exports (including credits for commercial fishing fleets, forest clearing for cattle ranching, and tourism on coral reefs), school curricula that devalue traditional knowledge, television programs that glorify modernism, and a pervasive loss of traditional religious beliefs associated with conservation practices (Terán and Rasmussen, 1994; Faust, 1998, forthcoming).

These changes need to be analyzed with explicit reference to the local effects of the North American Free Trade Agreement (NAFTA) and rapidly increasing investments by transnational agribusiness and biotechnology corporations locally, nationally, and throughout Latin America. Mechanization of production displaces peasants without the skills or education needed to compete for most of today's jobs, and export agribusiness increasingly focuses on high-value products, not basic grains for the poor. International policies and economic forces are thus crucial to understanding present-day linkages between population increase, land use, and environmental consequences.

4.4 Ancient Maya Adaptations

Nineteenth-century explorers and the first archaeologists to see the ruins of ceremonial centers in the middle of the "jungle" assumed, on the basis of observations of contemporary Maya settlements and agricultural practices, that there had also been a low-density population during pre-Columbian times. More recent research has included extensive settlement surveys in areas surrounding the centers, demonstrating that by the Late Preclassic period (400 B.C.–A.D. 250) the peninsula was supporting cities with dense populations. By the Late Classic (A.D. 600–800), the number and size of cities had increased, along with the rural populations sustaining them. Using housemound data, Rice and Culbert (1990:9) estimated 180 persons/km^2 for the southern lowlands; however, such very high estimates may be considerably reduced if seasonal and cyclical use of rural settlements is substantiated for the Classic period (see Chapter 1).

Archaeological findings of the past 20 years demonstrate that to support these dense populations the ancient Maya created complex trade networks (see Sabloff and Rathje, 1975; Matheny *et al*., 1983:205), systems of sophisticated water management (Matheny *et al*., 1983; Zapata, 1989; McAnany, 1990; Faust and Morales López, 1993; Domínguez-Carrasco, 1993; Scarborough and Gallopin, 1994; Fedick, 1995), and a relatively sustainable system of agriculture. The last of these was based on a variety of intensive technologies, including raised fields, canals with pisciculture, terraces, irrigation along rivers, contour soil trenches with ridges, raised seedbeds with replanting, watered gardens and orchards in houseyards, management of trees and root crops in fallow fields, use of both long- and short-cycle varieties, etc. (Siemens and Puleston, 1972; Harrison, 1978; Denevan, 1982; Turner, 1983; Turner and Harrison, 1983; Gómez-Pompa, 1987; Gómez-Pompa *et al*., 1987, 1993; Atran, 1993; Terán and Rasmussen, 1994, 1995). The Maya did all of this within a fragile ecosystem, without draft animals, the wheel, fossil fuels, or industrial machinery, relying on human labor, indigenous environmental knowledge, and a complex social organization. It is clear that Maya science and technology made possible an urban culture with specialists in the arts and sciences as well as scribes who recorded the growing knowledge and historical events in a complex writing system (Roys, 1943). Population grew at an escalating rate, particularly in the south-central lowlands, where in the 9th century there was a widespread cultural and demographic collapse. This has been alternatively attributed to the overuse of soils in swidden agriculture (see Lowe, 1985), exponential population growth (Ricketson and Ricketson, 1937), diseases such as yellow fever and malaria (Thompson, 1970; Crosby, 1972; Wilkinson, 1995), a breakdown in the salt trade (which had been essential for the maintenance of human health; Andrews, 1983:8–10), invasions from the west (Sabloff, 1995), and/or peasant revolts (Thompson, 1970).

More recent explanations for the 9th century collapse of the southern cities focus on an extended drought associated with global climate change (Gunn *et al*., 1995; Hodell *et al*., 1995). Parallels may be drawn to the recent situation in the Sahel, characterized by natural drought cycles and ecological disruption due to the introduction of new forms of agriculture (BOSTID, 1984a, 1984b; Bates and Plog, 1991). Given a densely populated, complex system, the external shock of climate change and declining agricultural yields could increase malnutrition and susceptibility to disease and decrease the energy available to clean the shallow irrigation canals, thereby increasing the breeding ground for mosquitoes, the disease vector for yellow fever. Shortened fallow cycles would make forest lands vulnerable to invasion by grasses, thereby extending naturally occurring cycles of drought and further disrupting cultural systems and political organization. Discontent with a declining domestic economy could have fomented political challenges to the ruling class, increased warfare between neighboring polities, and tempted external invaders. Indeed, evidence that wars increased in the period is found in the moats and walls surrounding some Classic cities, as well as in recently deciphered hieroglyphic texts and in the murals of ceremonial centers, particularly Bonampak. Defacement of sculpted figures, stelae, and paintings of royalty and associated gods also supports the hypothesis of internal rebellions.

The Maya collapse was not total. During the Terminal Classic and into the Postclassic periods, the population became concentrated in the northern area and around the coast, two areas where water was close to the surface and accessible through hand-dug wells and cenotes, as well as in cities along the southern river systems of Campeche, Tabasco, and Belize (Crosby, 1972; Thomspon, 1970). Even in the Petén, those population centers near lakes resisted the destabilizing effects of the collapse of powerful neighbors, maintaining sizable populations until the end of the 17th and beginning of the 18th centuries (Rice, 1987). This is an indication that the loss of social organization required to maintain large, artificial water systems in the south was crucial in the cities' collapse and in their subsequent failure to rebound. Mechanisms of social organization and technological knowledge which had been the intellectual property of the southern elite were most probably lost in the collapse – a collapse that substantially reduced the population, lessening the need to use areas which required the maintenance of massive waterworks. Today, water management is still the main problem of the new colonies of agriculturalists transferred to this region by government programs, who are not informed about ancient or contemporary Maya adaptations to this environment (Ericson, 1997).

4.5 History since the Encounter with Europeans

Historians have estimated population losses of 75–95% during the first century of European colonization (Cook and Borah, 1971; Crosby, 1972). Population losses were primarily due to "virgin soil epidemics" linked to ecological disturbances. Estimated rates of loss are similar to those on Pacific Islands in the 19th century, which were far better documented than those of the 16th-century Yucatán peninsula. In both regions, drastic changes in many ecological zones included the pasturing of herds of cattle, sheep, and horses on land once used for subsistence agriculture and indigenous management of forests and wildlife. Horses, cattle, and pigs subsequently became feral and multiplied, wreaking havoc on native ecosystems, particularly native grasses and soils. Malaria, hookworm, and amoebic dysentery caused population losses, both directly and through increased vulnerability to epidemics of smallpox, influenza, pneumonia, and measles.

After the population collapse of the 16th century, density was so low that labor-intensive methods of agricultural production were no longer appropriate (see Boserup, 1965). Even in areas remote from missionary and colonial control, any knowledge of labor-intensive methods that had survived the Maya collapse of the 9th century was probably lost. With more land available per person, swidden methods combined with hunting and gathering provided an ample and varied diet that was high in protein and essential vitamins and minerals. Some knowledge-intensive traditions, such as the management of rich biodiversity in *milpas* and houseyard gardens, have continued into the present (Terán and Rasmussen, 1995). Coastal populations that had relied on fishing, salt production, and trade fled to the interior to escape slave traders, pirate raids, and conscription to ships, generally leaving commercial fishing to immigrants from the Canary Islands and coastal areas of Spain.

Near the coast and in the lower northern areas, natural cenotes and shallow wells provided access to the normal underground water level. In some hilly areas, wells provided access to underground drainage channels. In the interior and the south of the peninsula, diseases (malaria, dengue, yellow fever, etc.) and lack of access to water transport made settlement unattractive to Europeans. There, many small Maya communities lived by swidden agriculture, maintaining small-scale, indigenous systems of rainwater management, as reported by Stephens ([orig. 1843], 1988:2:148), Sandoval and Morales López (1982:23), Faust (1988:248–262), Barrera Rubio (1987), and Zapata (1989). Such systems included underground cisterns, hollowed out and sealed with plaster or fired clay with necks just large enough for one person to enter for cleaning, and enlarged natural ponds with sealed bottoms and sides to prevent leakage into the limestone subsoil. The latter were sometimes combined with wells accessing perched water pockets and with canals bringing water from neighboring hills. All these groundwater systems were recharged directly by rainfall and indirectly by superficial seepage (Gates and Folan, 1993). Such systems provide some protection from the human and geological sources of contamination found in deeper underground water sources. The peninsula is formed geologically of limestone, which has vertical cracks facilitating the direct entrance of fecal matter (carrying coliform bacteria, amoebas, and other disease vectors) into the underground water without the filtration found in other types of terrain. In the southern area, government monitoring of wells shows that sulfites and other chemicals from geological sources exceed the recommended limits, not only for human consumption, but even for animal use and irrigation. Nitrates and nitrites from commercial agricultural operations further contaminate the water supply (Batllori, 1996).

From the 18th century to the beginning of the 20th century, many Maya men in Campeche and Quintana Roo were displaced from their communities during the dry season to haul dyewood from deep in the forests to export markets; later, *chicle* extraction removed many workers during the agriculture season. In the late 19th century, henequen became a large export industry in the northern area of the peninsula, predominantly in the state of Yucatán. Henequen (referred to as “green gold”) was produced for export by large landowners, who used systems of manipulated debt peonage to maintain their Maya labor forces at low cost while importing state-of-the-art technology for factories that initially produced only fiber for export.[1] Later, some local mills produced cordage products. In the 1960s these mills were bought by the federal government and managed by a parastatal firm, CORDEMEX (Brannon, 1991:247–248).

The environment suffered along with the workers, despite the fact that henequen was an indigenous crop domesticated by the Maya. Forests were felled to supply firewood for steam-powered machinery, which made rope and bailing twine from henequen fiber. Corn was cheap and was supplied to workers for food, but without enough of the traditional complements of beans, squash seeds, chilis, *chaya*, papayas, and other fruits and vegetables. The pellagra epidemics and other health problems that ensued gave corn a bad name. While workers on some *haciendas* were allowed small plots for *milpa* agriculture, on many others all land was reserved for the profit-producing henequen (Joseph, 1986; Brannon and Joseph, 1991; Patch, 1993; Faust, 1998).

4.6 Recent History

The grazing of large herds of cattle and horses by rich landowners was a constant threat to Maya orchards and fields until the 1970s, when a federal law required fencing. More recently, the most serious dangers to the local resources of Maya communities have come, ironically, from agribusiness projects. For example, a rice project introduced a foreign weed, Johnson grass, which has become a plague in traditional agricultural fields. Since the young plants of this species are good pasture for cattle, this has contributed to the expansion of cattle ranching on the peninsula, with much of the land cleared for rice being fenced for cattle. However, the low productivity (food calories produced per acre per year) of cattle compared with that of basic grains, the export (to both foreign countries and urban elites in Mexico) of the majority of the meat produced, and the very low level of employment associated with cattle raising combine to make the substitution of cattle raising for traditional *milpa* production extremely wasteful.

However, there are many individual Maya farmers who have learned to associate cattle raising with status and wealth, and hope to own as many head of cattle as possible (Faust and Dorantes, 1997). Government subsidies, export policies, and international debt repayment schedules are among the factors distorting the functioning of market forces in this situation and contributing to cattle expansion. Generally, the benefits accrue to a few large and politically powerful landowners while the losses are spread among a large number of poor peasants. There are also Maya cattle owners, who are usually distinctly better-off than those without cattle.[2]

Maya communities have adopted some of the new crops and technologies that do not require high capital investments and that fit in with the local ecosystems. One example is commercial honey production using modern hives and European bees: production doubled between 1960 and 1994 in the state of Yucatán (Cuanalo *et al*., 1996). Other agricultural products have increased even more rapidly over the period, including cattle (3.4 times), pork (9 times), poultry (15 times), eggs (7 times), watermelon (7 times), tomatoes (10 times), and oranges (9 times). Unfortunately, there are no figures concerning how much of this production is in the hands of Maya communities and how much is commercial. Informal observations indicate that the vast majority is produced commercially by non-Maya businesses, many of which employ Maya workers. Maya workers in agribusiness learn production techniques, and when sufficient savings and knowledge have been accumulated they often try small-scale production facilities modeled on those observed. This process has been well documented for commercial beekeeping by Merrill-Sands (1984) and is observable to some extent with the other products mentioned above.

In addition, government programs have introduced production techniques directly to some Maya communities, including diversified fruit and vegetable production for urban markets in some areas (see Gates, 1993) and aloe vera for export in others (S. Terán, 1997, personal communication). Part of the impetus for learning new forms of production is to replace lost income from henequen and corn production, which were once the mainstays of Maya communities in the north. From 1985 to 1994, corn production in the state of Yucatán declined from 134,000 tons to 95,000 tons. Average yield per hectare also fell from 880 kg/ha in 1960–1984 to 780 kg/ha in 1985–1994. This decline in productivity is probably due to a reduction in fertilizer use, from 52% in 1982 to 17% in 1994; average yield for fertilized land is 1,135 kg/ha versus only 704 kg/ha for unfertilized land (Cuanalo *et al*., 1996).[3]

4.7 Maya Agricultural Strategies and Associated Beliefs

As was described in 16th-century documents (Landa [orig. 1574–1975], 1982; Alvarez, 1980; De la Garza, 1983), Maya agricultural strategy traditionally involves diversification for risk reduction, with a loose division of labor by sex. Men generally plant *milpas*, manage apiaries, hunt, and participate in commerce, while women typically cultivate houseyard gardens, care for small domestic animals, collect firewood, and harvest wild plants for household remedies and condiments. Men, women, and children are all likely to produce handicrafts and use trees and plants for construction, tools (including slingshots and traps), and musical instruments (including leaves, some used as simple kazoos and others as trumpets).

Biodiversity as well as economic diversity has been maintained: 16 native species of food plants (with 36 distinctive varieties between them) mentioned by the 16th-century Spaniards as being cultivated for food in the intercropped *milpa* system are still grown in many of today's *milpas*, alongside introduced crops added at different times since the Spanish Conquest. These multiple varieties have been developed by deliberate selection practices, which continue as Maya cultivators experiment with new alternatives. Short- and long-cycle varieties of crops reduce risk from extreme climatic events, while other varieties take advantage of specific soil conditions. Of a total of 20 emergency species (used during drought years) mentioned in recent fieldwork, 13 are cultivated plants, including 4 trees and 2 root crops that can live in abandoned fields for many years (Terán and Rasmussen, 1995).

In tropical areas, nutrients are not in the soils but in the vegetation, and nutrient cycles are very fast due to the high temperature and humidity (Nye and Greenland, 1960). This is why it is crucial to incorporate the fertility from the vegetation into the soil through cutting and burning of trees, and why crop yields depend on the age of the forest burned. On the peninsula, the customary fallow period is 15–30 years, depending on the rate of forest regeneration and traditional practices (S. Terán, personal observation). Maya farmers leave tree stumps 1–1.5 m high so that the forest can sprout again, regenerating far more quickly than when reproduced by seed (Levy *et al*., 1995). When felling the forest for *milpa*, the Maya spare species useful for lumber, pasture, and emergency food (Zizumbo and Simá, 1988), as well as shade and fruit (B. Faust, personal observation). Burning is controlled by firebreaks cleared around fields to protect neighboring forests and around trees spared for future use. Even under conditions of some crowding, farmers traditionally leave substantial corridors of forests separating *milpas* from each other, thus maintaining habitat for wildlife, providing windbreaks, and reducing the spread of plant and animal pests from one plot to another. These patches of forest also speed succession of woody species into fallow fields, replenishing fertility and crowding out "weed" species of grasses that can otherwise easily take over a plot, making corn production difficult (Remmers and de Koeyer, 1989).

Maya cosmology, in which water is a central metaphor (Green, 1984; Faust, 1988), is based on an understanding of natural cycles: annual plant growth, daily solar movement, human life cycles, annual cycles of seasons, and longer cycles associated with astronomical events (Aveni, 1992; Freidel *et al*., 1993; Faust, 1988, 1998). Ceremonies of current Maya priest-shamans are associated with agricultural cycles, weather, and the health of people, animals, plants, and soil. The sacred is not separated from the mundane, physical world, but rather is central to it. The most sacred aspects of Maya existence are water, wind, forest, and corn, which are considered the essentials for survival in the local environment (Hunt, 1977; Tedlock, 1982; Tedlock, 1985; Green, 1984; Sosa, 1986; Freidel *et al*., 1993; Faust, 1998).

The human body is an analogue for the universe, and human coitus reflects the fundamental sexual forces that engendered the universe. Human reproduction is seen as participation in the processes of life that are continually reconstructing the universe: as male rain collects in female *aguadas* (small ponds), cenotes, and wells, making life possible in the dry season, so semen is transformed into new life in a watery female environment. These ceremonies are reminders of the dependence of the Maya on corn and water. There is no water for dry-season needs unless people "call the rains" with a rain ceremony and (in the southern areas) maintain the *aguadas* and wells and canals; and there is no corn without human work in planting.[4] But in addition to human effort, the efforts of spirit beings are also understood to be necessary for the production of rain and soil fertility, so that human labor can then produce the corn and save the water needed to survive the dry season. The Maya thus traditionally offer ritual foods and beverages in a reciprocal relation with the Sacred. The Sacred depends on candles, incense, the smell of flowers, and the sound of human prayers to survive so that He/She (the male/female force of life) may do His/Her work (Gossen [orig. 1974], 1984; Hunt, 1977; Sosa, 1986; Freidel *et al*; 1993; Faust, 1998).

4.8 The Economics of Contemporary Maya Agricultural Practices

The carrying capacity of the land can be estimated from ethnographic studies begun in the 1930s. Harvest figures for corn vary with soil and weather conditions (see *Table 4.1*). Steggerda (1941:149), working in several communities (including Pisté and Chan Kom) near the archaeological site of Chichén Itzá in the state of Yucatán, estimated that the land could support eight times as many people as were living on it during his fieldwork there in the 1930s (see *Figure 4.1* for locations

Table 4.1. Ethnographic agricultural data.

Community (date of study)	Harvest per person	Area planted per family (ha)	Harvest per hectare	Person-days of agricultural activity per year	Fallow period/ cultivation period (years)
Pisté plus neighboring communities (1930s)[a]	30 bushels (1,056 kg)	4	42 bushels (1,480 kg)	72	10/2
Chan Kom (1931)	498 kg	2.88 (0.64/pers.)[b]	831 kg	68–122	7/2
Cobá (1980–1981)	?	4.17 (0.62/pers.)[b]	289 kg (500 kg est. normal year)	75–157	?
Pich (1981–1983)	?	2 (est.)	1,183 kg	?	7/2
Xocen (1988–1989)	617 kg	4.16 (0.74/pers.)[b]	1,002 kg	?	7/2

Note: Locations of communities are shown in *Figure 4.1*.
[a] Figures are the average reported by Steggerda (1941) for the 1930s; the number of farmers interviewed was not specified.
[b] Estimated using 5.6 individuals/household.

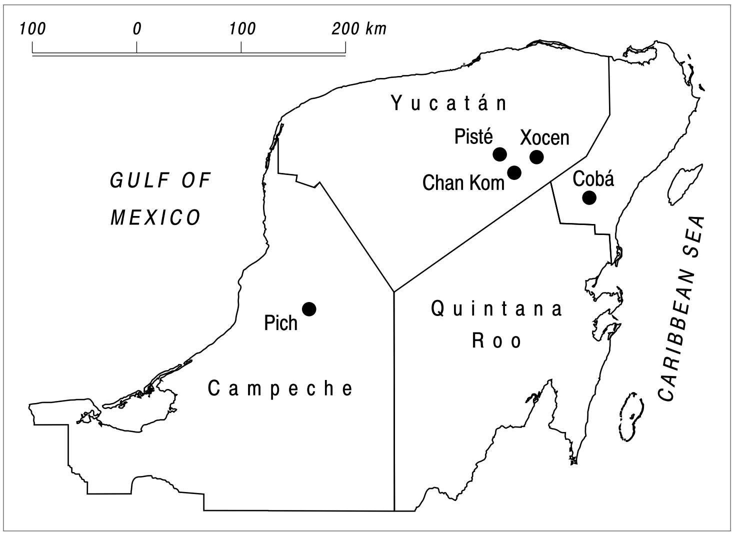


Figure 4.1. Communities with ethnographic information on the Yucatán peninsula.

of the communities discussed here). He based his calculations on an average plot size of 4 ha producing 168 bushels of corn, of which 64 were used to feed the typical family for the year; this production rate is 2.5 times that needed for subsistence, allowing 104 bushels for storage against crop losses in bad years and to sell for cash for other household needs. The number of days dedicated to agriculture averaged only 72 per year, the fallow period was 10 years, and the period of cultivation was 2 years, for a 1:5 fallow ratio. Redfield and Villa Rojas ([orig. 1934], 1962:52–53) reported that in Chan Kom in 1930 an average of 2.88 ha were planted per family. The average harvest was 2,394 kg, or 831 kg/ha. The estimate for consumption was 1,092 kg for an average family in one year (26 *cargas*, normal basket loads weighing approximately 42 kg each: Redfield and Villa Rojas, 1962:56), so that production was 2.2 times the consumption needs, compared with the 2.5 figure found by Steggerda (1941). The number of person-days dedicated to agriculture varied from 68 to 122 among the three cases recorded (Redfield and Villa Rojas, 1962:80). The amount planted varied with the price of corn, with more labor being invested in other productive activities during years when the price was low (Redfield and Villa Rojas, 1962:52).

The harvests reported near Chichén Itzá for the 1930s are substantially higher than those reported for Cobá, Quintana Roo, in 1980, a year described as a bad one by the three families intensively studied (Daltabuit-Godas *et al*., 1988:71). The average area planted by these families was 4.17 ha, with an average yield of only 289 kg/ha. The harvests reported by Redfield and Villa Rojas (1962) and Steggerda (1941) were above average. The Cobá families studied in the 1970s were planting 4.17 ha/family, nearly 50% more land per family than was planted in Chan Kom in the 1930s, but their average family size was 6.7 persons, or 24% greater than the 5.4 persons per family in Chan Kom. Dividing by the number of persons per average family in the two studies yields an average of 0.53 ha of land planted per family member in Chan Kom and 0.62 ha per family member in Cobá. The average harvest of the three families of Cobá was 1,095 kg, less than half the average harvest in Chan Kom (2,394 kg), providing only 163.4 kg/person for consumption compared with an average of 443.3 kg/person in Chan Kom.

Daltabuit-Godas *et al*.'s (1988) nutritional studies indicate that this harvest resulted in a nutritional deficit of calories and vitamins. Thus, average plantings of 0.53–0.62 ha/person do not produce enough in bad years to meet the minimum caloric needs of the population. Stored corn can buffer bad years, but desire for consumer products tempts families to sell rather than store their surplus.

In average years, 0.63 ha/person must be planted in swidden to provide subsistence needs; with a 1:5 fallow ratio (2 years of cropping followed by 10 years of fallow), the number of persons supported per square kilometer would only be

(100 ha/km^2)×(0.63 ha/person)×(1/5 [fallow ratio]), or 12.6. With an average 2:5 fallow ratio, which is increasingly common, the carrying capacity would be 25. However, 10 years is the shortest fallow understood by the elders as adequate to sustain good corn production with herbicides and fertilizer; in the absence of these costly modern inputs, a 20-year fallow is recommended for both the full recuperation of soil and the production of sufficient forest to fuel a fire hot enough to kill weed seeds and insect pests throughout the swidden plot (Faust, field notes from Pich, Campeche, and Sahcabá, Yucatán).

More details of harvest, labor costs, calorie consumption, and nutrition are available in the ethnography of Cobá. The harvest reported for the 1980 research year required between 75 and 157 days of labor (Faust, field notes from Pich, Campeche, and Sahcabá, Yucatán:77), averaging 114 days compared with the 72 days reported by Steggerda (1941) for research conducted in the 1930s. The average annual consumption for a typical family was calculated at 5.7 million calories (including beans, squash seeds, etc.), compared with an average production of only 4.7 million calories (Daltabuit-Godas *et al*., 1988:97). Clearly, the families' caloric needs were not met by *milpa* production during that year. Shortfalls of this type are traditionally compensated for by careful storage of corn or by the purchase of corn with money either borrowed from the local elite or saved from other productive activities. Borrowing often leads to a cycle of repeated borrowing and repayment with interest.

Harvest information is also available for 1989 and 1990 for Xocen, Yucatán. Terán and Rasmussen (1994:253–254) give the average amount planted as 104 *mecates*, or 4.16 ha/family (for the families interviewed), with an average harvest of 1,173 kg/ha for 1990 and 831 kg/ha for 1989. Even in the relatively poor year studied (1989), average *milpa* production was 3,457 kg of corn (4.16 ha at 831 kg/ha).[5] While mean family size is not given for Xocen, if the average for Chan Kom and Cobá (5.6 persons) is used (indeed, it is the number commonly used for pre-Columbian household size), dividing the average production by 5.6 results in an estimate of 617 kg of corn per person per year. The area of land planted per person is 0.74 ha in Xocen; with a 1:5 fallow ratio, the carrying capacity of the land in use would be 100/(.74)(5), or 27 persons/km^2 (assuming that the average amount planted does indeed provide the nutritional needs of the family for the year). With the population of Xocen at 1,158 (Terán and Rasmussen, 1994:101) and the total land area at 4,820 ha (Terán and Rasmussen, 1994:170), or 48.2 km^2, this yields an average of 4.16 ha/person, or a mean density of 24 persons/km^2, just slightly less than the 27-person carrying capacity estimated on the basis of the seven farmers interviewed in Xocen.[6]

Studies from the 1930s to 1990 report a 1:5 fallow ratio with a median of 0.66 ha/person planted (see *Table 4.1*). Since 1 km equals 100 ha, dividing 100 by the 0.66 ha required per person gives 152 persons/km^2; however, the need for a 5:1 fallow ratio reduces this to a carrying capacity of only 30 persons/km^2, or just over five families of 5.6 persons each. Since the recommended fallow period for swidden agriculture is commonly said to be 20–30 years, even only five families per square kilometer would have a long-term negative effect on soil quality. If we use the 20-year fallow figure instead of the 10 years used above, the carrying capacity would be only 2.5 families or 14.5 persons/km^2. Interviews in Pich, Campeche (Faust, 1998:115–118), reveal that until the 1970s, the clearing of new land in the local area was the usual response to population growth. This led to agricultural plots being located increasingly farther from the dwelling. When the distance became too inconvenient, farmers began to shorten the 20-year fallow to 10 and later to 7 years. During that decade, the availability of national lands (officially owned by the government of Mexico) for such uses also decreased substantially, because an agricultural development program began resettling peasant farmers there in collective organizations (*ejidos*) as well as selling plots to commercial ranchers and farmers.[7]

Ethnographies of Chan Kom, Cobá, Xocen, and Pich make clear that, prior to the 1970s, each of these communities sent groups of sons and daughters to new areas to establish communities. Thus out-migration to establish new plots on available lands, a process called extensification of agriculture (Bilsborrow and Geores, 1992), was the first response to land shortages. It is only more recently that the shortening of fallow periods has become common in response to the lack of available lands in nearby areas (e.g., Chan Kom, Pich, Xocen).[8] The shortening of fallow periods is accompanied by other forms of intensification, especially herbicide use rather than intensified hand weeding. Both hand weeding and the ancient Maya use of raised fields and terraces are now thought to require too much effort. In Sahcabá there has been little interest in "intensive *milpa*," a green manuring system that involves companion planting of corn with a leguminous species: only three traditional Maya farmers accepted it after three years of intensive effort by a local university to introduce it. Despite the availability of free seeds, chicken manure, and technical advice, men under 50 years of age prefer to migrate to Cancún or Mérida for wage labor. The reason most commonly given for rejection of the new intensive *milpa* system is that it is too much work given the unreliability of rain and the low price of corn. Men over 50 report that they would invest their labor in this system if irrigation were available, but they will not invest the extra labor given the vicissitudes of rain. A larger harvest with less work is usually available with traditional *milpa*, even though it requires more land and the most common fallow period is now 10 years (after 2 years' use) rather than the preferred 20 (Faust and Dorantes, 1997).

In Xocen, a shortening of fallow was also reported, from the 16–20-year period practiced by their ancestors to a 6-year period, or a ratio of 1:3–4 (Terán and Rasmussen, 1994:262). Despite such intensification, seven different group migrations founded new “daughter” communities in neighboring areas of Yucatán and Quintana Roo between 1930 and 1977 (Terán and Rasmussen, 1994:104,105). More recently, people have begun migrating to the tourist zone of Cancún. While exact fertility is unknown, in Xocen 40% of the population is under the age of 15 (Terán and Rasmussen, 1994:101), indicating high fertility. In Pich, more plentiful rain and deeper soils contribute to higher production levels per hectare; nevertheless, fallow periods have been shortened and people are migrating to cities (Faust, 1998:114).[9]

Farm families have become increasingly reluctant to leave the modern conveniences available in town to live in distant *rancheńas* during the agricultural season. Land that is near the village is therefore in sufficient demand that fallow has been shortened to 5–7 years, while more distant areas are unused. Urban migration does not result from a shortage of land, but rather from the fact that urban jobs offer more income and income security than farming, particularly given the lack of irrigation facilities. In Sahcabá (B. Faust, personal observation), Pich (B. Faust, personal observation), and Xocen (S. Terán, 1997, personal communication), people insist that rainfall has been becoming less dependable during the agricultural season. Despite the availability of unused local land, such a rainfall pattern may be contributing to both out-migration and a reluctance to invest the energy and time required to travel all the way to the most distant areas of the *ejido* lands, where fields have been fallow longest. The distance in some cases takes two days to walk, less time on a bicycle where there are trails or roads part of the way. Reluctance to use distant fields increases pressures to shorten fallow periods on fields close to the village.

4.9 The Traditional Maya System of Agriculture and Its Adaptation to Increasing Population Density

Traditional Maya swidden practices include interplanting of diverse species and varieties in 1–2-ha fields, normally two fields per family, one on high ground and one on low ground. When the rains become dependable, bean and squash seeds are mixed with the corn in a gourd. Handfuls of five to six seeds are deposited in holes made by a planting stick in soil softened by the earlier burning of slashed trees. The typical ratio of seeds is four corn to one bean and/or squash seed. The bean vines climb the corn stalks while the squash spreads over the earth, shading the soil and reducing weed growth. Different varieties of these three staples are planted in sections of each field, including early-maturing and late-maturing varieties of different qualities, to protect them from climate fluctuations, insect invasions, parasites, and disease. Within the field, small patches of especially good soil are planted with root crops, chili peppers, and sometimes flowers for the Day of the Dead.

As described in detail by Terán and Rasmussen (1994), this intercropped field has traditionally been only one part of a diversified portfolio of economic activities required to support Maya households. Families normally return to fallowing swidden plots to gather the orchard and root crops that they planted with the *milpa* and to hunt the animals attracted by the patch of young, growing vegetation. The most highly valued of these game animals are deer, wild turkey, and wild pigs, although agouti, rabbits, gophers, and other small game are also often obtained there. In addition to swidden, the Maya traditionally have produced a substantial amount of family food in their houseyards, including fruit (avocados, bananas, oranges, papayas, *guaya, zapote, mamey*, mango, *pitahaya*, etc.), animals (pigs, chickens, turkeys, ducks, doves, and an occasional orphaned deer or armadillo), eggs (usually only chicken eggs are eaten, the others are more often reserved for hatching), as well as chili peppers, tomatoes, onions, *chaya*, and various condiments and medicinal plants. Children bring home captured birds, fish, and turtles to cook and eat.

Fertility of soil in the houseyard gardens is high, since areas receiving animal and human "fertilizer" are shifted periodically and planted with fruit trees and other useful species. "Gray water" (from bathing, washing of clothing and dishes, etc.) is also normally "recycled," that is, thrown on the hanging pots and raised platforms of herbs, flowers, and vegetables. These houseyard gardens thus produce a variety of fruits and vegetables throughout the year. In a survey of 74 gardens in Chunhuhub, E.N. Anderson (1995) documented 234 species of plants intentionally maintained. Previously, Edgar Anderson (1952) found that throughout the tropical world, houseyard (or dooryard) gardens provide one-quarter or more of the calories consumed and virtually all the supply of vitamins A and C. Folan reports that in addition to the individual houseyards that form the sides of a block of houses, in Ticul, Yucatán, a central area (*chumuc lu'um*) with a common entrance is traditionally maintained as an orchard area for the use of block residents (Folan and Gallegos, 1996).

During the past 15–20 years, many of these traditional practices have been gradually abandoned in those areas most affected by government programs and other forms of modernization. The traditional intercropping and agroforestry practices of the Maya are maintained by many elders, but younger farmers tend to adopt modifications in response to population growth interacting with external forces. In 1994, 100,000 farmers reported planting 300,000 ha in swidden fields using hand tools, with an average harvest of less than 1 ton/ha (Martín and González, 1996). Because no machinery or irrigation is used, these farmers are referred to as "traditional" farmers; however, there are widespread, fundamental changes in their practices. The shortening of fallow to seven or fewer years requires the use of chemical fertilizers and increases weed problems, which in turn create a need for herbicides. Those that are locally available and affordable protect corn but kill squash and bean plants. The new practice is thus to plant corn alone on chemically fertilized soil. When the corn reaches 20–30 cm, a herbicide is applied; after 7–10 days, beans, squash, and other cultivars may be planted in the rows between the corn stalks. However, these species increasingly are not planted at all or are planted in separate areas. With these new patterns of monocropping, people report that there is more damage to crops from insects and diseases than before, but that now they can control them better with the chemical "poisons" (B. Faust, personal observation; S. Terán, personal observation; E. Kintz, personal observation).[10] Very few people believe that there may be long-term negative effects to themselves or their children. They have learned from experience to recognize the short-term dangers to themselves during the application of these biopoisons. Generally, the sprayer covers his or her nose and mouth with a piece of cloth to decrease inhalation and rinses his or her hands after use. Others working nearby or observing the operation take no precautions. Only those illnesses that immediately follow direct exposure – not the cumulative effects of the spraying – are understood (see Wright, 1990, for a case study and a general discussion of the problem in Mexico.)

4.10 Threats to the Environment from Modernization

Unusual rain during dry seasons and periods of drought during rainy seasons are becoming more common; both may be related to global warming (probably resulting from human perturbations of the atmosphere [Schlesinger, 1991] and to local deforestation [see Gunn *et al*., 1995]). The environment on the peninsula is fragile, with all but the southern area receiving low rainfall and with no significant lakes or rivers to retain the water, except in the extreme south. Evapotranspiration is high in the hot sun during most of the year (140 mm^3, compared with 180 mm^3 of rainfall; Batllori, 1996). The intensification of agriculture, its extensification through deforestation, rapidly increasing animal (especially cattle) populations that trample and compact the soil (BOSTID, 1984b, 1990), and the lack of improvements in methods of water storage (and, in fact, their serious deterioration, see Faust, 1998) have apparently combined to contribute to increasing soil desiccation and micro-climate change. This does not bode well for the future sustainability of agriculture on the peninsula.

Experience in similar climatic zones elsewhere in the developing world may provide useful lessons for the Yucatán peninsula. Human and animal population growth in much of Africa in recent decades have combined with naturally occurring climatic cycles to create a growing problem of vegetation and forest loss that is threatening the survival of the region's populations (BOSTID, 1984a, 1984b;

Timberlake, 1985; Acevi, 1990). Increasing sedentary or settled agricultural populations are competing for land with growing pastoralist populations and their herds. This increasing pressure of the population on the land is complicated by other forces, including loss of land (similar in this sense to the 19th century "enclosures" in England) to large government commercial farms (e.g., in the Sudan and in the Gezira) with accompanying displacements of population, who must migrate elsewhere in search of land or urban employment. Increasing demands for fuelwood have greatly exacerbated the loss of vegetation caused by rural population increase, and growing rings of virtually complete deforestation are now observed around a number of African cities, especially in the broad Sudano–Sahel belt across central Africa (see BOSTID, 1984a, 1984b:42; Ibrahim, 1987; Bilsborrow and DeLargy, 1991; and papers on the Sudan and Kenya in Little and Horowitz, 1987).

Some of the same forces at work in Africa also appear to be operating on the Yucatán peninsula, including large, misguided government and commercial farms (e.g., cotton, rice), lack of appropriate supports for traditional food crops, rapidly increasing animal herds, and deforestation associated with the extensification of agriculture. Although population density also appears to be low on the Yucatán peninsula, the main issue in determining the "carrying capacity" of the region is probably not land availability but water availability and accessibility. If so, this parallels the situation in much of Africa, as reported by Falkenmark and Widstrand (1992), and differs from that of most of Latin America, which has plenty of rainfall. In this case, climate change would be a serious concern and methods of improving the storage and use of water should be a high policy priority on the Yucatán peninsula.

Changes in agricultural practices on the Yucatán peninsula in the past 15–20 years include the introduction of fertilizers, herbicides, insecticides, pasture grasses, African bees, and Johnson grass, among many others. Not all were intentional introductions; some arrived accidentally, much like the disease epidemics of the 16th century. Some were brought to the peninsula with the best of intentions but have had negative effects, much like the intensive henequen production and cattle raising during earlier periods. Some practices have had mixed effects. For example, while fertilizers can replenish the nutrients used up by crops, allowing more frequent replanting, they do not add humus to the soil, which is needed since it rapidly decomposes under tropical conditions. Nor do they replace the trace minerals mined by micro-organisms in the soil and the large root systems of trees during long fallow periods. Herbicides poison not only weeds but also useful plants that traditionally are not weeded out by the Maya, but are allowed to remain to provide chemicals that protect the crops (Rosado-May, 1991). In addition, the industrially produced biopoisons make it impossible to grow the beans and squash together with the corn, thus eliminating two beneficial aspects of traditional Maya agriculture: beans are nitrogen-fixing legumes that add fertility to the soil, and squash plants have broad leaves that shade the soil, thereby lowering ground temperature and reducing evaporation as well as shading out many weeds. Herbicide use thus increases the need for both fertilizer and water, and helps create a need for other pesticides such as nematocides and fungicides (F.J. Rosado-May, 1997, personal communication). Finally, insecticides have the side effect of poisoning snakes, lizards, turtles, frogs, birds, and bats, which are natural enemies of many insect pests. The insect pest then can reproduce more rapidly, creating resistant new generations in short periods of time, each requiring new chemical insecticides which generally must be imported at high cost – a cost that has been even higher since the 1994–1995 dramatic devaluations of the peso (followed by continuing erosion of its value in international money markets).

The "Africanization" of the commercial bee population has been a challenge for beekeepers. The cross between African "killer bees" and commercial bees produces a bee that is more productive, but that is notoriously aggressive and swarms to new locations easily, particularly under conditions of drought or low pollen, and is susceptible to a parasite referred to as *boreaci*. Most small producers have given up; a few of the larger producers have invested in costly protective clothing and more careful supervision, provisioning, and protection from parasites. They are currently enjoying increased productivity and higher prices for honey.

Johnson grass has become a plague in the corn fields of a large area of the state of Campeche, where misconceived projects to grow rice existed for a while. The rice seed carried with it Johnson grass seed from the United States. The rice project involved rainfed rice, not irrigated rice, and costs of production were higher than world market prices. Large areas were deforested around Yohaltún and Edzná, to the southeast of the city of Campeche. Currently in this area, a non-native species of cotton is being sown on 15,000 ha by foreign corporations leasing land from *ejidos* (Ericson, 1997). Ironically, for centuries in this same area the ancient Maya cultivated a variety of native cotton that was highly valued by the Spanish as a tribute and trade item during colonial times. Contemporary cultivation of the non-native cotton includes repeated doses of powerful insecticides that in other areas of the world have resulted in serious wildlife loss and contamination of groundwater. Effects of insecticides on soil have combined with exposure to wind and rain to increase soil degradation and erosion. Negative health effects on human workers have also been widely reported.[11]

Honey production suffers from insecticide use, as does fruit production, since the bees fertilize the flowers of fruit trees. The customary hunting of deer, duck, wild peccary, and wild turkey – traditionally important sources of protein – is suffering from habitat destruction as more and more land is put into cattle production. Chickens and eggs are now mostly produced commercially in cages with imported feed and have less flavor than free-range chickens and their eggs. Unfortunately, the backyard chicken grower has no way to market chickens to city dwellers willing to pay more for better-tasting chicken and eggs. It is the same with the pigs raised in commercial lots, a practice that concentrates manure contamination. From such lots, coliform bacteria and amoebas seep down through cracks in the limestone rock to deep water sources tapped by government wells. The contaminated water is then pumped to the surface, treated with chlorine, and sent through black plastic pipes to homes as *agua potable*, or drinking water.[12] Tractors compact clay soils, destroying tilth and thus decreasing yields. Turning over the soil also increases wind erosion during the dry season.

Some traditional farmers are still producing corn, beans, and squash using local varieties developed over the centuries by their ancestors and adapted to vicissitudes in the weather and to local microclimates and soils. However, the price in the market is fixed to be equal to that of the less flavorful corn produced on mechanized farms using hybrid seeds and biocides. Meanwhile, health-conscious consumers in the cities purchase imported natural foods, medicines, and supplements because organically grown produce is not available in local markets.

Fresh fish has also become more costly and scarce due to competition from foreign markets. Fish stocks are being depleted both by general overfishing and by the use of large nets with small openings that catch even baby fish (Faust, 1990, field notes).[13] Petroleum leakage combined with large-scale dumping of plastics and other human garbage is seriously degrading the ecology of both the Gulf of Mexico and the Caribbean Sea. The shrimp industry is also overusing its resources, as is the timber industry. Many local carpentry shops are importing mahogany and cedar from Guatemala while the native *guayacán* is being sent to Japan. Intensive truck farming of European vegetables has resulted in serious white fly invasions in Dzitdzantún, Yobaín, Telchac, and Oxkutzkab (S. Terán, 1997, personal communication). Cancer rates for towns with the longest exposure to agrochemicals are not known, but Terán has found expressions of concern over this issue in Dzitdzantún.

The environmental risks to swidden production traditionally have been buffered by intensive production in houseyard gardens; by collecting wild plants, roots, and fruit; by hunting, fishing, and trapping; and by craft production and participation in the local market economy. The Maya now have new “needs”: television antennas sprout from thatched roofs and adolescents show off their new tennis shoes. The Maya also have new opportunities. Artisanal production has found new markets in the tourist zone from Cancún to Tulúm. Overcutting has reduced timber harvests, but cattle ranching has increased. Henequen plantations have been at least partially replaced by citrus orchards and truck farming. Fishing has increased markedly (lobster, shrimp, octopus, grouper, and red snapper), as has migration for both urban employment and seasonal agricultural work on agribusiness plantations.

Since NAFTA's ratification, *maquiladoras* (multinational assembly plants) producing clothing and textiles have sprung up around Mérida as well as in some smaller cities on the peninsula (Motul, Izamal, Tekit, Tekax, and Valladolid). The loss of the henequen fiber industry has been partially offset by these new factories, although migration to Quintana Roo has been a larger factor in providing employment for former henequen workers. In 1970 the hard fiber henequen industry employed 45.6% of all workers in the state of Yucatán, but by 1993 this figure had fallen to only 5.2%. On the other hand, the textile and clothing industry employed only 4.7% of the total employed labor force in 1970, but by 1993 this figure had risen to 30.3%, including the *maquiladoras*, which accounted for nearly 10% (García and Pérez, 1996:19–20). Unfortunately, wage rates on the peninsula are lower than elsewhere in Mexico; in 1993, the average monthly wage on the peninsula was equivalent to US$93, below the monthly wage rate in Honduras, one of the lowest rates in Latin America (García and Pérez, 1994:24).

The sowing of cotton in the state of Campeche may be related to the boom in the clothing and textile industries due to NAFTA. The notoriously heavy use of chemicals is likely to devastate honey production in the region, as well as increase human diseases and devastate biodiversity (Murray, 1994:27–54). This is in an area that borders a large biosphere reserve (Calakmul) whose interior ecosystems are largely intact. On the other side of the peninsula, around the coral reefs of Quintana Roo, continuing increases in tourism threaten the living coral and associated species that form an ecosystem both exceptionally rich in biodiversity and exceptionally fragile (Hale, 1996).

4.11 The Maya Alternative

Traditional Maya culture offers a logical basis for an integrated system of land use in which forests alternate with patches of intercropped fields maintaining a number of varieties that provide insurance against variations in climate. Wildlife habitat is also preserved by the long fallow periods of traditional swidden. Hunting and fishing need to be more carefully regulated, but with proper management they could continue as an integral part of rural community life. More cash income could be generated through improved craft production for the booming tourist market based on local cultural traditions and using local raw materials (many of the weavings and other craft items now sold to tourists come from Guatemala or the north of Mexico). Ecotourism could be complemented by ethnotourism, in which Mexican and foreign visitors could visit and observe Maya life and customs. This could be managed by Maya communities themselves, perhaps with assistance from the Department of Tourism. Further increases in the education and employment of women will continue to contribute to lowering birth rates, which is desirable for reducing population growth caused by the earlier reduction in death rates resulting from the introduction of modern medicine. Intensive food production in houseyard gardens could be expanded to grow food for the rapidly increasing market for organic fruits and vegetables. Traditional management of household animals could be studied, and pilot projects could test ideas for increased production. More efficient marketing and transportation mechanisms could increase the returns to peasant farmers and reduce prices for urban residents. Stocks of fish and marine animals could be protected by prohibitions of time, place, and equipment used in their capture – all of which are far easier to implement for most species than restrictions concerning the number, sex, and species of the catch (see Chapter 9).

The use of resources by Maya communities has a logic of collaboration with nature and of risk reduction that contrasts sharply with most of the innovations introduced in the past 50 years. That logic is resistant not to change, but rather to environmental destruction. Unfortunately, knowledge concerning long-term impacts and side effects of many introduced technologies is not made available to government technicians or to Maya communities. In addition, federal laws and a history of *hacienda* control have greatly diminished cultural memory concerning social mechanisms for controlling individual overuse just as new technologies are making the observation of such overuse very difficult. Trucks can easily carry deer carcasses out of the woods and to sale in city restaurants without being observed. Piped water is not metered in most villages, and the wealthy have tanks in which to store it. Trees can be felled and trucked out on lumber roads without anyone's knowledge in many parts of Campeche and Quintana Roo (Ericson, 1997). Drug dealers control some areas, shooting at (and sometimes killing) biologists and foresters (B. Faust, 1996, field notes; J. Ericson, 1997, personal communication). Indigenous knowledge is neither foolproof nor superstitious nonsense. It does include religious taboos and supernatural sanctions for overuse of resources, aspects difficult to maintain in an ever more secularized world.

The oral tradition is a source of information concerning the history of resource use and informal experimentation by a human population interacting with its local environment. It covers a time span of millennia and extends over thousands of square kilometers. In contrast, scientific ecological studies tend to be restricted to very small plots studied for very short periods of time. The two types of knowledge can, however, be complementary and should both be used to construct a new model of land use based on integrating limited elements of modern agriculture with the traditional understandings of the complex relationships between populations of flora, fauna, and humans under local conditions of climate, soils, and water resources.

The population of the peninsula is still below carrying capacity under the traditional food procurement practices of swidden agriculture, houseyard gardens, fishing, hunting, and collection of wild plants. However, the expansion of the area used for cattle ranching and export agriculture is reducing the land available for traditional practices and seriously reducing fallow periods below sustainable levels. Many communities are now experiencing land shortages and increasingly must buy much of their food, relying for cash income on the sale of handicrafts, honey, and commercial crops, as well as migration to cities and tourist zones for work.

Construction of new water management systems based on ancient Maya strategies of drainage and rainwater conservation could make intensive agriculture viable in the southern part of the peninsula where the soils are deep. Throughout this zone there is ample rainfall during the agricultural season and extremely low population density. The terraces, canals, and drained and raised fields of the ancient Maya may easily have extended the growing season, making two crops per year feasible in many areas. Rainfed reservoirs and underground cisterns once provided large populations with water for domestic use, without the need to resort to the deeper sources of underground water recently found to be contaminated, not only by human wastes but also by chemicals in the eroding karst (Batllori, 1996). However, the development of such systems at present could constitute a serious threat to the conservation of endangered species in the biosphere reserves of this zone. It might also threaten preservation of archaeological sites, particularly if it were to result in increased in-migration. On the other hand, if such systems were to encourage intensive use of small areas of land by those settlers currently engaged in extensive cattle ranching, they could contribute to conservation of local ecosystems with their rare and endangered species. Such a shift in productive activities would probably require outside assistance, since the present low density of the population cannot be expected to stimulate the adoption of intensive methods, particularly given the lack of capital for investment. This differs from most of the developing world, where growing populations continue to stimulate Boserupian intensifications of agriculture (Bilsborrow and Geores, 1992).

The relatively low population densities and the beginnings of a demographic transition mean that it is still possible to practice agricultural and other methods of production that maintain biodiversity on the peninsula. It is still possible to avoid the ecological destruction that has occurred in Haiti, El Salvador, and many other areas of Latin America. Public policy could greatly enhance the probability that future generations will escape the Four Horsemen of the Apocalypse, those ironically named "positive checks" described by Malthus. Employment of young women in *maquiladoras* is increasing, but health conditions, safety precautions, and environmental effects need to be carefully monitored by an industrial board, a national agency, or an international commission, with the costs paid by the employer.

Educational opportunities for girls could be increased by decreasing obstacles to attendance for all students. Families faced with educational costs beyond their means will make an effort to educate sons before daughters, especially at the high school and university levels. They should not have to make that choice. One such obstacle is the requirement of “modern” clothing in public schools, including shoes; students should be allowed to attend school in the clothing they own. Another impediment to education is the cost of supplies. Each rural school should have a basic supply of notebooks, pencils, and books for those children who cannot afford to buy them. A parent organization could provide lessons concerning traditional knowledge and language, and assist inexperienced teachers, who sometimes become abusive in their desperate attempts to maintain order in classrooms full of children accustomed to playing outdoors. Supervision of transportation, recesses, and school meals could also increase parental confidence that their adolescent daughters would not lose their virginity by attending school with boys. Parental fears constitute a major deterrent to girls’ continuing education and are apparently well founded (B. Faust, 1985–1997, personal observation).

Family planning has been successful in many areas of the Yucatán peninsula and needs to be further improved to increase access to the best modern methods for controlling the spacing of pregnancies. A well-organized public education campaign is also needed to disseminate information about acquired immunodeficiency syndrome (AIDS) and other sexually transmitted diseases. Increasing migration to urban areas, together with return migration, exposes both the migrants and their home partners to increased dangers. In many villages, the majority of men under the age of 50 spend two-week stints working in Cancún before coming home for a weekend. Others work in Mérida or Campeche, returning every weekend to their village.

Unfortunately, cash wages and job insecurity seem to be correlated with alcohol problems, family violence, and teenage pregnancies. Public education is needed about alcohol addiction. Alcoholics Anonymous is gaining more members in rural areas, and various Protestant organizations provide social support for not drinking. Women need to be protected from abusive husbands by policies that make divorce with alimony and child support easier, by the creation of agencies that provide legal and emotional support, and by media and educational programs that make the population cognizant of the pervasiveness and seriousness of the problem and therefore reduce its incidence in the first place. An agricultural policy that helps farm families to stay in rural areas rather than migrate in search of urban jobs would have benefits both directly for the families and indirectly for the country. Mushrooming urban squatter populations are currently without adequate services, including access to drinking water and protection from disease vectors present in raw sewage and garbage.

A policy encouraging houseyard gardens and subsistence agriculture could include education concerning the importance of preserving and propagating the many varieties of edible native plants domesticated by the Maya. Their nutritional benefits and their resistance to drought, flooding, insect invasions, etc., should be taught in the schools. Increasingly, young parents try to buy commercial vitamins and despair when the price goes beyond their reach. Vitamin injections are routinely prescribed in rural villages, instead of making use of produce from gardens to improve nutrition. This situation should be changed. Germplasm sought by foreign corporations is a national treasure that is being lost as farmers are encouraged to switch production techniques from small *milpa* patches surrounded by forest and characterized by interplanting to large areas of monocrops based on hybrid and "improved" seeds. Their approach fails to recognize that the old varieties are part of an integrated system of knowledge regarding the use of microhabitats for multicropping, which reduces risk from the frequent droughts, floods, winds, and insect invasions. In many communities the people who still have this knowledge are few and old; they often find no one interested in learning (except, on occasion, an iconoclastic anthropologist!). It is important to preserve this knowledge and the germplasm that has resulted from hundreds of generations of experimentation in the microhabitats of the peninsula. The best way to do this is in situ, providing incentives for the continuation of a living tradition while policymakers analyze how to incorporate this local knowledge into long-term planning to benefit the majority of the Maya population.

For ancient Maya knowledge and contemporary Maya traditions to be better utilized, a change must occur in the thinking of Mexico's policymakers. Maya technologies and land management strategies acknowledge the dependency of human communities on the natural environment, the need for sustainable agricultural methods, and the need to benefit the community rather than only a few individuals (Faust, 1998). This Maya ecology has a necessary corollary – the conservation of natural resources and the habitat needed to maintain biodiversity. If environmental damage from existing agricultural methods were taken into account, it is likely that the optimal path would be a return to Maya ecology, but with the incorporation of some modern methods consistent with that ecology. Such methods may include use of wind and solar power, rainwater conservation, soil conservation, bioecological control of insect pests, in situ preservation of germplasm, limited use of new seeds and soil supplements (not just fertilizers, which often do nothing for either humus or trace elements important to human, plant, and animal nutrition), and scientific monitoring of indicator species of fauna (including insects).

Notes

[1] Both factories and plantations manipulated debt peonage to ensure an adequate labor supply up to the time of the agricultural reforms in the late 1920s and early 1930s. Debt peonage is a system in which money is loaned in exchange for future work in a closed system, on a *hacienda*. The debts were often inherited, resulting in a de

facto system of slavery. Land for subsistence was severely limited and wages were kept low. Money was continually loaned in response to medical problems and other emergencies, as well as for purchases in a "company store" (*tienda de raya*), and repayment figures were manipulated by a literate "patron" with no accountability to an outside authority (Joseph, 1986).

[2] Most Maya farmers cannot afford private land to safeguard investments in pastureland cleared for monocrops of improved (often exotic) pasture grasses; cows kept on communal lands are usually fed crop residues as well as leaves of certain native trees and weeds that grow along the roadsides. Thus, these cattle are not associated with the ecological destruction of the commercial herds. These village cattle have traditionally functioned as a kind of savings account, being sold to outsiders for cash during hard times; now they are sometimes butchered locally and eaten within the community.

[3] This reduction in fertilizer use is related to both a rise in fertilizer prices and a reduction of government support. Fertilizer application had initially maintained productivity under conditions of increasingly shortened fallow (due to land shortage in some areas and to increasing unwillingness to invest time and energy in travel to distant fields).

[4] Corn is a domesticated crop that cannot grow from its own seeds without human intervention, required to release the kernels from the protection of the husks so that they can germinate in the Earth.

[5] *Milpa* farmers report that one out of three used to be poor years, but this has increased to two out of three in the 1990s. Farmers attribute this to the more severe droughts and to the increased concentration of rain in storms, rather than a more even dispersion throughout the rainy season.

[6] Dividing the population (1,158) by the number of households (300) gives an average of only 3.9 persons per family, a figure low enough to assume that some of the households were vacant due to the recurrent migrations of groups of families to establish daughter communities, reported by Terán and Rasmussen (1994:104,105,109).

[7] The vast majority of all these rural newcomers (the resettled peasants as well as the commercial ranchers and farmers) came from distant areas; very few were even from neighboring states.

[8] This process has been intensified by a new unwillingness to temporarily relocate entire families to remote areas during the agricultural season, as was previously the custom (Faust, 1998:55–58). People have become accustomed to the conveniences of modern village life and do not wish to live without them during the agricultural season.

[9] The statistics for Pich are taken from government census publications rather than from direct observation of harvests. Since farmers often lie to government census takers out of fear concerning the repayment of government credits, these harvest figures are probably low.

[10] Esteron (sometimes called Esterol) is the most common, according to peasants interviewed by Faust in 1996 and 1997.

[11] For a review of the hidden costs of cotton production, see Murray (1994). It is certainly ironic that such a destructive commercial crop has replaced varieties indigenous to Latin America and domesticated in Mexico, Central America, and Peru long before Europeans arrived.

[12] Many city dwellers can afford the delivery fees to purchase purified water delivered to their homes in five-gallon containers.

[13] The depletion of ocean fish stocks is a worldwide problem, not unique to the Yucatán peninsula (Brown *et al*., 1997).

References

Acevi, 1990, Environment: The other disaster (Environnement: l'autre desastre), *Jeune Afrique*, **1545-46**:78–81.

Alvarez, C., 1980, *Diccionario Etnolingüístico del Idioma Maya Yucateco Colonial*, Vol I, Mundo Físico, Instituto de Investigaciónes Filológicas, Centro de Estudios Mayas, UNAM, Mexico City, Mexico.

Anderson, E.N., 1952, *Plants, Man and Life*, University of California Press, Berkeley, CA, USA.

Anderson, E.N., 1995, Gardens of Chunhuhub, Paper presented at the Third International Congress of Mayanists, Chetumal, Quintana Roo, Mexico, July.

Anderson, E.N., 1996, *Ecologies of the Heart: Emotion, Belief and the Environment*, Oxford University Press, New York, NY, USA.

Andrews, A.P., 1983, *Maya Salt Production and Trade*, University of Arizona Press, Tucson, AZ, USA.

Antochiw, M., 1996, Apuntes: Para la Demografía Histórica de la Peninsula de Yucatán, Working Paper, Proyecto Población y Desarrollo Sustentable en Yucatán, CINVESTAV, CONAPO, and IIASA.

Atran, S., 1993, Itzá Maya tropical agro-forestry, *Current Anthropology*, **34**(5):633–700.

Aveni, A.F., ed., 1992, *The Sky in Mayan Literature*, Oxford University Press, New York, NY, USA.

Barrera Rubio, A., 1989, Obras hidráulicas en la región Puuc, Yucatán, México, *Bolet ín de la Escuela de Ciencias Antropológicas de la Universidad de Yucatán*, **87**:3–19, Mérida, Mexico.

Bates, D.G., and Plog, F., 1991, *Human Adaptive Strategies*, McGraw-Hill, New York, NY, USA.

Batllori, E., 1996, Tables of Water Contamination in the Yucatán Peninsula, Working Paper, Proyecto Población y Desarrollo Sustentable en Yucatán, CINVESTAV, CONAPO, and IIASA.

Bilsborrow, R., and DeLargy, P., 1991, Population growth, natural resource use and migration in the Third World: The cases of Guatemala and Sudan, in K. David and M. Bernstam, eds, *Resources, Environment and Population*, Population Council and Oxford University Press, New York, NY, USA, pp. 125–147.

Bilsborrow, R., and Geores, M., 1992, *Rural Population Dynamics and Agricultural Development: Issues and Consequences Observed in Latin America*, Cornell University Press, Ithaca, NY, USA.

Bodley, J.H., 1990 [orig. 1982], *Victims of Progress*, 3rd ed., Mayfield Publishing Co., New York, NY, USA.

Boserup, E., 1965, *The Conditions of Agricultural Growth*, Aldine, Chicago, IL, USA.

BOSTID (Board on Science and Technology for International Development), National Research Council of the USA, 1984a, *Agroforestry in the West African Sahel: Resource Management for Arid and Semiarid Regions*, National Academy Press, Washington, DC, USA.

BOSTID (Board on Science and Technology for International Development), National Research Council of the USA, 1984b, *Environmental Change in the West African Sahel*, National Academy Press, Washington, DC, USA.

BOSTID (Board on Science and Technology for International Development), National Research Council of the USA, 1990, *The Improvement of Tropical and Subtropical Rangelands*, National Academy Press, Washington, DC, USA.

Brannon, J.T., 1991, Conclusion: Yucatecan political economy in broader perspective, in J.T. Brannon and G.M. Joseph, eds, *Land, Labor and Capital in Modern Yucatán*, The University of Alabama Press, Tuscaloosa, AL, USA.

Brannon, J.T., and Joseph, G.M., 1991, *Land, Labor, and Capital in Modern Yucatán: Essays in Regional History and Political Economy*, The University of Alabama Press, Tuscaloosa, AL, USA.

Brown, L.R., Flavin, C., and French, H.F., eds, 1997, *The State of the World 1997*, W.W. Norton and Company, New York, NY, USA.

Cook, S.F., and Borah, W., 1971, *Essays in Population History: Mexico and the Caribbean*, University of California Press, Berkeley, CA, USA.

Crosby, A.W., Jr., 1972, *The Columbian Exchange: Biological and Cultural Consequences of 1492*, Greenwood Press, Westport, CT, USA.

Cuanalo, H., Navarrete, R., and Gomez, A., 1996, La Agricultura del Estado de Yucatán, Files 8–15 in the Web site of the Centro de Investigación y de Estudios Avanzados (CINVESTAV), Unidad Mérida, Yucatán, Mexico: http://uh.cieamer.conacyt.mx:8080. Working Paper, Proyecto Población y Desarrollo Sustentable en Yucatán, CINVESTAV, CONAPO, and IIASA, data taken from statistics collected and published by the present Secretaría de Agricultura y Desarrollo Rural (SAGAR); by the former Dirección General de Estadística (DGE), of the Secretaría de Industria y Comercio; and by the Instituto Nacional de Estadística, Geografía e Informática (INEGI) for the years 1960–1994.

Daltabuit-Godas, M., Rios Torres, A., and Pérez Plaja, F., 1988, *Cobá: Estratégias Adaptivas de Tres Familias Mayas*, Universidad Nacional Autónoma de México, Mexico City, Mexico.

De la Garza, M., ed., 1983, *Relaciónes Histórico-Geográficas de la Gobernación de Yucatán*, 2 vols., UNAM, Mexico City, Mexico.

Denevan, W.M., 1978, Hydraulic agriculture in the American tropics: Forms, measures, and recent research, in P.D. Harrison and B.L. Turner II, eds, *Pre-Hispanic Maya Agriculture*, University of New Mexico Press, Albuquerque, NM, USA.

Denevan, W.M., 1982, Hydraulic agriculture in the American tropics: Forms, measures, and recent research, in Kent V. Flannery, ed., *Maya Subsistence: Studies in Memory of Dennis E. Pileston*, Academic Press, New York, NY, USA, pp. 181–203.

Domínguez-Carrasco, M., 1993, Calakmul, Campeche y su sistema hidraulico, *Los Investigadores de la Cultura Maya* **1**:42–46, Universidad de Campeche, Campeche, Mexico.

Elmendorf, M., 1980, Changing Patterns of Fertility: The Impact of Contraceptive Technology on a Maya Village, Research Report for Research Institute for the Study of Man, A.I.D. Project No. 932-0616, New York, NY, USA.

Ericson, J., 1997, Regional Assessment of Population Dynamics around the Calakmul Biosphere Reserve, World Wildlife Fund Internal Report, Washington, DC, USA.

Falkenmark, M., and Widstrand, C., 1992, Population and water resources: A delicate balance, *Population Bulletin* (Population Reference Bureau), **47**(3):1–36.

Faust, B.B., 1988, *Cosmology and Changing Technologies of the Campeche-Maya*, Ph.D. dissertation, Syracuse University, Syracuse, NY, USA.

Faust, B.B., 1998, *Mexican Rural Development and the Plumed Serpent: Technology and Maya Cosmology in the Tropical Forest of Campeche, Mexico*, Greenwood, Westport, CT, USA.

Faust, B.B., Cacao beans and Chile peppers in a Yucatec Maya Ke'ex: Curing a pubescent girl, *Sex Roles*, forthcoming.

Faust, B.B., and Dorantes, R., 1997, Resumen de Opiniones sobre la Milpa Intensiva en Sahcabá, Yucatán, Report for the project, "Evaluación de la Sostenibilidad de la Milpa Intensiva, una Alternativa a la Roza-Tumba-Quema en Yucatán," financed by Consejo Nacional de Ciencia y Tecnología, México.

Faust, B.B., and Morales López, A., 1993, La aguada en la historia oral de Pich, Campeche: Adapciones a variaciones de clima en un pueblo Maya, paper presented in Session 341, *XIII International Congress of Anthropological and Ethnological Sciences: The Cultural and Biological Dimensions of Global Change*, 4 August 1993, Mexico City, Mexico.

Fedick, S.L., 1995, Observations on Archaeological Features within a Wetland of the El Eden Ecological Reserve, Northern Quintana Roo, Mexico, Report to the Instituto Nacional de Antropología e Historia, Department of Anthropology, University of California, Riverside, CA, USA.

Folan, W.J., and Gallegos, S., 1996, El uso del suelo del sitio arqueológico de Calakmul, Campeche, *Yum Kax (Boletín de Información Ecológico de la Universidad Autónoma de Campeche*, **2**(3):7–8.

Freidel, D., Schele, L., and Parker, J., 1993, *Maya Cosmos: Three Thousand Years on the Shaman's Path*, Morrow, New York, NY, USA.

García, A., and Pérez, S., 1996, Factores de localización de la industria maquiladora: El caso de Yucatán, México, in *Yearbook, Conference of Latin Americanist Geographers*, **22**:17–30.

García, A., Eastmond, A., and Córdoba, J., 1996, Informe sobre el Estado de la Población: 1970–1985, Working Paper, Proyecto Población y Desarrollo Sustentable en Yucatán, CINVESTAV, CONAPO, and IIASA.

Gates, M., 1993, *In Default: Peasants, the Debt Crisis, and the Agricultural Challenge in Mexico*, Westview Press, Boulder, CO, USA.

Gates, G., and Folan, W.J., 1993, The Hydrogeologic Setting of the Aguadas in the Calakmul Biosphere Reserve, Campeche, Mexico, Paper presented in Session 341, XIII International Congress of Anthropological and Ethnological Sciences: The Cultural and Biological Dimensions of Global Change, 4 August 1993, Mexico City, Mexico.

Gómez-Pompa, A., 1987, On Maya silviculture, *Mexican Studies*, **3**:1–17.

Gómez-Pompa, A., Flores, J.S., and Sosa, V., 1987, The "Pet Kot," a man-made tropical forest of the Maya, *Interciencia*, **12**:10–15.

Gómez-Pompa, A., Kaus, A., Jiménez, J., Bainbridge, D., and Rorive, V.M., 1993, Country profile: Mexico, in *Sustainable Agriculture and the Environment in the Humid Tropics*, National Research Council, Washington, DC, USA, pp. 483–548.

Gossen, G.H., 1984, *Chamulas in the World of the Sun: Time and Space in a Maya Oral Tradition*, Waveland, Prospect Heights, IL, USA [original work published 1974 by Harvard University Press, Cambridge, MA, USA].

Green, D.H., 1984, *Metaphor as Process*, Ph.D. dissertation, University of Texas, Austin, TX, USA.

Gunn, J.D., Folan, W.J., and Robichaux, H.R., 1995, A landscape analysis of the Candelaria watershed in Mexico: Insights into paleoclimates affecting upland horticulture in the southern Yucatán peninsula semi-karst, *Geoarchaeology*, **10**(1):3–42.

Hale, L. 1996, Working Paper on Fishing, Working Paper, Proyecto Población y Desarrollo sustentable en Yucatán, CINVESTAV, CONAPO, and IIASA,

Harrison, P.D., 1978, Bajos revisited: Visual evidence for one system of agriculture, in P.D. Harrison and B.L. Turner II, eds, *Pre-Hispanic Maya Agriculture*, University of New Mexico, Albuquerque, NM, USA, pp. 247–253.

Hernández-X., Bello, E., and Levy, S., eds, 1995, *La Milpa en Yucatán*, Vols 1 and 2, Colegio de Postgraduados, Estado de México, Mexico.

Hodell, D.A., Curtis, J.H., and Brenner, M., 1995, Possible role of climate in the collapse of Classic Maya civilization, *Nature*, **375**(1):391–394.

Howrigan, G.A., 1988, Fertility, infant feeding, and change in Yucatán, in *Parental Behavior in Diverse Societies: New Directions for Child Development*, No. 40, Jossey-Bass, San Francisco, CA, USA, pp. 37–50.

Hunt, E.P., 1977, *The Transformation of the Hummingbird: Cultural Roots of a Zinacantcan Mythical Poem*, Cornell University Press, Ithaca, NY, USA.

Ibrahim, F., 1987, Ecology and land use changes in the semi-arid zone of the Sudan, in P. Little and M. Horowitz, eds, *Lands at Risk in the Third World*, Westview Press, Boulder, CO, USA, pp. 213–229.

Joseph, G., 1986, *Rediscovering the Past at Mexico's Periphery: Essays on the History of Modern Yucatán*, University of Alabama Press, University, AL, USA.

Kintz, E., 1990, *Life Under the Tropical Canopy: Tradition and Change Among the Yucatec Maya*, Holt, Rinehart and Winston, New York, NY, USA.

Landa, F.D., 1982, *Relación de las Cosas de Yucatán*, Porrúa, Mexico City, Mexico [original work published approximately 1574–1975].

Levy, T., Hernández-X., E., García, E., and Castillo, A., 1995, Estudio de la sucesión secundaria bajo roza-tumba-quema en Yucatán, in E. Hernández-X., E. Bello, and S. Levy, eds, *La Milpa en Yucatán*, Vol. 1, Colegio de Postgraduados, Estado de México, Mexico, pp. 149–169.

Little, P.D., and Horowitz, M., eds, 1987, *Lands at Risk in the Third World: Local-Level Perspectives*, Westview Press, Boulder, CO, USA.

Lowe, J.W.G., 1985, *The Dynamics of Apocalypse: A Systems Simulation of the Classic Maya Collapse*, University of New Mexico Press, Albuquerque, NM, USA.

Malthus, T., 1960, *On Population*, Random House, New York, NY, USA [first essay originally published 1798, second essay, 1803].

Martín, M., and González, J.C., 1996, La Economía de la Península de Yucatán: Crecimiento a Largo Plaza, Working Paper, Proyecto Población y Desarrollo Sustentable en Yucatán, CINVESTAV, CONAPO, and IIASA.

Matheny, R.T., Gurr, D.L., Forsyth, D.W., and Hauck, F.R., 1983, *Investigations at Edzn á, Campeche, Mexico*, Vol. 1, Part 1, The Hydraulic System, Papers of the New World Archaeological Foundation, No. 46, Brigham Young University Press, Provo, UT, USA.

McAnany, P.A., 1990, Water storage in the Puuc region of the northern Maya lowlands: A key to population estimates and architectural variability, in T.P. Culbert and D.S. Rice, eds, *Precolumbian Population History in the Maya Lowlands*, University of New Mexico Press, Albuquerque, NM, USA.

Merrill-Sands, D.M., 1984, *The Mixed Subsistence Commercial Production System in the Peasant Economy of Yucatán, México: An Anthropological Study in Commercial Beekeeping*, Ph.D. dissertation, Cornell University, Ithaca, NY, USA.

Moran, E., 1982, An assessment of a decade of colonization in the Amazon basin, in J. Heming, ed., *Change in the Amazon Basin: The Frontier After a Decade of Colonization*, University of Manchester, Manchester, UK, pp. 92–102.

Moran, E., 1993, *Through Amazonian Eyes: The Human Ecology of Amazonian Populations*, University of Iowa Press, Iowa City, IA, USA.

Murray, D.L., 1994, *Cultivating Crisis: The Human Cost of Pesticides in Latin America*, University of Texas Press, Austin, TX, USA.

Nye, P.H., and Greenland, D.H., 1960, *The Soil Under Shifting Cultivation*, Commonwealth Agricultural Bureau, Technical Communication No. 51, Harpenden, Berkshire, UK.

Patch, R., 1993, *Maya and Spaniard in Yucatán, 1648–1812*, Stanford University Press, Stanford, CA, USA.

Redfield, R., and Villa Rojas, A., 1962, *Chan Kom: A Maya Village*, University of Chicago Press, Chicago, IL, USA [original work published in 1934 by the Carnegie Institution of Washington, DC, USA].

Remmers, J., and de Koeyer, H., 1989, El T'olche: Una Vegetación Forestal en los Límites de la Milpa Maya, unpublished manuscript, Agricultural University of Wageningen, Wageningen, Netherlands.

Rice, P.M., 1987, *Macanché Island, El Petén, Guatemala: Excavations, Pottery, and Artifacts*, University Presses of Florida, Gainesville, FL, USA.

Rice, D.S., and Culbert, T.P., 1990, Historical contexts for population reconstruction in the Maya lowlands, in T.P. Culbert and D.S. Rice, eds, *Precolumbian Population History in the Maya Lowlands*, University of New Mexico Press, Albuquerque, NM, USA, pp. 1–36.

Ricketson, O., and Ricketson, E.B., 1937, *Uaxactun, Guatemala, Group E. 1926–1931*, Publication 477, Carnegie Institution of Washington, Washington, DC, USA.

Rosado-May, F.J., 1991, *Ecological Role of Wild Mustard (Brassica Kaber [D.C., L.C. Wheeler]) in the Management of Soil-Pathogenic Fungi and Nematodes in a Corn Agroecosystem*, Ph.D. dissertation, University of California, Santa Cruz, CA, USA.

Roys, R., 1943, *The Indian Background of Colonial Yucatán*, Publication 548, Carnegie Institution of Washington, Washington, DC, USA.

Sabloff, J.A., 1995, Drought and decline, *Nature*, **375** (June 1).

Sabloff, J.A., and Rathje, W.L., 1975, The rise of a Maya merchant class, *Scientific American*, **233**(4):72–83.

Sandoval, J.M., and Morales López, A., 1982, Una aproximación metodológica para el estudio de un sistema hidraulico prehispánico en Yohaltún, Valle de Edzná, Campeche, *Boletín E.C.A.U.D.Y.* (Escuela de Ciencias Antropológicas de la Universidad de Yucatán), **9**(53).

Scarborough, V.L., and Gallopin, G.G., 1994, A water storage adaptation in the Maya lowlands, *Science*, **251**(4):658–662.

Schlesinger, W.H., 1991, *Biogeochemistry: An Analysis of Global Change*, Academic Press, San Diego, CA, USA.

Siemens, A.H., and Puleston, D.E., 1972, Ridged fields and associated features in southern Campeche: New perspectives on the lowland Maya, *American Antiquity*, **37**(2): 228–239.

Sosa, J., 1986, *The Maya Sky, the Maya World: A Symbolic Analysis of Yucatec Maya Cosmology*, Ph.D. dissertation, The State University of New York at Albany, Albany, NY, USA.

Steggerda, M., 1941, *Maya Indians of Yucatán*, Publication 531, Carnegie Institution of Washington, Washington, DC, USA.

Stephens, J.L., 1988, *Incidents of Travel in Yucatán* (illust. F. Catherwood), Vol. II. *Mexico: Panorama Editorial*, Dover, New York, NY, USA [original work published in 1843].

Tedlock, B., 1982, *Time and the Highland Maya*, University of New Mexico Press, Albuquerque, NM, USA.

Tedlock, D. (translation and commentary), 1985, *The Popol Vuh: The Mayan Book of the Dawn of Life*, Simon and Schuster, New York, NY, USA.

Terán, S., and Rasmussen, C., 1994, *La Milpa de los Mayas*, DANIDA-CICY, Mérida, Yucatán, Mexico.

Terán, S., and Rasmussen, C., 1995, Genetic diversity and agricultural strategy in 16th century and present-day Yucatecan milpa agriculture, *Biodiversity and Conservation*, **4**:363–381.

Thompson, J.E.S., 1970, *Maya History and Religion*, University of Oklahoma Press, Norman, OK, USA.

Timberlake, L., 1985, The Sahel: Drought, desertification and famine, *Draper Fund Report*, **14**:17–19.

Turner, B.L., II., 1983, *Once beneath the Forest: Prehistoric Terracing in the Rio Bec Region of the Maya Lowlands*, Westview Press, Boulder, CO, USA.

Turner, B.L., II., and Harrison, P.D., 1983, *Pulltrouser Swamp: Ancient Maya Habitat, Agriculture, and Settlement in Northern Belize*, University of Texas, Austin, TX, USA.

Wilkinson, R.L., 1995, Yellow fever: Ecology, epidemiology, and role in the collapse of the Classic lowland Maya civilization, *Medical Anthropology,* **16**:269–294.

Wright, A., 1990, *The Death of Ramón González: The Modern Agricultural Dilemma*, University of Texas Press, Austin, TX, USA.

Zapata, L., 1989, Los Chultunes: Sistemas de Captación y Almacenamiento de Agua Pluvial, Serie Arqueología, Instituto Nacional de Antropología e Historia, Mexico.

Zizumbo, V.D., and Simá, P., 1988, Prácticas de roza-tumba-quema en la agricultura maya-yucateca y su papel en la regeneración de la selva, in R. Uribe, ed., *Medio Ambiente y Comunidades Indígenas del Sureste*, Gobierno de Tabasco y UNESCO.

5

The Performance of the Economy of the Yucatán Peninsula from 1970–1993

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5.1 Introduction

During the past 150 years, the economy of the Yucatán peninsula has been largely shaped by three factors: the Caste War, henequen production, and tourism. The Caste War of 1847 was an indigenous Maya rebellion against the social organization imposed by the Spanish. This rebellion defined the geography of the regional economy. After the Caste War the Maya controlled the southeastern part of the peninsula and the people of Spanish descent controlled the rest. Market-oriented activities were predominantly carried out in the northwestern region, while a traditional *milpa* system was the principal economic activity in the central and southern areas.

The Maya engaged in small-scale cropping of henequen until the middle of the 19th century. Technologically intensive (and therefore highly capitalized) commercial henequen production began during the 1860s and 1870s. This shift in production intensity responded to a large increase in demand brought on by the improvement of the McCormick reaper–binder. Yucatán's proximity to the United States and the quasi-slavery conditions of its labor force led to low transportation and production costs. Henequen production was the main economic activity of the Yucatán peninsula for approximately one century. During the second half of the 19th century, Mérida, the peninsula's main economic center, became a booming city. Henequen-induced prosperity was reflected in the establishment of other industries. Railroads were built. Large sums of money were spent on imported luxury goods.

Henequen production reached its peak during the First World War. The 1937 agrarian reform created 200 *ejidos*, providing land to more than 50,000 farmers. The Mexican government controlled henequen production for more than 50 years. In 1964, it started controlling henequen processing as well. Government participation in the industry continued through 1992. The development of synthetic substitutes and agricultural techniques that use no natural hard fiber and the cumulative effects of an inefficient public administration explain the current henequen production crisis. Henequen's economic share in the economy of the Yucatán peninsula has declined, as has its physical output and real economic value.

The development of Cancún as a center for tourism was part of a governmental strategy initiated in the 1960s and aimed at creating tourist centers in the country as a means of obtaining foreign currency. Several sites were developed in this way (e.g., Los Cabos, Loreto, Manzanillo), including the northeastern littoral of the Yucatán peninsula, where development began in the first half of the 1970s. The establishment and development of Cancún has shifted the axis of the Yucatán peninsula's economy in a way that will influence future development of the peninsula.

5.2 Economic Growth in Campeche, Quintana Roo, and Yucatán

Economic growth of the three states that constitute the Yucatán peninsula has been uneven. *Table 5.1* shows the annual growth rates of gross domestic product (GDP) for the states of Campeche, Quintana Roo, Yucatán, and for the Yucatán peninsula and Mexico as a whole.

Campeche's economy has stagnated in recent years. The growth rate of 7% from 1970 to 1980 diminished to 0.5% for the 1988–1993 period.[1] The economy of the state of Yucatán also showed an important decline in its growth rate for most of the 1980s; the annual growth rate fell from 8.7% in 1970–1975 to 0.9% in 1985–1988. However, it subsequently recovered somewhat, rising to 4.0% from 1988–1993.[2] Whereas the growth rates of the economies of Campeche and Yucatán declined from the 1970s to the 1980s, Quintana Roo's economy had high growth rates throughout the period, except between 1980 and 1985, when the national economic crisis hurt the state's economy. Quintana Roo's economy grew at approximately 20% per year from 1970–1975, the period during which construction of Cancún's tourism industry began. The rate slowed in the 1980s, but rose again to 15% per year from 1988–1993. During the early 1990s, the economies of Quintana Roo and Yucatán showed a recovery; however, Campeche's economy did not.[3]

The indicators of growth – population growth and economic growth – are shown in *Tables 5.1, 5.2*, and *5.3*. Campeche's economy exhibited a sharp decline in per capita GDP between 1970 and the early 1990s (see *Table 5.3*). Per capita GDP grew at an annual rate of 2% from 1970 until the mid-1980s; from 1985–1993 there was stagnation and then a decline.[4] Yucatán's per capita GDP stagnated during the 1970s and declined from 1985–1988, with a slight recovery

Table 5.1. Inter-census yearly growth rates of gross domestic product (%).

Region	1970–1975	1975–1980	1980–1985	1985–1988	1988–1993
Campeche	7.3	7.4	3.8	2.8	0.5
Quintana Roo	20.3	15.0	4.3	9.5	15.2
Yucatán	8.7	5.2	2.9	0.9	4.0
Yucatán peninsula	10.0	7.7	3.4	3.6	7.3
Mexico	6.6	6.7	2.9	–0.2	2.9

Sources: Authors' calculations based on gross domestic product information at current prices from INEGI, 1992, 1994a, 1994b, 1996b; INEGI-PNUD, 1984, 1985, 1989; and SPP-Banco de Mexico-UNDP, 1981.

Table 5.2. Per capita gross domestic product (in 1993 pesos).

Region	1970	1975	1980	1985	1988	1993
Campeche	7,707	8,464	9,347	10,003	10,123	8,861
Quintana Roo	10,268	16,186	20,376	17,037	17,692	24,828
Yucatán	6,677	8,574	9,311	9,473	9,027	9,661
Yucatán peninsula	7,201	9,295	10,782	10,778	10,841	12,847
Mexico	9,340	10,895	12,768	13,329	12,494	12,955

Sources: Authors' calculations based on sources listed in *Table 5.1* and population information from INEGI, 1996a.

Table 5.3. Inter-census growth rates of per capita gross domestic product (%).

Region	1970–1975	1975–1980	1980–1985	1985–1988	1988–1993
Campeche	1.9	2.0	1.4	0.4	–2.6
Quintana Roo	9.5	4.7	–3.5	1.3	7.0
Yucatán	5.1	1.7	0.3	–1.6	1.4
Yucatán peninsula	5.2	3.0	0.0	0.2	3.5
Mexico	3.1	3.2	0.9	–2.1	0.7

Sources: Authors' calculations based on figures from *Table 5.2*.

from 1988–1993. Between 1985 and 1993, the growth rate of Yucatán's economy was slightly higher than that of the national economy.

Quintana Roo's economy maintained sustained growth of per capita GDP despite the low growth rate (1.3%) for the 1985–1988 period. The decline observed for 1980–1985 should be viewed with caution, since it may partly be the product of changes in accounting procedures. Quintana Roo's economy has grown faster than its population. In 1970, its per capita GDP was already higher than that of both Campeche and Yucatán, and by 1980, it was approximately twice that of the other two states. In 1993, the differences in per capita GDP between Quintana Roo and Yucatán and Campeche were even greater (see *Table 5.2*).

The high growth rates of Quintana Roo's economy seem to be related to its linkage to the international market.[5] The main sources of economic growth for

Table 5.4. Relative contribution of industrial branches to Campeche's gross domestic product (%).

Sector	1970	1975	1980	1985	1988	1993
Agriculture and fisheries	30	26	26	23	17	13
Mining	0	0	0	0	0	0
Manufacturing	15	11	10	10	8	7
Construction industry	4	10	8	5	5	6
Electricity, gas, and water	1	0	1	1	1	2
Commerce, restaurants, and hotels	23	25	25	27	27	27
Transportation, storage, and communication	4	4	5	11	17	11
Financial and insurance services and real estate	10	9	8	6	7	13
Communal, social, and personal services	13	15	17	18	18	23
Other banking services	–1	–1	–1	–1	0	–2
Total	100	100	100	100	100	100

Sources: Authors' calculations based on the sources listed in *Table 5.1*.

the state are investments in tourism infrastructure and tourism services (e.g., hotels, restaurants, and commerce). These services generate approximately 60% of the state's GDP. Quintana Roo accounts for more than 30% of Mexico's earnings from international tourism.

Quintana Roo has a comparative advantage in tourism. However, there are marked intrastate differences in resources. The northern part of the state has the best natural resources for tourism and has undergone the highest economic growth rates. In contrast, the economy of Chetumal has declined, and agriculture, an important sector in southern Quintana Roo, is facing serious economic difficulties.[6]

5.3 Campeche's Economy

One of the main causes of the stagnation of Campeche's economy is the crisis in the agricultural sector. This sector contributed 30% and 26% of the state's GDP for 1970 and 1980, respectively. However, in 1993 the sector contributed only 13% (see *Table 5.4*). In just 13 years, the contribution of the agricultural sector declined 50%. Historical economic analyses indicate the relative decline of the agricultural sector in the economy as a whole. However, in Campeche the decrease is not only relative, but also absolute. The agricultural sector's GDP, calculated in 1993 pesos, decreased from 724 million new pesos in 1984 to 642 million new pesos in 1993. *Table 5.4* shows the relative contribution of several economic activities to Campeche's GDP.

Manufacturing contributed 15% of the state's GDP in 1970 and only 7% in 1993. The decline of the manufacturing sector is similar to that of the agricultural sector. It had a positive growth, in absolute terms, between 1970 and 1980. Growth declined sharply during the 1985–1988 period, and from 1988–1993 annual growth was 1.5%. The manufacturing GDP, calculated at constant prices, was lower in 1993 than in 1985. Campeche's manufacturing industry is concentrated in foods and beverages, which constituted 77% of the manufacturing GDP in 1993, a percentage similar to that in 1970. Production of sugar and beverages and the processing of seafood and rice represent 50% of total manufacturing production. The incipient apparel and leather industries, which contributed 8.5% to the manufacturing GDP in 1980, have practically disappeared. Forestry activities have declined noticeably.

The restaurant and hotel sectors grew significantly from 1970–1985, but showed an annual decline of 8.1% from 1985–1988. They then recovered slightly, with an annual growth rate of 2.8% from 1988–1993. The communal, social, and personal services sector showed the highest growth rate in Campeche's economy, producing 13% of the state's GDP in 1970 and 23% in 1993 (see *Table 5.4*). Educational and medical services grew substantially from 1970–1988, however, their growth rate declined for the 1988–1993 period. Public administration and defense grew rapidly from 1970–1980, but declined thereafter.[7] It is interesting to note that communal, social, and personal services stagnated or declined between 1988 and 1993, with the exception of the branch denominated "other services," which had an annual growth rate of 7.8% between 1988 and 1993.

Oil production along the coasts of Campeche increased during the 1980s and 1990s. However, it has had only a marginal effect on the state's economy because Petroleos Mexicanos (PEMEX) brings employees from other states and buys goods and services from companies located outside Campeche. Only Ciudad del Carmen has benefited from oil-related activities in the state. Greater incorporation of oil production into the economy may have been reflected in higher economic growth rates.[8]

5.4 Quintana Roo's Economy

The high growth rate of Quintana Roo's economy originates from the development of tourism. In 1970, the agricultural sector and the commerce, restaurants, and hotels sector contributed 34% and 23% of the state's GDP, respectively. In contrast, in 1993 the agricultural sector contributed only 2% of the GDP, while commerce, restaurants, and hotels supplied 58% (see *Table 5.5*). In addition to sectoral changes in the economy, there have been geographical shifts in the intensity of the economic

Table 5.5. Relative contribution of industrial branches to Quintana Roo's gross domestic product (%).

Sector	1970	1975	1980	1985	1988	1993
Agriculture and fisheries	34	13	7	9	5	2
Mining	0	0	0	1	1	1
Manufacturing	8	4	3	6	5	4
Construction industry	6	26	7	4	3	2
Electricity, gas, and water	1	0	1	0	1	0
Commerce, restaurants, and hotels	23	29	52	50	59	58
Transportation, storage, and communication	3	4	8	8	9	7
Financial and insurance services and real estate	10	6	5	6	5	9
Communal, social, and personal services	16	17	18	17	13	18
Other banking services	–1	0	0	–1	–1	–1
Total	100	100	100	100	100	100

Sources: Authors' calculations based on the sources listed in *Table 5.1*.

activities. For instance, in 1970 the cities of Chetumal and Cozumel were Quintana Roo's main economic centers. The main source of income was tourism and the sale of imported goods. The city of Chetumal is now facing an economic crisis originating from Mexico's membership to the General Agreement on Tariffs and Trade (GATT) and the liberalization policies enacted during the past 15 years, which ended Chetumal's duty-free port advantage. Currently, the main economic center is the northern part of the state, with Cancún as its center.

Despite tourism's significant contribution to the state's economy, other economic activities are also important. As in the case of Campeche, the sharp decline in the agricultural sector's contribution to Quintana Roo's GDP is the result not only of the rapid growth of other economic sectors, but also of the crisis and decay of the agricultural sector nationwide. The decline of forestry activities is particularly marked in Quintana Roo, where in 1970 they constituted the main agriculture-related activity.[9]

Although the agricultural sector had positive growth rates in the 1970s, its growth declined between 1985 and 1993. Cattle production expanded during the 1980s, yet its growth rate decreased from 1988–1993. Hunting and fishing activities had sustained growth rates during the early part of the same period, but these rates declined during the later years. The economic value generated by the agricultural sector for 1993, assessed in constant pesos, is lower than that for 1985.

The manufacturing industry had an average growth rate of 5% per year – a relatively low growth rate compared with that of tourism. However, the growth rate increased to 14.2% for the 1988–1993 period. The importance of manufacturing to the state's economy is relatively low. However, its contribution at the peninsula level has increased significantly. In 1970, Quintana Roo's manufacturing industry contributed only 4% to the Yucatán peninsula's manufacturing GDP, whereas in 1993 it contributed 21%. In 1970, Quintana Roo had the smallest economy on the Yucatán peninsula but the highest per capita GDP. In 1993, Quintana Roo's GDP per capita was still the highest on the peninsula.

5.5 Yucatán's Economy

Economic stagnation in the state of Yucatán in the 1970–1988 period was chiefly caused by the henequen production and processing crisis, since for nearly one century henequen had been the main source of demand and investment of resources in the state. The decay of henequen production became evident in the 1960s, particularly in the *ejidos*. Consequently, maintaining the level of demand depended on subsidies provided by the federal government. In 1964, the federal government bought the private enterprise that carried out the processing of the henequen fiber and initiated an industrial modernization program. In 1970, the public enterprise Cordemex had an installed capacity to process 100,000 tons of henequen, roughly the amount of fiber production. Thus, in the early 1970s, the Mexican government controlled almost all henequen production and processing.

Prices of products made of henequen fiber increased on the international market during the first half of the 1970s, resulting in increased prices for henequen leaves and higher wages and demand in Yucatán. Thus, the state's economy grew at an annual growth rate of 8.7% for the 1970–1975 period. However, the hard fiber industry did not grow during this period. This is partly explained because measurements of GDP growth attempt to gauge real rather than monetary growth. So, even when there was an increase in financial resources, growth of physical henequen production was insignificant. Nonetheless, the contribution of the manufacturing industry to the state's GDP was around 25% (see *Table 5.6*).[10] In 1975, there was a crisis in the world hard fiber market, which decreased the intensity of Cordemex activities.

A useful indicator of the level of economic activity during the period considered here is the performance of the construction industry, which grew at approximately 20% per year. In general, most economic sectors, with the exception of forestry (not shown here), showed high growth rates as a result of the high demand in the state's economy. The poor performance of the forestry sector was due to the decline of forests in the jungle of the eastern part of the Yucatán peninsula in the 1970s.

Economic decline stemming from the henequen crisis was counterbalanced to some extent by the boom in construction in Cancún, Quintana Roo, as well as

Table 5.6. Relative contribution of sectors to Yucatán's gross domestic product (%).

Sector	1970	1975	1980	1985	1988	1993
Agriculture and fisheries	12	11	8	10	8	9
Mining	0	0	0	1	1	1
Manufacturing	22	26	17	16	22	12
Construction industry	4	7	9	7	6	6
Electricity, gas, and water	1	1	1	1	1	2
Commerce, restaurants, and hotels	30	26	30	32	31	22
Transportation, storage, and communication	4	6	6	7	8	12
Financial and insurance services and real estate	13	10	11	7	7	17
Communal, social, and personal services	14	14	19	19	18	21
Other banking services	–1	–1	–1	–1	–1	–2
Total	100	100	100	100	100	100

Sources: Authors' calculations based on the sources listed in *Table 5.1*.

by financial resources derived from oil exports, which were partly directed to the development of the state.[11] The latter helped to maintain a moderate level of subsidies for henequen production, thereby contributing to the state's economic demand.

Of the three peninsular states, industrial development was furthest along in Yucatán. There, capital accumulation from henequen-related activities contributed to industrial diversification, including leather processing, printing, and production of cement, nonmetallic and mineral products, footwear, and animal feed.

The growth of Yucatán's different economic branches was uneven during the 1985–1988 period. The agricultural sector's production declined because of the damage caused by Hurricane Gilbert in 1988. However, cattle production grew at 4.8% per year, and forestry production and fishing activities grew at an annual rate of 10%. The manufacturing industry had an annual growth rate of 5.2%, chiefly due to the recovery of the hard fiber industry, which, helped by a henequen-promoting program, grew at 7%. Cement production and the plastic products industry grew markedly. In contrast, the construction industry declined, as did the financial sector; growth in commerce and restaurants and hotels stagnated. The communication industries and leasing of real estate grew rapidly. Professional and educational services showed moderate growth, while growth of medical services was sluggish. Public administration, defense, and "other services" had high growth rates.

Yucatán's economy recovered from 1988–1993, showing an annual growth rate of 4%. During this period the manufacturing industry stagnated and then declined, performing at an average annual growth rate of 0.6%. Such behavior was mainly the result of a sharp decline in the fiber industry, which was not fully counterbalanced by the growth of the food and beverages industries. Communal, social, and personal services stagnated, except leisure services (cinema, radio, television, and nightclubs), which grew at 13.9% per year. The recovery of the state economy in this period was based on the high annual growth rates of the agricultural sector (approximately 10%), financial services and real estate leases (11%), communications (26%), electricity (10.4%), and restaurants and hotels (5.6%). The construction and transportation industries grew between 3% and 4% per year. The commercial sector had an annual growth rate of 1.5%.

The 1970s were the last time that henequen production in Yucatán was profitable. The 1980s saw a decline in the growth rate of the state's economy. Despite the deep crisis of the hard fiber industry, from 1988–1993 the state's economy grew at a rate higher than the national average (4% versus 2.8%). Although the production of nondurable goods (food, beverages, and tobacco) represented 50% of the manufacturing GDP, the manufacturing industry was more diversified in the 1990s than it was in the 1970s, when the hard fiber industry predominated.

5.6 Perspectives

The economy of the Yucatán peninsula has undergone a number of significant changes. The focus of investment has shifted from Yucatán to Quintana Roo. Tourism has replaced henequen production and processing as the main source of economic growth. At the same time, oil production along the coast of Campeche has increased significantly, but its impact on the peninsula's economy has been negligible. Of the three states that make up the peninsula, the economy of Quintana Roo is the largest, that of Yucatán is the most diversified, and that of Campeche is the least developed.

During the next 20 years, the peninsula's economy might be affected by the following processes:

- Tourism will expand, particularly in the Cancún–Tulúm corridor and in the southern region of Quintana Roo. As a result, Chetumal's economy might be revitalized. Increases in both tourism and population suggest that the main problems might be environmental. There is the risk that the chief basis of tourism, namely, unique natural resources, may be destroyed if private investment is not subject to strict environmental control. Tourism will be the most dynamic economic activity on the Yucatán peninsula in the short and medium terms. However, it is likely that tourism will face increasing competition from other countries in the Caribbean and elsewhere. In the long term, the high dependence on tourism and the lack of economic diversification may lead to the stagnation of Quintana Roo's economy.

- Oil production along the coast of Campeche has had a meager impact in the state's economy. However, the state's current economic, social, and political development requires the use of a larger proportion of oil revenues for development purposes.
- The promotion of *maquiladoras* in Yucatán may help to shape a new capital accumulation model. However, the effects of such a model on the regional economy may be limited. Nonetheless, *maquiladoras* can contribute to regulating the migratory flows from rural areas to the city of Mérida. The *maquiladora* program might be helpful in alleviating unemployment problems in the short term, but it should be considered only as a transitory and/or complementary measure. It should not replace industrial and agricultural development policies.
- In all three states of the peninsula, one problem must be solved: integrating the Maya into the modern economy without destroying their culture. In the past, development programs have paid little or no attention to their participation. This problem needs a prompt solution that addresses cultural, economic, political, and environmental concerns.

The development of this region requires scientific and technological innovation. Without such innovation, economic development will be limited to the peninsula's comparative advantages (natural resources, low wages). The continuous supply of well-paid employment is dependent on a regional economy in which enterprises, government, and academic institutions work together. International competition demands the development of competitive advantages. In doing so, corporate innovation, increasingly dependent on scientific and technological research, is central. Future economic growth of the Yucatán peninsula will be largely dependent on technological innovation policies.[12]

Notes

[1] Between 1980 and 1985 several adjustments were made to the methodology used to estimate the GDP that affected the comparability of information between different periods. Where possible, various minor modifications have been made to deal with these changes. The annual growth rate from 1988 to 1993, based on 1980 prices, is 1.3%, which is higher than that obtained using 1993 prices. In both cases, there is clear stagnation.

[2] It has not yet been be determined whether this recovery is a result of changes in the fundamentals of the economy.

[3] Translator's note: This divergence in economic performance may stem from the greater diversification of Yucatán's economy and its integration with the economy of Quintana Roo, as well as from the latter's dependence on the conditions of the external market and thus its lower susceptibility to changes in the national economy. In contrast, Campeche's economy relies on a small domestic market and lacks strong linkages with, and the dynamism originating from, external markets.

[4] The value of oil production has not been considered in these calculations. Using the per capita GDP growth rate based on 1980 pesos (1.3%), the per capita GDP decline would be still high (2%).

[5] Translator's note: Linkages with foreign markets make it possible for firms to attain economies of scale, and the domestic economy benefits from the impacts of competitive pressures on prices, product improvement, and technological advancement. In attaining such theoretical advantages, it is crucial to have a governmental system that will properly distribute resources to take care of those negatively impacted by economic growth.

[6] The economic problems of the state of Yucatán, resulting from its high reliance on henequen production, might suggest that a similar situation is likely for the state of Quintana Roo. Such a situation may originate from Quintana Roo's very high economic dependence on tourism, which increases the state economy's vulnerability to changes in the sector.

[7] A potential bias might arise from using the national implicit price indexes in the service sector calculations.

[8] The effects of PEMEX's activities in the state's budget were not taken into account for this discussion.

[9] The decrease in forestry activities may be explained by both the destruction of the rain forest, which decreases the availability of forest resources, and the increase in governmental regulations in the sector.

[10] The fiber industry generated approximately 50% of the manufacturing industry's economic value. The contribution of each sector to economic growth was calculated as follows:

$$[(GPit + 5)\text{-}GPit]/[(TGPt + 5)\text{-}TGPt],$$

where GP is gross domestic product for each industrial branch. The subscript i represents each of the 73 sectors; t represents the year 1970, 1975, 1980, 1985, and 1988; and TGP is total gross domestic product. During the 1985–1988 period, the formulas changed to t+3.

[11] The development of Cancún increased the demand of goods and services in the state of Yucatán; moreover, remittances to the state were received from Yucatecans who migrated to and worked in such centers.

[12] Translator's note: In general, given the accelerating rate of change, successful development of the Yucatán peninsula may require the establishment and functioning of

a set of processes at different organizational levels for making sense of a changing environment; for developing new internal resources and capabilities; for accessing new external resources; for defining new organizational, regional, state, and peninsular goals; and for coordinating available resources and capabilities in the pursuit of an evolving set of strategic development goals.

References

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1992, *Sistema de Cuentas Nacionales de Mexico 1987–1990, Resumen General*, Vol. I, Aguascalientes, Mexico.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1994a, *Sistema de Cuentas Nacionales de Mexico, Producto Interno Bruto por Entidad Federativa 1985 y 1988*, Aguascalientes, Mexico.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1994b, *Sistema de Cuentas Nacionales de Mexico 1990–1993, Resumen General*, Vol. I, Aguascalientes, Mexico.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1996a, *Censos Generales de Población y Vivienda de 1970, 1980, 1990 y Conteo 1995*, Aguascalientes, Mexico.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1996b, *Sistema de Cuentas Nacionales de Mexico, Producto Interno Bruto por Entidad Federativa 1993*, Aguascalientes, Mexico.

INEGI-PNUD (Instituto Nacional de Estadística, Geografía e Informática, Programa de las Naciones Unidas para el Desarrollo), 1984, *Sistema de Cuentas Nacionales de Mexico 1980–1982, Resumen General*, Vol. I, Aguascalientes, Mexico.

INEGI-PNUD (Instituto Nacional de Estadística, Geografía e Informática, Programa de las Naciones Unidas para el Desarrollo), 1985, *Sistema de Cuentas Nacionales de Mexico, Estructura Económica Regional, Producto Interno Bruto por Entidad Federativa 1970, 1975 y 1980*, Aguascalientes, Mexico.

INEGI-PNUD (Instituto Nacional de Estadística, Geografía e Informática, Programa de las Naciones Unidas para el Desarrollo), 1989, *Sistema de Cuentas Nacionales de Mexico 1981–1987, Resumen General*, Vol. I, Aguascalientes, Mexico.

SPP-Banco de Mexico-UNDP, 1981, *Mexico: System of National Accounts, General Summary*, Vol. 1, Secretaría de Programación y Presupuesto, Banco de Mexico and United Nations Development Programme, Mexico.

6

A Conceptual Model of the Aquifer of the Yucatán Peninsula

Miguel J. Villasuso and Renán Méndez Ramos

6.1 Introduction

Covering approximately 2 million square kilometers (km^2), Mexico's territory presents a great variety of geohydrological characteristics. In particular, the aquifer of the Yucatán peninsula is almost entirely formed by large, highly permeable limestone outcrops.[1]

Because water on the surface rapidly percolates through the underlying limestone, most of the Yucatán peninsula has no surface streams. After reaching the underground aquifer, water moves toward the coast, where it is discharged into the sea. Because of the Yucatán peninsula's particular geohydrological features and the fact that the aquifer is the principal source of fresh water for human activities, prudent management of the peninsula's water system is crucial to maintaining its stability and consequently its usefulness for the peninsula's socioecological systems. Providing a general notion of the essential characteristics of the underground aquifer may improve management of the aquifer.

This chapter presents a conceptual model of the Yucatán peninsula's aquifer. Section 6.2 gives a brief description of the peninsula's geology.[2] An account of the main geomorphological regions appears in Section 6.3. Section 6.4 describes the peninsula's geohydrology. Finally, Section 6.5, provides a hydrological balance of the Yucatán peninsula's aquifer.[3]

6.2 Main Geological Features of the Yucatán Peninsula

The Yucatán peninsula is made up of marine sedimentary rocks of the Tertiary period. The oldest rocks are located in the southern and central parts of the peninsula and correspond to limestones and evaporites of the undifferentiated Paleocene–Eocene periods (Butterlin and Bonet, 1960). These rocks are surrounded by

Table 6.1. Stratigraphy of the Yucatán peninsula.

Geological age	Northern zone	Southern and central zones
Holocene	Limestones with mollusks, sandbacks, clays, soils	Soils
Pliocene	Carrillo Puerto Formation	Undifferentiated
Miocene	Estero Franco Formation, Bacalar Formation	–
Oligocene	Lutites, limestones	Undifferentiated
Eocene	Chumbec Member (limestones), Pisté Member (limestones), Xbacal Member (limestones)	Chumbec Member, Pisté Member
Paleocene		Icaiché Formation (limestones, dolomites, evaporites)
Upper Cretaceous		Peten (?) (limestones)

Sources: Velázquez, 1986; Méndez Ramos, 1991.

calcareous deposits from the Miocene. The nearer to the coast, the younger the geological age of the materials. The stratigraphy of the Yucatán peninsula is shown in *Table 6.1*.

The Yucatán peninsula is almost completely covered by marine calcareous sediments. Such formations have a maximum thickness of approximately 1,000 m. They constitute a tectonically stable platform despite the plates and faults of the Cenozoic epoch that shaped the peninsula's current topographical landscape (Isphording, 1974, as cited by Back and Lesser, 1981). *Figure 6.1* shows some of the main geological structures of the Yucatán peninsula.

The principal structural axes of the peninsula have a west–northwest and north–northeast orientation and are associated with the Sierrita de Ticul and the Bacalar–Rio Hondo system, respectively. The major geological materials belong to the Icaiché Formation (Eocene–Paleocene); the Chichén Itzá Formation, which includes the Xbacal Member (Lower Eocene–Paleocene), the Pisté Member (Middle Eocene), and the Chumbec Member (Upper Eocene–Middle Eocene);[4] the Bacalar Formation (Miocene); the Estero Franco Formation (Pliocene–Upper Miocene); the Carrillo Puerto Formation (Pliocene–Upper Miocene);[5] and limestones with mollusks from the Holocene–Pleistocene (Weidie, 1974).[6] The limestones from the Eocene and Miocene–Pliocene occupy the largest area on the

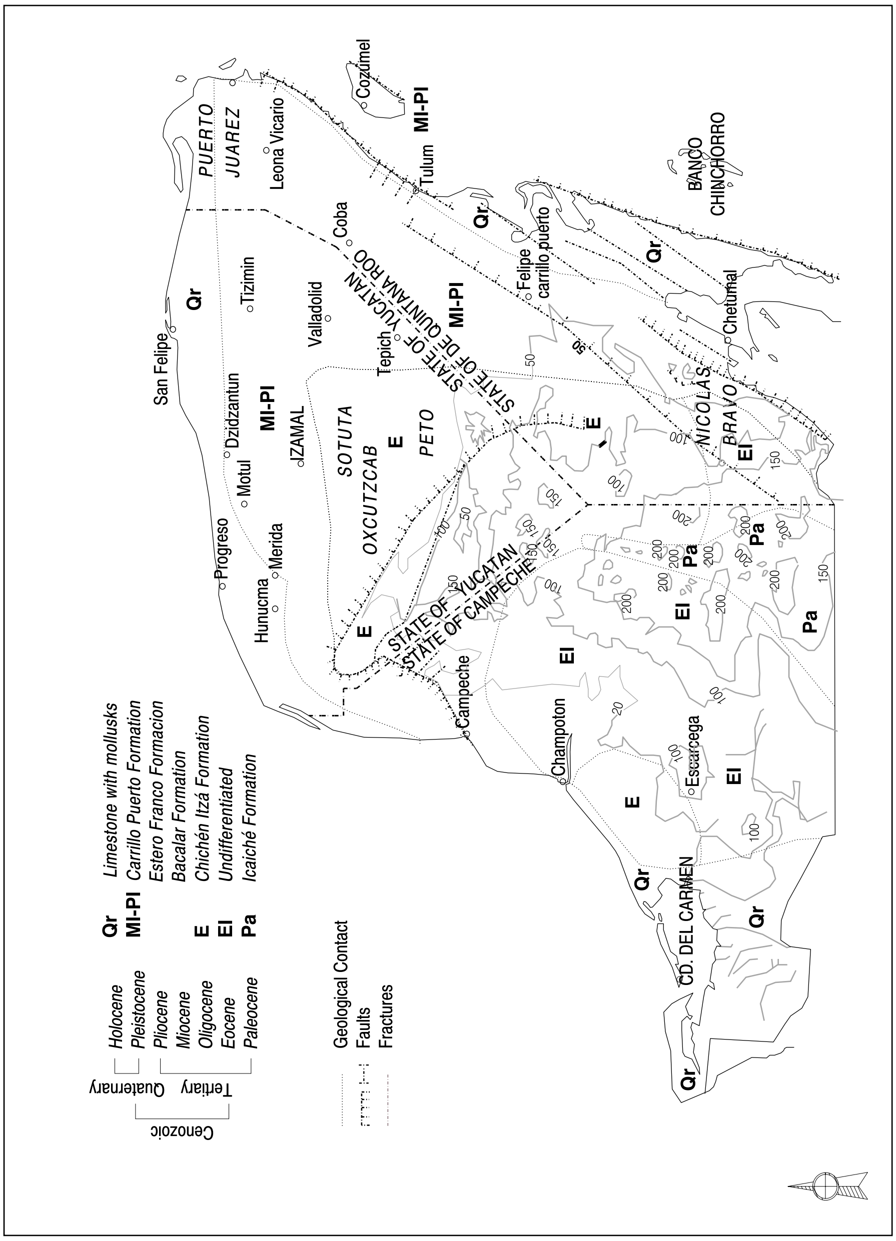

Figure 6.1. Stratigraphy of the Yucatán peninsula. Figures given indicate height above sea level (m).

peninsula. These limestones are highly fractured, allowing both the storage and flow of underground water between the open spaces of the rocks' structure.[7]

6.3 Geomorphological Regions

This characterization of the geomorphology of the Yucatán peninsula highlights features of specific sites or zones primarily found at or a few meters below the land surface and some characteristics of the karst that affect the permeability of the rocks and the flow of underground water.

The Yucatán peninsula has been divided into four geomorphological regions: (I) the coastal region; (II) the interior flatlands; (III) the hills and valleys region; and (IV) the block-fault basins region (Velázquez Aguirre, 1986).

The coastal region encompasses the beaches and coastal areas of the peninsula. As a result of intrusion of seawater, fresh water may have high sodium and chloride contents. The interior flatlands include the northern, eastern, and western parts of the peninsula. The water is suitable for human consumption and for agricultural and industrial use. The ring of cenotes is located in this region. The hills and valleys region encompasses the central and southern parts of the peninsula. This region has the oldest rocks, the deepest soils, and the tallest and densest vegetation, and the water table is deepest here. Because of the occurrence of evaporites, the underground water of this zone may have high concentrations of salt, calcium, and sulfates. The block-fault basins region, located in the state of Quintana Roo, is a karstic development associated with fault zones. Marshall *et al*. (1974) pointed out that at the close of the Cretaceous period, this region underwent uplift or faulting which exposed the Lower Cretaceous anhydrite.

The Yucatán peninsula is an open hydrological basin. Its aquifer is composed of limestone. Physiographically, the peninsula is a karstic entity at a medium stage of erosion in the geomorphological cycle. There are cavities and ducts in the calcareous rocks ranging from pores and cracks up to large caverns. The collapse of cavern ceilings has formed numerous rounded depressions called dolines. These formations are known locally as *rejolladas* or *sumideros* when they do not have water and as cenotes when water is visible at the bottom. With the exception of sandbanks along the coasts, the rock surface is formed by a compacted layer known regionally as *lajá*.[8]

A white, friable material called sascab can be observed in ground surface cuts, material deposits, and excavations.[9] This material corresponds to unconsolidated rock. Its consistency suggests that the crystallization from aragonite to calcite, a process necessary for consolidation of the rock, did not occur. Sascab may vary in thickness from a few centimeters to over a meter. Some limestones and chalky coquinas are also known as sascab. They are located under the *lajá* layer or occur as thin stratified limestone layers. The latter situation can be observed in the Chichén Itzá sacred cenote. Similarly, sascab-type materials can be found on the surface, as is the case in a large region in the southern part of the peninsula between Bacalar, Carrillo Puerto, and Chetumal.

Along the western coast, near Celestún and Isla del Carmen, there are calcareous rocks on or near the surface. At sites such as Ciudad del Carmen, calcareous sandy soils are prevalent. In general, this western part of the peninsula is a vast region, large areas of which are saline marshes. Its surface has been shaped by the water flows and silty materials carried by the Candelaria and Usumacinta Rivers. The area is partly covered by mangroves, where sandy and silty soils predominate, and elsewhere by shallow wetland areas underlain by a calcareous platform.

The area around the city of Campeche has four zones with different rock and soil types, namely, the rocky zone, the landfill zone, the sascab zone, and the *acalché* zone. A thin layer of calcareous rock underlies the landfill zone, which is covered by sascab of varying degrees of compactness. The *acalché* zone is characterized by a clay of the same name exhibiting high plasticity and large volumetric changes resulting from variations in its moisture content.

In the northern part of the peninsula, a narrow coastal zone originating from marine materials runs from Celestún to Cabo Catoché. It is separated from the main continental shelf by wetlands and saline lagoons. The tides affect the level of these water bodies. Similar zones are located along the eastern coast in areas between Cabo Catoché and Cancún, as well as between Tulúm and Chetumal.[10]

A configuration typical of the northeastern part of the peninsula is a series of hardened sand dunes underlain by calcareous rocks of the continental shelf, intermingled with lagoons and wetlands in which precipitation of animal and vegetal sediments took place. The island of Cancún is a coastal bank of recent formation that is partly the product of sand accumulated by wind action. The calcareous platform underlying Cancún and the land–sea interface in the northeastern part of the peninsula extends approximately 1.5 km from the shoreline into the sea at about 10 m deep, thereafter descending sharply into the deep Caribbean Sea. In general, the narrow land strips along the coast are made up of old cemented sand formations on which additional sand accumulates. Below these formations lies a layer of calcareous rock that corresponds to the extended marine platform. In contrast to the northern and western coasts, the eastern coast descends sharply into the sea up to several hundred meters of depth.

The Yucatán peninsula's morphological features seem to be related to the north–northeast orientation of the eastern coast, which appears to have been formed by faults, as well as to the south–southwest orientation of folded and faulted limestone ranges located at the base of the peninsula. The Laguna de Bacalar and the block-fault basins between the Soh Laguna and northern Belize and the western coast of the Bahia de Cozumel also have a south–southwest orientation. The hills in the Sierrita de Ticul as well as those in the Bolonchén region, located at or around the Ticul fault, are perpendicular to the series of faults in the eastern part of the peninsula. In addition, there are groups of geological structures on the peninsula that make up the line of contact between the most recent formations and those from the Eocene: (1) the current northern and western coasts; (2) the 10-fathom isobath; (3) and the large submarine platform known as the "Sonda de Campeche" or "Banco de Campeche." These structures coincide with the dominant orientation of the dissolution zones.

The main geomorphological and geological characteristics of the Yucatán peninsula are shown in *Table 6.2*. The carbonates from the Cenozoic epoch are highly fractured on the Yucatán peninsula, which facilitates the rapid infiltration of water. The horizontal limestones of the eastern part of the peninsula have many faults, which form a series of horst and graben easily recognizable from the surface (Lesser and Weidie, 1988).

The ring of cenotes is a hydrogeological frontier that forms a semicircle with a radius of approximately 80 km centered in Mérida (Marín and Perry, 1994) and ranging in width between 5 and 10 km. This structure was formed by a huge impact that caused a massive extinction of species in the late Cretaceous (Pope *et al*., 1991; Perry *et al*., 1992).[11] The crater is buried under approximately 1 km of sediments from the Tertiary period. However, the question is open as to how the geomorphological features of the Tertiary could reflect an event that took place earlier at the Cretaceous/Tertiary boundary. On the surface, the most prominent manifestation of this structure is the ring of cenotes, which defines the limits between fractured limestone located outside the structure and non-fractured limestone located within the structure. This frontier forms a barrier impeding lateral migration of underground water and consequently results in increased flows, dissolution, and the collapse of rocks. The geology of the surface indicates that the fractures created by the ring of cenotes are related to subsidence on the crater's frontier, to differences in the thickness of the rocks covering it, and to collapses caused by dissolution within the pores of the impact deposits. These factors have contributed to the high density of cenotes found in the ring.

6.4 Main Geohydrological Features of the Yucatán Peninsula

Most of the Yucatán peninsula has no surface streams. This is particularly true of the northern part. In the South there is incipient drainage, which disappears in water bodies on the surface or in natural sinks. Thus, most rainfall either evaporates

Table 6.2. Geomorphological and geological features of the Yucatán peninsula.

Geomorpho-logical unit	Subdivisions	Geoforms	Location	Geological features
I. Coastal region	Beaches	Long and narrow beaches	Along the northern and northwestern coasts	Recent deposits associated with marine erosion
	Tidal area	Flooded lagoons	–	Current deposits originating from tidal effects
	Caribbean coast	Rocky and narrow beaches; semi-circular beaches, submarine springs	–	Deposits associated with fractured and fault zones
II. Interior flatlands	North-western	Small dissolution cavities, superficial karst, low slopes, thin and discontinuous soils; small cenotes toward the SE	Northwestern zone of the peninsula	Karstic materials at an early stage of development
	Central–northern	Large-diameter dolines, slightly hilly terrain	Central and northern zones of the peninsula; Tizimin is the center	Karstic materials at an early stage of development
	Central interior	Diverse cenotes, small dolines, deep soils, karstic caverns, differentiated ducts	Central part of the peninsula and northern part of the Sierrita de Ticul	Young and mature karstic materials
III. Hills and valleys	Sierrita de Ticul	NW–SE hilly alignment, large caverns	From Maxcanú up to Oxkutzcab in a NW–SE orientation	Associated with differential lifting
	Colinas de Bolonchén	Hilly terrain, deep soils, large karstic cavities	Entire S–SW zone of the peninsula	Anticlinal folds pierced by materials from below
IV. Block-fault basins	North	Water bodies, cenotes, small karstic caverns, deep soils in basins, low slopes	NE of Quintana Roo	Young karstic materials associated with faults and fractures with a NE–SW orientation
	South	Water bodies, springs, large caverns, larger slopes than in the north	Southern part of Quintana Roo and NE of the Rio Hondo	Early mature karstic materials associated with fault-block structures

Source: Velázquez, 1986.

or transpires, and the remainder infiltrates to the underground aquifer. The underground water follows different flows, which are controlled by the characteristics of the deep karst. The regions with the most karstic soils are located in the southern part of the peninsula, where the oldest sediments from the Eocene–Paleocene are found (Velázquez Aguirre, 1986). *Figure 6.2* shows a geohydrological profile of the Yucatán peninsula.

In karstic aquifers, permeability depends on, among other things, the degree or combination of fractures and the permeability of carbonated rocks. However, enlargement of cracks due to dissolution effects is not uncommon. Such effects are differentiated according to the content of calcium carbonate in the rocks and the characteristics of the water in specific sites. This phenomenon is known as karstification. As a result of ongoing karstification, the heterogeneity of the aquifer's system is continuously increasing. Likewise, there is a tendency toward a higher density of fractures of the geological materials over time. Given the level of rainfall, the lack of surface streams clearly reflects the high permeability of the geological materials of the peninsula. Because of lithological and stratigraphical differences, the porosity and permeability of the calcareous material is not homogenous. The high transmissibility of the aquifer is reflected in a very small hydraulic gradient.[12]

Demarcation and assessment of replenishment and discharge areas is required to characterize the aquifer's system of flows. The replenishment of the underground aquifer follows the rainfall distribution pattern. The state of Quintana Roo has an underground water inflow from outside the peninsula (Lesser, 1980). The aquifer is constantly replenished, primarily at the highest points on the peninsula, in the states of Campeche and Quintana Roo. The water flows underground from there toward the state of Yucatán.

As a result of the characteristics of the karst and the effects of the karstification process, the movement and storage of underground water takes place through a network of interconnected fractures, cracks, strata, faults, channels, cavities, and caverns located at different depths in the subsoil.[13] The underground water of the peninsula circulates from the highest precipitation zones toward the coast, where the discharge of the natural aquifer takes place through a series of springs along the coastal zone, supplying water to marshes, lagoons, and the sea. In the eastern part of the peninsula, discharge from the aquifer takes place offshore and through submarine springs and fractures in coastal lagoons. Along the peninsula's western and northern coasts, discharge takes place through springs and underwater seepage. There is a strong freshwater discharge flow in the northern part of the state of Yucatán, in Celestún and Dzilam. The magnitude of this flow impedes inland penetration of seawater. In summary, the underground water generally flows from the highest region, located in the central part, outward in all directions.

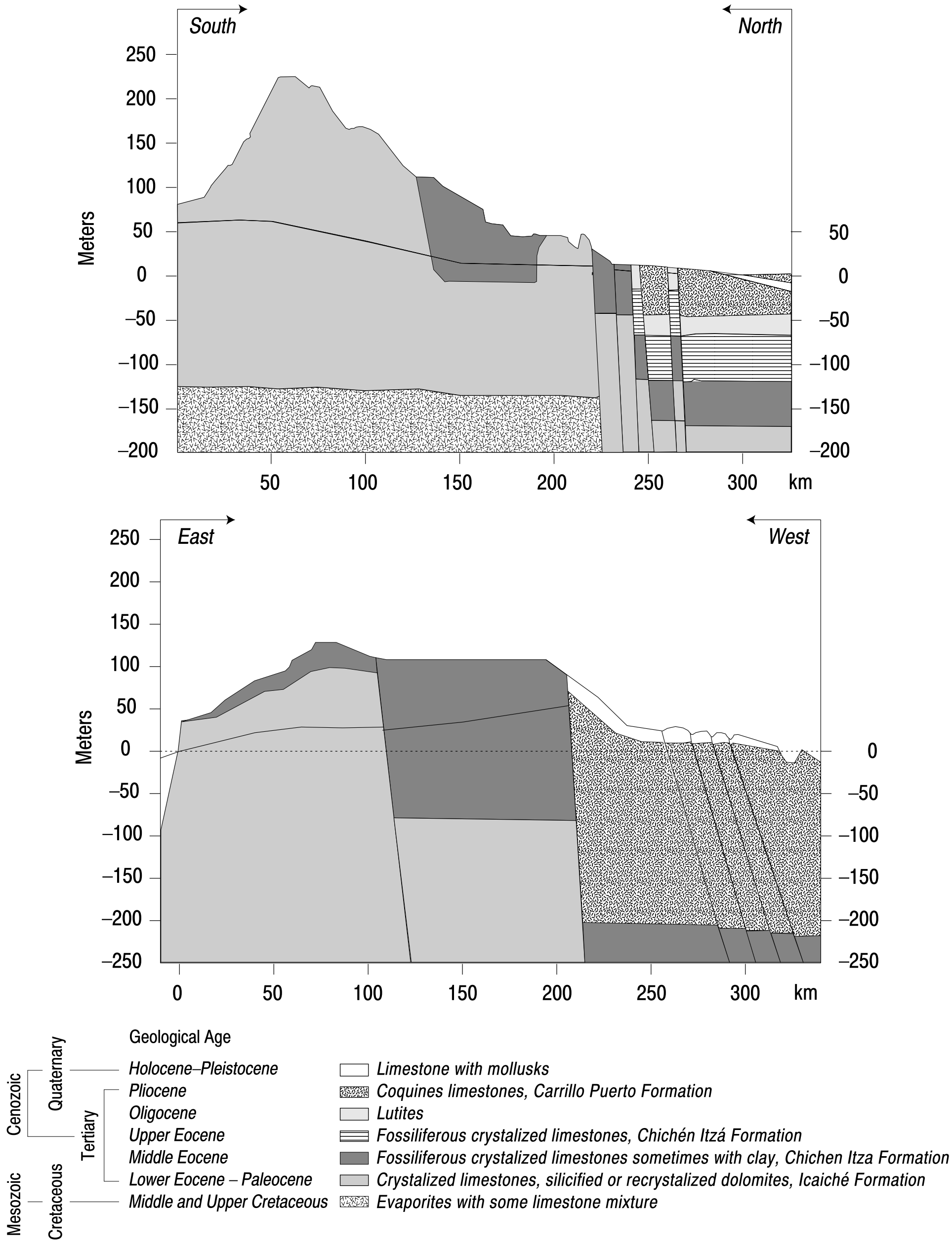

Figure 6.2. Geohydrological profile of the Yucatán peninsula.

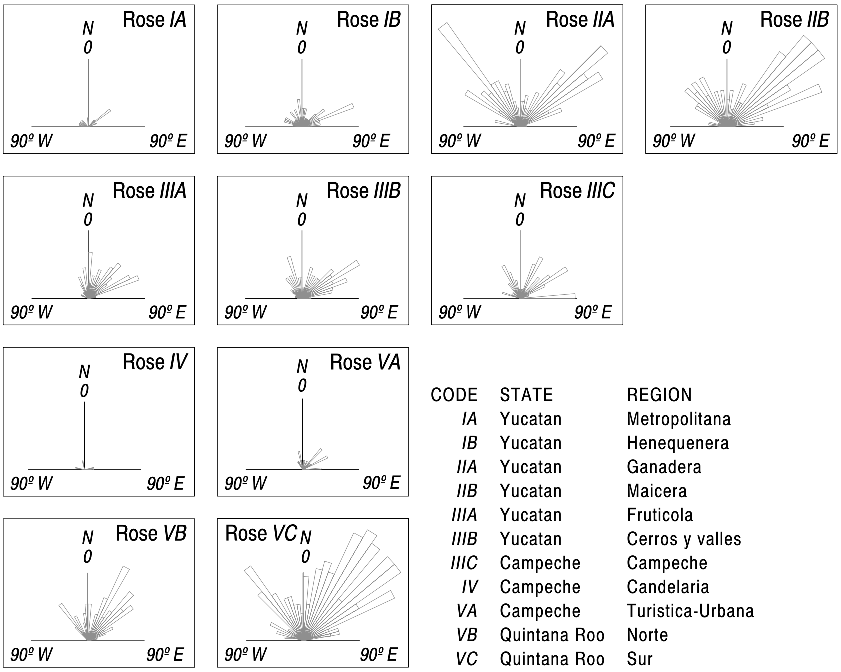

Figure 6.3. Main varieties of fracture systems in the socioecological regions of the Yucatán peninsula.

In the northern and southeastern flatlands, the underground aquifer is located at a depth of approximately 30–70 m, with a layer of saline water at about 40–80 m. The main source of saline water is the dissolution of the gypsum, anhydrite, and halite layers. Infiltrated water and underground fresh water flow toward the sea. The salinity of the underground water increases with depth.

In general, the aquifer of the Yucatán peninsula is surrounded by seawater. Fresh water floats on top of saline water. The latter penetrates from the coast toward the center of the peninsula. The depth of the saline water in the aquifer is a function of the height of the water table with respect to the average sea level and the density of the seawater, as well as the density of fractures, caverns, cavities, dissolution ducts, and cenotes, which allow the seawater access to the peninsula's interior. The depth of the water table is approximately 120 m in the hills and valleys region, 30 m in the flatlands, and 5 m in a 15-km zone parallel to the coast. *Figure 6.3* presents an overview of the varieties of fracture systems in the socioecological regions of the Yucatán peninsula.

There is intrusion of seawater along the coast due to the high permeability of the carbonated strata. The layer of fresh water is located only a few centimeters above the sea level. Its thickness increases toward the center of the peninsula. For this reason, human settlements along the coast obtain drinking water from sources located 15 or more kilometers inland.

The intrusion of seawater takes place in annual cycles. The lack of replenishment during the dry season combined with exploitation of the aquifer increases the amount of saline water in the aquifer. Saline water may intrude up to 12 km inland (Lesser and Weidie, 1988). During the rainy season, the saline interface moves rapidly toward the sea because of high inland replenishment and low water extraction levels during this period of the year. The high permeability of the geological materials facilitates such swift movement.[14]

The island of Cozumel offers a typical example of saline intrusion. The geological structure of the island, constituted by rocks from the Holocene and Pleistocene underlain by rocks from the Miocene and Pliocene, and the extent of water recharge permit the maintenance of a freshwater layer about 20 m thick. High freshwater extraction levels increase the intrusion of saline water, while low extraction levels allow almost instantaneous recovery of both freshwater levels and water quality. As the extraction of water increases, the level of fresh water decreases and the intrusion of saline water increases.

Intrusion of seawater along the coast of the Yucatán peninsula occurs where the freshwater head cannot prevent it. The aquifer in the north of Yucatán has a thin freshwater layer that flows above a dense intrusion of seawater. This saline water has penetrated more than 40 km inland from the coast (Back and Hanshaw, 1970; Durazo *et al*., 1980; Back and Lesser, 1981; Gaona *et al*., 1985; Perry *et al*., 1989). Geohydrological studies undertaken in the horticultural coastal zone and in Dzonot Carretero in the state of Yucatán have shown that saline water intrusion has reached up to 10–15 km inland (SARH, 1981, 1983). This increased intrusion was attributed to the high concentration of wells in the area. The studies indicated that high freshwater extraction levels were breaking the equilibrium between the fresh water and the saline water. For this reason, regulations were established restricting extraction of underground water within 20 km of the coast (Méndez Ramos, 1993).

The underground aquifer in the city of Mérida has a water lens approximately 40-m thick on average; this lens floats above saline water, which in turn is underlain by rocks of very low permeability. The mixing zone or saline interface is 37 m thick and ranges from 28 to 65 m deep (Villasuso *et al*., 1984).[15] The mixing zone is highly altered due to the discharge of wastewater.[16] There is a trade-off between the layer of fresh water and the layer of saline water. The former increases toward the center of the peninsula. Its thickness varies from 30 m, along a 20-km strip of land parallel to the coast to 70 m in the central zone of the peninsula (Perry and Marín, 1990).

In the northern and northwestern parts of the peninsula, there is a semiconfined mixed water layer underneath the marshes and coastal lagoons that presents special hydraulic conditions because it permits considerable variation in the thickness of both the saline water and freshwater layers.

The aquifer of the state of Yucatán is highly vulnerable because of the high permeability of the rocks constituting its subsoil and the shallow depth of the water table. The prevailing conditions lead to the pollution of underground water. On the one hand, the open spaces of the karstic terrain, the wide ducts of the aquifer, and the lack of filtrating material facilitates the access of pollutants to the aquifer and their rapid dissemination within it. On the other hand, the hardness and the low slopes of the calcareous materials impede the establishment of drainage systems in the main human settlements. Thus, wastewater is discharged directly into the soil or into septic holes. Many of the latter are neither well constructed nor well maintained, so large amounts of organic matter, fecal organisms, chemical compounds and detergents, and other pollutants enter the underground aquifer. These effects on the aquifer are not exclusive to urban areas, although their cumulative impacts are likely to be higher there than in rural areas, where availability of drainage systems is lower.

6.5 Hydrological Balance of the Underground Aquifer

The Yucatán peninsula has a humid tropical climate. The average annual temperature is 25°C. The months with the highest temperature are July and August; those with the lowest are December and January. The thermal regime is very stable throughout the year. The combination of high temperatures with abundant vegetation results in the evapotranspiration of about 85% of precipitation. Therefore, approximately 15% of precipitation infiltrates into the groundwater.

Annual rainfall ranges from less than 800 mm in the northwest to 1,300 mm along the eastern coast and 1,700 mm on the island of Cozumel (*Figure 6.4*). Approximately 90% of annual rainfall occurs between May and October. The average annual precipitation along the eastern coast of the Yucatán peninsula is 1,200 mm, and that of Progreso is 500 mm (SARH, 1989), reflecting a nonuniform spatial distribution of rainfall.

The main rainy season occurs from June to September. However, annual precipitation levels are highly variable spatially as well as both within and between years. In general, yearly precipitation levels are negatively correlated to population density and consequently to water extraction levels. However, this situation is partly compensated by underground water flows such as that flowing from the state of Quintana Roo to the state of Yucatán.

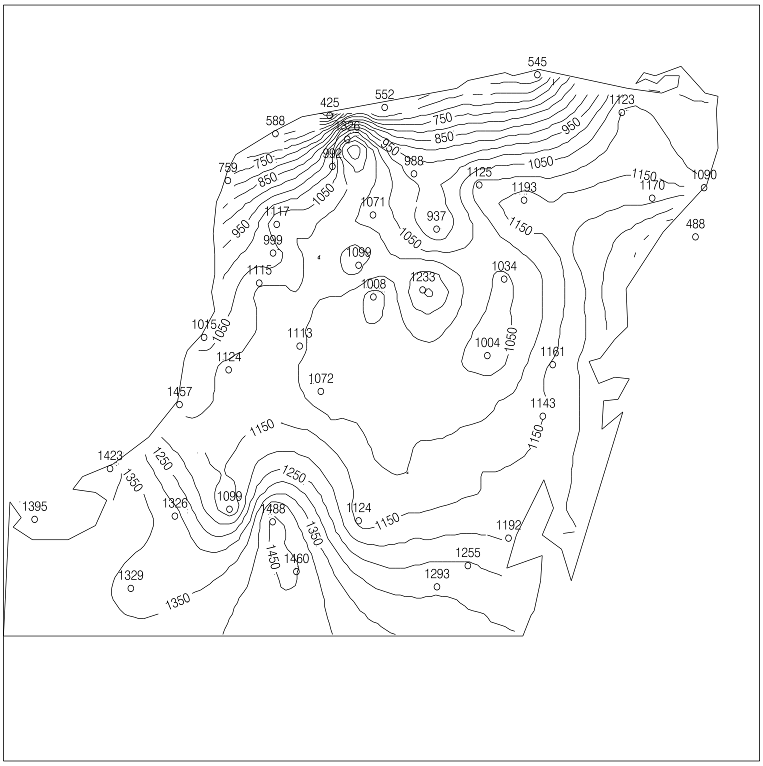

Figure 6.4. Precipitation isobars (in mm).

The evapotranspiration values (*Figure 6.5*) used to calculate the aquifer's water balance were those reported in the evapotranspiration and water deficit map of the Yucatán peninsula published by INEGI (1983).[17] Infiltrated water was calculated as the difference between rainfall and evapotranspiration.

Most of the Yucatán peninsula has no surface streams because of the prevailing low slopes, the shallowness of the soil, the proximity of the water table to the surface, and, above all, the high permeability of the underlying rocks. Consequently, the underground aquifer is the only source of fresh water for human activities. By and large, the aquifer is replenished by rainfall, which infiltrates into the aquifer rapidly.[18] Water inputs to the peninsula's aquifer also include underground water inflows, predominantly in the state of Quintana Roo.[19] The aquifer's main water outflows are transpiration; evaporation; water extracted for agricultural, industrial, and other purposes; and water flows discharged to the sea. The hydrological balance of the underground basin for a given time period is calculated as the difference between water inflows and water outflows.

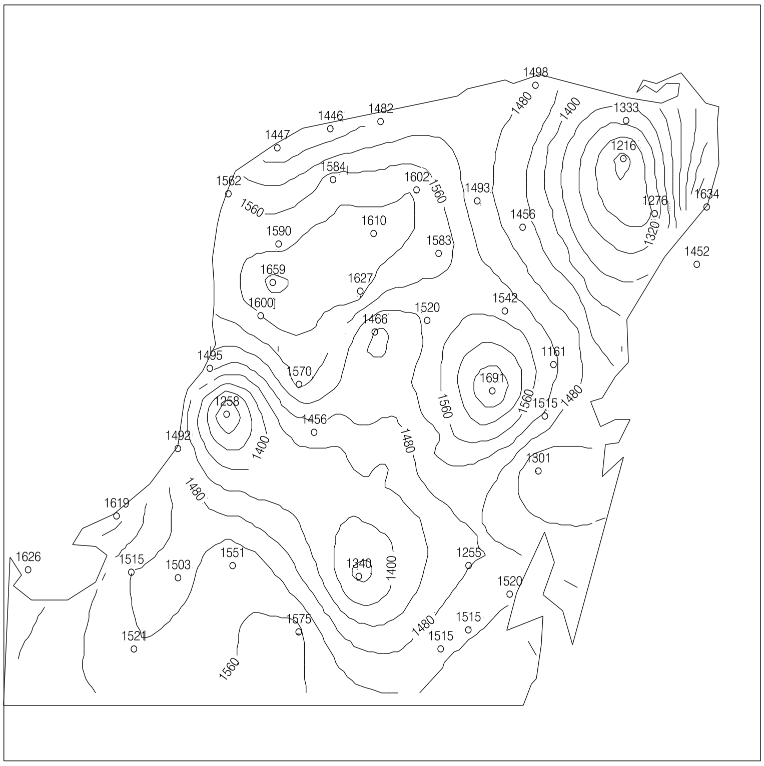

Figure 6.5. Evapotranspiration isobars (in mm).

Table 6.3. Current underground water usage in the three states of the Yucatán peninsula (million m^3/year).

Water use	Campeche	Quintana Roo	Yucatán
Agriculture	228.04	46.98	300.00
Households and urban services	75.97	99.24	235.00
Industrial	9.76	3.66	16.00
Other	0.33	0.40	19.00
Total	314.10	150.28	570.00

Source: Authors’ calculations.

One of the most important water outflows from the aquifer is the water used for the peninsula’s different development activities. *Table 6.3* shows the annual volume of water used in each of the three states.

Water volumes of rainfall, infiltration, and evapotranspiration as well as those of underground water inflows and outflows were used to establish the water balance

Table 6.4. Current hydraulic balance for the states of Campeche, Quintana Roo, and Yucatán, and for the Yucatán peninsula (million m^3/year).

Inflows		Outflows	
Campeche			
Precipitation	74,712.22	Evapotranspiration	63,698.66
		Underground flow to Yucatán	150.00
		Flow to the sea	10,549.56
		Underground water extraction	314.00
Total	74,712.22		74,712.22
Quintana Roo			
Precipitation	62,888.53	Evaportranspiration	48,902.12
Underground flow	2,485.00	Flow to Yucatán	1,350.00
		Rio Hondo's base flow	1,500.00
		Flow to the sea	13,471.13
		Underground water extraction	150.28
Total	65,373.53		63 373.53
Yucatán			
Precipitation	44,877.00	Evapotranspiration	35,902.00
Underground flow	1,500.00	Flow to the sea	9,905.00
		Underground water extraction	570.00
Total	46,377.00		46,377.00
Yucatán peninsula			
Precipitation	182,477.75	Evaportranspiration	148,502.78
Underground flow	2,485.00	Rio Hondo's base flow	1,500.00
		Flow to the sea	33,925.69
		Underground water extraction	1,034.28
Total	184,962.75		184,962.75

Source: Author's calculations.

of the aquifer in natural conditions (*Table 6.4*). The volume of water extracted was then subtracted to determine water availability.

The annual replenishment volume can be found by adding the figures for flow to the sea and underground water extraction, both in the outflows column of *Table 6.4*. For the state of Campeche, this volume is about 10,863 million m^3, the volume of water extracted is approximately 314 million m^3. Therefore, the yearly availability of water in the state's aquifer is approximately 10,549 million m^3. Only 2.89% of the aquifer's water for the state of Campeche is being used.[20]

The annual water replenishment volume in the state of Quintana Roo is approximately 13,621 million m^3; the volume of water extracted annually is about 150 million m^3. Therefore, the water available in the aquifer amounts to roughly 13,471 million m^3/yr. Approximately 1.1% of the aquifer's water for the state of Quintana Roo is currently being used.

The annual water replenishment volume in the state of Yucatán is roughly 10,475 million m^3. The volume of water extracted amounts to about 570 million m^3. Therefore, the water available in the aquifer in the state of Yucatán is approximately 9,905 million m^3/yr. Approximately 5.4% of the aquifer's water is being used.

The annual water replenishment volume for the Yucatán peninsula is roughly 34,960 million m^3. The volume of extracted water is about 1,034 million m^3/yr. Therefore, the water availability in the peninsula's aquifer is approximately 33,925 million m^3/yr. In general, about only 3% of the aquifer's water is being used (*Table 6.4*). Exploitation of the aquifer is highest in the state of Yucatán and lowest in the state of Quintana Roo.

The water availability data referred to above suggests that more detailed studies of the Yucatán peninsula's aquifer are needed, encompassing more information about the dynamics of current and likely future water usage and its relation to both environmental and water quality characteristics.

Notes

[1] Using the origin of the constituent geological materials as a basis for their categorization, Mexico's aquifers include, among others, a group constituted by unconsolidated and sedimentary rocks as well as a group composed of volcanic rocks, in addition to the aquifer of the Yucatán peninsula. The first group may occur in the Pacific Ocean, and in the Gulfs of California, Tehuantepec, and Mexico; the second may be found in the central part of the country and in the states of Sonora, Chihuahua, Baja California, Baja California Sur, and Tamaulipas (CNA, 1994).

[2] Translator's note: As we are dealing with an aquifer, information concerning the peninsula's geological characteristics is crucial.

[3] Although some hydraulic heads and underground flows have been assessed for different geological materials of the Yucatán peninsula, calculation of a more accurate balance of the underground aquifer has been hampered by the lack of hydrometric and piezometric information.

[4] Translator's note: The Chichén Itzá Formation is a group of mainly limestone rocks from the Eocene that were deposited in a single, permanent marine basin without great variation in sedimentary conditions. Lithological and microfaunal content differentiate the three members (Weidie, 1974).

[5] Translator's note: "The lower beds of the formation are represented by coquinas, which have a total thickness of less than 1 meter, overlain by yellowish, hard, massive limestones with mollusks, madrepores, and Peneroplidae. Above these are yellowish to reddish yellow and locally white, more or less hard, nodular, impure, arenaceous limestones, which may alternate with yellowish marls, sands, and sandstones. The upper levels … are represented by yellowish to white, hard limestone with arenaceous interbeds" (Weidie, 1974:6).

[6] Translator's note: "These limestones consist of cream-colored coquinas with a porous cryptocrystalline calcareous matrix, which are strongly weathered locally. They contain large quantities of mollusk shells" (Weidie, 1974:6).

[7] The limestones' aquifer-related characteristics originate from the rocks' secondary porosity; generally, the limestones' primary porosity is at a low or medium level.

[8] Translator's note: Hardening of surface limestone is widespread on the Yucatán peninsula during the dry season, when upward-moving pore water saturated with calcium carbonate ($CaCO_3$) re-precipitates calcite in the near surface zone (Isphording, 1974).

[9] Translator's note: "Soft sascab has been used by the Maya for centuries ... as a source of lime to soften corn, for plaster, and as a raw material for cement" (Isphording, 1974:79).

[10] Translator's note: This set of lagoons and wetlands is of paramount importance for the peninsula's biological diversity.

[11] Translator's note: The biodiversity changes triggered by this impact may be related to the appearance of mammals, and therefore of *Homo sapiens*, on Earth.

[12] Different hydraulic conductivity values have been determined for different parts of the Yucatán peninsula's underground aquifer. For instance, Méndez Ramos (1991) used a hydraulic conductivity value of 0.064 m/sec in a mathematical model of the Mérida aquifer. Modeling the aquifer of the northwestern part of the Yucatán peninsula, Marín (1990) used a k-value of 1.0 m/sec for a high- and 0.1 m/sec for a low-permeability layer with the latter underlying the former. Reeve and Perry (1990) determined k-values between 0.0003 and 0.5 m/sec in a site located north of Mérida near Chuburna Puerto. Martínez Guerra (1990) used k-values ranging from 0.001 to 0.01 m/sec in a mathematical model of the island of Cozumel. González Herrera (1984) determined k-values between 0.000001 and 0.005 m/sec in the laboratory using rock samples obtained at depths up to 80 m deep in the city of Mérida. Villasuso *et al*. (1984) and Villasuso (1990) applied a similar method in the field for assessing hydraulic conductivity in wells. Their k-values ranged from 0.00032 to 0.0087 m/sec. Back and Lesser (1981) determined a k-value of 0.01 m/sec.

[13] Three karstic ducts of preferential underground water flows were recently determined using geophysical records; they are located at depths of 8–12 m, 20–22 m, and 28 m. These ducts were associated with previous positions of the water table and with variations in the sea level during the Pleistocene (Buckley *et al*., 1994).

[14] The levels of underground water, measured in the northwestern part of the state of Yucatán, range between 0.45 m above the average sea level near Chuburna and 2.1 m above sea level in Sotuta, in the central part of the state. The variation of the water table between the dry and rainy seasons ranged between 0.05 m and 0.6 m in a two-and-a-half-year study that undertook such measurements (Marín, 1990).

[15] These values were obtained from chloride variation curves (Villasuso *et al*., 1984).

[16] Translator's note: Waste disposal represents both a hydrologic and a health problem, particularly in the northern and northwestern parts of the peninsula, where water extraction needs are highest because of population density and where precipitation is lowest. In some cases, this situation is further aggravated by the proximity to the sea. Water-borne diseases are common. Likewise, the conjunction of population density and the development of tourism activities increases the likelihood of future problems regarding the availability of good quality water.

[17] Monthly and annual evaporation data, based on daily measurements in class A evaporimeters, are available from meteorological stations on the Yucatán peninsula. However, the determination of a water balance for the regional aquifer requires evapotranspiration data. Such data generally are not available directly. However, they can be estimated using site-specific data for climatological variables such as solar radiation, relative humidity, wind speed, and temperature. The method used here to estimate evapotranspiration was that developed by Thornwaite in 1948.

[18] Translator's note: It is not uncommon to find mixed areas of shallow soils and areas of bare soil. In any case, it is the permeability of the rocks at the surface or underneath the soil that is central to the rapid infiltration of rainfall.

[19] The underground water inflow from outside the peninsula to the state of Quintana Roo amounts to approximately 2,485 million m^3/yr (Lesser, 1980).

[20] Translator's note: Because the dynamic features of the aquifer have not yet been properly assessed, at this stage it is difficult to determine the practical significance of the "low" percentage usage arrived at in these balances. For instance, 3% utilization of the aquifer, as low as it seems, may pose stability problems for the aquifer given that at some points the layer of fresh water is highly variable, thin, or highly susceptible to pollutants or to increases in extraction volumes and flows, and therefore to intrusion of saline water.

References

Back, W., and Hanshaw, B., 1970, Comparison of Chemical hydrogeology of the carbonate peninsulas of Florida and Yucatán, *Journal of Hydrology*, **10**:330–368.

Back, W., and Lesser, J.M., 1981, Chemical constraints of groundwater management in the Yucatán peninsula, Mexico, *Journal of Hydrology*, **51**:119–130.

Buckley, D.K., MacDonald, D.M.J., Villasuso, M., Graniel, E., Vazquez, J., and Jimenez, M., 1994, Technical Report WD/94/4C, Hydrogeology Series, Geophysical Loggin of a Karstic Limestone Aquifer for Hydrogeological Purposes at Mérida, Yucatán, Mexico; British Geological Survey; Natural Environment Research Council.

Butterlin, J., and Bonet, F., 1960, *Las Formaciones Cenozoicas de la parte Mexicana de la peninsula de Yucatán*, Instituto de Geologia, UNAM, Mexico.

CNA, 1994, Manual para Evaluar Recursos Hidráulicos Subterráneos, Comisión Nacional del Agua, Subdirección General de Administración del Agua, Mexico.

Durazo, J., Gaona, S., Trejo, J., and Villasuso, M., 1980, Observaciones sobre la interfase salina en dos cenotes del centro-norte de Yucatán, XXIII Congreso Nacional de

Investigación, in Física, Sociedad Mexicana de Física, Memorias, Guadalajara, Jal, pp. 24–28.

Gaona, S., Villasuso, M., Pacheco, J., and Cabrera, A. 1985, Hidrogeoquímica de Yucatán 1: Perfiles hidrogeoquímicos profundos en algunos lugares del acuífero del noroeste de la península de Yucatán, Boletín 16 del Instituto de Geofísica, UNAM, Mexico.

González Herrera, R., 1984, Correlación de Muestras de Roca en Pozos de la Ciudad de Mérida, Tesis, Facultad de Ingeniería de la Universidad Autónoma de Yucatán, Mérida, Yucatán, Mexico.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1983, Carta de Evapotranspiración y Déficit de Agua, Instituto Nacional de Estadística, Geografía e Informática, Mexico.

Isphording, W.C., 1974, Weathering of Yucatán limestones: The genesis of Terra Rosas, in A.E. Weidie ed., *Field Seminar On Water and Carbonate Rocks of the Yucatán peninsula, Mexico*, published by New Orleans Geological Society for Field Trip 2, 1974 Meeting, Miami, Geological Society of America, pp. 78–93.

Lesser, I.J.M., 1980, Estudio Hidrogeológico e Hidrogeoquímico de la peninsula de Yucatán, Secretaría de Recursos Hidráulicos, Dirección de Geohidrología y Zonas Aridas, Mexico.

Lesser, I.J.M., and Weidie, A.E., 1988, Region 25, Yucatán peninsula, chapter 28, The Geology of North America, Vol. 0-2 Hydrogeology, The Geological Society of America, pp. 237–241.

Marín, L.E., 1990, Field Investigations and Numerical Simulation of Groundwater Flow in the Karstic Aquifer of Northwestern Yucatán, Mexico, Thesis, Northern Illinois University, De Kalb, IL, USA.

Marín, L.E., and Perry, E.C., 1994, The hydrogeology and contamination potential of northwestern Yucatán, Mexico, *Geofisica Internacional*, **33**:619–623.

Martinez Guerra, R., 1990, Geohidrología de la Isla de Cozumel, Quintana Roo, Simposio Internacional sobre Planeación, Manejo e Investigación de los Recursos Hidraúlicos, Facultad de Ingeniería de la Universidad Autónoma de Yucatán, Mérida, Yucatán, Mexico.

Marshall, R.H., Ward, W.C., and Weidie, A.E., 1974, Stratigraphy and depositional history of subsurface mesozoic strata of the Yucatán peninsula, in A.E. Weidie, ed., *Field Seminar On Water and Carbonate Rocks of the Yucatán peninsula, Mexico*, Published by the New Orleans Geological Society for Field Trip 2, 1974 Meeting, Miami, Geological Society of America, pp. 10–23.

Méndez Ramos, R., 1991, Modelo de Comportamiento del Acuífero de la ciudad de Mérida, Yucatán, Comisión Nacional del Agua, Gerencia Estatal Yucatán, Subgerencia de Administración del Agua, Mérida, Yucatán, Mexico.

Méndez Ramos, R., 1993, Justificación Tecnica para la Propuesta de Reglamentacion del Acuifero de Yucatán, Comision Nacional del Agua, Gerencia Estatal Yucatán, Subgerencia de Administración del Agua, Mérida, Yucatán, Mexico.

Perry, E.C., and Marín, L., 1990, Possible adverse impact of coastal development on the Yucatán aquifer, Mexico, Simposio Internacional sobre Planeación, Manejo e Investigación de los Recursos Hidráulicos, Facultad de Ingeniería, Universidad Autónoma de Yucatán, Mérida, Yucatán, Mexico.

Perry, E.C., Swift, J., Gamboa, J., Reeve, A., Samborn, R., Marín, L., and Villasuso, M., 1989, Geologic and environmental aspects of surface cementation, north coast of Yucatán, Mexico, *Geology*, **17**:818–821.

Perry, E.C., Marín, L., Mc Clain, J., and Velazquéz, G., 1992, Ring of cenotes (sinkholes), northwest Yucatán, Mexico: Its hydrogeologic characteristics and possible association with the Chicxulub impact crater, *Geology*, **23**:17–20.

Pope, K.O., Ocampo, A.C., and Duller, C.E., 1991, Mexican Site for K/T impact crater? *Nature*, **351**:105.

Reeve, A., and Perry, E.C., 1990, Aspects and Tidal Analysis along the Western North Coast of the Yucatán peninsula, Mexico, AWRA, International Symposium on Tropical Hydrogeology, San Juan, Puerto Rico, pp. 327–337.

SARH, 1981, Estudio geohidrológico de la zona hortícola del Estado de Yucatán, Secretaría de Agricultura y Recursos Hidraulicos, Mexico.

SARH, 1983, Estudio geohidrológico de la zona Dzonot Carretero del Estado de Yucatán, Secretaría de Agricultura y Recursos Hidráulicos, Mexico.

SARH, 1989, Sinopsis Geohidrológica del Estado de Yucatán, Secretaría de Agricultura y Recursos Hidráulicos, Subsecretaría de Infraestructura Hidráulica, Dirección General de Administración y Control de Sistemas Hidrológicos, Mexico.

Velázquez Aguirre, L., 1986, Aplicación de Principios Geoquímicos en la Hidrología Karstica de la peninsula de Yucatán, Ingeniería Hidráulica en Mexico, pp. 21–29.

Villasuso, M., 1990, Informe Técnico sobre la Capacidad de Infiltración en dos Barrenos ubicados en la Ciudad Industrial de la ciudad de Mérida, Yucatán, Facultad de Ingeniería de la Universidad Autónoma de Yucatán, Mérida, Yucatán, Mexico.

Villasuso, M., González, R., Sánchez, I., and Frías, J., 1984, Alteración de la Interfase Salina por Pruebas de Inyección en Yucatán, Memoria del IV Congreso Nacional de Ingeniería Sanitaria y Ambiental, La Ingeniería Ambiental en el Futuro de Mexico, pp. 79–84.

Weidie, A.E., 1974, Note on the regional geology of Yucatán peninsula, in A.E. Weidie, ed., *Field Seminar On Water and Carbonate Rocks of the Yucatán peninsula, Mexico*, published by New Orleans Geological Society for Field Trip 2, 1974 Meeting, Miami, Geological Society of America, pp. 2–9.

Part II

Modeling the Future of the Yucatán Peninsula

7

Future Population and Education Trends: Scenarios to 2030 by Socioecological Region

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7.1 Introduction

This chapter proposes several possible paths of population and educational attainment for the Yucatán peninsula up to 2030. For this purpose, the population of each socioecological region (SER), as defined in Chapter 2, was projected along three main scenarios reflecting the potential future of the region: a stagnation scenario, a rapid development scenario, and a central scenario.

When defining the projection assumptions, special emphasis was placed on three parameters: education, migration, and rural/urban differences. The first focus derives from the premise that education may play an important role in shaping the region's demographic features. Education is seen as a factor of heterogeneity that can influence many variables of population change, such as fertility decline and the momentum of population growth. For example, the evidence of a negative relationship between education and fertility on the Yucatán peninsula is overwhelming.

The focus on migration reflects the population flows that have occurred in the region over the past 25 years. The population has grown rapidly, largely as a result of migratory flows into the tourist–urban region (Cancún) and northern block-fault basin region (see Chapter 3). The peninsula's economy is largely based on tourism, and this sector has the potential to further increase its share in the region's economy (see Chapter 8).

Another challenge lies in the division between the traditional rural Maya culture and the modern urban Western culture, a division that is the source of many demographic contrasts within the peninsula. Most of the rural parts of the peninsula are depressed areas that experience outward migration and higher rates of natural increase, lower life expectancies, and lower levels of educational attainment with higher rates of illiteracy than the urban parts of the peninsula.

7.2 The Starting Population Data

Data for the population projections are based on the 1990 census (INEGI, 1993) and on the population count carried out in 1995 (INEGI, 1996).[1] An important component of the projection exercise is the systematic inclusion of education as a differentiating factor in the population and in the determinants of demographic growth. The data collected for the 1990 census answer this need, since most figures are presented by level of education.

The population was divided into three educational categories: low, medium, and high education levels. The low education group comprises people with fewer than six years of primary/elementary education and those who have never attended school. People who have entered the last (sixth) year of primary education or who have had preparatory education and people attending technical and commercial schools are included under the medium education category. The high education category consists of people with at least a secondary education.

Children up to the age of nine are included in the low education category. People for whom a level of education was not specified in the census data were distributed equally between the low and the medium education groups.

The population is disaggregated by SER as well as education. These regions, defined for this study of the Yucatán peninsula on the basis of economic and socially integrated areas, are fictitious entities smaller than states but bigger than municipalities (see Chapter 2). Each of the 11 SERs consists of several municipalities, which are the smallest administrative unit for which the necessary information is available from the census. The information on the base-year population is calculated from the 1990 census by aggregating the relevant municipality-level data for each SER. The age and sex structure by SER was updated in 1995 with the population count results (INEGI, 1996).

The starting population is further stratified by five-year age groups and by sex. The oldest age group includes people aged 65 and over.

7.3 Estimation of Fertility, Mortality, and Educational Transition Levels for 1990

The population projection module requires empirical data on fertility, mortality, and migration by age, sex, education, and SER.[2] In addition, transition rates between the three educational groups for the population in school (ages 5 to 24) are necessary. The transition rates (from the low to medium education category and from the medium to the high education category) reflect levels of enrollment in the base year. The sociodemographic statistics for Mexico generated by INEGI (Mexico's National Statistics, Geography, and Informatics Institute) on the basis

Table 7.1. Estimates of total fertility rates by SER.

SER	CONAPO estimates[a] 1985–1990	Calculated from INEGI[b] 1988–1992	Adjusted for base period 1990–1995
Metropolitan region of Mérida	3.08	2.82	2.88
Former henequen-producing region	4.72	4.17	4.31
Cattle-producing region	4.71	4.63	4.32
Maize-producing region	4.95	5.28	4.52
Fruit-producing region	4.51	4.96	4.14
Hills and valleys region	4.52	3.79	4.15
Campeche region	3.17	3.08	2.94
Candelaria region	3.71	5.27	3.47
Tourist–urban region	3.11	3.21	2.91
Northern block-fault basin region	4.14	3.57	3.83
Southern block-fault basin region	3.88	4.84	3.60

[a] Source: CONAPO, 1995.
[b] Source: INEGI, 1994a.

of the 1990 census were the main source of information for estimating fertility, mortality, and transition levels in the base year.

Age-specific fertility rates for 1990 by education and by SER were defined on the basis of birth statistics by municipality for the 1988–1992 period (INEGI, 1994a). These statistics are derived from individual registration of births in Mexico by municipality. They include information on the age of and maximum level of education reached by the mother at the time of the birth, as well as her municipality of residence. To obtain a first estimate of age-specific fertility rates by level of education, the average number of births for the 1988–1992 period was divided by the number of women in each age and education group in 1990. Age-specific fertility rates were adjusted up or down (see *Table 7.1*) to reflect the total fertility rates estimated in 1996 by CONAPO (Consejo Nacional de Población) for the 1985–1990 period for each of the 11 SERs. However, age patterns and fertility differentials by educational group calculated directly from birth-registration data were applied.

A process similar to that described for estimating age-specific fertility rates by level of education and SER was used to estimate age-specific mortality rates. The sociodemographic statistics compiled by INEGI (1994b) include data on individual registration of deaths for the 1985–1993 period by age, sex, educational level, and municipality of residence. The number of deaths were totaled for the 1988–1992 period to reflect the age groups, the educational levels, and the SER defined for the modeling exercise. Corresponding life expectancies were calculated from the resulting age-specific mortality rates. There are substantial problems of possible mis- and underreporting of deaths in the INEGI statistics. Life expectancies were checked against estimates of life expectancies at the state level for 1990 (CONAPO, 1995). It was assumed that the calculation of age-specific mortality rates on the basis of registration data correctly reflects mortality differentials by educational level and SER. However, they may underestimate the respective mortality levels. Therefore, life expectancies and mortality rates were adjusted to equal estimates by CONAPO, while relative educational and sex-specific differences among SERs were maintained.

The rates of transition between levels of education introduce the dynamic of change between educational categories. Transitions in this model occur for the 5–24 age group and represent changes in levels of enrollment. Two types of transition were considered: from low- to medium-level education (for age groups 10–14 and 15–19) and from medium- to high-level education (for age groups 15–19 and 20–24). Transition rates for 1990 were estimated from education levels by age, sex, and SER as compiled from the census data (INEGI, 1993).

7.4 Definition and Justification of Assumptions for all SERs to 2030

Based on the 1990 census data, the population was projected over a 40-year period to 2030. Four population scenarios were defined to illustrate several hypothetical paths of future demographic change on the peninsula (*Table 7.2*). These scenarios bear economic names (e.g., rapid development and stagnation scenarios). It is assumed that they are consistent with certain economic and environmental scenarios. Scenarios were reproduced exactly in all SERs, which facilitates comparison of population results between SERs. The homogeneity of the scenarios does not necessarily mean the results are homogenous, for the 11 entities show heterogeneous demographic patterns in the base year. For instance, the central path for education supposes that enrollment rates are maintained at 1990 levels until 2030, therefore keeping educational differentials between SERs constant; the same is true of all mortality paths.

Only one central migration path was defined and applied to the four scenarios presented in *Table 7.2*.[3] The distribution of the absolute number of migrants by SER during the projection period is based on estimates of the annual migration rates by SER during the 1990–1995 period – the period between the two population censuses of 1990 (XI Censo General de Población y Vivienda) and 1995 (Conteo de Población y Vivienda).[4]

Migration rates during the 1995–2015 period depend on the projected number of tourists as calculated by the tourism model (see Chapter 8). In this model, the peninsula's population is divided into two regions. The first region includes both the tourist–urban and northern block-fault basin SERs. These SERs, located along the coastline, are considered the most likely to be important for the development

Table 7.2. Summary of assumptions for fertility, mortality, education, and migration for all SERs.

	Scenario			
	Rapid development (I)[a]	Stagnation (II)[b]	Central (III)[c]	Stagnation with educational efforts (IV)[d]
Fertility	Total fertility rate for women with education: High: 1.3 Medium: 1.9 Low: 2.5	Constant fertility by level of education at 1990 levels to 2030	Mean of high (I) and low (II) values by level of education to 2030	Constant fertility by level of education at 1990 levels to 2030
Mortality	Gain in life expectancy by educational category and by decade until 2030:			
	3 years	1 year	2 years	1 year
Education	Reach West European levels of enrollment by 2010–2015; constant thereafter	Rates in 2010–2015 are 20% lower than in 1990	Constant at 1990 levels	Reach West European levels of enrollment by 2010–2015; constant thereafter
Migration	See *Table 7.3*			

[a] Rapid development scenario with low fertility and mortality, high level of education, and central migration assumptions.
[b] Stagnation scenario with high fertility and mortality, low level of education, and central migration assumptions.
[c] Central scenario with central fertility, mortality, education, and migration assumptions.
[d] Stagnation scenario with educational efforts, with high fertility and mortality, high level of education, and central migration assumptions.

of tourism in the future. The other nine SERs are included in the second region. Growth of tourism will attract migrants seeking better employment opportunities, higher salaries, or higher standards of living than found in other SERs. Therefore, the number of in-migrants to the tourism region depends on the number of tourists and on population natural growth rates in these SERs. The migration rate for the tourism region fluctuates over time depending on the number of tourists and the available labor force. Simulation results for migration were taken from the base tourism scenario, which considers a steady exogenous growth path for tourism based on the trend seen over the past 20 years. The base scenario results in a population doubling in the tourism region and a 60% increase for the rest of the peninsula. Because the migration rate is very sensitive to changes in the number of tourists, migration flows vary greatly over the 20-year projection period. The

Table 7.3. Projected annual net number of migrants by SER and state, and for the Yucatán peninsula, 1995–2030.

SER	Number of migrants 1995–2000	2000–2005	2005–2010	2010–2030
Metropolitan region of Mérida	+20,070	+39,226	+73,128	+85,950
Former henequen-producing region	−6,684	−13,078	−24,380	−28,644
Cattle-producing region	−4,458	−8,708	−16,250	−19,104
Maize-producing region	−2,232	−4,366	−8,126	−9,548
Fruit-producing region	−1,110	−2,170	−4,066	−4,774
State of Yucatán	+5,586	+10,904	+20,306	23,880
Hills and valleys region	−3,348	−6,542	−12,184	−14,322
Campeche region	+2,232	+4,366	+8,126	+9,548
Candelaria region	+6,684	+13,078	+24,380	+28,644
State of Campeche	+5,568	+10,902	+20,322	23,870
Tourist–urban region	+47,740	+40,244	+20,618	+20,570
Northern block-fault basin region	+47,740	+40,244	+20,618	+20,570
Southern block-fault basin region	+6,684	+13,078	+24,380	+28,644
State of Quintana Roo	+102,164	+93,566	+65,616	+69,784
Yucatán peninsula	+113,318	+115,372	+106,244	+117,534

absolute number of migrants for the rest of the projection period is kept constant at 2010–2015 levels.

The former henequen-producing region, the cattle-, maize-, and fruit-producing regions, and the hills and valleys region continue to be marked by out-migration between 1995 and 2030 (see *Table 7.3*). The metropolitan region of Mérida, and the Campeche, Candelaria, tourist–urban, and northern and southern block-fault basin regions maintain a positive net migration balance throughout the projection period. With 40,000–48,000 in-migrants each per year, the tourist–urban and northern block-fault basin SERs in the state of Quintana Roo are the peninsula's two poles of attraction until 2005. Mérida also receives 20,000 migrants per year in 1995–2000 and 39,000 per year in 2000–2005. From 2005 on, the urban area of Mérida receives an increasing number of migrants: 73,000 per year from 2005–2010 and 86,000 per year from 2010–2030. Mérida will grow rapidly as the development of tourism on the peninsula increases employment opportunities in all economic sectors related to tourism in the peninsula's main city. The remaining absolute number of migrants is distributed equally between the Candelaria, tourist–urban, and northern and southern block-fault basin SERs, with 21,000–28,000 net-migrants each per year from 2005–2030. The increasing number of in-migrants in these four SERs originates partly within the peninsula itself, from the rural SERs: the former henequen-producing region, the cattle-, maize-, and fruit-producing regions, and the hills and valleys region. The population loss due to migration in those SERs increases from 18,000 per year from 1995–2000 to 76,000 from 2010–2030. In total, the absolute number of net-migrants is stable on the peninsula during the projection period, fluctuating between +106,000 and +118,000 per year.

The migration age pattern for each of the SERs exactly follows the age pattern for migration in Quintana Roo (estimated by CONAPO). As that state was already receiving the majority of migrants in the base period, its migration age structure was taken as the pattern for future migrants. In the absence of indications of gender differences, the same age pattern is assumed for males and females, and the total number of migrants is distributed equally between male and female migrants. All migrants in the 0–4, 5–9, and 65+ age groups have low levels of education. Migrants in the 10–14 age group are equally distributed between the low and medium educational groups. In the other age groups, the total number of migrants is divided equally between the three educational groups.

7.4.1 The rapid development scenario

This scenario envisages a situation favorable to economic development and corresponds to a case of rapid demographic transition. Couples opt for smaller families, which is consistent with higher incomes. As a result of a higher quality of life and improvements in the delivery and quality of health services, mortality declines rapidly, leading to rapid gains in life expectancy. Education is made a priority and enrollment rates increase for both sexes. The rapid development scenario does not imply tremendous changes for the urban areas of Mérida and Campeche and the tourist–urban region, which already have the demographic characteristics of developing countries. However, some rural regions (e.g., the maize- and cattle-producing and the northern and southern block-fault basin regions) still have many characteristics of underdevelopment and show only weak signs of demographic transition. For these areas, the trends implied by this scenario might be difficult to achieve.

For all SERs, fertility reaches the same low levels in each educational category. By the end of the projection period, fertility reaches 1.3 for women with a high level of education, 1.9 for women with a medium level of education, and 2.5 for women with a low level of education. The resulting overall fertility level by SER is low, between 1.5 and 1.7 from 2025–2030 – down from levels between 2.9 and 4.5 from 1990–1995. Men and women gain three years of life expectancy per decade. This assumption leads to high life expectancy for all educational categories and for both men and women. Most women with a low level of education achieve life expectancies above 85 years of age in 2035–2030 – with the exception of those in the fruit-producing and Candelaria regions, where life expectancies at birth for women with a low level of education are lower. In the cattle-producing, tourist–urban, and northern and southern block-fault basin regions, the life span of women with a high level education is above 90 years. Consistent with low fertility and low mortality assumptions, school enrollment reaches very high levels, comparable with West European rates, by 2010–2015 (mid-projection period). Of the school-aged children, more than 60% achieve at least a medium level of education and almost 50% leave school with a high level of education.

7.4.2 The stagnation scenario

The rapid development scenario represents the best-case scenario; the stagnation scenario models the opposite. The improvements in terms of fertility reduction are stopped (see *Table 7.1* for fertility levels in the base period 1990–1995), and those for mortality are slowed considerably. Rates of enrollment regress to past levels. This scenario envisages an almost complete stop in development on the peninsula. The poorest SERs (the former henequen-producing region, the cattle-, maize-, and fruit-producing regions, and the hills and valleys region) suffer the most in this scenario, and the richest continue to benefit from the demographic gains realized in the recent past: long life expectancies, low birth rates.

Fertility remains constant at 1990 levels by level of education. Therefore, education differentials are also maintained at the same level. Women with a low level of education have total fertility rates (TFRs) of around 4.0–5.0 (3.3 in the tourist–urban SER). TFRs are between 3.2 and 4.6 for women with a medium level of education and between 1.3 and 2.2 for women with a high level of education. Gains in terms of life expectancy are meager: four years during the 40 years of the projection period. By 2030, life expectancies will reach between 66 years (Candelaria) and 75 years for men and 74 years and 82 years (hills and valleys region) for women. Levels of enrollment deteriorate between 1990 and 2015, with a decrease of 20% in enrollment rates at all levels of education. The gender gap is kept constant. In the former henequen-producing region, the cattle-, maize-, and fruit-producing regions, and the hills and valleys region, only 30% (or less) of the school-aged population achieve at least a medium level of education. By 2010–2015, at most 10% of the school-aged population enter high educational levels, with the exception of the metropolitan region of Mérida, the Campeche and Candelaria regions, and the southern block-fault basin region, where the figure is slightly higher (between 11% and 19%).

7.4.3 The central scenario

Based on our knowledge of present conditions, the central scenario is, in our judgment, the most likely path for future demographic development. Improvements are realized in many areas; fertility declines, but at a slower pace than in the rapid development scenario. The fertility target for each educational category in 2025–2030 is calculated as the arithmetic mean of the high and low values described in

Sections 7.4.1 and 7.4.2. Overall fertility reaches levels between 2.3 and 3.3 in 2030: 1.3–1.8 for women with a high level of education, 2.5–3.3 for those with a medium level of education, and 2.9–3.8 for women with a low level of education. Mortality rates decline, leading to a rise in life expectancies of two years per decade during the projection period and within each educational category (compared with a life expectancy of one year under the stagnation scenario and three years under the rapid development scenario). By 2025–2030, men achieve life expectancies of 70–79 years and women, 78–86 years. Enrollment rates remain constant at 1990 levels. Between 30% and 49% of the children reach at least a medium level of education; between 7% and 18% continue further, reaching a high level of education, except for the two urban SERs of Campeche and Mérida, where this rate is 28–30% for both sexes. The gender gap is very small in most SERs and, interestingly, the small bias is in favor of girls in most SERs, especially for children enrolled in medium-level schools.

7.4.4 The stagnation scenario with educational efforts

This scenario replicates the fertility, mortality, and migration assumptions of the stagnation scenario (constant fertility at 1990 levels, low mortality improvements with a one-year gain of life expectancy per decade). However, in contrast to these assumptions of demographic stagnation, enrollment rates are assumed to reach high levels (comparable with West European levels), as under the rapid development scenario. What would be the impact of educational improvements in the case of demographic stagnation? A comparison between the two scenarios should allow us to show education's special role in affecting population change, especially fertility levels and the rate of population growth.

Following the scenarios described in *Table 7.2*, population projections were carried out using the multistate population module from the PDE (Population–Development–Environment) software. This module and previous versions of it have been used by the Population Project of the International Institute for Applied Systems Analysis, notably for the PDE Studies of Mauritius (Lutz, 1994) and Cape Verde (Wils, 1996). It has also been used for the study of future population and education trends in North Africa (Yousif *et al.*, 1996) and in the western Mediterranean region (Goujon, 1997).

7.5 Summary of Projection Results by SER

Age pyramids of selected states for 1990 and 2030 according to the different scenarios can be found in Appendix 7A. Summary tables of projection results for each SER can be found in Appendix 7B.

Table 7.4. Rate of average annual population growth by SER, by state, and for the Yucatán peninsula, 1990–2030, according to four scenarios (in %).

SER	Scenario: Rapid develop-ment (I)	Stagna-tion (II)	Central (III)	Stagnation with educa-tional efforts (IV)
Metropolitan region of Mérida	2.6	3.1	2.8	2.9
Former henequen-producing region	0.5	1.6	1.1	1.1
Cattle-producing region	–0.2	1.0	0.4	0.5
Maize-producing region	1.7	2.7	2.4	2.2
Fruit-producing region	1.5	2.5	2.1	2.0
State of Yucatán	1.9	2.6	2.3	2.3
Hills and valleys region	1.5	2.5	2.1	2.1
Campeche region	2.3	2.8	2.5	2.6
Candelaria region	3.4	4.0	3.7	3.7
State of Campeche	2.4	3.1	2.8	2.8
Tourist–urban region	4.1	4.5	4.3	4.4
Northern block-fault basin region	4.9	5.6	5.3	5.4
Southern block-fault basin region	2.9	3.5	3.2	3.2
State of Quintana Roo	3.7	4.3	4.0	4.0
Yucatán peninsula	2.5	3.1	2.9	2.9

7.6 Population Size

In all four scenarios, the population continues to increase far into the next century in all three states (see *Table 7.4* and Appendix 7B). Migration is the most important determinant of the level of population growth on the peninsula. Based on present migration trends, the migration assumptions set several “poles of attraction” on the peninsula. These are the metropolitan region of Mérida in the state of Yucatán – with up to 86,000 net-migrants per year during the 2010–2030 period – the city of Campeche, and the rural area of Candelaria in the State of Campeche. Most important, the state of Quintana Roo attracts between 70,000 and 100,000 migrants per year during the projection period, notably in the tourist–urban and northern block-fault basin regions. This assumption of strong and continuous population movements to certain SERs considerably affects the rate of population growth for the whole peninsula. In 1990, Quintana Roo had the smallest population of the three states of the Yucatán peninsula – almost three times smaller than the population of the state of Yucatán. Under the central scenario, in 2030 the state of Yucatán has a population only 1.5 times larger than that of Quintana Roo, which in turn is 1.5 times larger than that of Campeche.

All scenarios, whether they consider low or high assumptions for fertility, mortality, and migration, result in a four- to fivefold increase of the population of Quintana Roo. The 1990 census counted 493,000 people in Quintana Roo; the projection results show a population of 2.3 million in 2030 under the central scenario, 2.1 million under the rapid development scenario, and 2.6 million under the stagnation scenario. To a lesser extent, the same is true of Yucatán and Campeche. In these two states, the population will increase two- to threefold in the 1990–2030 period, with little variation between scenarios. The population in Campeche increases from 535,000 people in 1990 to 1.6 million in 2030 under the central scenario, 1.4 million under the rapid development scenario, and 1.8 million under the stagnation scenario. In Yucatán, the population increases from 1.4 million in 1990 to 3.4, 2.9, and 3.8 million, respectively, under the three main scenarios.

A closer looks at each SER and each scenario gives a more contrasted picture of the peninsula (*Table 7.4*). Very high population growth is limited to a few SERs. The rapid development scenario, which gives the lowest population result combines assumptions of low fertility, low mortality, high level of education, and central migration. Under this scenario, most SERs experience a doubling of their population by 2030. Only the populations of the former henequen-producing region and the cattle-producing region do not double during the projection period. The cattle-producing SER experiences negative growth during the 1990–2030 period (–0.2%). The population of the former henequen-producing SER declines after 2015. These two rural regions are the most affected by the out-migration of their labor force. Population growth under the central scenario is quite high, mostly as a result of the combination of migration flows and population momentum. Most rural SERs in the state of Yucatán maintain high fertility levels during the projection period (fertility rate above 3.0 in 2030). The average annual growth rate of SERs in Yucatán and Campeche is between 0.4% (cattle-producing region) and 3.7% (Candelaria region) for the 1990–2030 period. This figure is 4.3% for the tourist–urban region and 5.3% for the northern block-fault basin region. The population of the latter increases from 71,000 in 1990 to 562,000 in 2030.

The stagnation scenario results in very high population growth. The combination of high fertility rates and low enrollment rates rapidly pushes the population upward. The impact of high fertility is stronger in the Yucatán area. There is a 0.5–1.2% difference between the annual growth rate in 1990–2030 under the rapid development scenario and that resulting under the stagnation scenario. In Quintana Roo, and to a lesser extent in Campeche, the difference is not so marked. The influence of high-level education assumptions on the stagnation scenario is obvious in all SERs. It lowers the rate of population growth under the stagnation scenario to central-scenario levels, or even lower in the case of the former henequen-producing region, the maize- and fruit-producing regions, and the Candelaria and southern block-fault basin regions.

7.7 Population Aging

It seems that rapid aging of the population will not occur on the Yucatán peninsula in the next 40 years. The rapid development scenario is the most likely to lead to rapid aging. Under this scenario, which foresees a rapid transition to higher life expectancies and lower birth rates, the proportion of the population aged 60 and above in 2030 is between 10% and 15% – with the exception of the former henequen-producing and the cattle-producing regions, where respectively 18% and 24% of the total population are in the 60+ age group. In these two particular zones, the relative weight of the older age group in the population is increased because of the out-migration of the economically active population. The stagnation scenario models a path where fertility stagnates at 1990 levels and mortality decreases little and slowly. Consequently, the size of the 60+ age group remains very small – mostly below 10% of the total population – even stagnating at 1990 levels in the maize- and fruit-producing regions. It is interesting to see the impact of an increase in enrollment rates on population aging. Because the increase in enrollment rates leads to lower fertility rates, in turn it increases the proportion of the population in the elderly group. In the stagnation scenario with educational improvements, the proportion of the population aged 60 and above is closer to the proportion under the central scenario than that under the stagnation scenario (with the exception of the metropolitan region of Mérida and the Campeche, tourist–urban, and northern block-fault basin regions). The results of the central scenario are the averages of the rapid development and stagnation scenarios, with the proportion of the population aged 60 and above fluctuating between 8% and 17%.

One can foresee potential aging by observing the proportion of the population in the youngest age group. During the 1990 census, with the exception of the two urban areas of the peninsula, 40% or more of the population was below 15 years of age in all SERs. By 2030, this proportion diminishes dramatically – except in the stagnation scenario, where the ratios are more or less maintained at 1990 levels. For instance, the population in the 0–14 age group declines to 27–34% of the population under the central scenario. It is 16–24% under the rapid development scenario – very close to the proportion of the young age group in the total population of more developed regions in the 1990s. The impact of rapid educational improvements on the stagnation scenario is strong: the proportion of the population in the 0–14 age group obtained from this scenario is very close to that obtained from the central scenario. There is a difference of 0–3 percentage points between the proportion of the 0–14 age group in the central scenario and that in the stagnation with educational improvements scenarios, whereas the difference is 3–10 percentage points between the stagnation scenario and the stagnation with educational improvements scenario. This difference reflects the impacts of educational improvements in changing the overall fertility levels.

7.8 Education Level

The education level of the population will certainly increase in the future, primarily as a result of the momentum of growth in educational attainment. Most SERs have experienced large increases in enrollment rates for both sexes in the past few years. Because education has always been privileged on the political agenda, the peninsula already had quite high educational levels at the time of the 1990 census. It is interesting to note that on the peninsula, as for Mexico and for most Latin American countries, there is no gender gap in school enrollment rates or in the level of education of the population. The latter means that the equal access to school for both sexes was achieved some decades ago and is currently reflected in the total population. Thus, when discussing educational levels in this section, we make no further reference to gender differences in education (*Table 7.5*). We do, however, discuss the important differences in education levels between SERs. These differences seem to be related to two factors: the level of urbanization and the level of migration. Both factors are related to the level of development of the SER.

Statistics from 1990 show that education levels were similar in all three states: 60–64% of the total population had a low level of education, 24–27% had a medium level of education, and 12–13% had a high level of education. A comparison of education levels between SERs shows that this homogeneity does not exist when states are decomposed into smaller entities. In Yucatán, in particular, only the urban area of Mérida shows high levels of education, with 50%, 30%, and 20% of the population having a low, medium, and high level of education, respectively. In the rest of Yucatán, the proportion of the population with a low level of education is above 75% and the proportion with a high level of education is below 7% (and is as low as 4% in the maize-producing region). The differences between urban and rural SERs are less obvious in Campeche, but are still present. On average, the population of the hills and valleys region, and to a lesser extent that of the Candelaria region, has had less schooling than the population living in Campeche – in these SERs, 7%, 11%, and 19% of the population have a high level of education, respectively. The situation is very similar in Quintana Roo, where people with higher levels of education are concentrated in the tourist–urban region. Across states, it appears that the proportion of the population with a medium or high level

Table 7.5. Population by level of education in 11 SERs by scenario, both sexes, 1990 and 2030 (in %).

SER	Level of education	Base year 1990	Scenario in 2030: Rapid develop-ment (I)	Stagna-tion (II)	Central (III)	Stagnation with educa-tional efforts (IV)
Metropolitan region of Mérida	High	20	41	24	31	38
	Medium	30	28	30	31	27
	Low	50	31	47	38	35
Former henequen-producing region	High	5	39	4	6	36
	Medium	20	27	31	38	26
	Low	75	35	65	56	38
Cattle-producing region	High	5	37	1	1	35
	Medium	17	21	27	34	22
	Low	78	42	72	64	43
Maize-producing region	High	4	36	4	6	34
	Medium	18	27	26	31	26
	Low	79	37	70	63	40
Fruit-producing region	High	7	39	8	12	36
	Medium	19	27	27	32	26
	Low	75	34	64	56	38
State of Yucatán	High	12	40	16	21	37
	Medium	24	27	29	32	26
	Low	64	33	56	47	37
Hills and valleys region	High	7	39	8	12	35
	Medium	21	27	28	33	26
	Low	73	34	64	55	39
Campeche region	High	19	42	23	30	39
	Medium	30	28	30	32	27
	Low	52	30	47	38	34
Candelaria region	High	11	37	15	20	34
	Medium	27	28	29	32	27
	Low	61	35	55	48	39
State of Campeche	High	12	39	15	20	36
	Medium	25	28	29	33	27
	Low	63	33	56	47	37
Tourist–urban region	High	18	39	18	23	37
	Medium	31	30	33	36	28
	Low	51	31	48	41	35
Northern block-fault basin region	High	10	37	14	18	33
	Medium	28	28	30	34	27
	Low	62	35	56	48	40
Southern block-fault basin region	High	10	36	14	19	35
	Medium	24	28	29	33	27
	Low	65	35	56	48	38
State of Quintana Roo	High	13	38	16	20	36
	Medium	27	29	31	34	27
	Low	60	33	53	45	37
Yucatán peninsula	High	12	39	16	21	36
	Medium	25	28	30	33	27
	Low	63	33	55	47	37

of education is much lower in the rural SERs of Yucatán state than in all other SERs, even the rural SERs of Campeche and Quintana Roo.

Under the stagnation scenario, the differences in the levels of education are maintained, since all enrollment rates are decreased by 20% over the 1990–2015 period. Interestingly, between 1990 and 2030 the proportion of the population with a low level of education continues to decrease while the proportion with a medium or high level of education increases. The population above age 20 remains unaffected by the decline in enrollment rates until the end of the projection period. Therefore, past improvements in enrollment rates for the 20+ age group are translated into higher education levels. Past educational efforts have mostly benefited the medium education level in rural areas and the high education level in urban areas and SERs experiencing in-migration.

This momentum effect can also be seen when looking at the rapid development scenario. This scenario implements an increase in enrollment rates to West European levels over the 1990–2015 period. However, it will take until 2070 for the improvements to reach the 60–65 age group. This momentum of educational improvements must be kept in mind when thinking about the peninsula's development, especially with regard to the equal development of all areas.[5]

The central scenario shows what the level of education would be in the case of moderately decreasing fertility and mortality and stagnating enrollment rates at 1990 levels. The educational momentum induces the level of education to continue to increase in the population. In 2030, only 5 of 11 SERs have populations with 50% or more having only a low level of education (less than 6 years of primary education) compared with all 11 SERs in 1990. In the urban areas of Mérida and Campeche, only 38% of the population are in the low education group. The rural areas of the Yucatán peninsula maintain the lowest level of education. However, the increase in the proportion of the population with a medium level of education is noticeable on the peninsula, with a gain on average of 8 percentage points between 1990 and 2030. Amazingly, the proportion of the population with a medium level of education is quite homogeneous across the country: one-third of the population has received a medium level of education. At the high level of education, heterogeneity again prevails, with between 1–6% (the former henequen-producing region and the cattle- and maize-producing regions) and 31% (the metropolitan region of Mérida) of the population receiving a high level of education.

As expected, under the stagnation scenario with educational efforts the level of education in the population in 2030 is very close to that attained under the rapid development scenario. In general, more people have a low level of education in the latter than in the former. This is due to the different fertility assumptions in the two scenarios.

7.9 Conclusion: Alternative Scenarios for the peninsula

The analysis in the preceding section was structured based on the 11 SERs, defined to better assess differences within the peninsula in terms of social, economic, and environmental characteristics. This concept has proved useful in population projections, since it allows the application of more realistic assumptions regarding fertility, mortality, migration, and education for each of the 11 SERs.

The population of the Yucatán peninsula will continue to grow during the 40-year projection period. Starting with a population of 2.4 million in the base year, 1990, the population for the year 2030 obtained in the four scenarios ranges between 6.4 million in the rapid development scenario and 8.2 million in the stagnation scenario. Thus, over the course of the projection period, the population of the Yucatán peninsula grows at an annual rate of 2.5% in the rapid development scenario and at 3.1% per year in the stagnation scenario. The central scenario and the stagnation scenario with educational efforts both yield a peninsula population of 7.3 million people at an average annual growth rate of 2.9%.

The demographic future of the peninsula will be closely linked to the region's economic and tourism development and to the implications in terms of migration. According to the scenarios envisaged here, the rate of natural increase would vary at the end of the projection period from 1.3% in the rapid development scenario to 2.6% in the stagnation scenario. The central scenario leads to a 2.0% rate of natural increase compared with 2.3% in the base-year period (see *Table 7.6*). These rates of population increase are offset by the migration trends implemented in the scenarios, as shown in *Table 7.7*. The crude migration rate in 1990–1995 was 1.6 per 100 people. At the end of the projection period, it is between 1.7 under the stagnation scenario and 2.0 under the rapid development scenario (1.8 under the central scenario). This means, for instance, that in the rapid development scenario, the growth rate (3.3%) in 2025–2030 will be twice the natural increase rate (1.3%). This comparison is not only valid at the end of the projection period. Through most of the 1995–2030 period, the crude birth rate is lower than the crude migration rate under the central and rapid development scenarios, and only to 2005 under the stagnation scenario.

The age pyramid of the Yucatán peninsula in the base year, 1990, shows a relatively small population aged 60 years and over (6.5% of total population) compared with the population in the 0–14 age group (38.9%). The median age of the population on the Yucatán peninsula is 19.8, which indicates a young population structure. Although there is an increase in the proportion of people aged 60 years and over in the next decades and in all four scenarios, aging is not yet on the peninsula's agenda in 2030. The most significant change in the age structure is observed in the rapid development scenario, where 13.2% of the population is elderly in 2030. In the other scenarios, the percentage of people aged 60 years and over ranges between

Table 7.6. Rate of natural increase at state and peninsula levels, 1990–1995 and 2025–2030 (in %).

Region	Base year 1990–1995[a]	Scenario in 2025–2030 Rapid develop-ment (I)	Stagna-tion (II)	Central (III)	Stagnation with educa-tional efforts (IV)
Yucatán	2.22	1.23	2.63	1.98	1.77
Campeche	2.45	1.24	2.63	1.97	1.84
Quintana Roo	2.51	1.35	2.55	1.99	1.94
Peninsula	2.32	1.27	2.61	1.98	1.84

[a] Source: García de Fuentes *et al*., 1996.

Table 7.7. Crude migration rate at state and peninsula levels, 1990–1995 and 2025–2030 (per 100 persons).

Region	Base year 1990–1995[a]	Scenario in 2025–2030 Rapid develop-ment (I)	Stagna-tion (II)	Central (III)	Stagnation with educa-tional efforts (IV)
Yucatán	0.46	0.87	0.71	0.78	0.78
Campeche	1.26	1.90	1.56	1.70	1.69
Quintana Roo	4.85	3.68	3.15	3.38	3.35
Peninsula	1.62	1.99	1.65	1.80	1.79

[a] Source: García de Fuentes *et al*., 1996.

8.7% and 10.7% in 2030 (up from 6.5% in the base year, 1990). This slow process of population aging in settings of low mortality and rapidly declining fertility is due to the heavy in-migration of labor force (especially those aged 20–35) to the peninsula. The proportion of the 15–59 age group in the total population remains over 55% throughout the projection period and even reaches levels above 60% under the rapid development and central scenarios.

In the rapid development scenario, the proportion of children 0–14 years old declines most significantly, reaching the lowest projected level of 22.2%. In the other scenarios, the percentage of population aged 0–14 varies between 29.7% in the central scenario and 35.5% in the stagnation scenario, compared with 38.9% in the base year.

The population projections illustrate possible future educational developments on the Yucatán peninsula in the next four decades. In the base year, 63% of the total population received a low level of education, 25% a medium level of education, and 12% a high level of education. All four scenarios show a substantial decline in the percentage of the population with a low level of education for both men and women. Even under the stagnation scenario, which envisages a situation where levels of enrollment decline 20% from 1990–2015, there is actually an increase in the level of education of the whole population, with 46% of the people having medium and high levels of education in 2030 compared with 37% in 1990. The highest educational improvement on the Yucatán peninsula is observed in the rapid development scenario, which combines educational advancement with low fertility and mortality rates. In this scenario, the percentage of the total population with a high level of education increases by a factor of 3, reaching 39% in 2030. Only in this scenario is the percentage of the population with a high level of education larger than the percentage of population with a low level and that with a medium level of education.

The second most substantial decline in the percentage of population with a low level of education is observed in the stagnation scenario with educational efforts. The number of people with a high level of education in the projected period reaches 36% of the total population. If fertility rates conditional on education remain constant at 1990 levels but levels of enrollment reach European levels, then the total fertility rate will decline substantially, from 3.5 to 2.5, entirely on the basis of education (using constant fertility differentials by education). In this case, the new cohorts of women, benefiting from the increase in the enrollment rate, will enter their fertile years with higher levels of education and will adopt patterns of lower fertility reducing the overall fertility rates. The stagnation scenario and the stagnation with educational efforts scenario differ only with respect to school enrollment rates. The age-specific fertility rates conditional on the educational attainment of mothers are not altered. Nonetheless, the former results in a population of 8.2 million in 2030, whereas in the latter scenario the population is 7.3 million.

Notes

[1] The 1990 census was the most recent one available when this study began in 1995. Mexico completed another census in 1995 and data became available in 1996–1997.

[2] In the model, migration is considered as a projection assumption. See Section 7.4 for details.

[3] The fact that migration is independent of the scenarios is a drawback of this model. It was not the authors' original intention to have one migration path, but rather to have one migration path calibrated to each scenario. However, the premature end of the project prevented further integration of the tourism and population models.

[4] Estimates of the annual migration rates by SER during the 1990–1995 period are from García de Fuentes *et al*. (1996).

[5] It should be kept in mind that fertility and mortality trends also have an effect on scenario results. In the stagnation scenario, fertility and mortality stagnate; in the development scenario, fertility and mortality decline. The trends assumed for fertility and mortality counteract the momentum effect and therefore mitigate its impact on education level.

Appendix 7A:
Age Pyramids for Selected SERs, All Scenarios

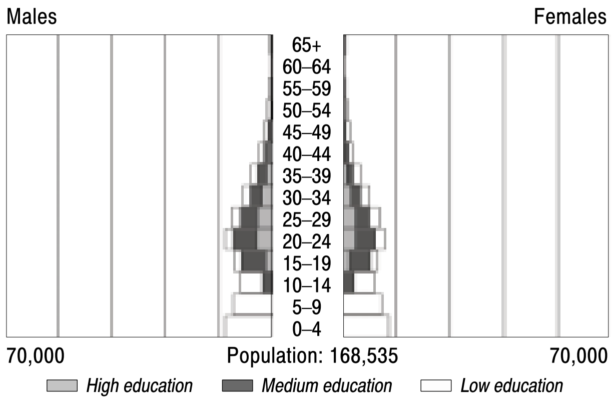

Figure 7A.1. Population of tourist–urban SER, 1990.

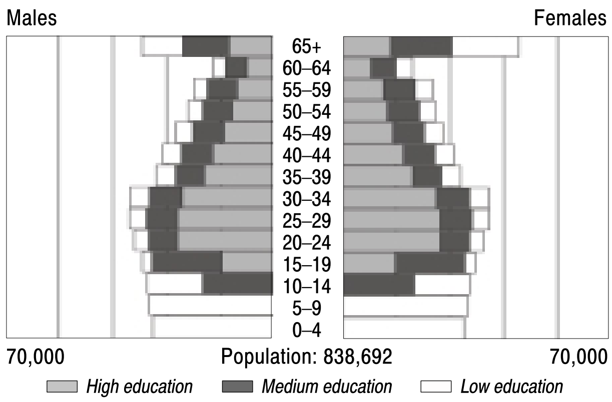

Figure 7A.2. Population projection of tourist–urban SER, rapid development scenario (low fertility, low mortality, and high level of education), 2030.

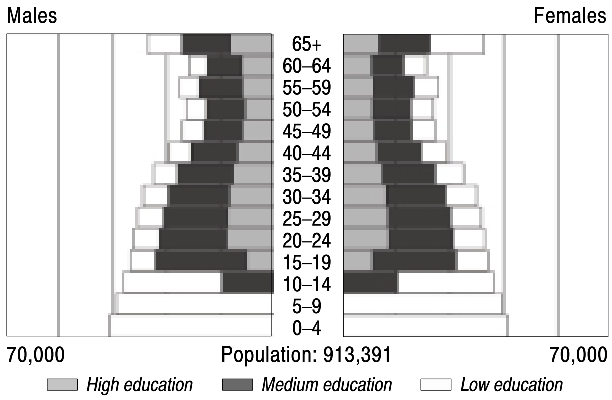

Figure 7A.3. Population projection of tourist–urban SER, central scenario (central fertility, central mortality, and medium level of education), 2030.

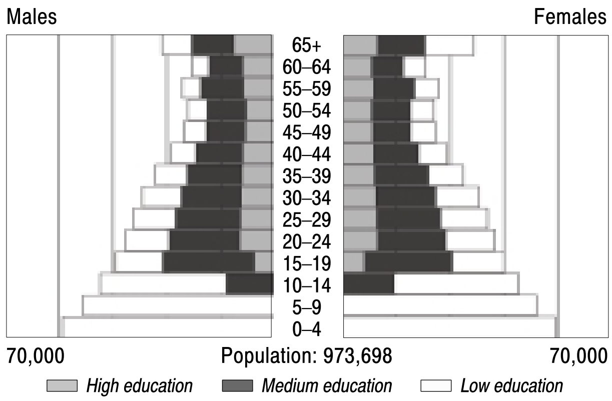

Figure 7A.4. Population projection of tourist–urban SER, stagnation scenario (high fertility, high mortality, and low level of education), 2030.

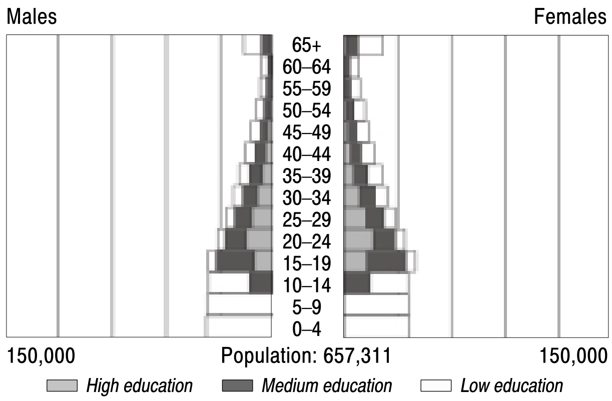

Figure 7A.5. Population of metropolitan region of Mérida, 1990.

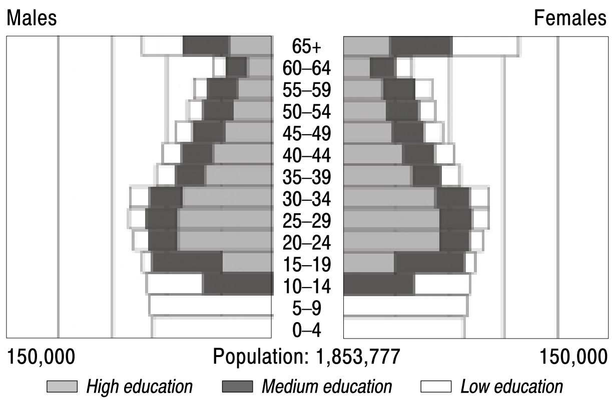

Figure 7A.6. Population projection of metropolitan region of Mérida, rapid development scenario (low fertility, low mortality, and high level of education), 2030.

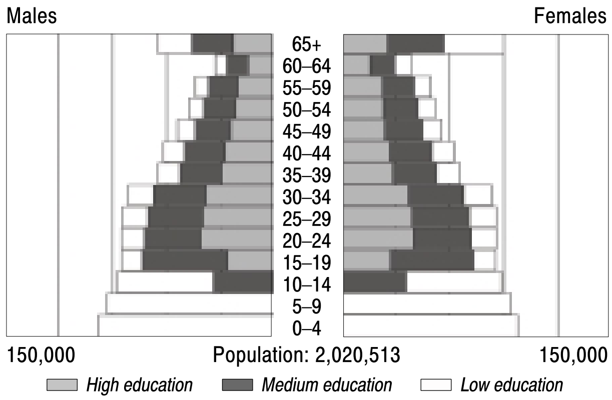

Figure 7A.7. Population projection of metropolitan region of Mérida, central scenario (central fertility, central mortality, and central level of education), 2030.

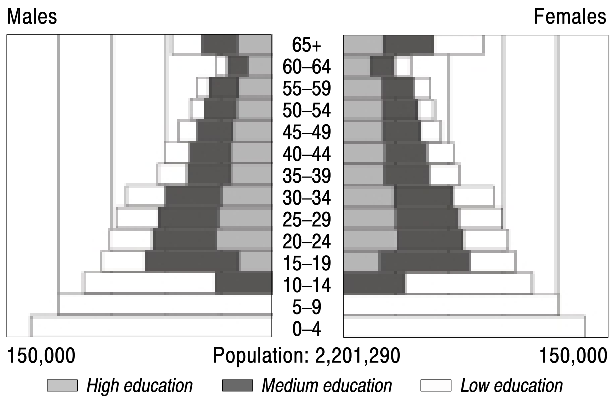

Figure 7A.8. Population projection of metropolitan region of Mérida, stagnation scenario (high fertility, high mortality, and low level of education), 2030.

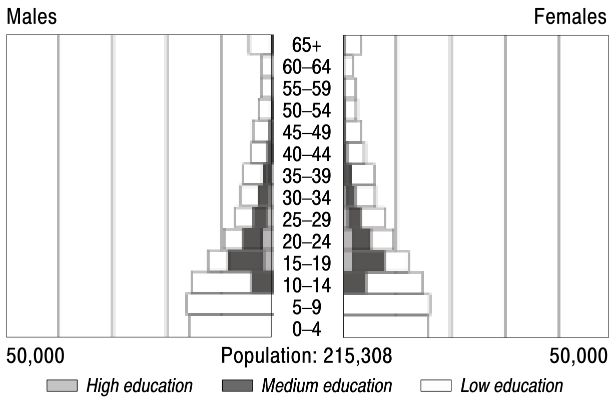

Figure 7A.9. Population of hills and valleys SER, 1990.

Figure 7A.10. Population projection of hills and valleys SER, low scenario (low fertility, low mortality, and high level of education), 2030.

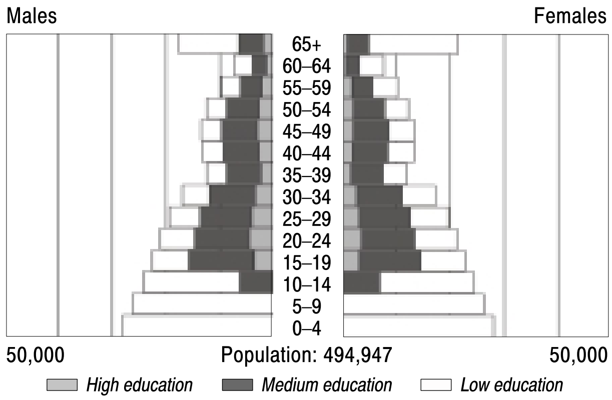

Figure 7A.11. Population projection of hills and valleys SER, central scenario (central fertility, central mortality, and medium level of education), 2030.

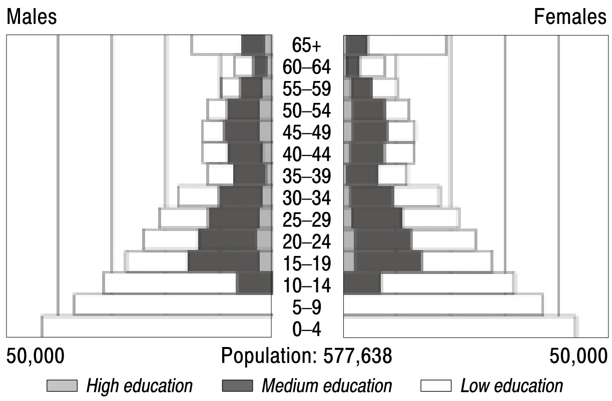

Figure 7A.12. Population projection of hills and valleys SER, high scenario (high fertility, high mortality, and low level of education), 2030.

Appendix 7B:
Summary Results to 2030, All SERs, All Scenarios

	Yucatán state											
	IA				IB				IIA			
Fertility	C	L	H	H	C	L	H	H	C	L	H	H
Mortality	C	L	H	H	C	L	H	H	C	L	H	H
Education	C	H	L	H	C	H	L	H	C	H	L	H
Migration	C	C	C	C	C	C	C	C	C	C	C	C
Total population size – both sexes (in thousands)												
1990	657	657	657	657	248	248	248	248	101	101	101	101
1995	773	773	773	773	267	267	267	267	113	113	113	113
2010	1170	1147	1190	1179	346	330	358	351	136	130	141	138
2015	1361	1316	1400	1372	356	328	376	361	133	122	142	135
2020	1566	1491	1637	1579	366	321	398	368	129	113	143	131
2030	2021	1854	2201	2036	388	305	466	386	120	94	150	124
Percentage of population aged 60+ – both sexes												
1990	8.1	8.1	8.1	8.1	8.7	8.7	8.7	8.7	7.1	7.1	7.1	7.1
1995	7.9	7.9	7.9	7.9	8.9	8.9	8.9	8.9	7.9	7.9	7.9	7.9
2010	7.6	7.9	7.3	7.3	8.0	8.5	7.5	7.6	9.1	9.7	8.6	8.7
2015	8.3	8.8	7.7	7.9	9.1	10.2	8.2	8.6	10.6	11.9	9.6	10.1
2020	9.2	10.1	8.4	8.7	10.4	12.4	9.0	9.7	12.8	15.3	11.0	12.0
2030	11.2	13.3	9.3	10.1	12.5	17.5	9.1	11.0	17.1	23.6	12.4	15.0
Percentage of population aged 0–14 – both sexes												
1990	33.5	33.5	33.5	33.5	39.7	39.7	39.7	39.7	41.7	41.7	41.7	41.7
1995	31.5	31.5	31.5	31.5	34.9	34.9	34.9	34.9	38.7	38.7	38.7	38.7
2010	32.2	30.6	33.6	33.0	40.1	37.0	42.3	41.2	39.2	36.1	41.5	40.5
2015	30.4	27.9	32.6	31.2	37.0	31.7	40.4	37.8	37.2	31.5	40.5	38.1
2020	29.1	25.7	32.3	29.9	33.9	25.8	38.6	33.6	34.0	25.1	38.7	33.8
2030	27.7	22.5	32.9	28.8	31.5	18.2	39.6	29.7	29.8	16.4	38.2	28.9
Total fertility rate												
1990-1995	2.88	2.88	2.88	2.88	4.31	4.31	4.31	4.31	4.32	4.32	4.32	4.32
1995-2000	2.80	2.70	2.85	2.78	4.20	4.00	4.31	4.13	4.16	4.01	4.30	4.32
2010-2015	2.50	2.05	2.93	2.56	3.58	2.52	4.30	3.52	3.71	2.66	4.41	3.72
2015-2020	2.43	1.86	2.99	2.45	3.44	2.02	4.38	3.06	3.60	2.13	4.48	3.27
2020-2025	2.35	1.71	3.05	2.36	3.29	1.70	4.39	2.80	3.44	1.76	4.51	2.95
2025-2030	2.27	1.59	3.08	2.30	3.11	1.48	4.41	2.68	3.29	1.48	4.53	2.72
Life expectancy – male (in years)												
1990-1995	66.4	66.4	66.4	66.4	68.0	68.0	68.0	68.0	70.4	70.4	70.4	70.4
1995-2000	67.4	67.7	67.0	67.0	69.0	69.2	68.6	68.6	71.4	71.6	70.9	70.9
2010-2015	70.5	72.0	68.7	68.8	72.1	73.5	70.2	70.4	74.6	76.1	72.6	72.8
2015-2020	71.7	73.9	69.3	69.4	73.3	75.2	70.8	71.1	75.8	77.9	73.2	73.5
2020-2025	73.0	76.1	69.9	70.0	74.6	77.6	71.5	71.8	77.1	80.1	73.8	74.3
2025-2030	74.6	78.8	70.5	70.7	76.2	80.6	72.1	72.5	78.5	83.0	74.4	75.0
Life expectancy – female (in years)												
1990-1995	73.3	73.3	73.3	73.3	72.8	72.8	72.8	72.8	75.1	75.1	75.1	75.1
1995-2000	74.0	74.2	73.7	73.7	73.6	73.7	73.3	73.3	75.9	76.1	75.6	75.6
2010-2015	76.9	77.9	75.4	75.5	76.4	77.7	74.9	75.1	78.9	80.6	77.2	77.5
2015-2020	78.2	79.8	76.0	76.1	77.8	79.6	75.4	75.8	80.2	82.6	77.7	78.3
2020-2025	79.7	82.0	76.6	76.9	79.3	81.9	76.1	76.7	81.6	85.0	78.4	79.1
2025-2030	81.5	85.7	77.4	77.7	81.0	85.7	76.9	77.6	83.2	88.1	79.1	80.0
Migration – both sexes												
1990-1995												
1995-2000	20070	20070	20070	20070	-6684	-6684	-6684	-6684	-4458	-4458	-4458	-4458
2000-2005	39226	39226	39226	39226	-13078	-13078	-13078	-13078	-8708	-8708	-8708	-8708
2005-2010	73128	73128	73128	73128	-24380	-24380	-24380	-24380	-16250	-16250	-16250	-16250
2010-2015	85950	85950	85950	85950	-28644	-28644	-28644	-28644	-19104	-19104	-19104	-19104
2015-2020	85950	85950	85950	85950	-28644	-28644	-28644	-28644	-19104	-19104	-19104	-19104
2020-2025	85950	85950	85950	85950	-28644	-28644	-28644	-28644	-19104	-19104	-19104	-19104
2025-2030	85950	85950	85950	85950	-28644	-28644	-28644	-28644	-19104	-19104	-19104	-19104

Abbreviations: IA = Metropolitan region of Mérida; IB = Former henequen-producing region; IIA = Cattle-producing region.
CCCC/Central scenario: central fertility, central mortality, central education, and central migration.
LLHC/Rapid development scenario: low fertility, low mortality, high education, and central migration.
HHLC/Stagnation scenario: high fertility, high mortality, low education, and central migration.
HHHC/Stagnation scenario with educational efforts: high fertility, high mortality, high education, and central migration.

	Yucatán state								Campeche state			
	IIB				IIIA				IIIB			
Fertility	C	L	H	H	C	L	H	H	C	L	H	H
Mortality	C	L	H	H	C	L	H	H	C	L	H	H
Education	C	H	L	H	C	H	L	H	C	H	L	H
Migration	C	C	C	C	C	C	C	C	C	C	C	C
Total population size – both sexes (in thousands)												
1990	251	251	251	251	102	102	102	102	215	215	215	215
1995	289	289	289	289	116	116	116	116	250	250	250	250
2010	423	404	437	428	164	158	169	166	358	343	369	363
2015	471	433	497	474	181	168	189	182	390	362	411	396
2020	522	456	565	518	197	176	212	197	423	377	456	427
2030	636	492	741	606	233	187	269	227	495	397	578	495
Percentage of population aged 60+ – both sexes												
1990	6.9	6.9	6.9	6.9	6.8	6.8	6.8	6.8	5.7	5.7	5.7	5.7
1995	7.3	7.3	7.3	7.3	7.1	7.1	7.1	7.1	6.2	6.2	6.2	6.2
2010	6.7	7.1	6.3	6.4	6.0	6.4	5.7	5.7	6.8	7.2	6.4	6.5
2015	7.2	8.0	6.5	6.8	6.7	7.5	6.1	6.3	7.5	8.3	6.9	7.2
2020	7.8	9.3	6.9	7.5	7.6	8.9	6.6	7.1	8.8	10.2	7.7	8.3
2030	8.9	12.6	6.9	8.4	9.0	12.5	7.0	8.3	10.9	14.6	8.6	10.0
Percentage of population aged 0–14 – both sexes												
1990	43.3	43.3	43.3	43.3	43.7	43.7	43.7	43.7	44.0	44.0	44.0	44.0
1995	40.0	40.0	40.0	40.0	39.9	39.9	39.9	39.9	40.7	40.7	40.7	40.7
2010	40.0	36.9	42.2	41.0	39.0	36.2	41.0	40.0	38.8	36.1	40.9	39.9
2015	38.5	33.2	41.7	39.0	37.4	32.6	40.4	38.1	36.9	32.3	40.1	37.8
2020	36.6	28.7	40.9	35.9	35.2	28.3	39.2	35.0	34.8	28.0	39.0	35.1
2030	33.8	21.1	40.6	30.8	32.0	20.9	38.6	30.0	31.7	20.8	38.8	31.5
Total fertility rate												
1990-1995	4.52	4.52	4.52	4.52	4.14	4.14	4.14	4.14	4.15	4.15	4.15	4.15
1995-2000	4.36	4.19	4.52	4.52	3.99	3.85	4.10	4.14	4.00	3.86	4.15	4.15
2010-2015	3.81	2.71	4.54	3.80	3.47	2.53	4.10	3.45	3.41	2.50	4.05	3.44
2015-2020	3.65	2.20	4.60	3.35	3.32	2.08	4.14	3.05	3.25	2.10	4.08	3.12
2020-2025	3.49	1.82	4.64	2.93	3.17	1.75	4.17	2.72	3.11	1.79	4.12	2.90
2025-2030	3.32	1.56	4.66	2.64	3.03	1.54	4.20	2.51	2.98	1.56	4.15	2.75
Life expectancy – male (in years)												
1990-1995	67.8	67.8	67.8	67.8	67.1	67.1	67.1	67.1	71.0	71.0	71.0	71.0
1995-2000	68.8	69.1	68.4	68.4	68.0	68.2	67.6	67.6	71.9	72.1	71.5	71.5
2010-2015	72.0	73.4	70.1	70.3	71.0	72.5	69.2	69.3	74.7	76.1	73.2	73.3
2015-2020	73.2	75.2	70.7	71.0	72.3	74.4	69.8	70.0	76.0	78.1	73.7	73.9
2020-2025	74.4	77.6	71.3	71.7	73.7	76.5	70.5	70.7	77.5	80.2	74.4	74.6
2025-2030	76.0	80.5	71.9	72.4	75.3	79.6	71.2	71.6	79.1	83.4	75.1	75.4
Life expectancy – female (in years)												
1990-1995	73.0	73.0	73.0	73.0	70.5	70.5	70.5	70.5	77.5	77.5	77.5	77.5
1995-2000	73.9	74.1	73.5	73.5	71.4	71.6	71.1	71.1	78.3	78.4	78.0	78.0
2010-2015	76.9	78.4	75.2	75.5	74.5	75.6	72.8	73.1	81.1	82.4	79.4	79.5
2015-2020	78.1	80.4	75.8	76.3	75.7	77.4	73.4	73.8	82.4	84.2	80.1	80.1
2020-2025	79.5	82.9	76.5	77.2	77.0	79.9	74.1	74.6	83.9	86.5	80.8	80.9
2025-2030	81.3	86.1	77.1	78.0	78.9	83.5	74.7	75.4	85.6	89.7	81.6	81.6
Migration – both sexes												
1990-1995												
1995-2000	-2232	-2232	-2232	-2232	-1110	-1110	-1110	-1110	-3348	-3348	-3348	-3348
2000-2005	-4366	-4366	-4366	-4366	-2170	-2170	-2170	-2170	-6542	-6542	-6542	-6542
2005-2010	-8126	-8126	-8126	-8126	-4066	-4066	-4066	-4066	-12184	-12184	-12184	-12184
2010-2015	-9548	-9548	-9548	-9548	-4774	-4774	-4774	-4774	-14322	-14322	-14322	-14322
2015-2020	-9548	-9548	-9548	-9548	-4774	-4774	-4774	-4774	-14322	-14322	-14322	-14322
2020-2025	-9548	-9548	-9548	-9548	-4774	-4774	-4774	-4774	-14322	-14322	-14322	-14322
2025-2030	-9548	-9548	-9548	-9548	-4774	-4774	-4774	-4774	-14322	-14322	-14322	-14322

Abbreviations: IIB = Maize-producing region; IIIA = Fruit-producing region; IIIB = Hills and valleys region.
CCCC/Central scenario: central fertility, central mortality, central education, and central migration.
LLHC/Rapid development scenario: low fertility, low mortality, high education, and central migration.
HHLC/Stagnation scenario: high fertility, high mortality, low education, and central migration.
HHHC/Stagnation scenario with educational efforts: high fertility, high mortality, high education, and central migration.

	Campeche state								Quintana Roo state			
	IIIC				IV				VA			
Fertility	C	L	H	H	C	L	H	H	C	L	H	H
Mortality	C	L	H	H	C	L	H	H	C	L	H	H
Education	C	H	L	H	C	H	L	H	C	H	L	H
Migration	C	C	C	C	C	C	C	C	C	C	C	C
Total population size – both sexes (in thousands)												
1990	171	171	171	171	141	141	141	141	169	169	169	169
1995	205	205	205	205	188	188	188	188	312	312	312	312
2010	298	291	304	301	316	307	322	318	569	560	577	574
2015	335	323	346	339	380	363	393	382	649	631	664	656
2020	375	355	395	381	451	421	475	452	733	702	759	742
2030	461	418	512	472	608	539	672	605	913	839	974	928
Percentage of population aged 60+ – both sexes												
1990	6.8	6.8	6.8	6.8	4.9	4.9	4.9	4.9	1.9	1.9	1.9	1.9
1995	7.0	7.0	7.0	7.0	5.1	5.1	5.1	5.1	2.2	2.2	2.2	2.2
2010	7.8	8.1	7.5	7.6	5.2	5.4	5.0	5.0	3.9	4.0	3.8	3.8
2015	8.9	9.5	8.4	8.6	5.8	6.2	5.4	5.6	5.2	5.4	4.9	5.0
2020	10.3	11.2	9.4	9.7	6.8	7.5	6.1	6.5	7.1	7.6	6.6	6.7
2030	13.0	15.3	10.9	11.8	8.5	10.4	7.0	7.8	12.5	14.3	10.9	11.5
Percentage of population aged 0–14 – both sexes												
1990	35.3	35.3	35.3	35.3	40.0	40.0	40.0	40.0	36.7	36.7	36.7	36.7
1995	32.5	32.5	32.5	32.5	37.8	37.8	37.8	37.8	35.3	35.3	35.3	35.3
2010	33.3	31.5	34.9	34.2	35.7	33.7	37.3	36.5	32.5	31.3	33.6	33.3
2015	30.9	28.2	33.3	31.9	34.1	30.9	36.5	34.6	30.6	28.6	32.3	31.5
2020	29.2	25.5	32.8	30.4	32.9	28.5	36.3	33.2	29.1	26.1	31.5	30.0
2030	27.7	22.0	33.6	29.5	31.1	24.4	36.7	31.4	27.1	21.8	31.0	28.4
Total fertility rate												
1990-1995	2.94	2.94	2.94	2.94	3.47	3.47	3.47	3.47	2.91	2.91	2.91	2.91
1995-2000	2.86	2.77	2.94	2.94	3.36	3.26	3.47	3.47	2.83	2.76	2.91	2.91
2010-2015	2.54	2.05	3.01	2.60	2.86	2.24	3.35	2.87	2.58	2.21	2.91	2.68
2015-2020	2.45	1.85	3.08	2.48	2.74	1.98	3.38	2.67	2.51	1.98	2.95	2.58
2020-2025	2.37	1.69	3.13	2.40	2.64	1.78	3.42	2.53	2.44	1.78	2.97	2.51
2025-2030	2.29	1.57	3.16	2.37	2.55	1.64	3.45	2.44	2.37	1.62	2.98	2.48
Life expectancy – male (in years)												
1990-1995	68.3	68.3	68.3	68.3	62.0	62.0	62.0	62.0	66.7	66.7	66.7	66.7
1995-2000	69.2	69.6	68.8	68.8	63.0	63.4	62.6	62.6	67.6	67.9	67.2	67.2
2010-2015	72.5	74.3	70.5	70.6	66.3	68.1	64.3	64.4	70.9	72.5	68.9	69.1
2015-2020	73.8	76.2	71.1	71.3	67.5	70.0	64.9	65.1	72.1	74.4	69.5	69.9
2020-2025	75.1	78.3	71.7	71.9	68.8	72.2	65.5	65.8	73.5	76.7	70.1	70.7
2025-2030	76.5	80.7	72.4	72.6	70.2	74.5	66.1	66.4	75.0	79.6	70.7	71.4
Life expectancy – female (in years)												
1990-1995	75.4	75.4	75.4	75.4	70.1	70.1	70.1	70.1	75.3	75.3	75.3	75.3
1995-2000	76.2	76.4	75.9	75.9	70.9	71.2	70.6	70.6	76.2	76.4	75.8	75.8
2010-2015	79.0	80.1	77.5	77.6	73.9	75.1	72.3	72.3	79.2	80.7	77.5	77.8
2015-2020	80.1	82.1	78.1	78.2	75.0	76.8	72.8	72.9	80.5	82.7	78.2	78.5
2020-2025	81.7	84.4	78.8	78.8	76.3	79.2	73.5	73.5	82.0	85.1	78.8	79.3
2025-2030	83.4	87.5	79.4	79.4	78.1	82.2	74.1	74.1	83.7	88.2	79.5	80.1
Migration – both sexes												
1990-1995												
1995-2000	2232	2232	2232	2232	6684	6684	6684	6684	47740	47740	47740	47740
2000-2005	4366	4366	4366	4366	13078	13078	13078	13078	40244	40244	40244	40244
2005-2010	8126	8126	8126	8126	24380	24380	24380	24380	20618	20618	20618	20618
2010-2015	9548	9548	9548	9548	28644	28644	28644	28644	20570	20570	20570	20570
2015-2020	9548	9548	9548	9548	28644	28644	28644	28644	20570	20570	20570	20570
2020-2025	9548	9548	9548	9548	28644	28644	28644	28644	20570	20570	20570	20570
2025-2030	9548	9548	9548	9548	28644	28644	28644	28644	20570	20570	20570	20570

Abbreviations: IIIC = Campeche region; IV = Candelaria region; VA = Tourist–urban region.
CCCC/Central scenario: central fertility, central mortality, central education, and central migration.
LLHC/Rapid development scenario: low fertility, low mortality, high education, and central migration.
HHLC/Stagnation scenario: high fertility, high mortality, low education, and central migration.
HHHC/Stagnation scenario with educational efforts: high fertility, high mortality, high education, and central migration.

	Quintana Roo state								States and peninsula			
	VB				VI				Yucatán state			
Fertility	C	L	H	H	C	L	H	H	C	L	H	H
Mortality	C	L	H	H	C	L	H	H	C	L	H	H
Education	C	H	L	H	C	H	L	H	C	H	L	H
Migration	C	C	C	C	C	C	C	C	C	C	C	C
Total population size – both sexes (in thousands)												
1990	71	71	71	71	244	244	244	244	1359	1359	1359	1359
1995	104	104	104	104	288	288	288	288	1558	1558	1558	1558
2010	292	284	299	296	475	463	487	479	2239	2169	2295	2262
2015	351	335	364	358	562	538	584	565	2502	2367	2604	2524
2020	416	387	439	424	657	613	696	656	2780	2557	2955	2793
2030	562	490	626	578	867	765	967	854	3398	2932	3827	3379
Percentage of population aged 60+ – both sexes												
1990	3.7	3.7	3.7	3.7	4.1	4.1	4.1	4.1	7.8	7.8	7.8	7.8
1995	3.6	3.6	3.6	3.6	4.7	4.7	4.7	4.7	7.9	7.9	7.9	7.9
2010	3.7	3.5	3.9	3.9	5.5	5.7	5.2	5.3	7.5	7.9	7.1	7.2
2015	4.8	5.1	4.5	4.6	6.3	6.7	5.8	6.0	8.3	9.0	7.6	7.9
2020	5.7	6.3	5.2	5.4	7.3	8.0	6.5	6.9	9.3	10.6	8.3	8.8
2030	8.4	10.2	7.0	7.6	9.2	11.1	7.5	8.5	11.3	14.6	8.9	10.2
Percentage of population aged 0–14 – both sexes												
1990	39.3	39.3	39.3	39.3	43.4	43.4	43.4	43.4	37.8	37.8	37.8	37.8
1995	36.2	36.2	36.2	36.2	39.9	39.9	39.9	39.9	34.8	34.8	34.8	34.8
2010	37.0	35.2	38.6	38.1	36.1	34.3	37.8	36.8	36.0	33.7	37.8	37.0
2015	35.7	32.7	38.1	36.9	34.3	31.4	36.8	34.7	34.0	30.1	36.8	34.8
2020	34.0	29.5	37.3	35.2	32.8	28.6	36.3	32.7	32.1	26.4	36.0	32.3
2030	31.6	24.0	37.1	33.0	30.5	23.6	36.2	29.9	30.0	20.9	36.3	29.4
Total fertility rate												
1990-1995	3.83	3.83	3.83	3.83	3.60	3.60	3.60	3.60				
1995-2000	3.70	3.57	3.83	3.83	3.48	3.37	3.60	3.60	3.5	3.4	3.6	3.5
2010-2015	3.12	2.47	3.65	3.30	2.89	2.36	3.39	2.87	3.1	2.3	3.7	3.1
2015-2020	3.01	2.15	3.70	3.12	2.77	2.03	3.41	2.62	3.0	2.0	3.7	2.8
2020-2025	2.90	1.87	3.75	2.99	2.66	1.79	3.46	2.44	2.9	1.7	3.8	2.6
2025-2030	2.78	1.65	3.78	2.90	2.57	1.64	3.53	2.33	2.7	1.6	3.8	2.5
Life expectancy – male (in years)												
1990-1995	68.3	68.3	68.3	68.3	69.2	69.2	69.2	69.2				
1995-2000	69.3	69.5	68.9	68.9	70.1	70.3	69.7	69.7	68.3	68.5	67.9	67.9
2010-2015	72.5	74.1	70.7	70.9	73.4	74.7	71.6	71.8	71.4	72.9	69.5	69.7
2015-2020	73.8	76.1	71.2	71.7	74.6	76.6	72.2	72.6	72.6	74.7	70.1	70.3
2020-2025	75.2	78.4	71.9	72.4	76.0	79.0	72.8	73.4	73.9	77.0	70.8	71.0
2025-2030	76.8	81.4	72.5	73.2	77.7	82.3	73.4	74.2	75.5	79.8	71.4	71.7
Life expectancy – female (in years)												
1990-1995	75.2	75.2	75.2	75.2	75.8	75.8	75.8	75.8				
1995-2000	76.1	76.3	75.8	75.8	76.6	76.8	76.3	76.3	73.9	74.0	73.5	73.5
2010-2015	79.2	80.5	77.6	77.8	79.6	80.8	78.1	78.3	76.8	78.0	75.2	75.4
2015-2020	80.5	82.5	78.2	78.6	80.9	82.7	78.7	79.1	78.1	79.9	75.8	76.1
2020-2025	81.9	85.0	78.8	79.3	82.3	85.3	79.4	79.9	79.5	82.2	76.4	76.9
2025-2030	83.7	88.3	79.5	80.2	84.3	88.8	80.1	80.7	81.3	85.8	77.2	77.7
Migration – both sexes												
1990-1995												
1995-2000	47740	47740	47740	47740	6684	6684	6684	6684	5586	5586	5586	5586
2000-2005	40244	40244	40244	40244	13078	13078	13078	13078	10904	10904	10904	10904
2005-2010	20618	20618	20618	20618	24380	24380	24380	24380	20306	20306	20306	20306
2010-2015	20570	20570	20570	20570	28644	28644	28644	28644	23880	23880	23880	23880
2015-2020	20570	20570	20570	20570	28644	28644	28644	28644	23880	23880	23880	23880
2020-2025	20570	20570	20570	20570	28644	28644	28644	28644	23880	23880	23880	23880
2025-2030	20570	20570	20570	20570	28644	28644	28644	28644	23880	23880	23880	23880

Abbreviations: VB = Northern block-fault basin region; VI = Southern block-fault basin region.
CCCC/Central scenario: central fertility, central mortality, central education, and central migration.
LLHC/Rapid development scenario: low fertility, low mortality, high education, and central migration.
HHLC/Stagnation scenario: high fertility, high mortality, low education, and central migration.
HHHC/Stagnation scenario with educational efforts: high fertility, high mortality, high education, and central migration.

	States and peninsula											
	Campeche state				Quintana Roo state				Yucatán peninsula			
Fertility	C	L	H	H	C	L	H	H	C	L	H	H
Mortality	C	L	H	H	C	L	H	H	C	L	H	H
Education	C	H	L	H	C	H	L	H	C	H	L	H
Migration	C	C	C	C	C	C	C	C	C	C	C	C
Total population size – both sexes (in thousands)												
1990	528	528	528	528	484	484	484	484	2371	2371	2371	2371
1995	643	643	643	643	704	704	704	704	2905	2905	2905	2905
2010	972	941	995	982	1336	1307	1363	1349	4547	4417	4653	4593
2015	1105	1048	1150	1117	1562	1504	1612	1579	5169	4919	5366	5220
2020	1249	1153	1326	1260	1806	1702	1894	1822	5835	5412	6175	5875
2030	1564	1354	1762	1572	2342	2094	2567	2360	7304	6380	8156	7311
Percentage of population aged 60+ – both sexes												
1990	5.8	5.8	5.8	5.8	3.3	3.3	3.3	3.3	6.5	6.5	6.5	6.5
1995	6.1	6.1	6.1	6.1	3.4	3.4	3.4	3.4	6.4	6.4	6.4	6.4
2010	6.6	6.9	6.3	6.4	4.4	4.5	4.3	4.4	6.4	6.6	6.1	6.2
2015	7.3	7.9	6.8	7.1	5.5	5.8	5.1	5.3	7.2	7.8	6.7	6.9
2020	8.5	9.6	7.6	8.1	6.9	7.4	6.3	6.5	8.3	9.3	7.5	7.9
2030	10.6	13.1	8.7	9.7	10.3	12.2	8.7	9.5	10.7	13.2	8.7	9.7
Percentage of population aged 0–14 – both sexes												
1990	40.1	40.1	40.1	40.1	40.5	40.5	40.5	40.5	38.9	38.9	38.9	38.9
1995	37.2	37.2	37.2	37.2	37.3	37.3	37.3	37.3	36.0	36.0	36.0	36.0
2010	36.1	33.9	37.9	37.1	34.8	33.2	36.2	35.6	35.6	33.5	37.3	36.5
2015	34.1	30.6	36.8	34.9	33.1	30.5	35.2	33.9	33.6	30.2	36.2	34.4
2020	32.4	27.4	36.2	33.0	31.6	27.8	34.6	32.2	31.9	27.0	35.4	32.3
2030	30.3	22.6	36.5	30.9	29.4	23.0	34.4	30.1	29.7	22.2	35.5	29.9
Total fertility rate												
1990-1995												
1995-2000	3.4	3.3	3.6	3.6	3.2	3.1	3.3	3.3	3.4	3.3	3.5	3.5
2010-2015	3.0	2.3	3.5	3.0	2.8	2.3	3.2	2.9	3.0	2.3	3.5	3.0
2015-2020	2.8	2.0	3.5	2.8	2.7	2.0	3.3	2.7	2.8	2.0	3.5	2.8
2020-2025	2.7	1.8	3.6	2.6	2.6	1.8	3.3	2.6	2.7	1.8	3.6	2.6
2025-2030	2.6	1.6	3.6	2.5	2.5	1.6	3.4	2.5	2.6	1.6	3.6	2.5
Life expectancy – male (in years)												
1990-1995												
1995-2000	68.4	68.7	68.0	68.0	68.9	69.1	68.5	68.5	68.4	68.7	68.0	68.0
2010-2015	71.3	73.0	69.5	69.6	72.1	73.6	70.2	70.5	71.6	73.1	69.7	69.9
2015-2020	72.4	74.7	69.9	70.1	73.4	75.6	70.8	71.3	72.7	74.9	70.3	70.5
2020-2025	73.6	76.7	70.4	70.6	74.8	77.9	71.5	72.1	74.0	77.1	70.8	71.2
2025-2030	74.9	79.0	70.9	71.1	76.4	81.0	72.2	72.9	75.5	79.9	71.4	71.8
Life expectancy – female (in years)												
1990-1995												
1995-2000	75.5	75.7	75.1	75.1	76.3	76.5	76.0	76.0	74.8	75.0	74.5	74.5
2010-2015	78.1	79.3	76.5	76.6	79.4	80.7	77.8	78.0	77.8	79.1	76.2	76.4
2015-2020	79.2	81.0	77.0	77.0	80.6	82.7	78.4	78.8	79.1	81.0	76.8	77.1
2020-2025	80.5	83.2	77.6	77.6	82.1	85.1	79.0	79.5	80.5	83.3	77.5	77.8
2025-2030	82.0	86.0	78.1	78.1	83.9	88.4	79.7	80.3	82.3	86.7	78.2	78.6
Migration – both sexes												
1990-1995												
1995-2000	5568	5568	5568	5568	102164	102164	102164	102164	113318	113318	113318	113318
2000-2005	10902	10902	10902	10902	93566	93566	93566	93566	115372	115372	115372	115372
2005-2010	20322	20322	20322	20322	65616	65616	65616	65616	106244	106244	106244	106244
2010-2015	23870	23870	23870	23870	69784	69784	69784	69784	117534	117534	117534	117534
2015-2020	23870	23870	23870	23870	69784	69784	69784	69784	117534	117534	117534	117534
2020-2025	23870	23870	23870	23870	69784	69784	69784	69784	117534	117534	117534	117534
2025-2030	23870	23870	23870	23870	69784	69784	69784	69784	117534	117534	117534	117534

Abbreviations:
CCCC/Central scenario: central fertility, central mortality, central education, and central migration.
LLHC/Rapid development scenario: low fertility, low mortality, high education, and central migration.
HHLC/Stagnation scenario: high fertility, high mortality, low education, and central migration.
HHHC/Stagnation scenario with educational efforts: high fertility, high mortality, high education, and central migration.

References

CONAPO (Consejo Nacional de Población), 1995, *Estimaciones y Projecciones Demográficas*, Mexico City, Mexico.

García de Fuentes, A., Eastmond, A., and Cordoba Ordoñez, J., 1996, *Peninsula de Yucatán, Población y Desarrollo Sustentable, Informe Sobre el Estado de la Población 1970–1995*, Mérida, Mexico, and Madrid, Spain.

Goujon, A., 1997, Population and Education Prospects in the Western Mediterranean Region, IIASA Interim Report, International Institute For Applied Systems Analysis, Laxenburg, Austria.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1993, *XI Censo General de Población y Vivienda 1990*, Aguascalientes, Mexico.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1994a, *Estadísticas Sociodemográphicas, Natalidad*, Aguascalientes, Mexico.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1994b, *Estadísticas Sociodemográphicas, Mortalidad*, Aguascalientes, Mexico.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1996, *Conteo de Población y Vivienda 1995*, Aguascalientes, Mexico.

Lutz, W., ed., 1994, *Population, Development, Environment: Understanding their Interactions in Mauritius*, Springer-Verlag, Berlin, Germany.

Wils, A., 1996, PDE – Cape Verde: A Systems Study of Population Development and Environment, WP-96-9, International Institute For Applied Systems Analysis, Laxenburg, Austria.

Yousif, H.M., Goujon, A., and Lutz, W., 1996, *Future Population and Education Trends in the Countries of North Africa*, RR-96-11, International Institute For Applied Systems Analysis, Laxenburg, Austria.

8

Integrated Dynamic Modeling: An Application for Tourism on the Yucatán Peninsula

Patricia P.A.A.H. Kandelaars

8.1 Introduction and Motivation

This chapter presents an integrated dynamic model of the interactions between population, economic development, environment, and tourism on the Yucatán peninsula. The model aims to represent the dynamics of population, economic development, and environment (PDE) interactions (see Lutz, 1994) and to explain the behavior of the system. It is not intended to forecast future developments, but to show how interesting questions can be answered using dynamic modeling and simulation. It should be emphasized that the model is not a black box into which the user has no insight. It is an interactive model in which variables, relationships, and even modules can be changed or added. This allows the model to be easily updated. The model can also serve as a basis for researchers or firms building models to forecast future developments. The model as presented in this chapter may be useful for teaching and policy analysis. However, the model does not include certain elements that would be needed for policy recommendations. For instance, the equations of the model in its present form have not been calibrated using historical data, and for many variables and interactions the correct data are missing. The model is meant to give indications of how dynamic modeling can be done in a transparent way. The model is user friendly, and the graphical interface allows the user to see interactions in the system. Thus, with its graphical and mathematical interface, the model may serve as a basis for further exploration of PDE and tourism interactions.

In the PDE modeling for the peninsula, special attention is given to the tourism sector for three reasons: it is the most important economic sector on the peninsula; it has developed rapidly in the past few decades and is expected to grow in the coming years; and there are many interesting interactions between tourism, other economic sectors, population, and the environment.

This chapter is organized as follows: Section 8.2 discusses the peninsula's tourism industry, with an emphasis on the historical development of the tourism region. Section 8.3 gives an overview of the literature and describes the methodology used. The model structure and the modules of the model are presented in Section 8.4. Section 8.5 presents the scenarios and the model's preliminary economic, demographic, and environmental results. Conclusions are presented in the final section.

8.2 Tourism on the Peninsula

This section presents the interactions between population, environment, and the economy, with an emphasis on tourism as one of the economic sectors. The development and growth of tourism is also discussed.

The dynamic model is applied to tourism because tourism is the Yucatán peninsula's main economic sector as measured by gross national product, or GNP (Inskeep and Kallenberger, 1992). Tourism has developed significantly over the past 20–30 years and is expected to grow in the future (Inskeep and Kallenberger, 1992; World Tourism Organization, 1996). Per capita income is higher on the peninsula than in other regions of Mexico because of earnings from tourism. As a result of these income differences and the economic development of the region, there has been migration to Yucatán from other parts of Mexico. Other economic sectors that are important on the Yucatán peninsula are fisheries (see Chapter 9) and agriculture.

Development of tourism and the environment are major issues in the tourism industry (Inskeep and Kallenberger, 1992). The decrease in the quality of the environment concerns not only tourists but also the tourism industry, mainly because of the loss of income.

Tourism may have an impact on the size and age structure of the population. More job opportunities, higher salaries, or a higher standard of living may attract people from other regions. The structure of the population may change because migrants are generally from the younger generation. In addition to the quantitative changes in population, there may be social, cultural, and economic changes as well.

The interactions between tourism and other economic sectors are apparent, but it is not possible to quantify which parts of commerce, construction, fisheries, or agriculture are related to tourism. Another economic issue is the allocation of investments on the peninsula. Does tourism create its own investments or does it absorb a part of the investments that otherwise would have been made in other economic sectors? How does water quality affect tourism demand?

The growth of tourism on the Yucatán peninsula, and especially in the Cancún area, was planned by the national government (see *Figure 8.1*). In the late 1960s, the Mexican government created a plan to develop and stimulate tourism in several new resort areas. The primary goal was to develop tourism in rural areas with tourist attractions (beaches and historical sites) but with few or no other sources of employment or economic development. Secondary goals were to stimulate other economic sectors in these areas, to stimulate tourism in Mexico as a whole, and to generate income in foreign currencies.

Mexico has many beach resorts for domestic and, since the late 1940s, international tourism. International tourism can be divided into three groups: urban (e.g., Mexico City and Guadalajara), border tourism in the north, and resort tourism. Urban and border tourism are highly dependent on the domestic economy; resort tourism is not (Inskeep and Kallenberger, 1992).

In an evaluation focusing on the economy, including the tourism sector, the coastline of Quintana Roo was chosen to be one of the six (later reduced to five) zones for tourism development. Among the places considered in Quintana Roo were Cozumel, Isla Mujeres, and Cancún. The potential areas to be developed were evaluated according to water supply characteristics, accessibility, natural attractions, land ownership, and historical or cultural attractions.

Cancún was chosen as a tourist resort because of its geographical features: a strip of land and beach enclosing a large lagoon. At the beginning of the 1970s, four main elements were planned and developed: the beach hotels, the international airport, the new urban zone, and the conservation areas. A new town was needed for Cancún's increasing population, which grew from only 117 inhabitants in 1970 (Inskeep and Kallenberger, 1992) to 18,000 in 1976 and to 300,000 in 1991. The conservation areas were mainly designed to protect the lagoon.

The natural environment provides several services to the local population and the tourists. The marine ecosystem includes several types of fish (see Chapter 9) and corals. This ecosystem is attractive for tourists because of the good beaches and water sport facilities (for diving and snorkeling). Tourism has a negative impact on the coral reefs: these reefs are very sensitive and may easily be damaged or killed by human activities such as diving, snorkeling, and fishing.

The expansion of tourism on the peninsula, which was stimulated by local (regional) policymakers to develop the region, has been very rapid. Although the peninsula's economy is largely based on tourism, there are other economic sectors, such as fisheries, agriculture, local services, and construction. Parts of those sectors are related to tourism – for example, the construction of hotels. The number of people employed in agriculture has decreased rapidly on the peninsula, as in other regions where tourism was promoted by the government (see, e.g., Long, 1991, for the case of Santa Cruz in the Huatulco area).

For Mexico as a whole, international tourism has increased from 1.3 million tourists in 1970 to 17.2 million in 1994, mostly as a result of the increase of beach

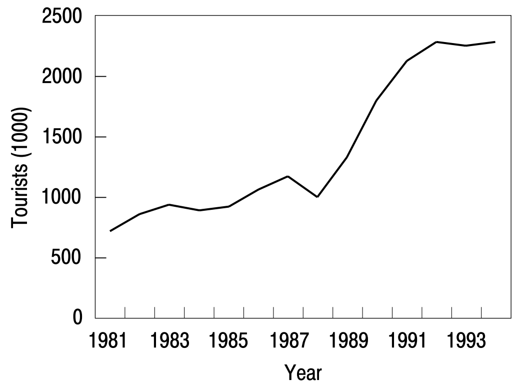

Figure 8.1. The total number of tourists (in thousands) visiting the tourism area in Quintana Roo, 1981–1994. Sources: INEGI (1994) and World Tourism Organization (1994).

tourism (Inskeep and Kallenberger, 1992; World Tourism Organization, 1994). The share of tourism in the GNP was 3.2% in 1994 (World Tourism Organization, 1994). The number of people directly or indirectly employed in tourism was estimated to be 2.1 million in 1994.

The tourism sector has evolved over the past 10 years in particular (see *Figure 8.1*). In the 1981–1994 period, the number of tourists increased by 362%, more than 25% per year. Only in 1988 did the number of tourists decline as a result of severe damage caused by Hurricane Gilbert. The percentage of international tourists as a fraction of all tourists has increased from 51.2% in 1981 to 73.8% in 1994. This increase mainly occurred at the beginning of the 1980s, and since 1984 has stabilized at around 70–75% (INEGI, 1994; World Tourism Organization, 1994).

Cancún's development as a tourist resort has had a direct impact on the surrounding region, for example, the island of Cozumel. *Table 8.1* shows the increase in the number of tourists in both places and for Mérida, a city in which tourism development did not receive special attention. The increase in the number of tourists has a direct effect on services needed for those tourists, such as accommodation (see *Tables 8.1* and *8.2*).

The area's development has also had great impacts on the economy and the society of the rest of the Yucatán peninsula. Before, most of the peninsula's population lived in rural areas; now, most of the people live in urban areas (Aguilar and Rodriguez, 1995). The Cancún project has attracted people from other parts of Yucatán and from the rest of Mexico. Positive migration into the state of Quintana Roo is the main reason for the region's population growth. The infrastructure (the

Table 8.1. Number of tourists (in thousands) in the three main tourist destinations.

	Cancún	Cozumel	Mérida
1981	540.8	174.3	558.7
1994	1,958.1	321.0	459.2
Growth between 1981 and 1994 (%)	262	84	–18

Sources: INEGI, 1994; World Tourism Organization, 1994.

Table 8.2. Number of rooms in the three main tourist destinations.

	Cancún	Cozumel	Mérida
1981	5,225	1,725	3,138
1994	18,859	3,350	3,331
Growth between 1981 and 1994 (%)	261	94	6

Sources: INEGI, 1994; World Tourism Organization, 1994.

international airport, regional highways, water supply, electric power, and telecommunications) has also been improved.

The area around Cancún, especially the island of Cozumel and to a lesser extent the small island of Isla Mujeres, has also developed as a result of the tourism boom. Improved infrastructure and the presence of coral reefs for diving and snorkeling have made these islands especially attractive to tourists. Before the development of Cancún, Mérida was where most tourists on the peninsula stayed to visit the Maya ruins of Uxmal and Chichén Itzá. Now, however, tourists can also stay in the Cancún area when visiting these ruins. For international tourists, it is more attractive to go to Cancún because the international flights to Cancún are generally cheaper than those to Mérida.

In Cancún, the number of international tourists increased by more than a factor of 5 between 1981 and 1994, whereas the number of national tourists increased by less than a factor of 2 over the same period. During the same period, there was a 60% increase in the number of national tourists in Cozumel (from 52,900 to 85,500), and the number of international tourists nearly doubled. For the city of Mérida, which is not on the coast, the number of international tourists remained the same over that period, indicating development quite different from that in Cancún or Cozumel. The number of national tourists to Mérida has decreased by almost 25%.

The strip of coastal land from Cancún south to Tulum is currently being developed. Playa del Carmen now serves as one of the main alternatives to highly developed Cancún. The archaeological site at Tulum is a popular day trip for people on holiday in Cancún. In fact, the large number of buses near the site has created so much air pollution that the buses are now required to park relatively far from it.

8.3 Simulation and Modeling

Among the interesting questions regarding the tourism and PDE interactions are the following: How will tourism growth affect the migration rate into the tourism region? How will tourism policies affect tourism and foreign investment in the region? What effect will tourism or population growth have on water use and water quality? Will investments in other sectors in the tourism region decrease or increase as a result of investment in the tourism sector? Will a policy to clean up the water have an effect on the tourism sector? How will the tourism industry affect the environment? A dynamic model that can be used to address these sorts of questions is presented here. An overview of studies on tourism is given first and then the model is discussed.

Economic studies on tourism generally describe and analyze the current situation, on the basis of which recommendations or forecasts are made (see, e.g., Van Dijk *et al.*, 1991; De Freytas and Arts, 1989; Shah, 1995). Sociological or anthropological studies describe the impacts of tourism on the local population. Various positive and negative effects on the economic well-being and culture of the local population and on the environment are described. These studies are usually qualitative (historical) descriptions without quantitative dynamics. Some examples of the findings from such studies include the following:

- The effects of tourism on the local population can either be positive or negative (based on Long, 1991).
- Among the positive economic impacts of tourism are the possibility of a higher standard of living (Hudman, 1978; Leathers and Misiolek, 1986; Crandall, 1987); more job opportunities, which may keep the local population from migrating to other areas or countries (Pizam and Milman, 1986; Smith, 1988); more chances of finding work for women (de Kadt, 1979; Samy, 1980; Dogan, 1989); and diversification of the economy (Runyan and Wu, 1979).
- At the societal level, tourism may have positive impacts: growing interest in the local culture on the part of tourists may stimulate the cultural heritage (MacCannell, 1984; Deitch, 1989; Dogan, 1989) and production of local crafts (Crandall, 1987; Greenwood, 1989; Swain, 1989); the interest in culture may also stimulate the development of museums and the growth or revival of a minority language (Hunter and Green, 1995).
- Negative economic impacts of tourism may include the replacement of traditional jobs by jobs in tourism, which can make the local economy overly dependent on tourism (Mathieson and Wall, 1982; Crandall, 1987; Wilkinson, 1989). This crowding-out effect is not an effect of tourism in itself, but of a general failure to develop a diverse economy. This principle is the same for tourism as it is for coffee, oil, or cotton.

- Negative social or cultural impacts of tourism may include exposure to another lifestyle (Smith, 1988; Evans, 1994); mass production of traditional products, leading to a reduction in their physiological or religious value for the local people (Graburn, 1977; de Kadt, 1979); changes in tradition, such as changes in clothing, eating, and ways of spending leisure time; changes in values and norms, such as an increase in criminality; loss of (historical) artifacts; and changes in cultural landscape, such as the introduction of new types of houses (Hunter and Green, 1995).
- Negative environmental impacts of tourism include pollution, erosion, use of natural resources (for case studies on the Maldives and Nepal, see Brown *et al*., 1995; for a study of overfishing, see Chapter 9), and negative visual impacts, such as from large parking lots (Hunter and Green, 1995). The increase in, for example, pollution may be harmful to the community and may, after a period of time, drive the tourists away, leaving the community with a polluted environment and no income from tourism (Mathieson and Wall, 1982). Edwards and Cleverdon (1982) give an extensive overview of the economic and social impacts of (international) tourism on developing countries.

Interactions between tourism, the economy, and the environment have been studied for various regions and countries. Most of these studies are (historical) descriptions. For example, Ramsamy (1994) describes the development of tourism and the environmental problems caused by it for the island of Mauritius. Sinclair (1991) studies the distribution of the earnings from safari and beach tourism in Kenya. Shah (1995) analyzes the demand and supply for wildlife viewing. An exception to these descriptive studies is a study by van den Bergh (1996) that models the Northern Sporades, a group of islands in Greece. This study shows that the number of tourists in certain fragile areas should be limited to protect the marine system and the species living there.

In contrast to the above descriptions and analyses, in this chapter tourism is modeled with its interactions with population, the environment, and the rest of the economy. The goal of the model is to obtain insight into these dynamic interactions.

The spatial component of the model is related to the economy. The Yucatán peninsula is divided into two economic regions: the tourism region (Quintana Roo) and the rest of the peninsula (Yucatán and Campeche).[1] Tourism is concentrated in the northern part of the state of Quintana Roo, and the other economic sectors are in the south of Quintana Roo and in the states of Yucatán and Campeche.

Programming of, and dynamic simulation using, the model presented in Section 8.4 is performed in the graphical modeling language Stella/ithink.[2] This model allows separate modules (i.e., partial models) to be integrated into a single model, permitting a view of direct or indirect relationships between various modules. Besides the mathematical interface, the model has a graphical interface that displays the interactions between the modules. Furthermore, the dynamic model permits viewing of delayed effects and accumulation and changes over time.

Additional insights can be obtained from quantitative modeling, such as changes in the population and the age structure of the population due to tourism development and growth. For example, policymakers might be interested in the effects of water purification policies on the number of tourists visiting the Cancún area. Among the questions that might be asked are the following: (1) What water purity standards should the government set? (2) Who will pay for the cleanup, the government, the tourism industry, the population, the tourists, or a combination of these groups? If the government policy states that the tourism industry needs to pay for a part of the cleanup, the hotel owners will be upset unless there is a positive impact from higher tourist demand and higher prices. On the topics of population, development, environment, and tourism, many kinds of interesting questions can be asked, especially with regard to their interactions – for instance, the effects changes in investments or policies on (foreign) investment have on tourism and the rest of the economy, and the relationship between the environment and tourism.

Several scenarios can be used to simulate policies, future developments, and radical changes. The government can impose policies, for example, to clean up the water, to limit investment in hotels, or to curb international investment. Future developments or changes can be simulated in all modules, variables, and parameters. Examples of possible developments include a lower birth rate, a change in the popularity of Yucatán as a tourist destination, reduced migration because other parts of Mexico become more attractive, changes in investments, and reduced attractiveness of the beaches or archaeological sites. Radical changes that may affect the Yucatán peninsula are, for instance, a hurricane like Gilbert in 1988, when the tourism industry experienced a substantial setback.

8.4 Model Structure

This section describes the model's structure. The model is descriptive, with causal relationships specified through differential equations. The model comprises five modules, one each for the economy, the tourists and tourist accommodations, the population, the environment, and the government. These modules, the building blocks of the model, interact with one another. Often these modules are studied separately. *Figure 8.2* shows the modules with their main variables. In the description of the five modules and their interactions, only the most important relationships are addressed. There are various indirect linkages between the modules, for instance, between tourism and the population via the economy: the more tourists

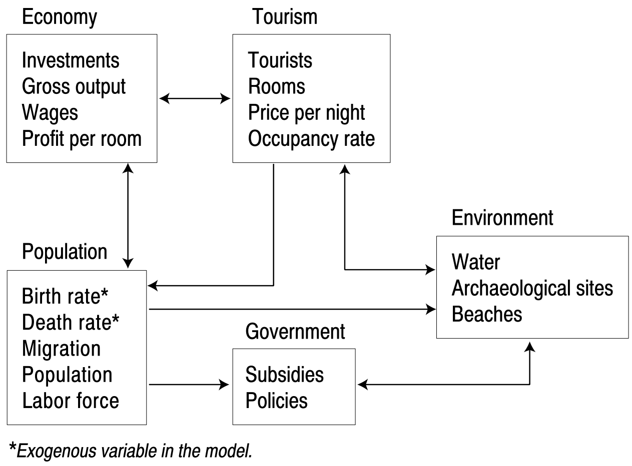

Figure 8.2. The general model structure.

visit the peninsula, the more people are needed to work in the tourism industry, which may lead to migration into the tourism region.

The model uses 1995 as a base year and makes computations for each year thereafter until 2015. The initial conditions and the relationships are based on data from various sources on numbers of tourists and rooms (Inskeep and Kallenberger, 1992; World Tourism Organization, 1994; INEGI, 1994); on Mexico's economy (World Bank, 1994; OECD, 1995); on water use (Gelting, 1995); on the Yucatán peninsula's economy (CINVESTAV, 1996); and on demographics (see Chapter 7). The initial conditions and equations of the model are presented in Appendix 8A.

The Economic Module

The economy as modeled consists of two sectors: the tourism sector (region 1) and the rest of the economy, which is the aggregate of all other sectors (region 2). Ideally, the economic module would deal with various economic sectors separately to give a more accurate description of the economic system. For practical reasons, however, only the tourism sector is dealt with in detail.

The gross output of the tourism sector depends on the number of tourists, the price per night of accommodation, and the number of nights stayed. A part of the gross output goes toward wages. The wage per worker depends on the occupancy rate, intermediate consumption by the tourism sector, gross output, and the number of people working in tourism. The profit of the tourism sector depends on gross output and the occupancy rate of the hotel rooms (see Equations E1–E9 in Appendix 8B).

Total investment is the sum of three types of investment: international investment in the tourism industry, which depends on the profit per room; national investment, which depends on the profit per room; and regional investment, which depends on the wages and profits in both the tourism and the aggregated sectors. The regional (Yucatán) investment depends on the profits and the wages in sectors 1 and 2: invyuc=.4*(profit1+profit2)+.1*(wage1+wage2) (see Equation E19 in Appendix 8B). The distribution of the regional investments over the two sectors depends on the change in the profit per room in the preceding year (see Equations E10–E22 in Appendix 8B).

For the aggregated sector, the gross output depends on the labor force, the capital stock, and the price. The gross output of this sector is also divided into purchased intermediate inputs, wages, and profits. The wage per worker is determined by the part of the gross output dedicated to labor and the number of people working in the sector (see Equations E1–E40 in Appendix 8B).

The Tourism Module

Tourism demand depends on the price per room; the quality of water, beaches, and archaeological sites; and exogenous factors (e.g., the general popularity of Mexico, which may depend on marketing strategies or even the political situation in various countries). The exogenous factors are based on the historical growth rate of tourism in the region (INEGI, 1994) The supply of rooms depends on the total availability of rooms and the price per room. When the price is very low, the hotel owners will not supply any rooms, because the costs of opening them are higher than the revenues. When the price is very high, the supply of rooms will be equal to the total number of rooms available. In general, the price equates the demand for rooms to the number that are made available. The number of rooms that are available depends on investment in the tourism sector and the depreciation rate of rooms.

The Population Module

The population is divided according to the peninsula's two regions. The birth and death rates of both regions are adopted from the forecasts (central scenario) in Chapter 7. An important aspect of growth of tourism in the tourism region is internal migration. The net migration rate for the peninsula depends on the number of tourists that visit. After rewriting Equations D7–D10 in Appendix 8B, the number of migrants to the tourism region (miginVab) depends on the number of tourists, the size of the population, and its natural growth rate: miginVab=2*tourists*.085-(popVab+natgrowth). The more tourists there are, the more jobs will be available, which attracts people to the peninsula, especially to the tourist areas. Internal migration to the tourism region comes partly from the rest of the peninsula and partly from other parts of Mexico or other countries. Migration to the peninsula is temporary, because when there no longer are jobs in the tourism sector, people move away again.

The Environmental Module

This module consists of three broad environmental quality indicators: the quality of water, beaches, and archaeological sites. Water quality depends on the amount of water used, the water's natural purification rate, and government policies to clean up the water. The initial value (1995) is set at 100. The quality of the archaeological sites depends on the number of tourists that visit the sites. The quality of the beaches depends on the occupancy rate of the hotels – that is, the number of tourists divided by the number of hotel rooms. When a new hotel is built, a new strip of beach is developed and thus made available for tourists. It is assumed that the average tourist likes a semi-crowded beach and not a totally empty or overcrowded beach.

The Government Module

The government is modeled in a limited way. The government can impose only two policies: one concerning the cleaning of water used by the resident population, and one concerning the cleaning of water used by tourists. The government only pays for cleaning of the water used by the resident population. This payment from the government to the peninsula can be seen as a subsidy. The tourism sector (i.e., the hotel owners) pays for cleaning of the water used by the tourists.

Interactions between Various Modules

The tourists represent an important interaction between the economic module and the tourist module. The demand for tourist nights and the supply of rooms determine the equilibrium price per tourist per night, which is an important variable in the economic module.

The price per tourist night, the occupancy rate, and the profit per room partly determine the investment in both sectors (and regions). The labor force needed in the tourism industry depends on the number of tourists visiting every year. Internal migration is flexible. If the labor is no longer needed in the tourism region, people return to their home regions. The part of the labor force not working in the tourism industry is assumed to work in one of the other economic sectors. Thus, unemployment is included as a part of the rest of the economy. The labor force in the rest of the economy directly influences this sector's output.

The quality of water depends on water use and water cleaning policies. The demand for tourist nights depends on the quality of the beaches, the archaeological sites, the water, and other (exogenous) factors. The quality of the beaches and the sites has a one-year delayed effect on the number of tourists. Thus the quality of both will affect next year's tourists. Water quality has a direct effect on the number of tourists. It is an accumulated variable, equal to the previous year's water quality plus subsequent changes (positive or negative).

8.5 Scenarios and Preliminary Results

To address some of the questions raised in Section 8.3, this section describes a base scenario and examples of two types of analysis: policy analysis and sensitivity analysis. The base scenario serves as a reference scenario for the policy scenario and the sensitivity run; it should not be seen as a best guess or the most probable outcome. The simulation results should be seen as indicative and should be compared with each other without looking at specific levels or paths.

The base scenario has a steady exogenous growth path for tourism based on the trend of the past 20 years. In this scenario, no policies are imposed. The policy scenario analyzes the effects of government-imposed policies to clean the water used by the resident population and the tourists. It is assumed that these policies are implemented totally and that they are effective. In this case, the indicator for the water quality remains the same over time. The government pays for cleaning the water used by the resident population, and the tourism sector (i.e., hotel owners) pays for cleaning the water used by tourists. In the sensitivity run, the population and the tourists are assumed to use twice as much water as in the base scenario. Water use per day is not known precisely; therefore, it is useful to analyze the effects of different levels of water use. The policy and sensitivity analyses are illustrations of the type of analysis that is possible with dynamic modeling and simulations. Many other policy and sensitivity analyses can also be performed.

Various indicators for each module give an overview of the results of the scenarios. In this section, indicators marked with an asterisk (*) are presented and explained systematically.

- Tourism indicators: number of tourists*, rooms*, occupancy rate*, price per night.
- Economic indicators for both regions: gross output, price, investment, value added; for the tourism region: international investment*, profit per room*.
- Demographic indicators for both regions: population size*, labor force, migration rate*, wages.
- Environmental indicators: water quality*, quality of beaches and sites.
- Governmental indicators: policy percentages, subsidy.

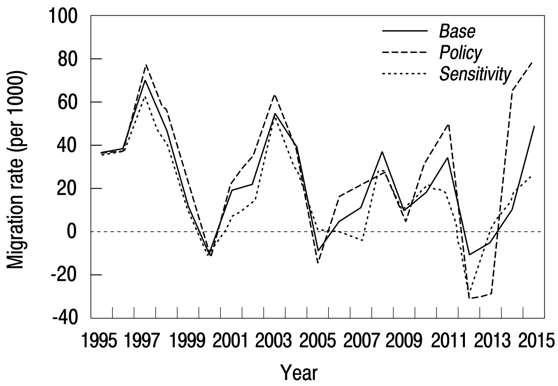

Figure 8.3. The migration rate (per thousand) in the tourism region for the three scenarios.

Table 8.3 shows the changes in the population in the two aggregated regions of the peninsula. The birth and death rates for both regions are exogenous and equal in the three runs. In the base scenario, the population in the tourism region more than doubles in the 20-year period from 1995–2015. For the rest of the peninsula, the population increases by 60% over that period. The migration rate for the tourism region changes over time depending on the number of tourists and the labor force available (see *Figure 8.3*). The migrants come partly from the rest of the peninsula and partly from other parts of Mexico. The internal migrants may migrate back if there are no jobs available. The migration rate is very sensitive to changes in the number of tourists.

The migration rate to the tourism region is higher on average in the policy scenario than in the base scenario, because there are more tourists in the former because water quality is better. Thus, over the 20-year period, the population in the tourism region increases more in the policy scenario than in the base scenario. The population in the rest of the peninsula in 2015 is slightly lower than in the base scenario because part of the migration to the tourism region comes from other parts of the peninsula. The peninsula's population in 2015 is higher in the policy scenario than in the base scenario.

In the sensitivity run the quality indicator for the water is lower than in the base scenario, which has a negative impact on the number of tourists. Therefore, less labor is needed in the tourism region, implying a lower migration rate to it. The population in the tourism region in 2015 is lower than in the base scenario, while in the rest of the peninsula the population is higher than in the base scenario. The total population in 2015 is slightly lower in this run than in the base scenario.

In the base scenario, the number of tourists more than doubles in the tourism region between 1995 and 2010 at an average rate of about 5% per year (see *Figure 8.4*

Table 8.3. Total population and population in the two regions for the three scenarios, 1995–2015 (in thousands).

	Base			Policy			Sensitivity		
Year	Total	Tourism region	Other region	Total	Tourism region	Other region	Total	Tourism region	Other region
1995	2,903	416	2,487	2,903	416	2,487	2,903	416	2,487
2000	3,415	576	2,840	3,422	588	2,833	3,410	566	2,845
2005	3,970	727	3,243	3,983	755	3,228	3,952	690	3,261
2010	4,542	847	3,696	4,559	883	3,677	4,520	800	3,720
2015	5,152	976	4,177	5,189	1,053	4,136	5,120	906	4,216

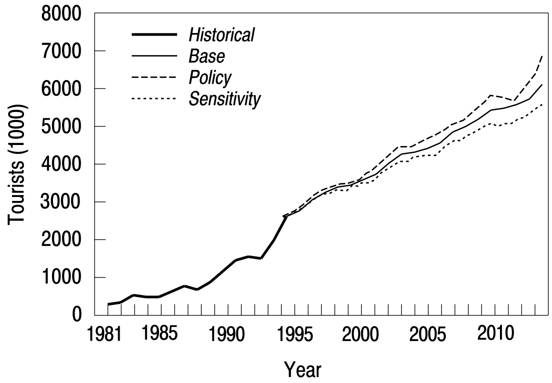

Figure 8.4. Number of tourists (in thousands), historical and in the three scenarios.

Table 8.4. Number of tourists (in thousands) in the three scenarios.

Year	Base	Policy	Sensitivity
1995	2,600	2,600	2,600
2000	3,430	3,495	3,367
2005	4,325	4,470	4,148
2010	5,168	5,459	4,899
2015	6,129	6,795	5,571

and *Table 8.4*). The quality of the archaeological sites is directly related to the number of tourists. The quality of beaches decreases slightly because the increase in the number of tourists is faster than the increase in the number of rooms. The quality of beaches and archaeological sites decreases as they become more congested. The number of rooms, which depends on investment in tourism, increases from 8,000 to 14,000 in the Cancún area. The occupancy rate increases because the number of tourists increases faster than the number of rooms (the number of tourists per room and the number of days that people stay remain the same over time). The profit per room increases steadily until 2004, after which it fluctuates between 258 and 283 pesos (in 1994 pesos) per night (see *Table 8.5*).

The growth in tourism is higher in the policy scenario than in the base scenario because of the government-imposed water policies. Over the 20-year period, the number of tourists is about 10% higher than in the base scenario. As in the other scenarios, the quality of the sites decreases with the number of tourists. The number of tourists and rooms (i.e., occupancy rate) also have an important effect on the quality of the beaches. In this scenario, the occupancy rate increases, and therefore, all else being equal, the quality of the beaches decreases. The number of rooms depends on the profit per room, and thus the number of rooms is higher as well (see *Table 8.5*). The occupancy rate is, on average, higher than in the base scenario. The

Table 8.5. Number of rooms, occupancy rate, and profit per room (in 1994 pesos) in the three scenarios.

	Base			Policy			Sensitivity		
Year	Rooms	Occupancy rate	Profit per room	Rooms	Occupancy rate	Profit per room	Rooms	Occupancy rate	Profit per room
1995	8,106	0.64	158	8,106	0.64	156	8,106	0.64	158
2000	8,974	0.76	221	8,989	0.78	230	8,955	0.75	212
2005	10,373	0.83	267	10,440	0.86	279	10,296	0.81	251
2010	12,128	0.85	258	12,132	0.90	285	12,047	0.81	228
2015	14,178	0.86	283	14,451	0.94	323	14,058	0.79	233

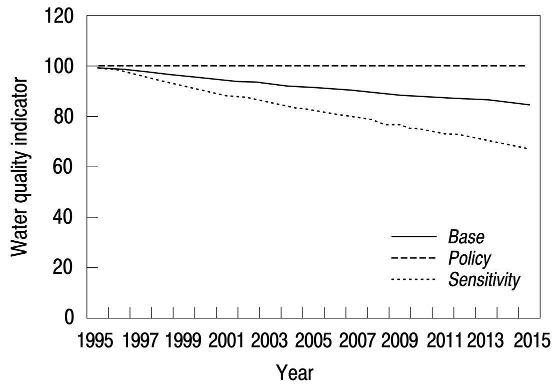

Figure 8.5. Water quality indicator for the three scenarios.

costs to the tourists increase over time because of higher demand. An interesting result is that, although the hotel owners have to pay for cleaning the water, they gain from the governmental policy because the profit per room increases. This result may help the government to impose this policy, because they could show that it is profitable in the long run for the tourism sector.

The number of tourists increases less rapidly in the sensitivity run than in the base scenario. In 2015, the number of tourists is 10% lower in the former than in the latter. The quality of the beaches remains the same while the quality of the sites decreases with the number of tourists. The number of rooms and the profit per room increase, but at a lower rate than in the base scenario (see *Table 8.5*).

Figure 8.5 shows that the water quality indicator in the base scenario decreases over time as a result of water use by the resident population and the tourists. Per day, the tourists use more water than the local population, but of course each tourist stays only for a short period. The water quality affects the number of tourists. It has a natural purification rate that depends on the quality indicator. However, over the course of a year, water use has more impact than the natural purification rate, resulting in decreasing water quality.

In the policy scenario, water quality remains at the same level because of policies ensuring that all the water that is used is cleaned. When twice as much water is used as occurs in the sensitivity analysis, the water quality decreases more than in the base scenario. It is interesting to see how water use may affect tourism, the rest of the economy, and the population in both regions.

Figure 8.6 shows international investment in the tourism sector. International investment depends on the profit per room. In the base scenario, international investment increases, but fluctuates slightly, over time. The policy scenario shows more international investment in the tourism region, because more tourists visit

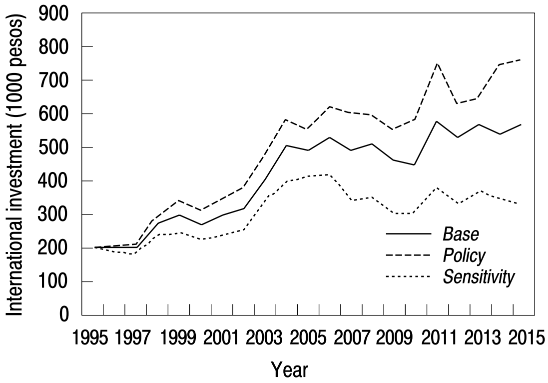

Figure 8.6. International investment in the tourism sector (in thousands of 1994 pesos) in the three scenarios.

and therefore the profit per room is higher. The fluctuation is a result of changes in prices and number of tourists and rooms. In the sensitivity run, international investment increases less than in the base scenario.

In the base scenario, economic sectors outside of tourism are also the recipients of national and regional investment. The capital stock increases with those investments. With a growing labor force and increasing prices in this region, the gross output and the profits increase as well. The wages in this region increase because the growth in gross output is higher than the growth in the labor force and the share of gross output going to labor changes only slightly (see Equations E2, E3, E8, and E9 in Appendix 8B).

For the rest of the economy, the policy scenario does not have an important effect on gross output, profits, or wages because the increase in the capital stock outweighs the decrease in labor force in this region.

In the sensitivity run, investments in the rest of the economy, gross output, and profits are lower than in the base scenario. The labor force is slightly higher and the gross output is lower, so the wages in this sector are lower than in the base scenario.

8.6 Conclusions

The goal of this study was to analyze the interactions between tourism, other economic sectors, environment, and population in a dynamic simulation model in which different policy and development path scenarios can be analyzed. We have constructed a mechanistic model that tries to explain the structure and the behavior of the system dynamically. A dynamic model is used to show the impacts over time and to include delayed effects. It is important to emphasize that the model does not provide predictions. It is intended to explain the structure and the dynamic behavior of the system. Like all models, it is a simplification of reality and therefore not all interactions and variables can be included.

In comparison with many other (optimization, equilibrium, or static) models, the dynamic model is very flexible. It allows one to change interactions, variables, or parameters. Therefore, the model can be updated when new insights, data, or relationships are acquired, which makes it a useful tool for future studies. The model is useful for policymakers because it gives some insights into the effects of policies. The graphical interface, which is user friendly and easy to learn, allows users to visualize the interactions that are part of the model and change them according to their own insights.

The model divides the economy into two sectors, the tourist sector and the other economic sector. This economic division is directly related to the two geographic regions distinguished in the model: the tourism region, which is mainly in the area around Cancún, and the rest of the peninsula, where the other economic sectors are located. This regional–economic division roughly represents the reality.

The environmental part of the model can be further specified for increased accuracy. The module for the environment is basic, and more aspects could be included, which may make the model more realistic – for example, by including land use and infrastructure. The population module can be refined and updated – for instance, to include the age structure of the population. The economy can be divided into more than two aggregated economic sectors.

In the future, the model will have to be updated, refined, and improved. The first step may be to integrate the modules presented in Chapters 7, 8, 9, and 10 into a general model. This way of improving the model will make it more useful for policymakers and stakeholders in various economic sectors.

Notes

[1] The tourism region is the aggregate of the tourist–urban and the northern and southern block-fault basin socioeconomic regions (SERs); the other region of the peninsula is the aggregate of all other SERs.

[2] Stella/ithink is a software package for developing dynamic models and performing dynamic simulation (see Peterson and Richmond, 1994 and 1996). Hannon and Ruth (1994) and Grant *et al*. (1997) provide good introductions to dynamic modeling and systems analysis using Stella/ithink.

Appendix 8A: Exogenous and Endogenous Variables

The model's exogenous and endogenous variables are presented here. These are the names that can be used in the model (for more information on using the model, see Appendix 8B).

Economic variables

gross_output1 (2) = gross output in Region 1 (Region 2)
p1 (2) = price in Region 1 (Region 2)
Si1 (2) (exogenous) = part to intermediate consumption in Region 1 (Region 2)
va (va1, va2) = value added in Region 1 (Region 2)
profit1 (2) = profit in Region 1 (Region 2)
Sk1 (2) = part to capital in Region 1 (Region 2)
wage1 (2) = wage in Region 1 (Region 2)
Sl1 = part of gross output to labor in Sector 1
Sl2 = part of gross output to labor in Sector 2 (exogenous)
lab1 (2) = labour in Region 1 (Region 2)
out2 = output sector 2
cap2 = capital in sector 2
wagemex = wage in Mexico
inv (inv1, inv2) = investments in peninsula (in Region 1, in Region 2)
invint = international investments
invyuc (invyuc1, invyuc2) = regional investments in peninsula (in Region 1, in Region 2)
invmex (invmex1, invmex2) = national investments in peninsula (in Region 1, in Region 2)
intprofitrate (exogenous) = international profit rate
gdpmex = GDP in Mexico
nat_profitrate (exogenous) = national profit rate

Variables related to tourism

tourists = number of tourists
tourproom = tourists per room
new_rooms = number of new rooms
rooms_out = number of rooms depreciated
profit_perroom = profit per room
rooms = number of rooms

occrate = occupancy rate
other = other factors influencing the number of tourists (exogenous)
demvar = factors influencing the demand for tourism

Demographic variables

popVab (poprest) = population in Region 1 (in Region 2)
birthVab (birthrest) = number of births in Region 1 (in Region 2)
miginVab (miginrest) = migration into region in Region 1 (in Region 2)
deathVab (deathrest) = deaths in region in Region 1 (in Region 2)
cbrVab (cbrrest) = crude birth rate (in 1/1000) in Region 1 (in Region 2) (exogenous)
cdrVab (cdrrest) = crude death rate (in 1/1000) in Region 1 (in Region 2) (exogenous)
popneedVab = population needed in Region 1 to perform labor
popnat = population with natural growth (without migration) in region Vab
natgrowth = natural growth of population in region Vab
mgrVab (mgrrest) = migration rate in Region 1 (in Region 2) (in 1/1000)
totpop = total population in Yucatán

Environmental variables

water_use = the use of water
cleaning = natural and policy-imposed cleaning
nat_cleaning = natural cleaning
beach_quality = quality of the beaches
water_quality = water quality
sites_quality = congestion at archaeological sites

Variables related to government policy

tour_clean = amount of water used by tourists that is cleaned
pop_clean = amount of water used by the population that is cleaned
perc_pop_clean = percentage of the water used by the population that is cleaned (exogenous, policy variable)
perc_tour_clean = percentage of the water used by tourists that is cleaned (exogenous, policy variable)
subsidy = subsidy for cleaning of water
costs_to_clean = costs to clean

Appendix 8B: Model Equations

This appendix presents the model equations and briefly explains them. The equations are written in a Stella/ithink format. Throughout the following equations the tourism sector is denoted as Sector 1 (in region 1), and the sectors in the other region as Sector 2 (in region 2).

Economic module

gross_output1 = p1*tourists*7/1000; (E1)
Si1 = 0.1; (E2)
va1 = gross_output1*(1-Si1); (E3)
profit1 = gross_output1*Sk1-costs_to_clean; (E4)
costs_to_clean = tour_clean*10/(2876*16.8/1000000); (E5)
profit_perroom = profit1*1000/rooms; (E6)
wage1 = Sl1*gross_output1/lab1; (E7)
Sk1 = GRAPH(occrate) (0.00, 0.11), (0.1, 0.12), (0.2, 0.16), (0.3, 0.213), (0.4, 0.345), (0.5, 0.37), (0.6, 0.383), (0.7, 0.403), (0.8, 0.408), (0.9, 0.42), (1, 0.428); (E8)
Sl1 = 1-Si1-Sk1; (E9)

The gross output of Sector 1 depends on the price and the number of tourists. The gross output is divided between intermediate consumption (Si1), capital (Sk1), labor (Sl1), cleaning costs, and profits. The part that goes to capital depends on the occupancy rate of the rooms. The value added is the gross output minus the intermediate consumption. The part of the gross output dedicated to labor is divided by the number of workers. The profit per room is the profit divided by the number of rooms.

inv1 = invint+invyuc1+invmex1; inv2 = invmex2+invyuc2; (E10)

Investment in the tourism sector is the sum of the international, national, and regional investment in tourism. Note that all international investments go to tourism. Investment in Sector 2 is the sum of the national and regional investment in this sector.

invint = if profit_perroom<intprofitrate then dummyg else 5*(profit_perroom-intprofitrate); (E11)
dummyg= if 1995 then 185 else 0; intprofitrate = 170; (E12)

International investment is zero if the profit per room is lower than the international profit rate.

invmex = if profit_perroom<nat_profitrate then dummyf else .005*gdpmex; (E13)
dummyf=if 1995 then 3770 else 0; (E14)
invmex1 = 0.5*invmex; (E15)
invmex2 = invmex-invmex1; (E16)
nat_profitrate = 140; (E17)
gdpmex = 686406*(1+0.05*(time-1994)); (E18)

National investment is zero if the national profit rate is higher than the profit per room, otherwise it is a part of Mexico's GDP. In the base scenario national investment is divided equally between Sectors 1 and 2. Mexico's GDP increases over time.

invyuc = profit1*0.4+0.1*wage1*lab1+.4*profit2+.05*wage2*lab2; (E19)
invyuc1 = if profit_perroom<nat_profitrate then 0.1*invyuc else dummyb; (E20)
dummyb= if delay(profit_perroom,1)-delay(profit_perroom,2)>0 then 0.6*invyuc else 0.4*invyuc; (E21)
invyuc2 = invyuc-invyuc1; (E22)

Regional investment depends on the profits and wages in both sectors. A small part of that investment goes to tourism if the profit per room is lower than the national profit rate. Otherwise, this part depends on the development in profit per room.

out2 = 0.005*SQRT(lab2)*sqrt(cap2); (E23)
gross_output2 = out2*p2; (E24)
profit2 = va2-wage2*lab2; (E25)
Si2 = 0.5; (E26)
Sl2 = 0.3; (E27)
va2 = gross_output2*(1-Si2); (E28)
wage2 = Sl2*gross_output2/lab2; (E29)

The output of Sector 2 depends on the labor (lab2) and the capital stock in Sector 2 (cap2). The gross output is the output times the price. The gross output is divided among the intermediate consumption (Si2), labor costs (Sl2), and profits. The value added is gross output minus intermediate consumption. Wages in Sector 2 depend on the part of the gross output dedicated to labor costs and the number of people working in Sector 2 (lab 2).

cap2(t) = cap2(t - dt) + (cap2_in - cap2_out) * dt; (E30)
INIT cap2 = 4000; (E31)
cap2_in = inv2/12; (E32)
cap2_out = 0.05*cap2; (E33)

The capital stock of Sector 2 increases with the investments and decreases with a fixed depreciation rate of 5%. The initial capital stock (1995) is 4000.

p2(t) = p2(t - dt) + (p2_in - p2_out) * dt; (E34)
INIT p2 = 2000; (E35)
p2_in = if dummyd>0 then 70 else 0; (E36)
p2_out = if dummyd<0 then -50 else 0; (E37)
dummyd = (delay(lab2,1)*delay(wage2,1)-
delay(wage2,2)*delay(lab2,2))/(delay(wage2,2)*delay(lab2,2)); (E38)

The price of the output of Sector 2 depends on the growth rate of wages in Sector 2.

va = va1+va2; (E39)

The value added is the sum of the value added in both sectors.

wagemex = 15; (E40)

Wages in Mexico.

Tourism module

tourists(t) = tourists(t - dt) + (tour_in - tourist_out) * dt; (T1)
INIT tourists = 2600; (T2)
tour_in = dem9; (T3)
tourist_out = if time>1995 then dummye else 2600; (T4)
dummye = delay(tour_in,1); (T5)

The number of tourists is the result of the demand, the supply, and the price of rooms. The number of tourists in 1995 is an extrapolation of the historical number of tourists.

occrate = min((tourists*6/(rooms*tourproom)),10); (T6)
tourproom = 3; (T7)

The occupancy rate depends on the number of tourists, the number of rooms, and the number of tourists per room (fixed at three people per room). The average tourist stays six nights.

rooms(t) = rooms(t - dt) + (new_rooms - rooms_out) * dt; (T8)
INIT rooms = (18859+3350)*365/1000; (T9)
new_rooms = inv1/9; (T10)
rooms_out = .03*rooms; (T11)

The number of rooms depends on the investment in tourism (inv1) and on the depreciation rate (3%). The number of rooms in 1995 is exogenous.

other = GRAPH(time) (1994, 1.84), (1998, 2.33), (2001, 2.61), (2005, 3.14), (2008, 3.45), (2012, 3.94), (2016, 4.40); (T12)

The impact of factors that are not included in the model changes over time. In the base scenario the “other” factors increase. Thus, Yucatán becomes more popular.

(T13) demvar =
other*delay(beach_quality,1)*sqrt(water_qual/100)*delay(sites_cong,1)/100;

The demand for tourist nights depends on the “other” factors and the quality of the water, the beaches, and the archaeological sites. The quality of the beaches and the sites have a one-year delayed effect on demand.

(T14) equilibrium price

The equilibrium price makes demand equal to supply. The supply of rooms depends on the price and the number of rooms. When the number of rooms increases, the supply of rooms at a certain price also increases. When the price is zero, the supply of rooms is zero; when the price is very high, the supply of rooms is equal to the number of rooms. The demand for rooms depends on the price and the other variables.

Stella II/ithink cannot solve equations simultaneously, which means that the demand, supply, and price have to be solved by an iterative process within each year. This process results in the approximation of the equilibrium price (p1) and the demand (dem9) that equals the supply.

Demographic module

popVab(t) = popVab(t - dt) + (birthVab + miginVab - deathVab) * dt; (D1)
INIT popVab = 415.890; (D2)

The initial population in 1995 is exogenous. The population changes according to the number of births, deaths, and migrants (region 1).

birthVab = popVab*cbrVab/1000; (D3)
cbrVab = GRAPH(time) (1995, 29.2), (1996, 29.2), (1997, 29.2), (1998, 29.2), (1999, 29.2), (2000, 25.3), (2001, 25.3), (2002, 25.3), (2003, 25.3), (2004, 25.3), (2005, 22.7), (2006, 22.7), (2007, 22.7), (2008, 22.7), (2009, 22.7), (2010, 21.5), (2011, 21.5), (2012, 21.5), (2013, 21.5), (2014, 21.5), (2015, 21.0); (D4)

The number of births depends on the crude birth rate (per 1000) and the population (region 1).

deathVab = popVab*cdrVab/1000; (D5)
cdrVab = GRAPH(time) (1995, 2.45), (1996, 2.45), (1997, 2.45), (1998, 2.45), (1999, 2.45), (2000, 2.28), (2001, 2.28), (2002, 2.28), (2003, 2.28), (2004, 2.28), (2005, 2.16), (2006, 2.16), (2007, 2.16), (2008, 2.16), (2009, 2.16), (2010, 2.12), (2011, 2.12), (2012, 2.12), (2013, 2.12), (2014, 2.12), (2015, 2.08); (D6)

The number of deaths depends on the crude death rate (per 1000) and the population (region 1).

lab1 = tourists*.085; (D7)
popneedVab = 2*lab1; (D8)
miginVab = popneedVab-popnat; (D9)
popnat = popVab+natgrowth; (D10)
mgrVab =miginVab*1000/popVab; (D11)
natgrowth = popVab*((cbrVab/1000)-(cdrVab/1000)); (D12)

The number of migrants depends on the labor force needed in the tourism region (region 1).

poprest(t) = poprest(t - dt) + (birthrest + miginrest - deathrest) * dt; (D13)
INIT poprest = 2486.782; (D14)

The initial population in 1995 is exogenous. The population changes according to the number of births, deaths, and migrants (region 2).

birthrest = poprest*cbrrest/1000; (D15)
cbrrest = GRAPH(time) (1995, 29.2), (1996, 29.2), (1997, 29.2), (1998, 29.2), (1999, 29.2), (2000, 27.7), (2001, 27.7), (2002, 27.7), (2003, 27.7), (2004, 27.7), (2005, 25.5), (2006, 25.5), (2007, 25.5), (2008, 25.5), (2009, 25.5), (2010, 23.5), (2011, 23.5), (2012, 23.5), (2013, 23.5), (2014, 23.5), (2015, 22.5); (D16)

The number of births depends on the crude birth rate (per 1000) and the population (region 2).

deathrest = poprest*cdrrest/1000; (D17)
cdrrest = GRAPH(time) (1995, 3.61), (1996, 3.61), (1997, 3.61), (1998, 3.61), (1999, 3.61), (2000, 3.19), (2001, 3.19), (2002, 3.19), (2003, 3.19), (2004, 3.19), (2005, 2.86), (2006, 2.86), (2007, 2.86), (2008, 2.86), (2009, 2.86), (2010, 2.62), (2011, 2.62), (2012, 2.62), (2013, 2.62), (2014, 2.62), (2015, 2.42); (D18)

The number of deaths depends on the crude death rate (per 1000) and the population (region 2).

lab2 = .5*poprest; (D19)
miginrest = mgrrest*poprest/1000; (D20)
mgrrest = 5-(0.5*miginVab*1000/poprest); (D21)

The labor force in region 2 is a fixed part of the population. Migration depends on the migration into the tourism region. Half of the migration (positive or negative) into the tourism region comes from the rest of the peninsula.

totpop = (popVab+poprest); (D22)

The total population in the peninsula is the sum of the population in the two regions.

Environmental module

water_qual(t) = water_qual(t - dt) + (cleaning - water_use) * dt; (N1)
INIT water_qual = 100; (N2)
water_use = (tourists*6* 2 1/3+pop*365)/1000000; (N3)

Water quality depends on water use and water cleaning.

cleaning = nat__cleaning+tour_clean+pop_clean; (N4)

nat__cleaning = (1-(water_qual/100))*(water_qual/100)*10; (N5)
pop_clean = perc_pop_clean*pop*365/1000000; (N6)
tour_clean = perc_tour_clean*tourists*6* 2 1/3 /1000000; (N7)

Cleaning is the sum of the natural cleaning and the cleaning of the water used by the tourists and the population. The natural cleaning depends on the water quality; population cleaning depends on the percentage of the water the government wants to clean (see government) and the number of people. The tourist cleaning depends on the percentage of the water the government wants to clean (see government) and the number of tourists.

beach_quality = GRAPH(occrate) (0.00, 0.673), (0.1, 0.695), (0.2, 0.723), (0.3, 0.75), (0.4, 0.765), (0.5, 0.783), (0.6, 0.793), (0.7, 0.793), (0.8, 0.78), (0.9, 0.758), (1, 0.723); (N8)

The higher the quality of beaches, the greater the demand for tourist nights. The quality of beaches depends on the occupancy rate of the rooms. If the occupancy rate is very low, tourists will not want to come.

sites_quality = max(100-5*(tourists/1000),10); (N9)

The quality of the sites depends on the number of tourists. The fewer the tourists, the higher the quality of the sites.

Governmental module

perc_pop_clean =0; (G1)
perc_tour_clean =0; (G2)

The government can impose a policy to clean the water used by the population (perc_pop_clean) or the tourists (perc_tour_clean). In the policy scenario, both policies are imposed, making perc_pop_clean =1 and perc_tour_clean=1 (see Section 5.2).

subsidy = pop_clean*10*(87/5)/((2468.782+415.890)*365/1000000; (G3)

When the government imposes a policy to clean the water used by the population it has to pay for it. This can be seen as a subsidy whose size depends on the amount of water to be cleaned.

References

Aguilar, A.G., and Rodriguez, F., 1995, The dispersal of urban growth in Mexico, 1970–90, *Regional Development Studies*, **1**:1–26 (Winter 1994/95).

Bergh, J.C.J.M. van den, 1996, *Ecological Economics and Sustainable Development*, Edward Elgar Publishing Limited, Cheltenham, UK and Brookfield, USA.

Brown, K., Turner, R.K., Hameed, H., and Bateman, I., 1995, Tourism and Sustainability in Environmental Fragile Areas: Case Studies from the Maldives and Nepal, SCERGE Working Paper GEC 95-30, Norwich, UK.

CINVESTAV (Centro de Investigaciones y Estudios Avanzados), 1996, Reporte de los Avances del Modelo de Economia del Proyecto Población y Medio Ambiente para un Modelo de Desarollo Sustentable, Unidad Mérida, Mérida, Mexico.

Crandall, L., 1987, The social impacts of tourism on developing regions and its measurement, in J.R. Ritchie and C.R. Goeldner, eds, *Travel, Tourism and Hospitality Research*, John Wiley and Sons, New York, NY, USA.

Deitch, L., 1989, The impact of tourism on the arts and crafts of the Indians of the southwestern United States, in V.L. Smith, ed., *Hosts and Guests: The Anthropology of Tourism*, 2nd edition, University of Pennsylvania Press, Philadelphia, PA, USA.

Dogan, H., 1989, Forms of adjustment: Socio-cultural impacts of tourism, *Annals of Tourism Research*, **16**:216–236.

Dijk, J.S. van, Hagens, J.S., and Windmeijer, F.A.G., 1991, A Simulation Model of the Dutch Tourist Market: A Technical Report on 'Toermodel', SEO Report 255, SEO, Foundation for Economic Research of the University of Amsterdam, Netherlands.

Edwards, A.D., and Cleverdon, R., 1982, *International Tourism to 1990*, ABT Books, Cambridge, UK.

Evans, G., 1994, Whose culture is it anyway? Tourism in Greater Mexico and the Indigena, in A.V. Seaton, C.L. Jenkins, R.C. Wood, P.U.C. Dieke, M.M. Bennett, L.R. MacLellan, and R. Smith, eds, *Tourism: The State of the Art*, John Wiley and Sons, London, UK.

Freytas, W. de, and Arts, L., 1989, Tourism on Cura cao: A New Deal Based on Visitors' Experience, Research Memorandum FEW 409, Department of Economics, Tilburg University, Tilburg, Netherlands.

Gelting, R.J., 1995, Water and Population in the Yucatán Peninsula, WP-95-87, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Graburn, N., 1977, *Ethnic and Tourist Arts*, University of California Press, Berkeley, CA, USA.

Grant, W.E., Pederson, E.K., and Marín, S.L., 1997, *Ecology and Natural Resource Management: Systems Analysis and Simulation*, John Wiley and Sons, New York, NY, USA.

Greenwood, D., 1989, Culture by the pound: An anthropological perspective on tourism as cultural commoditization, in V.L. Smith, ed., *Hosts and Guests: The Anthropology of Tourism*, 2nd edition, University of Pennsylvania Press, Philadelphia, PA, USA.

Hannon, B., and Ruth, M., 1994, *Dynamic Modeling*, Springer-Verlag, New York, NY, USA.

Hudman, L., 1978, Tourist impacts: The need for regional planning, *Annals of Tourism Research*, **10**:112–125.

Hunter, C., and Green, H., 1995, *Tourism and the Environment: A Sustainable Relationship?* Routledge, London and New York.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1992, XI Censo General de Población y Vivienda, INEGI, Aguascalientes, Mexico.

INEGI (Instituto Nacional de Estadística, Geografía e Informática), 1994, Anuario Estadistico de los Estados Unidos Mexicanos, INEGI, Aguascalientes, Mexico.

Inskeep, E., and Kallenberger, M., 1992, *An Integrated Approach to Resort Development: Six Case Studies*, World Tourism Organization, Madrid, Spain.

Kadt, E. de, 1979, *Tourism: The Passport to Development?* Oxford University Press, Washington, DC, USA.

Leathers, C., and Misiolek, W., 1986, Cost-benefit analysis in planning for tourism development: The special problem of socio-culture costs, *Tourism Recreation Research*, **11**:85–90.

Long, V.H., 1991, Government–industry–community interaction in tourism development in Mexico, in M.T. Sinclair and M.J. Stabler, eds, *The Tourism Industry: An International Analysis*, C.A.B. International, London, UK.

Lutz, W., ed., 1994, *Population–Development–Environment: Understanding their Interactions in Mauritius*, Springer-Verlag, Berlin, Germany.

MacCannell, D., 1984, Reconstructed ethnicity: Tourism and cultural identity in Third World communities, *Annals of Tourism Research*, **11**:375–391.

Mathieson, A., and Wall, G., 1982, *Tourism: Economic, Physical and Social Impacts*, Longman Group Limited, London, UK.

OECD (Organisation for Economic Co-operation and Development), 1995, OECD Economic Surveys, Mexico 1994–1995, OECD, Paris, France.

Peterson, S., and Richmond, B., 1994, *Stella II*, High Performance Systems, Hanover, NH, USA.

Peterson, S., and Richmond, B., 1996, *Ithink Analyst Software*, High Performance Systems, Hanover, NH, USA.

Pizam, A., and Milman, A., 1986, The social impacts of tourism, *Tourism Recreation Research*, **11**:29–33.

Ramsamy, M.S., 1994, Sustainable tourism, in W. Lutz, ed., *Population–Development–Environment: Understanding their Interactions in Mauritius*, Springer-Verlag, Berlin, Germany.

Runyan, D., and Wu, C., 1979, Assessing tourism's more complex consequences, *Annals of Tourism Research*, **6**:448–463.

Samy, J., 1980, Crumbs from the table? The workers' share in tourism, in F. Rajotte and R. Crocombe, eds, *Pacific Tourism: As Islanders See It*, The Institute of Pacific Studies of the University of the South Pacific, Fiji.

Shah, A., 1995, *The Economics of Third World National Parks: Issues of Tourism and Environmental Management*, Edward Elgar, Aldershot, UK.

Sinclair, M.T., 1991, The tourism industry and foreign exchange leakages in a developing country: The distribution of earnings from safari and beach tourism in Kenya, in M.T. Sinclair and M.J. Stabler, eds, *The Tourism Industry: An International Analysis*, C.A.B. International, London, UK.

Smith, V.L., 1988, Geographical Implications of 'Drifter' Tourism: Borocay, Philippines, Paper presented at the Symposium on Tourism, International Geographical Union, Christchurch, New Zealand.

Swain, M., 1989, Developing ethnic tourism in Yunnan, China: Silin Sani, *Tourism Recreation Research*, **14**:33–40.

Wilkinson, P., 1989, Strategies for tourism in island microstates, *Annals of Tourism Research*, **16**:153–177.

World Bank, 1994, Mexico, Country Economic Memorandum, Report 11823-ME, World Bank, Washington, DC, USA.

World Tourism Organization, 1994, *El Turismo en Mexico 1994*, World Tourism Organization, Madrid, Spain.

World Tourism Organization, 1996, http://www.world-tourism.org/trends95.htm

9

A Dynamic Simulation Model of Population Impacts on the Environment: A Fisheries Model

Lauren Hale

9.1 Introduction

This chapter provides an explanation of a preliminary fisheries model. More specifically, the chapter addresses the historical, current, and potential status of fisheries in the three Mexican states that make up the Yucatán peninsula: Yucatán, Campeche, and Quintana Roo. The first part briefly describes the issues surrounding the future of the fishing industry, particularly with regard to a changing population and environment. The second part provides the necessary explanatory documentation of the ideas used to create the fisheries module of the dynamic simulation model.

In general, the model projects the dynamics of the fish, shrimp, and lobster populations while monitoring price, demand, and supply trajectories for a 20-year time horizon (1995–2015). The model includes a variable that represents the various factors that degrade the environment. This degradation often arises on the Yucatán peninsula from oil spills and the effects of trawling. The carrying capacity of the environment for fish, shrimp, and lobster is considered to be random. An important part of the model is the policy sector, which allows students and policymakers to explore various options – such as closed seasons, quotas, and cleanup investment – in an interactive manner. The methodology and its usefulness are discussed in some detail. The equations to the model can be found in Appendix 9A.

9.2 Why Study Yucatán Fisheries?

The population–development–environment (PDE) approach necessitates a delicate balance between priority and depth of information. Therefore, when selecting the relevant variables, we must carefully examine the characteristics of the specific region of study – in this case, the Yucatán peninsula. For the Yucatán peninsula, there are very good reasons for including a fisheries model in the overall PDE model. Economically, this industry is the second largest on the peninsula after tourism (see Chapter 8). In Campeche, in particular, where there is little tourism, 83% of the industry in the state is related to fisheries (Aldape, 1997). Yet even in the state with the most tourism, Quintana Roo, income from the lobster industry is one-third of the state income.

From a biological standpoint, there is also good reason to include fisheries in the model. One of the goals of the PDE model is to include an indicator of environmental change. Often, however, data regarding the multidimensional quality of a biological system are lacking. Fortunately, in this case the renewable resource of the fisheries, for which there is much quantitative data and well-documented research, can serve as an indicator of environmental health and biological integrity.

Finally, including the fisheries in the PDE is very appealing from a modeling perspective, because there are interesting growth relationships and feedback loops between the biological populations, fishery systems, and the environment. It is also an area in which policy alternatives need to be understood, and these policy options can make a difference to the health of the environment. Fisheries are an excellent example of an interactive commons and a renewable resource that quite explicitly integrates biological, economic, and political factors. From the modeler's perspective, a fisheries model offers a wealth of opportunities to learn about the interactions between population and the environment.

9.3 Fisheries Modeling: A Complex and Compelling Discipline

> To the uninitiated, a study dealing with the economics of commercial fishing might appear to represent a routine application of the theory of competitive industry. But by building upon such basic contributions as those of Lotka (1956), Gordon (1954), and Zellner (1962), the economics of fishing becomes almost unique in the breadth of demands on modern economic concepts. The problems of stock-flow dynamics, externalities in production, the relation between man and his natural environment, social control or regulation, public investment, and the economic significance of property rights, all arise in an important and natural way in the economic analysis of fishing. [Quirk and Smith, 1969]

As Quirk and Smith suggest, the study of fisheries bioeconomics has become its own well-developed discipline. In 1954, Gordon wrote on the fishery as a common property resource. In 1955, Scott built on Gordon's common property model by considering intensity of fishing based on structure of efforts – individual ownership versus common property. In 1962, Zellner expanded the field of study by describing fisheries management as a dynamic optimization problem (Zellner, 1992). Clark's influential text *Mathematical Bioeconomics: The Optimal Management of Renewable Resources* (1976, 1990) firmly established the merit of treating resource management as a dynamic optimization exercise by integrating concepts from biology and economics.

Some of the basic mathematics is derived from ecology, while other equations come directly from economics. Mathematically, the underlying model relies on the logistic growth function. In 1838, Verhulst incorporated this growth function into a model of human population growth. In 1927, this same notion was applied to fruit fly populations by the ecologist Pearl, followed by Gause (1935) and numerous others. This model, sometimes referred to as the pure compensation model, has the proportional growth rate $r(x)$, which is a monotonically decreasing function of the number of individuals in the population, x, until the model reaches carrying capacity, K, at which point it becomes zero. Numerous similar growth models have since been developed and discussed. The depensation model developed by Neave (1953), for example, has a growth rate that is an increasing function of x until a certain critical point K^*. The critical depensation model maintains the same properties of the original depensation model but is slightly more complex, because at a certain value of x near zero, the rate of growth is actually negative. Thus all values below K_0, the minimum viable population level, are too low to support an actual population (Clark, 1990).

There are numerous criticisms of such modeling attempts that should be addressed. For example, these models assume a constant growth rate in a static environment. Furthermore, the equations used are based on highly uncertain empirically derived estimates of carrying capacity and intrinsic growth rate. Nonetheless, for many purposes, the models have provided a mathematical understanding of the dynamics of population growth and forms of overexploitation.

Overfishing, for example, can come in two basic forms. The first form, growth overfishing, refers to fishing that removes juvenile fish from the water, resulting in a population that has younger and smaller individuals. Policies that respond to concerns of growth overfishing include size quotas and gear restrictions. The more severe form of overfishing, recruitment overfishing, reduces the adult numbers to a level that decreases egg production enough to affect the future population.

The Schaeffer model of an open-access fishery involves a complex relationship between effort, yield, and cost–price ratios of catching fish. It incorporates the notion that as more fish are extracted from the ocean, it becomes harder to catch fish, resulting in a reduced catch per unit effort (CPUE). The price subsequently increases as more fishermen exert effort and costs rise. Yet, simultaneously, the demand decreases according to the elasticity of the demand function.

Although the academic history of fisheries models is extensive, few of the current fisheries models incorporate a demand function that changes over time (Conrad, 1995). In this study, however, the projections of a changing population are included in the model. In particular, it is assumed that consumers' diets will remain relatively constant over time and thus the variable affecting demand for sea resources is population growth, mostly in the form of tourism. In this way, the model presented here takes a simple multispecies fisheries model and incorporates economics and biology into the population and tourism projections. The addition of the tourism and population projections is particularly influential on the Yucatán peninsula because of the area's rapidly growing population (see Chapters 7 and 8).

9.4 Current Situation of Peninsula Fisheries

As mentioned above, the three states of the Yucatán peninsula boast strong fishing industries, each with different characteristics. In Quintana Roo, for example, the primary species caught is the spiny lobster (Arceo and Seijo, 1991). An artisanal fleet catches the lobster using traditional practices (Miller, 1989). The most commonly used traditional method of catching the lobster involves establishing artificial shelters, known as *casitas*, on the bottom of the ocean floor. The migratory lobsters travel to these *casitas* seeking refuge from predators. Since the fishermen know where the *casitas* are located, however, the shelters make easy targets (Lipcius and Eggleston, 1994). Many policies have been implemented to control the resources spent on lobster harvesting (Sosa-Cordera *et al*., 1993). In particular, there is a six-month off-season from July until December. Many of the cooperatives are run through a management scheme in which the fishermen have special tradable rights to the *casitas*. This has proved successful in that each individual *casita* does not suffer from a commons problem (Schlager and Ostrom, 1992). On the other hand, since the fishing fleet has increased and the yields are still reduced, many studies have indicated that on the whole the lobster population is substantially overfished (see *Figure 9.1*; Sosa-Cordera *et al*., 1993).

Throughout Campeche there are over 500 vessels catching clams, shark, octopus, and a variety of small fish. However, economically the most important catch in Campeche is shrimp (see *Figure 9.2*). In fact, the shrimp catch from Campeche ranks among the highest of the states in Mexico. There are two main environmental impacts from the shrimp industry. First, the shrimp trawlers disturb the fragile ecosystem floor. Although there has been some debate, most biologists believe this destructive mechanism substantially reduces the ecosystem's integrity (Auster *et al*., 1996). The second impact of the shrimp industry is the high level of bycatch – the fish and other living organisms that are thrown overboard by the fishermen. The Food and Agriculture Organization of the United Nations (FAO) estimates that for

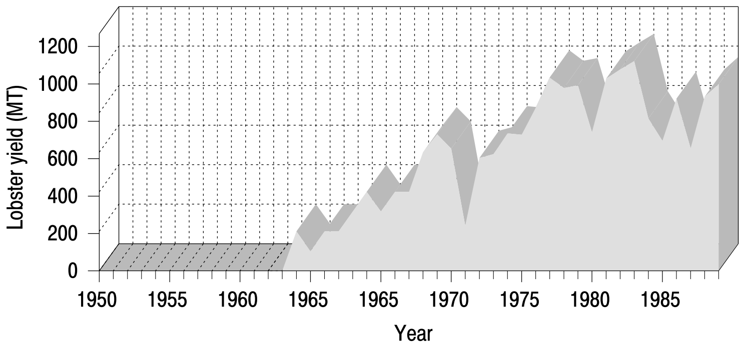

Figure 9.1. Lobster yield, 1950–1989. Source: FAO, 1994a.

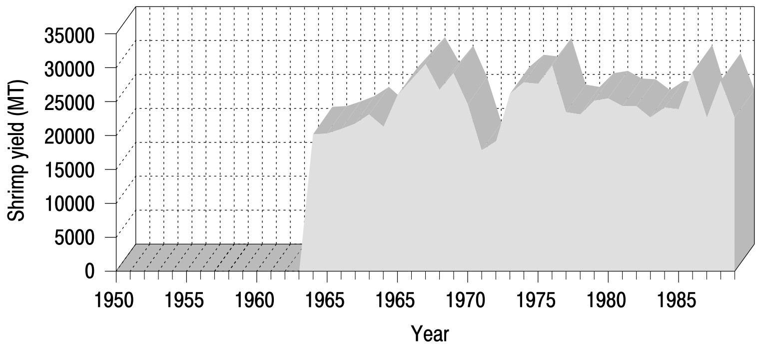

Figure 9.2. Shrimp yield, 1950–1989. Source: FAO, 1994a.

every kilogram of shrimp caught in the Gulf of Mexico, 5–10 kg of other living matter are thrown overboard as trash catch because they are juvenile fish or are less profitable than the shrimp (FAO, 1994a).

In Yucatán, the economically important fishing industries suffer from heavy fishing and mismanagement (Sadovy, 1994; Salas and Torres, 1996). As with most fish caught off the coast of Yucatán, the numbers of grouper harvested are not well documented. According to FAO data (see *Figure 9.3*), the red grouper stock plummeted around 1983. Yet, the records for grouper NEI show a sharp increase in grouper harvested around the same time as the reported decline of the red grouper population.[1] This is likely the result of a change in the method of species classification. Such a mistake in databases can be quite misleading to policymakers and scientists.

Historically, the catches of these primary species are quite varied and depend heavily on the policies in place and on the environmental situation. In 1988, Hurricane Gilbert caused a great collapse of many aquatic populations, such as the

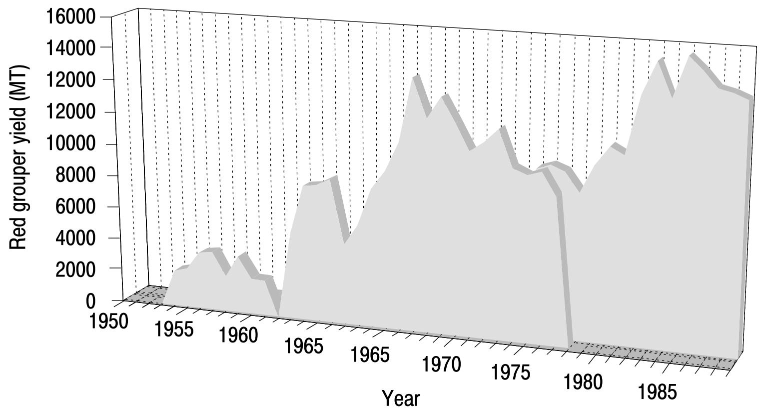

Figure 9.3. Yield of red grouper (*Epinephelus morio*), 1950–1989. Source: FAO, 1996.

lobster and octopus populations. It is clear that this is a complex and fragile system composed of both human social and economic dynamics as well as complex ecological behavior. In an effort to better understand and manage the system and to suggest potential policies, the following model was created.

9.5 Structure of the Model

The conceptual model of this system is represented in *Figure 9.4*. As shown, there are four primary sectors – biology, fisheries economics, population, and environment. Understanding the nature of fisheries on the Yucatán peninsula requires that these sectors run simultaneously. Each sector represents a system that is usually studied on its own. The fifth sector – the policy sector – indicates the various options through which a change in human behavior can yield results throughout the interconnected system.

9.5.1 Biology sector

The biology sector serves as the core of the model. Ideally, this sector would interactively involve all biota to create a more accurate depiction of the relationships. However, for the model to maintain its balance of simplicity with dynamics, three functional groups serve as indicators of the various populations: red grouper (*Epinephelus morio*), shrimp (*Penaeus* spp.), and spiny lobster (*Panulirus argus*). These were determined as the most useful functional groups based on an understanding of the different impacts and driving factors of the three fishery types. For

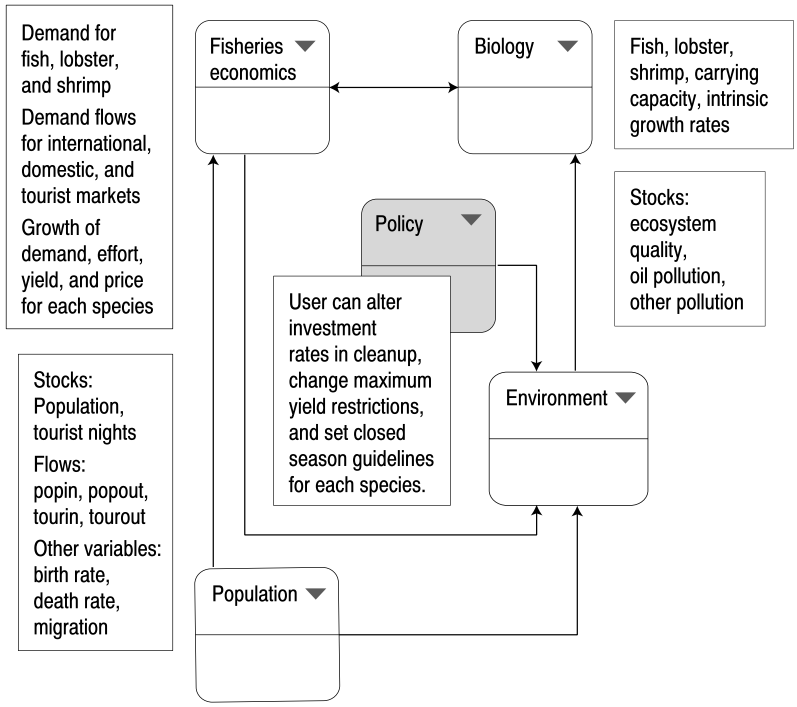

Figure 9.4. Sector map of the model.

instance, the lobster industry is primarily driven by tourism, but the shrimp industry is driven by international demand. The red grouper stock is consistently highly fished and has experienced low populations in recent years (Sadovy, 1994).

The populations of the three functional groups grow according to the Pearl–Verhulst logistic growth function, where the initial carrying capacity K is defined as 100:

$$dN/dt = r(1 - N/K) \ , \tag{9.1}$$

where N is the number of individuals in the population, r is the intrinsic growth rate, and K is carrying capacity. Thus, at any point in the model run, one can understand the population as being a percentage of the initial carrying capacity. Furthermore, the use of this equation makes the model easier to alter should new estimates of intrinsic growth rates and carrying capacity become available.

The r-values (intrinsic growth rate) are potentially dynamic but are held constant in this model. I opted to keep these values constant because of the relatively short-term analysis involved. In order for the intrinsic growth rate of the population to change significantly, serious environmental and evolutionary changes must occur.

In reality, many elements of environmental change influence the growth characteristics of the species. In this model, environmental change is manifested through a dynamic carrying capacity. The carrying capacity of the ecosystem changes in relation to overall ecosystem quality (*EQ*). *EQ* is somewhat predictable, based on quantifiable types of environmental destruction, but it is also the result of many unpredictable factors, creating much uncertainty. To deal with this uncertain environment, a relationship was created between carrying capacity and *EQ* that incorporates an auto-correlative random function. This results in a dynamic carrying capacity that varies over time. The equation that describes the relationship is

$$Baseline\ carrying\ capacity = 100 * (EQ\ (t) + \varepsilon(t))\ , \tag{9.2}$$

where

$$\varepsilon(t) = \alpha \cdot \varepsilon(t-1) + \mu\sigma^2,$$

$$\varepsilon(0) = 0,$$

$$0 < \alpha < 1\ ,$$

where $\alpha = 0.7$ and μ is an independently and normally distributed random variable with mean equal to 0 and variance (σ^2) equal to 0.3.

The α-parameter determines the strength of the auto-correlation function, such that a higher α causes the function to walk in a certain direction for a longer period of time. The σ^2-parameter, on the other hand, defines the stochastic nature of the environment per time period, such that a higher σ^2 results in a more variable environment. Although the values for σ^2 and α can be changed quite easily, they were selected based on characteristics of change in the environment per month. It makes sense that the α-value is relatively high, because the *EQ* is representative of a longer-term environmental component, such as availability of mangroves for habitat for the larvae of all the species, health of the coral reefs, or the introduction of an exotic virus.

9.5.2 Economic sector

The economic sector contains basic components: demand, effort, yield, and price. The demand for each type of catch is determined by the population structure and by the international market. Yields are defined as a percentage of initial carrying capacity. The grouper (Contreras *et al.*, 1994; Sadovy, 1994) and shrimp yields (Keithly and Roberts, 1994) for the area are currently assumed to be around maximum sustainable yield at time 0. Current lobster yields are slightly below the maximum sustainable yield given the current policy arrangements (Arreguin-Sanchez *et al.*,1993; Cabrera-Pérez *et al.*, 1994).

Table 9.1. Values for the economic sector.

Initial values, based on current estimates	Fish	Lobster	Shrimp
Demand	1.0[a]	1.0	1.0
Elasticity of demand	–0.8	–0.3	–1.6
Effort	r^*K/4.8	r^*K/3.2[b]	R^*K/5.1
Elasticity of supply	1.0	1.0	1.0
Price/metric ton[c]	\$2,633[d]	\$10,440	\$10,440[e]

[a] Baseline values are normalized to 1.0.
[b] Effort values larger than $r^*K/4.0$ do not lead to sustainable yields. It may look as though this is the case for lobster, but it is not, because the lobster season is only six months a year.
[c] Quantity taken from 1994 US dollars based on the FAO yearbook (FAO, 1996).
[d] Figure given in 1994 US dollars based on the FAO yearbook for fisheries commodities that include fresh, chilled, or frozen fish exports (FAO, 1996).
[e] Figure given is representative of the value per metric ton in 1994 of crustaceans and mollusks that are fresh, salted, dried, etc. (FAO, 1996).

The units for effort, demand, and price are in ratio form, with the numerator being the value at a given time and the denominator being the initial value. Thus, any of these numbers can be read and compared on the same graph and be easily understood as the percentage increase since the baseline time. All of these values can be easily converted given the initial values at the baseline time.

The endogenous pricing mechanism in the model is based on a simple supply–demand equilibrium that changes according to the elasticities given in *Table 9.1*. The yield is assumed to be equivalent to the amount of effort in person-hours exerted in fishing. Exceptions exist under the following conditions:

- When the population of the species is below the desired demand, the yield will equal only half of the remaining fish and shrimp.[2]
- When quotas are imposed by the policy sector, the yield will be equivalent to the maximum allowable yield according to the designated quota.

Admittedly, this model is a vast oversimplification of the relationship between effort and yield.

9.5.3 Population sector

The components of the population sector include the domestic population, the number of tourists, and a quantity representative of international demand. The population sector drives the fisheries sector by driving the demand functions. The data acquired for this sector are exogenous projections made by the IIASA PDE Yucatán

Table 9.2. Values for environment sector.

Proximal cause	Initial parameters for monthly change (with initial *EQ*=1.0)	Distal cause
Oil pollution	–.01	Population and industrial growth
Other pollution (input/month) (t=0); changes as a function of population and tourism growth	–0.1	Population and tourism growth
Ecosystem cleanup (cleanup of *EQ*/month), such as creating a marine reserve or removing pollution from the water	.02	.015 from policy investment +.05 natural cleanup, with an endogenous resilience such that the natural cleanup is doubled when ecosystem quality is decreased to 60% of its current state

model (Chapter 7). The number of tourists is also an exogenous variable that comes from the IIASA PDE tourism module (see Chapter 8).

The international market is the last component of the population sector. Growth of the international market follows constant international trends. The relevant international demand for shrimp in the USA has increased 7–9% annually since the early 1980s (NMFS, 1996), whereas the international demand for lobster and fish has only increased around 3.0% annually (FAO, 1994a).

9.5.4 Environment sector

The environment sector focuses on a simple, and purposely ambiguous, indicator of environmental health. This highly simplified indicator is based on the starting point of *EQ* = 1.0. In this model, the *EQ* variable is a function of two types of pollution: oil pollution and all other kinds of pollution (*Table 9.2*). The amount of pollution from the oil industry is determined by industry projections. Other pollution is a function of the population and number of tourists.

9.5.5 Policy sector

The policy sector is perhaps the most important part of the model because it represents those variables that are affected by short-term human behavior. The three policy options that are most influential include setting a maximum quota, defining closed seasons, and altering the water cleanup capabilities.

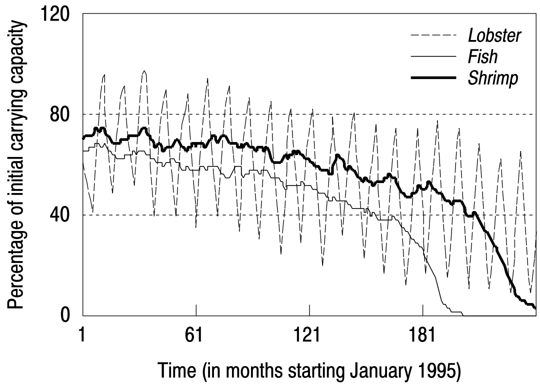

Figure 9.5. Projections of lobster, fish, and shrimp populations at current extraction rates with endogenous quota at p = 0.5.

The maximum quota is defined according to estimates of the current amount of harvesting allowed; however, these can be changed by the model user (J.C. Seijo, personal communication, July 1996; Salas and Torres, 1996). The second policy option involves defining a closed season for the species to allow the stock to grow back (Stockhausen, 1996). The last policy option involves changing the amount of investment in ecosystem cleanup; this includes removing trash, enforcing pollution laws, and delineating no-fishing zones for habitat rejuvenation (Bohnsack, 1994).

9.6 Preliminary Results

From the model, numerous graphs can be created using the software. Only a few of the interesting scenarios and corresponding policy responses are presented here.

9.6.1 Central scenario

The central scenario gives a projection of fish populations based on the central scenario data for tourism growth (see Chapter 8). The fishing policy assumes that a quota is implemented in years where demand exceeds the maximum sustainable yield (MSY). The MSY, computed from the Pearl–Verhulst logistic growth function in Equation (9.1), is $r^*K/4$ if K is constant (Clark, 1990). Unfortunately, in this model, where fish stocks and the environment behave randomly, the MSY level from Equation (9.1) may not be sustainable (see *Figure 9.5*).[3] In *Figure 9.5*, all three populations experience a severe decline or collapse. The trajectories in the figure do not indicate the time series for each species. Rather, what is shown is the average stock (out of 100 runs) calculated at p = 0.5.[4] Thus, the sequence shown

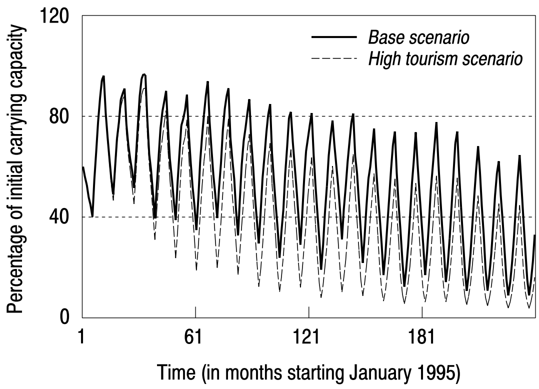

Figure 9.6. Simulation of high-tourism scenario to show effect on lobster populations with $p = 0.5$.

is much smoother than an actual time series of an individual run under a changing environment.

9.6.2 High-tourism scenario

The high-tourism scenario is the same as the base scenario except that tourism has a greater impact on the environment. Thus, as shown in *Figure 9.6*, the changing environmental impact and increasing demand result in even greater depletion of sea resources. In the high-tourism scenario, values for tourism are taken from the tourism module of the PDE model (see Chapter 8). In *Figure 9.6*, tourism growth is reflected in the lobster population, since lobster are more heavily fished when there is greater demand from tourists. The effects are increased over time, however, because the tourists' impact on the land also affects the health of the ecosystem.

9.6.3 Oil spill scenario

In the oil spill scenario, the conditions are identical to those in the high-tourism scenario with one minor adjustment. At 90 months, an arbitrary date, the amount of pollution in the water is increased by a factor of five. The oil spill lasts for only 12 months, but the effects are longer lasting. Rather than showing the effects for all three populations at once, I give a more specific example of how probabilistic projections can be useful in this framework. When discussing an oil spill, it is very difficult to know how much the environment and carrying capacity will be affected. As shown in *Figure 9.7*, an oil spill of five times the regular impact will result in an immediate drop in population. Yet, in the longer term, as a result of environmental change alone, the base scenario (at $p = 0.1$) without an oil spill can also produce

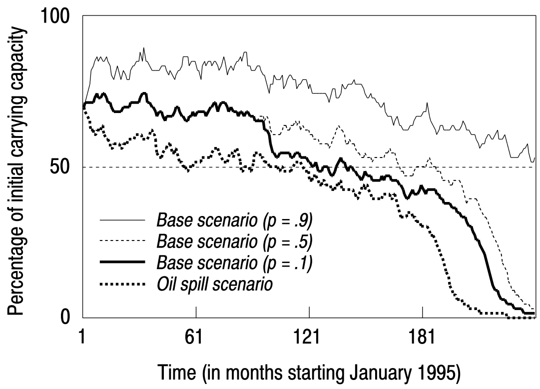

Figure 9.7. Probabilistic projection of shrimp population under base scenario at p = 0.1, 0.5, and 0.9, as well as an oil spill scenario at p = 0.5.

outcomes that have an even less sustainable shrimp population than in the oil spill scenario (p = 0.5).

9.6.4 Policy options

The various policy options can yield interesting patterns in stock dynamics. Quite intuitively, a lower total quota will result in a population that is more resilient to environmental change. Another policy option would be to reduce the amount of pollution flowing into the water. Both of these policies, however, are relatively difficult to enforce, and the fishermen and the polluters do not feel the benefits of adhering to them. Even if these policies were well administered, the impacts might not be very clear – that is, even in a clean environment or heavily managed fishing population, a fish population can still collapse (see *Figure 9.8*). On the other hand, implementing a policy such as a closed season permits the stock to replenish itself. The impacts of such a policy can be quite significant, even if the closed season is for a short period of time. For example, as can be seen in *Figure 9.8*, using the central scenario and median reading for the shrimp population, a dramatic change can result from a two-month closed season.

9.7 Analytical and Political Limitations

By no means does the PDE approach to ecology and resource management claim to hold the answer to the common-property resource problems facing us. Instead, it provides insight into just one part of the complex picture.

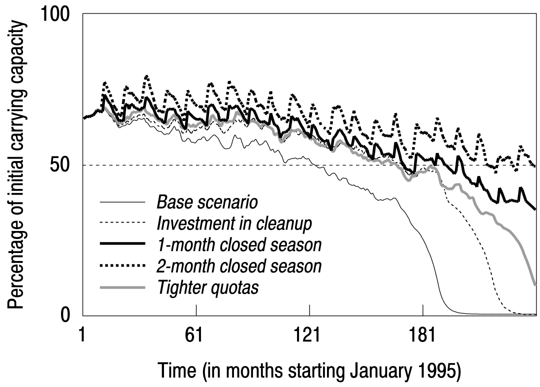

Figure 9.8. Projections of the fish populations in various policy scenarios at $p = 0.5$.

Before effective recommendations can be made, the atmosphere and attitudes of the people affected by the policies must be assessed. By addressing the specific concerns and attitudes of the community, a closer match can be made between policy and compliance.

An important political limitation is that the decisions made by individual fishermen rarely comply with the guidelines defined by neoclassical economics and profit-maximization strategies. Commercial fisherman, skipper, and researcher Menakhem Ben-Yami (1996) described the difficulties of creating generalizations about fisherman succinctly, “Average people don’t go fishing. They stay on solid land. But, at sea, even an average fisher wouldn’t be able to take many average decisions, for s/he is not working under any average conditions.”

The opinions of area fishermen regarding prudent fishery management strategy are surprisingly divided. In the small-scale cooperative artisanal fisheries of Belize – immediately south of Yucatán – 40% of the fishermen agreed to reduce their catch now in order to ensure better harvests in the future, whereas 39% disagreed.

An important analytical limitation is that the model discussed in this chapter makes unrealistic assumptions. For example, the equations assume that the process of implementing the policies will be immediate and 100% effective. In reality, there are lag times before a policy is implemented, and behavior of fishermen changes – often for the worse – until the policy goes into effect. Actual numbers on participation in illegal activities are understandably hard to gather, making such activity quite difficult to include in a model. Since these figures are not quantified in the model, they should be considered as a predictable and important source of error.

9.8 Potential Usefulness

Despite the limitations described in Section 9.7, this type of model can be of use beyond its academic role. At many levels, it informs the user about the system in ways that static optimization models cannot.

With the variety of marine resources, fisheries, and economies involved, many sorts of models could be applied to study fisheries. Each model might emphasize a different approach to fisheries management. In the literature, the primary goal is often one of the following:

- Conservation of the biological species that are harvested.
- Maximization of profit for the fishing industry.
- Utilization of the maximum biological yield from the available resources.

Clearly, however, there are many other goals of fisheries management that go unstated and are not modeled. For example, managers care about maintaining orderly entry into and exit from the industry, improving the rural economy, avoiding concentrated economic power, enhancing family fishing, and maintaining the number of domestic fishermen (Bishop *et al*., 1981).

The diversity of these goals provides some idea of the heterogeneity of possible models. As more knowledge is gained, scientists are coming closer to a consensus about the best way to model a fisheries system.

The form of modeling used in this project is flexible. Rather than calculating a specific output, this form of simulation modeling allows the decision maker to get a sense of the dynamics that are involved and test a number of variables at once. For example, testing policy options against an uncertain environment can be very useful and informative. The nature of this technique also allows environmental managers to play with the model and incorporate relationships based on assumptions and knowledge germane to their location. Although this technique does not provide answers, it gives these managers a framework within which to think about the many variables involved (Grant *et al*., 1997).

9.9 Conclusions

While the output graphs created by the dynamic simulation model do not promise to be precise measures of the prices, demands, or supplies of the species of the Yucatán, they depict interesting and informative situations. Conclusions can be drawn from this project at various levels.

Historically, the fisheries of the Yucatán peninsula have lacked sound management practices and have experienced several biological collapses with concomitant economic losses. As the community of scientists and fishermen gain knowledge, they can achieve a better understanding of how the ecosystem works. In this way, they can develop and implement better management policies. By regulating the fishing seasons and the maximum quota as well as providing responsible cleanup practices, a sustainable fishing environment can be maintained.

By remaining flexible and open to new information, modeling the management strategies can be an effective way for biologists, economists, and fishermen to work together to design optimal fishing policies. This can be achieved by involving the stakeholders in describing their system and contributing to the model. Such a policy approach could create a community of informed and aware individuals.

Dynamic simulation models can be a very useful technique for gaining a greater understanding of the depth and quality of the interactions that occur in the complex system. They allow for unknown variables to be altered as more information is gathered and permit the user to explore various alternative futures. Most important, such models serve as a heuristic device enabling the user to learn about and develop a better sense of the complex relationships involved in the system.

Acknowledgments

This chapter and corresponding model certainly are not the product of my mind or effort alone. I owe credit to an outstanding assemblage of colleagues, friends, and fishfolk. First, I thank Warren Sanderson, my supervisor, for his attentive guidance. Also, at IIASA, I wish to acknowledge Patricia Kandelaars, Wolfgang Lutz, and the rest of the Population Project. I offer my sincerest thanks to all of the members of the fishing community who provided me with information and enthusiasm to complete this project. In particular, I would like to thank Juan Carlos Seijo, Silvia Salas, Eloy Sosa-Cordera, Doug Cross, David Miller, Luis Coba-Cetina, Ana Minerva-Arce, and Juan Schmitter-Soto. Special thanks to the library help from Kay Hale, Tom Parris, and Aviott John.

Notes

[1] The FAO uses the term “NEI” to indicate species that are “nowhere else included” in their records. Thus, “grouper NEI” refers to all grouper fish not documented in the database (FAO, 1994a).

[2] This is not the case, however, with the extraction of lobster because of the very effective method of catching lobster using the *casita* method (Lipcius and Eggleston, 1994).

[3] The estimated quotas that take effect in the model are $r^*K/4.5$, $r^*K/4.8$, and $r^*K/2.5$ for fish, shrimp, and lobster, respectively.

[4] The p-value indicates the percentile of all the values at a given time for the numerous runs of the model. For example, if $p = .1$, then 10% of the numbers from the stochastic runs are below the value, whereas 90% are above the value.

Appendix 9A: Equations of the Fisheries Model

This appendix presents the model's equations and briefly explains them. The equations are written in a Stella/ithink format.

Biology Sector

Fish(t) = Fish(t - dt) + (Fishin - Fishout) * dt
INIT Fish = 65; Fishin = FishGR; Fishout = Fish_Yield; FishGR = Fish_R*Fish*(1-Fish/FishK); FishK =
100 * (ECOSYSTEM_QUALITY+2)/3 * (1+Autoregressive_Error); Fish_R = .24

LOBSTER(t) = LOBSTER(t - dt) + (LobsterIn - LOBSTEROUT) * dt
INIT LOBSTER = 60; LobsterIn = LOBST_GR; LOBSTEROUT = (Lobster_Yield); Lobster_K =
100*(ECOSYSTEM_QUALITY+3)/4*(1+Autoregressive_Error); LOBST_GR = lobst_r*LOBSTER*(1-LOBSTER/Lobster_K); lobst_r = .57

SHRIMP(t) = SHRIMP(t - dt) + (SHRIMPIN - SHRIMPOUT) * dt
INIT SHRIMP = 70; SHRIMPIN = SHR_GR; SHRIMPOUT = (Shrimp_Yield)
Shrimp_K = 100*(Autoregressive_Error+1)*(ECOSYSTEM_QUALITY+2)/3; shrimp_r = .43
SHR_GR = shrimp_r*SHRIMP*(1-SHRIMP/Shrimp_K)

These three populations grow according to a logistic growth curve specific to the nature of the biological species. The variables for each population growth rate include intrinsic growth rate, carrying capacity, initial population, and amount of population harvested each month. Each growth curve also includes an autoregressive error function described as follows:

Autoregressive_Error(t) = Autoregressive_Error(t - dt) + (Change) * dt;
INIT Autoregressive_Error = 0; Change = (.7-1)*Autoregressive_Error+normal; normal = normal(0,.3,seed); seed = 124

The random numbers are selected based on a random distribution of numbers between -1 and 1, where the standard deviation is 0.3. The arbitrary value of the seed, which is 124 in the example above, allows for repetition of runs by providing the same series of random numbers, it can be changed to give a different random selection of numbers.

Environment Sector

Ecosystem_Quality(t)=Ecosystem_Quality(t - dt)+(Ecorestore -Ecodegrade)*dt
INIT Ecosystem_Quality=1; Ecorestore=IF(Ecosystem_Quality>.6)
THEN(Ecosystem_Quality*(Ecocleanup+.005))
ELSE(Ecosystem_Quality*(Ecocleanup+.005*2));

```
ECODEGRADE=(Oil+Other Pollution+(ShrimpEffort)*0.002)*Ecosystem_Quality
OIL =(SQRT(International_Market/INIT(International_Market))*.01)
OtherPollution =
SQRT(Population/INIT(Population))*.006+SQRT(Tourism/INIT(Tourism))*.002
```

The state of the environmental sector is expressed on a scale that ranges between 0 and 1, where 0 refers to the state where environment is destroyed and 1 refers to the state where environment is unaffected by people. In 1995, the state of the environment was assumed to be 1. The variables that adversely affect the environmental quality are oil pollution, other pollution, and shrimp trawling effort. The environment is cleaned up by a natural restoration process and through investment in cleanup.

Fisheries Economics

```
FishEffort(t) = FishEffort(t - dt) + (FishEffortChange) * dt
FishEffortChange = IF(FishPriceChange<0) THEN(-FishEffort*.01)
ELSE(FishEffort*.01)
FishPrice(t) = FishPrice(t - dt) + (FishPriceChange) * dt
FishPriceChange = IF(FishDiff>0) THEN(-FishPrice*.01) ELSE(FishPrice*.01)
Fish_Demand(t) = Fish_Demand(t - dt)+(FishDemandFlow+Eq_Fish_DemandFlow)*dt
FishDemandFlow =
Fish_Demand*(.6*change_in_tourism_each_month+.2*change_in_population_
each_month+.2*(International_Market-Delay(International_Market,1)))
Eq_Fish_DemandFlow = IF(FishPriceChange>0) THEN(-Fish_Demand*.008)
ELSE(Fish_Demand*.008)
LobsterEffort(t) = LobsterEffort(t - dt) + (LobsterEffortChange) * dt;
LobsterEffortChange =
IF(LobsterPriceChange<0) THEN(-LobsterEffort*.01) ELSE(LobsterEffort*.01)
Lobster_Demand(t) = Lobster_Demand(t - dt) + (External_Lobster_Demand_Flow +
Eq_LobsterDemand_Flow)* dt
External_Lobster_Demand_Flow=(.03*change_in_population_each_month+.96*
change_in_tourism_each_month+.01*(International_Market-
Delay(International_Market,1)))*Lobster_Demand
Eq_LobsterDemand_Flow = IF(LobsterPriceChange>0) THEN(-Lobster_Demand*.005)
ELSE(Lobster_Demand*.005)
Lobster_Price(t) = Lobster_Price(t - dt) + (LobsterPriceChange) * dt
LobsterPriceChange=IF(LobsDiff>0) THEN(-.01*Lobster_Price)
ELSE(.01*Lobster_Price)
ShrimpDemand(t)=ShrimpDemand(t-dt) +
(ShrimpDemandFlow+Eq_Shrimp_Demand_Flow)*dt
ShrimpDemandFlow = ShrimpDemand*(.5*(International_Market-
DELAY(International_Market,1))+.25*change_in_tourism_each_month+change_in_
population_each_month*.25)
Eq_Shrimp_Demand_Flow = IF(ShrimpPriceChange>0) THEN(-ShrimpDemand*.016)
ELSE(ShrimpDemand*.016)
ShrimpEffort(t) = ShrimpEffort(t - dt) + (ShrimpEffortChange) * dt
```

ShrimpEffortChange = IF(ShrimpPriceChange<0) THEN(-ShrimpEffort*.01) ELSE(ShrimpEffort*.01)
ShrimpPrice(t) = ShrimpPrice(t - dt) + (ShrimpPriceChange) * dt
ShrimpPriceChange = IF(ShrimpDif>0) THEN(-ShrimpPrice*.01) ELSE(ShrimpPrice*.01)
FishDiff = FishYieldRatio-Fish_Demand
FishEffOff = IF(Yearly_Cycle>=12-Closed_Fish) THEN(0) ELSE(FishEffort)
FishYieldRatio = Fish_Yield/INIT(Fish_Yield)
Fish_Price_1994 = FishPrice*2633
Fish_Yield = MIN(Fish_R*INIT(FishK)/Fish_A, (INIT(FishK)*Fish_r/4.8)*FishEffOff/INIT(FishEffort),Fish/2)
LobsDiff = LobstYieldRatio-Lobster_Demand
LobstEffOff = IF(Yearly_Cycle>=12-Closed_Lobster) THEN(0) ELSE(LobsterEffort)
Lobster_Price__1994 = Lobster_Price*10440
Lobster_Yield = MIN(lobst_r*INIT(Lobster_K)/Lobster_A, Lobster, (lobst_r*INIT(Lobster_K)/3.2)*LobstEffOff/INIT(LobsterEffort))
LobstYieldRatio = Lobster_Yield/INIT(Lobster_Yield)
ShrimpDif = ShrimpYieldRatio-ShrimpDemand
ShrimpEffOff = IF(Yearly_Cycle>=12-Closed_Shrimp) THEN(0) ELSE(ShrimpEffort)
ShrimpYieldRatio = Shrimp_Yield/INIT(Shrimp_Yield)
Shrimp_Price_1994 = ShrimpPrice*10440; Shrimp_Yield = MIN(INIT(Shrimp_K)*shrimp_r/Shrimp_A, SHRIMP/2, shrimp_r*Shrimp_K/5.1*ShrimpEffOff/INIT(ShrimpEffort))

The values for effort, yield, and price for the three functional biological groups are given as multiples of the base year (1995). The value 1.0 is used as the initial value for each simulation. The effort is determined by the policy regulations and the demand for fish, and the yield is a function of the biological population available at the time of catching. The price is determined by the equilibration of demand and supply functions.

Policy Playground

Closed_Fish = 0; Closed_Lobster = 6; Closed_Shrimp = 0; ECOCLEANUP = .015
Fish_A = 4.5; Lobster_A = 2.5; Shrimp_A = 4.8;

The various policy decisions are codified in this section. "Closed" refers to the number of months out of the year that the season in not open to fishing. "Ecocleanup" represents the amount of investment in cleanup of the environment, where .015 is the current amount of investment. The "A" values indicate the denominator in the equation determining quota, where a value of "4.0" corresponds to a harvest equaling the maximum sustainable yield at initial conditions.

Population

INTERNATIONAL_Market(t) = INTERNATIONAL_Market(t - dt) + (International_Inflow) * dt

INIT INTERNATIONAL_Market = 1
International_Inflow = .0025*INTERNATIONAL_Market
change_in_population_each_month =
(Population!-DELAY(Population!,1))/INIT(Population!)
change_in_tourism_each_month = (Tourism!-Delay(Tourism!,1))/INIT(Tourism!)
Population! = GRAPH(t)
(0.00, 2903), (12.0, 2997), (24.0, 3096), (36.0, 3205), (48.0, 3313), (60.0, 3415), (72.0, 3510), (84.0,
3615), (96.0, 3724), (108, 3847), (120, 3970), (132, 4071), (144, 4180), (156, 4294), (168, 4422), (180,
4542), (192, 4662), (204, 4792), (216, 4905), (228, 5024), (240, 5152)
Tourism! = GRAPH(t)
(0.00, 2600), (12.0, 2769), (24.0, 3037), (36.0, 3259), (48.0, 3386), (60.0, 3430), (72.0, 3576), (84.0,
3737), (96.0, 4027), (108, 4278), (120, 4325), (132, 4433), (144, 4571), (156, 4835), (168, 4980), (180,
5167), (192, 5447), (204, 5493), (216, 5576), (228, 5739), (240, 6129)

The population numbers utilize the output from the population and tourism model for this project (see Chapter 8).

Yearly_Cycle = COUNTER(1,12).

References

Aldape, V., 1997, Mexico Online, http://www.mexicool.com.

Arceo, P., and Seijo, J.C., 1991, Fishing Effort Analysis of the Small Scale Spiny Lobster (*Panulirus argus*) Fleet of the Yucatán Shelf, Fish Report 431, Food and Agriculture Organization, Rome, Italy, pp. 59–74.

Arreguín-Sánchez, F., 1987, Population dynamics of tropical fisheries: The Mexican experience, in E.A. Chavez, ed., *Memorias del Seminario México-Australia en Ciencias Marinas*, Vol. 1, Mérida, Yucatán, Mexico, pp. 241–256.

Arreguín-Sánchez, F., 1990, A Multispecies Simple Approach to Estimate Catch Tendencies with Application to the Caribbean Fisheries of México, CINVESTAV-IPN, Unidad Mérida, Yucatán, Mexico.

Arreguín-Sánchez, F., 1991, Time recovery for exploited fish populations based on surplus yield models, *Fishbyte*, ICLARM, Philippines.

Arreguín-Sánchez, F., Chavez, E.A., and Menchaca, J.A., 1992, A multispecies stock assessment of a pelagic coastal fishery of the southwest Gulf of Mexico, *Aquaculture and Fisheries Management*, **23**:103–112.

Arreguín-Sánchez, F., Seijo, J.C., and Valero-Pacheco, E., 1993, An application of ECOPATH II to the north continental shelf ecosystem of Yucatán, Mexico, in V. Christensen and D. Pauly, eds, *Trophic Models of Aquatic Ecosystems*, ICLARM Conference Proceedings 26, Philippines, pp. 269–278.

Arreguín-Sánchez, F., Valero-Pacheco, E., Vega-Cendejas, M.E., and Hernández, M., 1994, Preliminary estimates of community response to fishing using trophic box models: The beach seine fishery along the northwestern coast of Yucatán, in M.H. Goodwin *et al*, eds, *Proceedings of the Forty-Third Annual Gulf and Caribbean Fisheries Institute*, GCFI, Charleston, SC, USA, pp. 337–345.

Auster, P.J. *et al*., 1996, The impacts of mobile fishing gear on seafloor habitats in the gulf of Maine (northwest Atlantic): Implications for conservation of fish populations, *Reviews in Fisheries Science*, **4**(2):185–202.

Ben-Yami, M., 1996, Re: Fisher Behavior and Decision Making, in an e-mail to Fishfolk Listserv, 2 August 1996.

Bishop, R.C., Bromley, D.W., and Langdon, S., 1981, Implementing multiobjective management of commercial fisheries: A strategy for policy-relevant research, in L.G. Anderson, ed., *Economic Analysis for Fisheries Management Plans*, Ann Arbor Science Publishers, Inc., Ann Arbor, MI, USA, pp. 197–219.

Bohnsack, J.A., 1994, How marine fishery reserves can improve reef fisheries, in M.H. Goodwin *et al*., eds, *Proceedings of the Forty-Third Annual Gulf and Caribbean Fisheries Institute*, GCFI, Charleston, SC, USA, pp. 217–241.

Cabrera-Pérez, J.L., Salas-Márquez, S., and Arreguín-Sánchez, F., 1994, Una aproximacion preliminar para estimar migraciones: El caso de la langosta *Panulirus argus* de Yucatán, México, in M.H. Goodwin *et al*., eds, *Proceedings of the Forty-Third Annual Gulf and Caribbean Fisheries Institute*, GCFI, Charleston, SC, USA, pp. 263–278.

Carter, J., Marrow, G.J., and Pryor, V., 1994, Aspects of the ecology and reproduction of Nassau grouper (*Epinephelus striatus*) off the coast of Belize, Central America, in M.H. Goodwin *et al*., eds, *Proceedings of the Forty-Third Annual Gulf and Caribbean Fisheries Institute*, GCFI, Charleston, SC, USA, pp. 65–111.

Clark, C.W., 1981, Bioeconomics, in R. May, ed., *Theoretical Ecology: Principles and Applications*, 2nd edition, Blackwell Scientific Publications, Oxford, UK.

Clark, C.W., 1990, *Mathematical Bioeconomics: The Optimal Management of Renewable Resources*, 2nd edition, John Wiley and Sons, Inc., New York, NY, USA, pp. 110–113.

Clark, C.W., 1996, Operational environmental policies, *Environment and Development Economics*, **1**:103–109.

Conrad, J.M., 1995, Bioeconomic models of the fishery, in D. Bromley, ed., *The Handbook of Environmental Economics*, Blackwell Handbooks in Economics, Oxford, UK.

Contreras, M. *et al*., 1994, Mortality and population size of the red grouper (Epinephelus morio) fishery from the Campeche Bank, in M.H. Goodwin *et al*., eds, *Proceedings of the Forty-Third Annual Gulf and Caribbean Fisheries Institute*, GCFI, Charleston, SC, USA, pp. 392–401.

Diaz-De-Leon, A.J., and Seijo, J.C., 1992, A multicriteria non-linear optimization model for the control and management of a tropical fishery, *Marine Resources Economics*, **7**:23–40.

FAO (Food and Agriculture Organization), 1994a, FISHSTAT Database Program.

FAO (Food and Agriculture Organization), 1994b, A Global Assessment of Fisheries Bycatch and Discards, Fisheries Technical Paper 339, FAO, Rome, Italy.

FAO (Food and Agriculture Organization), 1996, *Yearbook of Fishery Statistics*, FAO, Rome, Italy.

Gause, G.F., 1935, *La Theorie Mathematique de la Lutte pour la Vie*, Hermann, Paris, France.

González de la Rosa, E., Sánchez, J.A., and Sánchez, F.A., 1994, Population dynamics of the red snapper (*Lutjanus campechanus*) fishery from the Campeche bank, Mexico, in M.H. Goodwin *et al*., eds, *Proceedings of the Forty-Third Annual Gulf and Caribbean Fisheries Institute*, GCFI, Charleston, SC, USA, pp. 29–42.

Gordon, H.S., 1954, The economic theory of a common property resource: The fishery, *Journal of Political Economy*, **808**(4):761–768.

Grant, W.E., Pederson, E.K., and Marin, S.L., 1997, *Ecology and Natural Resource Management: Systems Analysis and Simulation*, John Wiley and Sons, Inc., New York, NY, USA.

Griffin, W.L., and Stoll, J.R., 1981, Economic issues pertaining to the Gulf of Mexico shrimp management plan, in *Economic Analysis for Fisheries Management Plans*, Ann Arbor Science Publications, Ann Arbor, MI, USA.

INEGI (Instituto Nacional de Estadística Geografía e Informática), 1995, *Estad ísticas del Medio Ambiente México, 1994*, Aguascalientes, Mexico, June.

Keithly, W.R., Jr., and Roberts, K., 1994, Central and South American shrimp and their role in the U.S. shrimp market, in M.H. Goodwin *et al*., eds, *Proceedings of the Forty-Third Annual Gulf and Caribbean Fisheries Institute*, GCFI, Charleston, SC, USA, pp. 586–604.

Lee, K.N., 1993, *Compass and Gyroscope: Integrating Science and Politics for the Environment*, Island Press, Washington, DC, USA.

Lipcius, R.N., and Eggleston, D.B., 1994, Shelter limitation and stock enhancement of spiny lobster [abstract], in M.H. Goodwin *et al*., eds, *Proceedings of the Forty-Third Annual Gulf and Caribbean Fisheries Institute*, GCFI, Charleston, SC, USA, p. 684.

Lotka, A.J., 1956, *Elements of Mathematical Biology*, Dover Publications, New York, NY, USA.

Lutz, W., ed., 1994, *Population Development Environment: Understanding their Interactions in Mauritius*, Springer-Verlag, Berlin, Germany.

Miller, D., 1989, The evolution of Mexico's Caribbean spiny lobster fishery, in *Common Property Resources: Ecology and Community-Based Sustainable Development*, Bellhaven Press, London, UK.

Neave, F., 1953, Principles affecting the size of pink and chum salmon populations in British Columbia, *Journal of the Fisheries Research Board of Canada*, **9**:450–491.

NMFS (National Marine Fisheries Service), 1996, *Fisheries Bulletin*, August.

Pearl, R., 1927, The growth of populations, *Quarterly Review of Biology*, **2**:532–548.

Quirk, J.P., and Smith, V.L., 1969, Dynamic Economic Models of Renewable Resource Management, Research Paper 22, Department of Economics, University of Kansas, Lawrence, KS, USA.

Recksiek, C.W., and Pollnac, R.B., 1990, Coral reef management areas: Prospects and problems, in M.H. Goodwin *et al*., eds, *Proceedings of the Forty-Third Annual Gulf and Caribbean Fisheries Institute*, GCFI, Charleston, SC, USA, pp. 525–547.

Sadovy, Y., 1994, Grouper stocks of the western central Atlantic: The need for management and management needs, in M.H. Goodwin *et al*., eds, *Proceedings of the Forty-Third Annual Gulf and Caribbean Fisheries Institute*, GCFI, Charleston, SC, USA, pp. 43–64.

Salas, S., and Torres, R., 1996, Factors Affecting the Success of Fisheries Management in a Mexican Fishery, Fisheries Center, University of British Columbia, Vancouver, Canada, unpublished paper.

Sánchez-Chávez, J.A., *et al*., 1994, A simple robust approach for virtual population analysis using spreadsheets with an application to the red snapper fishery from the Campeche bank, in M.H. Goodwin *et al*., eds, *Proceedings of the Forty-Third Annual Gulf and Caribbean Fisheries Institute*, GCFI, Charleston, SC, USA, p. 327.

Schlager, E., and Ostrom, E., 1992, Property-rights regimes and natural resources: A conceptual analysis, *Land Economics*, **68**(3):249.

Schmitter-Soto, J.J., and Gamboa-Pérez, H.C., 1966, Composicion y distribucion de peces continentales en el sur de Quintana Roo, Peninsula de Yucatán, México, *Rev. Biol. Trop.*, **44**(1):199–212.

Scott, A.D., 1955, The fishery: The objective of sole ownership, *Journal of Political Economy*, **63**:116–124.

Sosa-Cordera, E., Medina-Quej, A., Ramirez-Gonzalez, A., Dominguez-Veveros, M., and Aguilar-Davila, W., 1993, Invertebrados marinos explotados en Quintana Roo, in S.I. Salazar-Vallejo and N.E. Gonzalez, eds, *Biodiversidad Marina y Costera de México*, Comisión Nacional de Biodiversidad, CIQRO, Mexico, pp. 709–734.

Suarez-Caabro, J.A., 1994, An overview of the fisheries of the Caribbean and adjacent seas, in M.H. Goodwin *et al*., eds, *Proceedings of the Forty-Third Annual Gulf and Caribbean Fisheries Institute*, GCFI, Charleston, SC, USA, pp. 292–304.

Stockhausen, B., interview by author, Gloucester Point, VA, 27 November 1996.

Tucker, J.W., Jr., 1994, Symposium summary biology and aquaculture, in M.H. Goodwin *et al*., eds, *Proceedings of the Forty-Third Annual Gulf and Caribbean Fisheries Institute*, GCFI, Charleston, SC, USA, pp. 476–482.

Verhulst, P.-F., 1838, Notice sur la loi que la population suit dans son accroissement, *Correspondence Mathématique et Physique* **10**:113–121.

Zellner, A., 1992, Three-stage least squares: Simultaneous estimation of simultaneous equations, in H. Theil, B. Raj, and J. Koerts, eds, *Henri Theil's Contributions to Economics and Econometrics*, Vol. 1, Econometric Theory and Methodology, Advanced Studies in Theoretical and Applied Econometrics, Vol. 23, Kluwer Academic Publishers, Dordrecht, Netherlands, pp. 147–178 [previously published in 1962].

10

Land Use on the Yucatán Peninsula: System and Model Description and Land-Use Scenarios

Leonel Prieto

10.1 Introduction

Among the factors that determine land-use changes are history, population, the economy, the biophysical environment, and the social and political organization of societies. Therefore, land-use patterns at a given point in time may be both partly responsible for and a result of environmental degradation or preservation, economic growth, and social development in a given area.[1] Land-use changes on the Yucatán peninsula have been largely defined by the interaction between market forces and state intervention in regional development. The aim of this chapter is to describe the main components of the land-use system and to explore some probable land-use scenarios for the Yucatán peninsula. For this purpose, an algorithm incorporating the effect of land productivity and user-defined specifications on land-use dynamics is used.[2]

The chapter is structured as follows: Section 10.2 provides a description of the land-use system. Section 10.3 gives a brief presentation of the land-use model. Procedures incorporating food security concerns for the rural population and water availability constraints in commercial agriculture are also described. Scenario and sensitivity analyses are presented in Sections 10.4 and 10.5, respectively. Section 10.6 presents a discussion of the main results. Conclusions are presented in Section 10.7.

10.2 Description of the Land-Use System

The following land-use categories are considered: primary and secondary forest, nature reserves, traditional agriculture, commercial agriculture, pastureland, and physical infrastructure.

10.2.1 Primary and secondary forest

Because of its distinctive natural conditions, the peninsula supports relatively specialized flora and fauna. Approximately 17% of the recorded species are endemic, and a large proportion are not found in other parts of Mexico (Espejel, 1987). The proportion of territory dedicated to nature reserves is higher on the peninsula than in the rest of the country (14% versus 4%; CONABIO, 1996). Throughout the centuries, the relatively low-level, intermittent use of natural resources on the peninsula has affected the primary forest very little. Only during the past 20–30 years has extensive clearing of forests for the expansion of private cattle ranches and the establishment of *ejidal* colonization projects threatened the survival of the primary forest. However, the establishment of new pastures seems to have abated.[3] Extensive clearings for henequen (*Agave* spp.) plantations (see Section 10.2.4), firewood and charcoal production, and repeated cycles of milpa (see Section 10.2.3) and pastures have drastically altered forests in the drier, more densely populated northwestern region. Except for a few isolated patches, the original deciduous ecosystems have been succeeded by complex patterns of secondary vegetation.[4] In the 1960s, commercial timber production practically exhausted forest resources in the northeastern part of the state of Yucatán. Conversion of secondary and primary forest into pastureland was highest in this region. Currently, there are some small enterprises exploiting precious hardwoods in southern Quintana Roo and Campeche. Apart from some nature reserves, primary forest is mainly located in the central, eastern, and southern parts of the peninsula. Since the peninsula's economy has been based on the use of natural resources – namely, hardwoods extraction, *haciendas*, henequen and cattle production, and tourism – most of the negative impacts on primary and secondary forest have been caused by these activities.

10.2.2 Nature reserves

The peninsula has approximately 2,600,000 hectares (ha) of nature reserves (INE and CONABIO, 1995; CONABIO, 1996). Reserves are, by and large, run by the federal government. Most reserves are located at the land–sea interface. The resources to be protected include coral reefs (e.g, Arrecife Alacranes and Siam Ka'an); lagoon–estuarine systems with mangroves, wetlands, and aquatic ecosystems (e.g., Laguna de Términos and Ría Celestum); feeding, nesting, and breeding grounds of marine and migratory birds (e.g., Isla Contoy, Arrecife Alacranes, Ría Lagartos, and Ría Celestum); rich forested ecosystems (e.g., Calakmul); and archaeological sites (e.g., Ría Lagartos, Calakmul, and Siam Ka'an). Major threats to the ecosystems of the nature reserves include overfishing, uncontrolled tourism, water pollution, extraction of wood, charcoal production, potential anthropogenic changes to hydrological flows, and unsettled land tenure. These factors are already negatively impinging on the biophysical environment in various areas. Therefore, their control is central to the preservation of the peninsula's nature reserves and natural resources.

10.2.3 Traditional agriculture

Traditional agriculture is known regionally as the milpa system. It is the main economic activity of hundreds of small dispersed human settlements. The milpa system provides most of the food produced on the peninsula. It is a system of continuous fallow rotation.[5] The main milpa crop is maize (*Zea mays*), which is usually intercropped with beans (*Phaseolus* spp.) and squash (*Cucurbita* spp.). Maize yields on the peninsula are usually low (among the lowest in Mexico) and highly variable. Mean yields are approximately 650 kg/ha (Cuanalo de la Cerda *et al*., 1996).[6] In an attempt to adapt to this variability, which is partly due to soil heterogeneity, the milpa system includes a diverse and flexible mixture of crops and activities.[7] The timing of cropping operations closely matches the seasonal fluctuations of climatic conditions. High rainfall variability and crop protection (against weeds and pests) are the main technical problems of the milpa system (Gallegos, 1981). Yearly precipitation variability may have a greater effect on milpa yields than the length of the fallow period (Cuanalo de la Cerda, 1996).[8] A similar effect on crop production may originate from intrayear rainfall variability. The importance of the length of the fallow period and the burning process is related more to weed competition than to soil fertility (Ewell, 1984). Economic returns from the milpa system are usually negative except in very good years (Ewell, 1984; Cuanalo de la Cerda, 1996).[9] The peasants' primary interest seems to be producing food for their families and not so much obtaining a profit.[10] Technically derived improvements in agricultural productivity are possible. Because of the low and highly variable milpa yields, people from small villages – mainly in the maize-producing, fruit-producing, and hills and valleys socioecological regions, or SERs (see Chapter 2) – have migrated to larger villages and cities in the metropolitan region of Mérida and the Campeche, tourist–urban, and northern and southern block-fault basin SERs, where availability of schools, health services, and employment seems higher. Most of the recent migrants have been attracted by jobs in the construction and service sectors.

10.2.4 Commercial agriculture

The peninsula's main commercial crops include henequen, oranges (*Citrus sinensis*), tomatoes (*Lycopersicon esculentum*), and watermelon (*Citrullus vulgaris*). From the end of the 19th century until the 1960s, henequen production was a major export activity on the peninsula, and in the state of Yucatán in particular. A marked decline of total fiber production, yields, and area in production has occurred over the past three decades (Ewell, 1984; Cuanalo de la Cerda *et al*., 1996). Oranges are one of the most economically important fruits on the peninsula, and a large proportion of the total production is exported (Cuanalo de la Cerda, 1996). Citrus tristeza virus (*Closterovirus*) and fruit fly (*Anastrepha* spp.) are major threats to crops. Fruit production in diversified household orchards is very common.[11] Fruit and vegetable production for the regional fresh market is common in an area around the Puuc hills as well as in the area of Dzidzantúm. Tomato and watermelon production, albeit on a small scale, have been traditional components of the milpa system. Small patches within the milpa are intensively cultivated with tomatoes, watermelons, and other vegetables, as well as with cassava (*Manihot esculenta*) and sweet potatoes (*Ipomoea batatas*). A recent trend has been the expansion of the area devoted to tomato and watermelon production for commercial purposes.[12] Both total production and the area devoted to these crops have increased significantly during the past 30 years. Intensive production techniques have resulted in productivity increases. Production is very sensitive to changes in price and to the incidence of pests and diseases.[13] Commercial production of horticultural crops requires large amounts of inputs (including water and energy). Thus, the system has the potential to pollute land and water resources or it can be properly managed, attain high productivity, and protect the environment.

10.2.5 Pastureland

Cattle production has been an important agricultural activity on the peninsula. Shrubs, tree leaves (e.g., from *Brosimum alicastrum*), and natural grasses are usually the dominant feedstock in small-scale production units (e.g., in production units of better-off milpa peasants and small-scale cow–calf systems). During the past 30 years, commercially oriented production units (mainly for raising steers) have increasingly incorporated the use of improved pastures (mainly with grasses such as *Panicum* spp. and *Cynodon* spp., which are often interspersed with endemic legumes such as *Leucaena leucocephala* and others); improved animal genotypes (e.g., *Bos taurus*–*Bos indicus* crossbreeds and improved *Bos indicus* breeds); and feed supplements and anabolic steroids. Tizimín, in the state of Yucatán, is the most commercially oriented cattle-production area on the peninsula. Both the expansion of pastureland and the intensification of cattle production were highest from approximately 1970–1986.[14] The area of pastureland has remained stable during the past decade. Thus, the deforestation caused by pasture establishment and competition with the milpa system for land seems to have abated.

10.2.6 Physical infrastructure

Before the 1950s, a large and dense area of forest separated the Yucatán peninsula from the rest of Mexico. Until a road and railroad were constructed linking the states of Tabasco and Campeche with the state of Yucatán, the main traffic flows of people and tradable goods were carried out by sea. Since the 1960s the physical infrastructure on the peninsula has grown in response to efforts to integrate the peninsula into the national economy.[15] In the 1960s, it was thought that the southeast could produce and supply a large proportion of the country's food demand.[16]

In addition to increased residential land demand and the associated physical infrastructure that arose from both the natural increase of the population and immigration to the region, the most recent increases in physical infrastructure are related to the expansion of the tourism sector. Since the 1970s, roads, highways, and urban physical infrastructure have been constructed to enhance tourism in areas of the peninsula. Such expansion is likely to continue for the foreseeable future. Furthermore, the physical infrastructure is bound to increase via direct and multiplier effects if a series of prospective projects is realized.[17] The effects of the physical infrastructure in terms of the land area occupied are unlikely to be of major significance. Disturbances to the natural resources may originate from changes in natural drainage and from the lifestyle of the people living on the peninsula.

10.3 Description of the model

This section contains a description of the inputs and outputs for each land-use category. The aim is to identify the main interrelations between these categories. A simple accounting mechanism that considers food security for the rural population is also presented. A procedure that takes into account water availability constraints on land use is then described.

10.3.1 Main interrelations between land-use categories

The land-use flows between land-use categories are shown in *Figure 10.1*. *Primary forest* can only originate from secondary forest. However, it can be converted into nature reserves or pastureland, or can be used for traditional or commercial agriculture, or physical infrastrucutre. The model incorporates a natural succession rate from secondary to primary forest. This rate takes into account the degree of disturbance of secondary forest. The rate's baseline value was set at a low 0.5% per year.

Secondary forest can stem from traditional or commercial agriculture or pastureland. There are exceptions to this rule due to the management history of the land

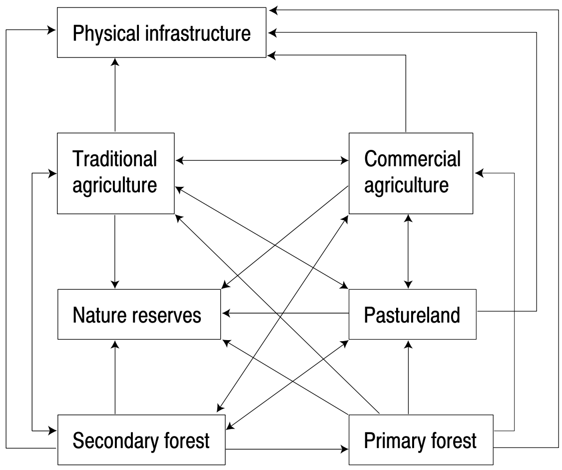

Figure 10.1. Land-use categories and flows.

and the specific features of the biophysical environment; however, it suffices for our purposes. Secondary forest can become primary forest, nature reserves, traditional agriculture, pastureland, commercial agriculture, or physical infrastructure.

Nature reserves can originate from any land use except physical infrastructure. This category cannot revert to any other land use.

Pastureland can derive from primary forest, secondary forest, traditional agriculture, or commercial agriculture. It can be converted into secondary forest, nature reserves, traditional agriculture, commercial agriculture, or physical infrastructure.

Traditional agriculture can stem from primary forest, secondary forest, pastureland, or commercial agriculture. It can revert to pastureland, nature reserves, secondary forest, commercial agriculture, or physical infrastructure.

Commercial agriculture can originate from primary forest, secondary forest, pastureland, or traditional agriculture. It can become pastureland, nature reserves, secondary forest, or physical infrastructure.

Physical infrastructure can derive from all other land-use categories but nature reserves. It cannot revert to any other land use.

A matrix indicates both the feasibility and the magnitude of land transfers between the different categories. The model encompasses a small set of accounting equations.[18] It is driven by land productivity, user specifications, or a combination of both.[19] In the first case, land demand at time t for land-use category i (in km^2/yr) is defined by the following function:

$$LD_{it} = EO_{it}/P_{it} \; , \tag{10.1}$$

where EO_{it} is economic output of land-use category i at time t (in pesos/yr) and P_{it} is productivity of land-use category i at time t (in pesos/km^2). Productivity of land-use category i is defined by economic output of i at a given point in time t divided by the area of i (in km^2) at time t. Land demand for physical infrastructure is at least the residential land requirements if population growth is positive. Residential land, RL_t (in km^2/yr), at time t is the product of the following arguments:

$$RL_t = M * PC_t + SS_t * PC_t / PRL_t \ , \tag{10.2}$$

where M is minimum residential land requirements (m^2/person);[20] *PC* is population change (persons/yr) at t;[21] *SS* is the share of shelter expenses in pesos/yr (after ENIGH, 1992) at t as a proportion of private consumption;[22] *PC* is private consumption at t (pesos/yr); and *PRL* is the price of residential land at t in pesos/m^2 (after ENIGH, 1992; Anonymous, 1996).

Under the allocation procedure driven by land productivity, in meeting land demand priority is given to the land-use category with the highest productivity. Land is supplied from the land-use category with the lowest productivity. In 1993, the output value of the economic activities carried out in physical infrastructure represented 91% of total economic value (Anonymous, 1996). Therefore, at the beginning of the period, land productivity of physical infrastructure is, by far, the highest of all land-use categories.[23] Land productivity of primary and secondary forest is the lowest. This is partly explained because monetary valuation of the goods and services provided by these land-use categories is highly controversial (Freeman, 1986; Ahmad *et al*., 1989; Bartelmus *et al*., 1989; Costanza, 1991; Maunders and Burritt, 1991; Gray, 1992; Howarth and Norgaard, 1992; Repetto, 1992; Callenbach *et al*., 1993; Blamey and Common, 1994). Their function in maintaining and providing non-rival goods is usually unaccounted for.[24] Therefore, user specifications of minimum land areas for specific land-use categories are a means of taking into account different value systems. This may reflect the desirability and willingness to preserve ecosystems of special interest.

Nature reserves do not enter into the procedure of allocating land according to its productivity. The same applies for traditional agriculture, because its main goal is to produce food for the rural family. It is assumed that increased demand for nontraditional products is reflected in the demand for commercial agriculture. Although some commercial production takes place, peasants generally do not have the financial means to purchase land, since accumulation of wealth is minimal. Thus, even when the productivity of traditional agriculture, as defined here, is higher than that of other land uses, land demand for traditional agriculture cannot be satisfied. At the same time, for cultural and economic reasons, Maya peasants have an “attachment” to the land that keeps them in rural areas even in the face of serious deficiencies.[25] Thus, they may not be willing to sell their land.

If stipulated by the user, the amount of land in a particular land-use category that can be converted to a different feasible land-use category can be lower than the amount of land available. As mentioned, a matrix indicates both the feasibility and the magnitude of land transfers between different categories. The latter can be changed by the user. The need to account for user stipulations stems from the role that state planning interventions have played in defining both the pattern of land use on the peninsula (e.g., through support programs for certain economic activities and land colonization/intensification projects) and the situation of the state's economy (Ramírez, 1994). The user can specify a land-use change to take place at any time during the simulation run.

10.3.2 Taking into account food security for the rural population

The algorithm estimates a minimum area for traditional agriculture. This area is a function of rural population, mean rural family size, yearly maize requirements for an average rural family, and an average maize yield per unit area per unit time.[26] At the beginning of the period, the proportion of rural population is assumed to be 25% (INEGI, 1994). This proportion diminishes in time according to an assumed rate of urbanization, which can be changed to reflect user-defined scenarios. The mean rural family is assumed to have seven members (after INEGI, 1994; Cuanalo de la Cerda *et al*., 1996).[27] Yearly maize requirements for an average rural family of median economic status was assumed to be 2,600 kg (Ewell, 1984). It is assumed that 2,200 kg are eaten in various forms and that 400 kg are fed to livestock (after Ewell, 1984). It is also assumed that the average family can cultivate 4 ha and that the average maize yield per hectare is 650 kg (Cuanalo de la Cerda, 1996). The land a family can cultivate is usually a function of available family labor. The most labor-intensive task is weeding. Assumed maize yields seem reasonable given the current trend toward shorter fallow periods and the decreasing use of agrochemicals in traditional agriculture. In calculating the minimum land area required per rural family, the assumed length of the fallow period is 10 years.[28]

10.3.3 Incorporating water availability constraints

A procedure incorporating water availability constraints was developed. It readjusts the area devoted to commercial agriculture under irrigation if water availability is lower than water demand. The irrigated crops considered are rice, sugarcane, fruit trees, maize, and other irrigated crops. The yearly amount of water used to irrigate a hectare of a given crop is estimated using irrigation requirements for the specific crop modified by a scalar taking into account the efficiency with which irrigation water is delivered from the source to the crop in the field. The efficiency of water delivery assumed in the model is 50% (after FAO, 1991). These efficiency multipliers can be modified in accordance with the prevailing specific conditions of the irrigation system being used. Yearly irrigation requirements were drawn from the simulation models of the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) series (G.A. Kiker, personal communication, October 1996). The amount of irrigated land for a specific crop decreases proportionally to the crop's share of irrigated land up to the point where water availability equals water demand.[29] Water availability and water used for irrigated agriculture were derived from Chapter 2.

10.4 Scenario Analysis

Two case scenarios were constructed to explore possible land-use futures for the Yucatán peninsula. Therefore, the range of scenarios is delimited by two different positions, namely, a pro-growth position, emphasizing only the growth of the regional economy, and a pro-development stance, taking a more integrated view of socioecological systems.[30] The pro-growth scenario encompasses high fertility and mortality, high economic growth, and less land dedicated to nature reserves. The pro-development scenario comprises low fertility and mortality, moderate economic growth, and more land dedicated to nature reserves.

10.4.1 Pro-growth scenario

The main features defining this scenario are the following:

- Population growth is assumed to be equal to that under the stagnation scenario (high fertility, high mortality, low education, and central migration) described in Chapter 7.
- It is assumed that the proportion of the rural population decreases linearly from 25% to 15% from 1990 to 2020. This decrease is in line with the country's current urbanization trends (Ruiz Chiapetto, 1993; HABITAT, 1996).
- The annual change in the output values of physical infrastructure activities and commercial agriculture are 10% and 7%, respectively. Performance of physical infrastructure activities over the past 10 years is extrapolated into the future.
- Because of requirements from development projects, 150 km^2 are added to the physical infrastructure (for likely development of physical infrastructure, see Section 10.2.6).
- It is assumed that 1,500 km^2 of land are converted to irrigated agriculture. This is consistent with current plans to implement some agricultural development projects (e.g., plan Bajo Usumacinta and plans to increase commercial citrus production).

Table 10.1. Pro-growth land-use scenario.

Category	1990	1995	2000	2005	2010	2015	2020
Nature reserves	23,268	23,268	23,268	23,268	23,268	23,268	23,268
Primary forest	32,228	30,944	29,474	27,290	24,612	21,367	17,706
Secondary forest	40,837	40,027	39,016	378,35	36,683	35,579	34,710
Pastureland	18,808	19,760	20,757	21,805	22,907	24,063	25,278
Traditional agriculture	30,001	30,001	30,001	30,001	30,001	30,001	30,001
Commercial agriculture	3,119	3,742	4,527	5,977	7,627	9,518	11,201
Physical infrastructure	1,952	2,471	3,169	4,036	5,115	6,417	8,049
Required traditional agriculture[a]	33,857	38,611	42,365	45,829	48,626	51,531	52,286
Population	2.37	2.90	3.37	4.01	4.65	5.4	6.1

Note: Figures for land-use categories are given in km^2; population figures are given in millions of people.
[a] Minimum land requirements for food production for the rural population.

The results for the pro-growth scenario are given in *Table 10.1*. In all simulations, the results are merely indicative of possible general trends. Primary forest decreases nearly 50%. Over 6,000 km^2 of secondary forest are lost. The loss of primary and secondary forest will manifest in loss of biodiversity and will probably negatively affect the functioning of the peninsula's ecosystems. There is an increase in pastureland of over 6,000 km^2, despite pastureland's performance on the peninsula over the past decade, during which production stagnated.[31]

The land required by the rural population to attain a living at the subsistence level increases by more than 18,000 km^2. However, it is unlikely that the area devoted to traditional agriculture will increase significantly, because most peasants do not have the monetary resources to purchase land. Likely consequences include a substantial increase in migratory flows from rural to urban centers, increasing the demand for public services and for employment opportunities, and a decrease in land per rural family, leading to a still shorter fallow period, decreased yields, and increased degradation of natural resources.

Increases in commercial agriculture (increased output and increased irrigated land) cause its share of the territory of the peninsula to rise to over 7%. This is still a small proportion of the total land on the peninsula. The major effects of commercial agriculture on the natural environment and the economy will depend on how commercial agricultural activities are carried out rather than on the area occupied or the direct changes in land use caused by the sector's expansion. The knowledge and technology required to achieve higher agricultural productivity per unit area while minimizing the negative effects on the natural environment are already available.[32] An important effect that should be considered explicitly is the increase in water use resulting from increases in commercial agriculture (see Section 10.5.6).

Physical infrastructure's area increases fourfold. However, this represents only just over 5% of the total territory of the peninsula. In considering the potential increase in physical infrastructure, a key question is to what extent such an increase will directly or indirectly affect the natural environment. In the future, proper planning could make it feasible to both preserve ecosystems of special interest (e.g., lagoons, land–sea interface ecosystems, specific vegetation types) and the biophysical environment in general, as well as expand physical infrastructure as required. The increase in area of physical infrastructure may be lower than estimated in this scenario if land productivity levels are higher than those considered here. In addition, in "mature" economies up to 90% of investment in physical infrastructure takes place in existing physical infrastructure (Batty, 1996). This situation may be more relevant for the peninsula toward the end of the simulation period.

10.4.2 Pro-development scenario

This scenario is defined by the following assumptions:

- Population growth is assumed to be equal to that under the rapid development scenario elaborated in Chapter 7.
- The rural population is assumed to decrease linearly from 25% at the beginning of the period to 10% in year 30 of the simulation run. A smaller rural population is consistent with a society that depends less directly on the use of natural resources.
- An additional 5,000 km^2 are added to the stock of nature reserves. Additional nature reserves make it possible to preserve ecosystems of special interest.[33]
- The natural succession from secondary to primary forest is assumed to increase from 0.5% to 1% per year. In this scenario, a low rate was used because secondary forest is used for honey production and for extraction of wood and plants. It is also supposed that with a lower rural population density, the secondary forest will be disturbed less than with a higher rural population density.
- The annual growth rates of output from physical infrastructure and commercial agriculture are assumed to be 5% and 3%, respectively.[34]
- There are user-defined restrictions regarding the minimum area for primary and secondary forest. These lower limits are set at 30,000 km^2 for both land-use categories.
- Output from the regional economy is assumed to be 8%, 6%, and 4% for years 1–10, 11–20, and 21–30, respectively.
- Average family size of the rural population is 7, 5, and 4 members for years 1–10, 11–20, and 21–30, respectively.

Table 10.2. Land-use changes in a pro-development scenario.

Category	1990	1995	2000	2005	2010	2015	2020
Nature reserves	23,268	23,268	25,268	27,268	28,268	28,268	28,268
Primary forest	32,228	32,333	31,812	30,949	30,565	30,673	30,000
Secondary forest	40,837	39,228	36,633	34,165	31,833	30,574	29,970
Pastureland	18,808	19,760	20,757	21,805	23,133	24,063	25,020
Traditional agriculture	30,001	30,001	30,001	30,001	30,001	30,001	30,001
Commercial agriculture	3,119	3,339	3,505	3,678	3,860	4,051	4,252
Physical infrastructure	1,952	2,133	2,236	2,346	2,458	2,582	2,692
Required traditional agriculture[a]	33,857	37,286	38,743	39,160	37,858	35,054	30,962
Population	2.37	2.90	3.39	3.91	4.41	4.9	5.41

Note: Figures for land-use categories are given in km^2; population figures are given in millions of people.
[a] Minimum land requirements for food production for the rural population.

The results for the pro-development scenario are given in *Table 10.2*. Projected total population is over 5 million. In this scenario, the land distribution among land-use categories is more even than in the pro-growth scenario. Primary and secondary forest reach the user-specified lower thresholds, the former about halfway through the simulation period and the latter approximately 10 years later. Therefore, the decrease of primary and secondary forest is underestimated if the protection implied by these thresholds is not made operational. Pastureland increase is similar to that in the pro-growth scenario because most reductions in land for physical infrastructure and commercial agriculture are associated with increases in primary and secondary forest. Minimum land requirements for food production for the rural population increase to more than 39,000 km^2 around the middle of the simulation period and decrease thereafter to approximately 30,000 km^2 by the end of the simulation period. At this point, even when total population has more than doubled, the land requirements for food security for the rural population are lower than at the beginning of the period. This result is the product of the decreased proportion of the rural population and the reduction in the average family size of the rural population. The area of land dedicated to commercial agriculture and physical infrastructure increases approximately 1,100 km^2 and 700 km^2, respectively. However, for both land-use categories, the area's share of the peninsula's territory remains low.

10.5 Sensitivity Analysis

Both the sensitivity analysis and the scenario analyses can be considered in assessing the model.

Table 10.3. Sensitivity of the demand for residential land (km^2) to changes in population.[a]

Scenario	1990	1995	2000	2005	2010	2015	2020
Stagnation scenario[b]	1.8	2.2	2.56	3.04	3.53	4.28	4.69
Central scenario[c]	1.8	2.2	2.58	3.00	3.45	3.92	4.43
Rapid development scenario[d]	1.8	2.2	2.57	2.97	3.35	3.66	4.11

[a] Population growth scenarios are those reported in Chapter 7.
[b] Assumes high fertility and mortality, low education, and a central value for migration. Population (in millions) for simulation years was 2.37 (1990), 2.90 (1995), 3.37 (2000), 4.01 (2005), 4.65 (2010), 5.4 (2015), and 6.17 (2020).
[c] Assumes medium fertility, mortality, and education, and a central value for migration. Population (in millions) for simulation years was 2.37 (1990), 2.90 (1995), 3.40 (2000), 3.96 (2005), 4.54 (2010), 5.16 (2015), and 5.83 (2020).
[d] Assumes low fertility and mortality, high education, and central migration values. Population (in millions) for simulation years was 2.37 (1990), 2.90 (1995), 3.39 (2000), 3.91 (2005), 4.41 (2010), 4.9 (2015), and 5.41 (2020).

10.5.1 Sensitivity of demand for residential land to changes in population

As shown in *Table 10.3*, the sensitivity of demand for residential land to changes in population is minor. *Table 10.3* refers to increases in residential land originating from changes in population. At the end of the simulation period, the difference between the stagnation scenario and the rapid development scenario is less than 1 km^2 – a difference of no practical significance in land use at the peninsula level. Increases in residential land represent only about 5% of the total increase in area of physical infrastructure.

Variables used to calculate the demand for residential land – such as price of residential land per unit area, share of private consumption in total output, and minimum land requirements per person – change little (results not shown) as a consequence of changes in population growth. This result is explained because the sensitivity of the aggregated calculation (demand of residential land) is very small, therefore the sensitivity of its arguments is smaller still. The effects of population growth on land use are not restricted to residential land. The nature of the economic activities carried out by the population is very important. As shown in Section 10.4.2, increases in economic output together with low land productivity result in substantial increases in land use.

10.5.2 Sensitivity of traditional agriculture's land requirements

The sensitivity of traditional agriculture's land requirements (TALRs; see Section 10.3.2) to changes in the population growth and urbanization rates is shown

Table 10.4. Sensitivity of traditional agriculture's land requirements (km^2) to changes in population growth[a] and urbanization rates.

Scenario[b]	1990	1995	2000	2005	2010	2015	2020
Pro-growth							
(1)	33,857	38,661	42,325	45,829	48,626	51,531	52,286
(2)	33,857	37,286	38,514	40,161	39,918	38,631	35,311
Central							
(1)	33,857	38,661	42,743	45,257	51,886	49,241	49,971
(2)	33,857	37,286	38,857	39,661	38,974	36,914	33,366
Pro-development							
(1)	33,857	38,661	42,617	44,686	46,616	46,760	46,371
(2)	33,857	37,286	38,743	39,160	37,858	35,054	30,962

[a] Population (in millions) for simulation years was 2.37 (1990), 2.90 (1995), 3.37 (2000), 4.01 (2005), 4.65 (2010), 5.4 (2015), and 6.17 (2020) for the pro-growth scenario; 2.37 (1990), 2.90 (1995), 3.40 (2000), 3.96 (2005), 4.54 (2010), 5.16 (2015), and 5.83 (2020) for the central scenario; and 2.37 (1990), 2.90 (1995), 3.39 (2000), 3.91 (2005), 4.41 (2010), 4.9 (2015), and 5.41 (2020) for the pro-development scenario. (Figures from Chapter 7.)
[b] Scenario alternatives are as follows: (1) The proportion of the rural population declines linearly from 25% at initialization to 15% at the end of the simulation period. The average rural family size remains at 7 members throughout the simulation period. (2) The proportion of the rural population declines linearly from 25% at initialization to 10% at the end of the simulation period. The average rural family size is 7 for the 1990–2000 period, 5 for 2001–2010, and 4 for 2011–2020.

in *Table 10.4.* At the end of the simulation period, there is a difference in TALRs of approximately 22,000 km^2 between the pro-growth scenario with a decline in the proportion of rural population from 25% to 15% and the pro-development scenario with a decline from 25% to 10%. At the same level of urbanization, TALRs are highest for the pro-growth scenario. In the pro-growth scenario, TALRs decline during the latter part of the simulation period as a result of the decrease in the proportion of the rural population. For the central scenario, TALRs peak at around the middle of the simulation period and decline thereafter. In this case, increased urbanization offsets the effect of the population increase. The behavior of the pro-development scenario is similar to that of the central scenario: when the proportion of the rural population decreases from 25% to 10%, TALRs peak at around the middle of the simulation period and decline thereafter. Changes in the rate of urbanization have a greater effect on TALRs than do changes in population growth.

There are no effects on the other land-use categories, because TALRs are only assumptions. Traditional agriculture's land demand is not satisfied because, in general, those practicing traditional agriculture do not have the financial means to purchase new land.

Table 10.5. Sensitivity of the pro-growth scenario to changes in the rate of natural succession from secondary to primary forest.

Scenario[a]	1990	1995	2000	2005	2010	2015	2020
Primary forest							
(1)	32,228	30,944	29,474	27,290	24,612	31,367	17,706
(2)	32,228	31,743	31,204	29,877	27,986	25,461	22,463
Secondary forest							
(1)	40,837	40,027	39,016	37,835	36,683	35,579	34,710
(2)	40,837	39,627	37,287	35,248	33,309	31,484	29,941

Note: Figures for land-use categories are given in km^2.
[a] Scenario alternatives are as follows: (1) Rate of natural succession from secondary to primary forest was assumed to be 0.005 per year [baseline scenario]; (2) rate of natural succession from secondary to primary forest was assumed to be 0.01 per year.

10.5.3 Sensitivity of the pro-growth scenario to changes in the rate of conversion from secondary to primary forest

As shown in *Table 10.5*, the increase in the rate of conversion from secondary to primary forest results in a higher land area for primary forest and a lower area for secondary forest in 2020. Compared with the baseline pro-growth scenario, there is a land transfer from secondary to primary forests. All other land-use categories remain at the same level in both scenarios because land demand is supplied entirely from primary and secondary forest. Such a transfer may be possible if market or policy conditions promote the preservation of the remaining primary forest and its future expansion. These conditions may include a regional economy less directly dependent on the use of natural resources; a decreased rural population; an increased valuation, by society, of the natural resource base; and greater increases in productivity than in economic output.

10.5.4 Sensitivity of the pro-development scenario to productivity and economic output of commercial agriculture and physical infrastructure

This scenario gives a rough idea of the expected changes in land use resulting from changes in productivity and economic output of the more dynamic land-use categories. The sensitivity of land use to changes in productivity and economic output of commercial agriculture and physical infrastructure is shown in *Table 10.6*. Productivity and economic output of commercial agriculture were increased from 3% to 5% per year and from 4% to 7% per year, respectively. Similarly, productivity and economic output of physical infrastructure was increased from 5% to 8% per year and from 7% to 10% per year, respectively.

Table 10.6. Sensitivity of the pro-development scenario to changes in productivity and economic output of commercial agriculture and physical infrastructure.

Category[a]	1990	1995	2000	2005	2010	2015	2020
Primary forest							
(1)	32,228	32,333	31,812	30,949	30,565	30,673	30,000
(2)	32,228	32,664	32,342	31,840	31,829	32,311	32,085
(3)	32,228	31,741	30,366	30,318	30,000	30,000	30,000
(4)	32,228	32,151	31,180	30,371	30,314	30,000	30,000
Secondary forest							
(1)	40,837	39,228	36,633	34,165	31,833	30,574	29,970
(2)	40,837	39,274	36,734	34,316	32,351	30,824	29,949
(3)	40,837	39,228	36,172	31,404	29,696	29,692	29,696
(4)	40,837	39,228	36,633	33,770	31,044	29,921	29,925
Pastureland							
(1)	18,808	19,760	20,757	21,805	23,133	24,063	25,028
(2)	18,808	19,775	20,772	21,819	22,920	24,076	25,298
(3)	18,808	19,760	20,757	21,805	20,653	17,961	14,645
(4)	18,808	19,760	20,757	21,805	22,907	23,588	22,771
Commercial agriculture							
(1)	3,119	3,339	3,505	3,678	3,860	4,051	4,252
(2)	3,119	3,153	3,005	2,865	2,731	2,604	2,482
(3)	3,119	3,742	4,528	5,640	6,627	8,018	9,700
(4)	3,119	3,533	3,882	4,266	4,688	5,152	5,662
Physical infrastructure							
(1)	1,952	2,133	2,236	2,346	2,458	2,582	2,692
(2)	1,952	2,080	2,091	2,103	2,114	2,131	2,129
(3)	1,952	2,474	3,121	3,940	4,969	6,275	7,902
(4)	1,952	2,273	2,492	2,732	2,992	3,285	3,585

Note: Figures for land-use categories are given in km^2.
[a] Categories are as follows: (1) baseline pro-development scenario as described in Section 10.4.1; (2) annual productivity of commercial agriculture increased from 0.03 to 0.05; annual productivity of physical infrastructure increased from 0.05 to 0.08; (3) annual increase in economic output of commercial agriculture increased from 0.04 to 0.07, and that of physical infrastructure increased from 0.07 to 0.10; (4) increases in commercial agriculture's annual productivity and economic output of 0.05 and 0.07, respectively; increases in physical infrastructure's annual productivity and economic output of 0.08 and 0.10, respectively.

The land areas for nature reserves and traditional agriculture are not shown because they remain the same as in the baseline pro-development scenario. Compared with the baseline scenario, the higher annual increases in productivity of commercial agriculture and physical infrastructure result in an increase in primary forest of approximately 2,000 km^2, a decrease in area of commercial agriculture of approximately 1,700 km^2, a decrease in physical infrastructure's area of approximately 600 km^2, and an increase in pastureland of nearly 200 km^2. The threshold value for primary forest (30,000 km^2) is reached approximately 10 years earlier than under the baseline scenario when either economic output or both economic output and productivity are increased [cases (3) and (4) for primary forest]. The area of secondary forest is very similar for the four scenarios because the minimum area of this land-use category is reached in the four cases. However, this threshold is reached earlier when only the yearly rate of economic output is increased.

Pastureland's area is lowest when economic output of commercial agriculture and physical infrastructure is increased. The next lowest value for pastureland occurs when both productivity and economic output are increased, because the thresholds for primary and secondary forest are reached and land demand for commercial agriculture and physical infrastructure is supplied from pastureland.

Compared with the baseline scenario, land occupied by commercial agriculture decreases nearly 40% when productivity increases. In comparison, the land occupied by commercial agriculture more than doubles when only an increase in economic output of commercial agriculture and physical infrastructure takes place. When both productivity and economic output of commercial agriculture and physical infrastructure increase, the area of commercial agriculture increases approximately 1,400 km^2 compared with the baseline scenario. The general trend for physical infrastructure is similar to that for commercial agriculture.

10.5.5 Sensitivity of the pro-development scenario's traditional agriculture land requirements to changes in maize requirements, maize yield, and length of fallow period

The sensitivity of TALRs, as estimated under the pro-development scenario, to changes in maize requirements, maize yields, and length of fallow period is shown in *Table 10.7*. Scenario (1) depicts further deterioration of the socioeconomic conditions on the peninsula (decreased availability of off-farm jobs) and increased reliance of the rural population on traditional agriculture. Scenario (2) occurs if the density of rural population increases, the use of agrochemicals in traditional agriculture remains at a low level, and the length of the fallow period decreases further. Scenario (3) originates from a decrease in the density of rural population, an increase in the urbanization rate, and the rural population's increased reliance on off-farm produce.

Increases in maize yields can be obtained from an increase in the use of agrochemicals in the production process of traditional agriculture or from other improvements in agricultural technology. The land required to ensure a certain level of food security for the rural population from traditional agriculture increases when maize requirements per person per year are increased by 20% (scenario 2), when

Table 10.7. Sensitivity of traditional agriculture's land requirements (km^2) to changes in food requirements, maize yields, and length of fallow period.

Scenario[a]	1990	1995	2000	2005	2010	2015	2020
(1)	33,857	37,286	38,743	39,160	37,858	35,054	30,962
(2)	40,655	44,772	46,521	46,950	45,389	42,027	37,121
(3)	27,073	29,814	30,979	31,265	30,226	28,081	24,720
(4)	28,258	31,119	32,335	32,634	31,549	29,212	25,802
(5)	37,677	41,492	43,114	43,511	42,065	38,949	34,402
(6)	50,786	55,929	58,114	58,740	56,787	52,581	46,443
(7)	42,387	46,679	48,503	48,950	47,323	43,817	38,702
(8)	30,142	33,194	34,491	34,809	33,652	31,159	27,522

[a] Scenarios are as follows: (1) traditional agriculture land requirements as calculated under the pro-development scenario [baseline] in Section 10.4.2; (2) 20% increase in maize requirements per person per year; (3) 20% decrease in maize requirements per person per year; (4) 20% increase in maize yield per hectare per year; (5) 10% decrease in maize yield per hectare per year; (6) length of fallow period increased from 10 to 15 years; (7) 15-year fallow period and a 20% increase in maize yield per hectare per year; (8) 8-year fallow period and a 10% decrease in maize yield per hectare per year.

maize yield (kg/ha/yr) is decreased by 10% (scenario 5), when the fallow period is increased from 10 to 15 years (scenario 6), or when the fallow period is increased to 15 years and the maize yield increases by 20% (scenario 7). As scenario 7 in *Table 10.7* indicates, a 20% increase in maize yield is not sufficient to counterbalance an increase in the fallow period from 10 to 15 years. Similar trade-offs between several variables can be estimated. Probably one of the most desirable scenarios, in accordance with the results from Section 10.5.4, is that in which productivity increases take place.

10.5.6 Irrigated land and water used for irrigation under the pro-growth and the pro-development scenarios

Table 10.8 shows the amount of water used for irrigation purposes and the corresponding area of irrigated land under the pro-growth and the pro-development scenarios. The use of irrigation water is proportional to the area irrigated. Since the irrigated land under the pro-growth scenario is nearly twice that under the pro-development scenario, nearly twice as much water is used for irrigation. Assuming an equal distribution of irrigated crops, water use under the pro-growth scenario will be approximately 5,200 million m^3 higher than in the pro-development scenario. This figure is only meaningful if particular areas are considered, since sustainable water extraction rates may be different for different zones of the peninsula's territory.

Table 10.8. Use of irrigation water and irrigated area under the pro-growth and the pro-development scenarios.

Scenario	1990	1995	2000	2005	2010	2015	2020
Pro-growth							
Water used (mln m^3/yr)	4,300	5,158	6,259	7,223	8,265	9,397	11,059
Area irrigated (ha)	160,000	191,930	232,506	268,476	307,274	349,850	411,697
Pro-development							
Water used (mln m^3/yr)	4,300	4,603	4,831	5,070	5,321	5,585	5,861
Area irrigated (ha)	160,000	171,294	179,772	188,670	198,008	207,808	218,094

10.6 Discussion

The different assumptions used to generate the pro-growth and pro-development scenarios are reflected in the following scenario differences: Over 12,000 more square kilometers of primary forest are preserved under the pro-development scenario than under the pro-growth scenario. The potential value of preserving remaining primary forest increases as the area of primary forest decreases. The unique features of the peninsula's vegetation, the biodiversity, the existence or option value of primary forest intermingling with archaeological sites, and the biophysical functions of primary forest with regard to the sustained functioning of ecosystems and economic activities on the peninsula may justify the non-use-value considerations that characterize the pro-development scenario. A number of policies may be used to make the user-defined minimum areas for primary and secondary forest operational, including the use of economic incentives to protect the remaining forests or to facilitate the succession from secondary to primary forest and the further development of the secondary and tertiary sectors of the regional economy. The area of remaining secondary forest is approximately 5,000 km^2 larger in the pro-growth scenario than in the pro-development scenario. This is because the constraint imposed regarding minimum primary forest area in the pro-development scenario causes land demand to be increasingly supplied from secondary forest during the second half of the simulation period. The effects of changes in primary and secondary forest on honey production in the two scenarios may cancel each other out. This is because honey production depends on, among other things, the combination of old and young vegetation (Chemas and Rico-Gray, 1991), and in the pro-development scenario the area of secondary forest is lower and that of primary forest is higher than in the pro-growth scenario.

Given that productivity and output values for pastureland are equal for the two scenarios, projected pastureland increases approximately 7,000 km^2 in both cases. Considering the low economic returns of extensive cattle production, increasing awareness about past destruction of primary and secondary forest due to pasture establishment, and the likely integration and intensification of beef production in the North American Free Trade Agreement (NAFTA) area, it seems plausible to expect an increase in the area of pastureland.[35]

The area required for securing a minimum level of food supply for the rural population is approximately 22,000 km^2 higher in the pro-growth scenario than in the pro-development scenario. This may be an overestimate if the economy growing at a higher rate provides more employment opportunities and stimulates additional migration from rural to urban areas. On the other hand, the size of the difference casts doubts on the economy's capacity to supply jobs to the currently unemployed and underemployed, and to the increasing economically active population. Similarly, a growth scenario where natural resources are squandered may not be realized in the long term simply because it may undermine the very basis of its growth. The area of commercial agriculture is approximately 6,000 km^2 greater in the pro-growth scenario than in the pro-development scenario. Under the former scenario, a small proportion of the rural population may find jobs in commercial agriculture, alleviating the pressure exerted on the primary and secondary forest. However, a potential shortcoming of this scenario is the remarkable increase in water used for irrigation purposes and, consequently, the possibility of disruption of the peninsula's water flows and water quality. Furthermore, it remains to be seen if such increases in irrigated agriculture are economically feasible; cultural and biophysical factors have limited the success of previous intensive agricultural projects in the southeast.

The projected area of physical infrastructure is over 5,000 km^2 greater in the pro-growth scenario than in the pro-development scenario. Even at the highest projected level, physical infrastructure's effect on the biophysical environment due to the area occupied will be minor. Rather, the most important effects will be determined by the specifics of the expansion of physical infrastructure (e.g., where and how). Effective partnerships between the government, the private sector, the communities concerned, and researchers may rationalize the conciliation between environmental preservation and the continuing increase of the physical infrastructure.[36]

Projected population in the pro-development scenario is approximately 760,000 inhabitants lower than in the pro-growth scenario. How the land will be able to sustain the additional people is an unresolved issue, since in the extreme case the difference will be approximately 16,000 rural households. This additional population pressure could cause significant productivity increases in economic activities carried out in rural areas, exacerbate development and environmental problems in the countryside, and shift the development problems of the rural settings to the urban centers. The change in the area of primary forest is one of the largest among all land-use categories, because primary forest is the category supplying most of land. The amount of secondary forest may decrease further if parts of it are made available for expansion of traditional agriculture.

Market and nonmarket considerations have implications for land-use changes, including diverse degrees of internalization of non-rival goods as expressed in the weights given to traditional agriculture and nature reserves, and the enactment of regulations controlling the growth of physical infrastructure and commercial agriculture. Thus, the specific combination of allocation driven by land productivity and user-defined land-use changes largely determines the results obtained.

In the case of traditional agriculture, pastureland, and primary and secondary forests, land productivity may not correctly respond to economic demand. For instance, even when pastureland may have higher land productivity than other land-use categories, it may not expand if the activity (cattle production) is not economically attractive, as has been the case during the past decade.

Due to model specifications, the greatest sensitivity originates from changes in productivity and economic output. A recurring suggestion in the set of results is that increases in productivity may allow both substantial growth rates of the regional economy and the protection of the natural resource base. However, this may not necessarily be so if savings derived from increases in productivity are used to increase consumption.

In general, the sensitivity of land use to changes in population variables is small, since land use on the peninsula is not significantly affected by the range of population sizes simulated. Rather, it will be largely affected by what the population, in the form of its social organizations, does or does not do. The degree of urbanization has a large and obvious effect on the calculated land requirements for traditional agriculture. Recent structural changes in the economy and an increasing devolution of political power on local and regional levels suggest that the most important threats to the preservation of natural resources will originate from the expansion of diverse economic activities in the secondary and tertiary sectors of the economy. Soil and climatic conditions of the peninsula suggest both the potential to and the desirability of establishing tree plantations (precious hardwoods, commercial softwoods, fruit trees). Economically, socially, and environmentally desirable and feasible land patterns will require matching the biophysical characteristics of Yucatán with a prosperous socioeconomic environment.

Increased political regionalism together with an increasing concentration of power and wealth can result in either increased squandering of natural resources in the name of "progress" or in the responsible management of both natural and human resources. Responsible management will require a more inclusive, comprehensive, integrated, and long-term vision on the part of the regional elites and more participation in decision making and policy implementation on the part of the peninsula's population. A problem common to most development projects has been lack of proper consideration of the specific social, economic, and cultural characteristics of the population and the biophysical processes of the peninsula. In future project developments, “social shortcomings” may be circumvented through completely market-oriented commercial units using intensive production techniques. However, this will require “buffering” or accommodation in other economic sectors.

The future of the Yucatán peninsula’s economy may require the combination of a better-managed tourist sector and a sizeable increase in knowledge-based employment. Such changes may be necessary for a number of reasons. First, overexpansion of tourist activities may negatively affect not only the environment, but also the industry itself (see Chapter 8). Second, an increase in commercial agriculture will be constrained by the demand of the regional market. Finally, regarding the potential increase in manufacturing employment, the *maquiladora* option has resulted in minor increases in the supply of new job opportunities during the past decade (Ramírez, 1994).

Large areas of the peninsula have population densities below 10 persons/km^2. This suggests that the most important land-use issue is neither the biophysical capacity of the land nor the size of the population, but the characteristics of the social organization prevailing on the peninsula. The pro-development land-use approach referred to above may need to be employed within 25–30 years simply because if a pro-growth approach is followed, the features of the biophysical environment at that time may limit the development options that remain. The difference is that in the latter case, the natural resource base and the development possibilities may be poorer than they are at present.

10.7 Conclusions

The major conclusions are as follows:

- The results of the land-use model are largely a function of the relative effects of allocation driven by land productivity and user-specified land-use changes.
- Primary and secondary forest are the land-use categories with the largest absolute decreases in land area.
- The land requirements for ensuring a certain level of food security for the rural population largely depend on the growth of the rural population, the yield from agricultural production, and the length of the fallow period in the milpa system.
- Pastureland’s area increases in most scenarios except when high minimum land area threshold values are set for primary and secondary forest.

- Relative changes in land area for commercial agriculture and physical infrastructure are, in most cases, large. However, their share of total regional land remains small.
- Land-use changes are sensitive to changes in productivity and economic output. Changes in the population variables of the model lead to minor land-use changes, except in the case of land requirements for traditional agriculture.
- The present model may be improved through interaction with a water dynamics model, an economic model, and a GIS system, as well as through continuous process of consultation and synthesis with the main social actors of the peninsula.

Notes

[1] This implies a problem of circularity. Therefore, any mechanistic approach to modeling land use needs to be complemented by information, discussions, and action in the socioeconomic environment.

[2] Land productivity of a given land category is expressed in pesos per square kilometer. User-defined specifications refer to potential changes in the parameters or initial values of the model that the user may make.

[3] In the state of Yucatán, the area of pastureland has remained fairly stable over the past 10 years (Cuanalo de la Cerda, 1996).

[4] There are different stages and types of secondary vegetation arising from combinations of microclimatic conditions, specific soil properties, and variants of land management. The different types of secondary vegetation are closely observed by the Maya peasants, who then decide where, when, and what to crop in the milpa system.

[5] In any given year, a peasant will usually work two plots (one plot in its first year of production and another in its second year) of a modal area of approximately 4 ha. After two years of production, plots are abandoned because yields decline markedly and the labor required for weed control becomes too high. After the second year, the land is allowed to revert to fallow. Third- and fourth-year milpas are very rare. Thus, only a small fraction of the forest in *ejidos* is cleared and cultivated in any given year.

[6] Average yield appears to be decreasing as a result of the elimination of government subsidies for agrochemicals and the shortening of the fallow period.

[7] The Maya classify soils according to their use characteristics, including the natural vegetation they support. A milpa plot is often a patch of several soil types, and the combination and density of the crops as well as other management factors are adjusted in response to soil differences.

[8] It is not always possible to generalize when comparing one production factor with another because of potential effects of thresholds and multifactor interactions on production.

[9] From the microeconomic viewpoint, economic returns in the long run are counterintuitive. However, they may be explained because the milpa system is frequently just one potential source of income, employment, and food. Family members may obtain off-farm employment or gather resources from the forest. In addition, factors such as the flexibility and freedom enjoyed by living and working on their own and the lack of "overall" better alternatives may also partly explain why peasants have endured such harsh conditions for so long.

[10] However, this may be changing because of the population's changing needs The intensification and commercialization of crops, at a small scale, suggest both the need and the desire to achieve a higher penetration in the regional market.

[11] Beneficial effects of the biodiversity of these traditional systems may include the potential for obtaining a certain degree of integrated pest management, the attainment of synergies in nutrient cycles, the spread of risk and time distribution of production, and environmental protection. However, the economic feasibility of this system is attenuated by some of the characteristics of the current framework, namely, the relatively small demand for produce and requirements such as large amounts of produce, uniformity of size and degree of ripening, and long shelf life.

[12] This is partly the result of increased demand in the regional market and the effect of government programs promoting horticultural production as part of an effort to diversify the economy and as a response to the decline of henequen production.

[13] Erratic produce prices have created booms and busts, which in turn have tempered growth of intensive production modes. Export alternatives are limited because by and large the market is, and will continue to be, only regional: because of productivity differences, horticultural production on the peninsula cannot compete on the national or international market with production from the northwest and from El Bajío (central–west region of Mexico).

[14] This period was characterized by increased demand for beef in the regional and national markets, the availability of soft loans and credits for pasture establishment and for purchasing animals, and an almost continuous increase in economic returns. Pasture establishment appears to have lagged in Campeche and Quintana Roo. In these states, the early stages of pasture expansion coincided with decreasing beef production returns, and therefore the expansion of pastureland did not reach the level it attained in Yucatán.

[15] Another important factor shaping this trend was the discovery in the 1970s of Mexico's richest oil and gas fields in Tabasco and Campeche and their subsequent exploitation.

[16] People from many states where there were land tenure problems were offered *ejido* lands, mainly in the sparsely populated states of Campeche and Quintana Roo. Moreover, within the peninsula, there were migration flows from population centers with the highest population densities, by and large located in the state of Yucatán, to the forest/agricultural frontier.

[17] Prospective projects include the Progreso harbor (affecting mainly the Mérida–Progreso corridor), the Cancún–Xel-ha southward corridor, the road network linking the main Maya archaeological sites of the peninsula to those in Chiapas and Guatemala, and the transcontinental rail link in the Istmo de Tehuantepec.

[18] The incorporation of more elaborate functional relationships and methods (e.g., regression, path analysis, deterministic and stochastic functions, and inter-scale relationships) was precluded by the lack of useful data.

[19] Values used throughout refer to average values for the time step (in this case, one year).

[20] Considering the area occupied by the household and used in the provision of related services, it was assumed to be 20 m^2/person.

[21] These values were derived from the simulation data in Chapter 7.

[22] Housing expenditures were computed to be 10.8% of private consumption, a figure derived by the author from data from the 1992 National Survey on Income and Expenditures of Households (ENIGH, 1992). Private consumption was assumed to be 25% of gross economic output (after ENIGH, 1992).

[23] In simulation modeling, what is of interest is the status of the system at a given moment and its behavior as a function of time. Therefore, to begin running the model, initial values are required for the stocks of the land-use categories and parameters.

[24] Non-rival goods can be defined as those goods in which one person's consumption does not detract from another's consumption of the same good.

[25] Some peasants may not have other options. Maintaining their rural way of life may give them more security and a greater sense of freedom than would be obtainable with urban lifestyles. It can be argued that the Maya people, like others, are not simply closely related to their biophysical environment, but are also constituted by those very environmental relationships.

[26] Proportion of rural population, mean rural family size, yearly maize requirements for an average rural family, and average maize yield per unit area per unit time are exogenous variables. Thus they can take different values either in different simulation runs or at different times of a given simulation run.

[27] The calculations were carried out on a per family basis because income, expenditures, and food are usually managed at the family level.

[28] Given the biophysical characteristics of the peninsula, the required fallow period seems to be between 15 and 20 years, although the fallow period may decrease if intensive production techniques are used.

[29] The algorithm described above is written in CSMP (Continuous System Modeling Program). The time step used is 1 year. A period of 30 years was used in the simulations presented in Sections 10.4 and 10.5.

[30] The pro-growth and the pro-development notions are used here with the connotation of ecological economics. The pro-growth notion emphasizes economic output; the pro-development notion also pays due attention, at the societal level, to income and wealth distribution, the dynamics of biophysical resources, pollution levels, and health and education (from the extensive literature on the topic, see Freeman, 1986; Daly and Cobb, 1990; Costanza, 1991; Maunders and Burritt, 1991; Howarth and Norgaard, 1992; Repetto, 1992; Blamey and Common, 1994; Common, 1995; Gray, 1992, 1996).

[31] From 1986–1996, pastureland in the state of Yucatán remained fairly stable (Cuanalo de la Cerda *et al*., 1996). The same trend has been observed in other cattle-producing states in the southeast (e.g., Tabasco, Veracruz). The main reasons are the stagnation of demand for beef on the domestic market and the disappearance of credits and soft loans for pasture establishment and cattle production.

[32] It can be argued that although some knowledge and technological components can be found on the market, they are not necessarily available for a given production process if their incorporation into that process is constrained. Major constraints for technology adoption include the need to adjust the technology to the peninsula's particular production conditions and the need for a functional coupling of intensive agricultural production with the rest of the economy.

[33] Due to their biotic and economic functions, ecosystems located in the land–sea interface will be prime candidates for expansion of nature reserves. In addition, protection of specific sites inland (e.g., remaining patches of rare vegetation types, ecosystems of critical interest for certain species) may require special regulations.

[34] Considering that economic output from physical infrastructure currently amounts to more than 90% of total output (Anonymous, 1996) and that the trend is toward increased participation in the secondary and above all the tertiary sectors, it is reasonable to envisage a growing regional economy with simultaneous protection of the biophysical environment.

[35] It should be noted that future pastureland changes will be largely determined by factors external to the region, namely, interest rates, the beef-producing regions' share of the national market's supply, the proportion in beef supply between extensive and intensive cattle production, and the world market price of grains. The effects of the external environment on the survival and evolution of the peninsula's socioecological systems are likely to be as important as those originating within the peninsular system.

[36] A shared vision of socioecological development between the main social actors may encompass strategies, action plans, and actions incorporating the following: "eco-development" of the physical infrastructure (including eco-tourism); increases in land productivity, more integrated and efficient management of production factors, and minimization of external effects in commercial agriculture; an amalgamation of more agroecological practices and minimal use of agrochemical inputs in traditional agriculture; expansion of legume–grass pastures and better management practices in pastureland; integration of conservation of nature reserves with other land uses; and a

common commitment and effective enforcement of policies to maintain and enhance both primary and secondary forests (e.g., through the implementation of a multiple-use programs, which may be coupled, in some cases, with intensive plantations of tropical trees).

References

Ahmad, Y.J., El Serafy, S., and Lutz, E., eds, 1989, Environmental Accounting for Sustainable Development, The World Bank and United Nations Environment Programme, Washington, DC, USA.

Anonymous, 1996, Módulo Economía, CINVESTAV-Mérida, Mexico.

Bartelmus, P., Stahmer, C., and Van Tongeren, J., 1989, SNA Framework for Integrated Environmental and Economic Accounting, Lahnstein, Germany.

Batty, M., 1996, Urban change, Editorial, *Environment and Planning B*, **23**:513–514.

Blamey, R.K., and Common, M., 1994, Sustainability and the limits to pseudo market valuation, in J.C.J.M. van den Bergh and J. van der Straaten, eds, *Toward Sustainable Development: Concepts, Methods, and Policy*, Island Press, Washington, DC, USA, pp. 165–205.

Callenbach, E., Capra, F., Goldman, L., Lutz, R., and Marburg, S., 1993, *Ecomanagement: The Elmwood Guide to Ecological Auditing and Sustainable Business*, Berrett-Koehler, San Francisco, CA, USA.

Chemas, A., and Rico-Gray, V., 1991, Apiculture and management of associated vegetation by the Maya of Tixcacaltuyub, Yucatán, México, *Agroforestry Systems*, **13**:13–25.

Common, M.S., 1995, *Sustainability and Policy: Limits to Economics*, Cambridge University Press, Melbourne, Australia.

CONABIO, 1996, Ecosistemas, Comisión Nacional de Biodiversidad, Internet.

Costanza, R., ed., 1991, *Ecological Economics: The Science and Management of Sustainability*, Columbia University Press, New York, NY, USA.

Cuanalo de la Cerda, H.E., 1996, Project: Development of Traditional Farm Production Units in the State of Yucatán, First Annual Report Submitted to the W.K. Kellogg Foundation, manuscript.

Cuanalo de la Cerda, H.E., Navarrete Ortegón, R., and Gómez, A., 1996, La Agricultura del Estado de Yucatán, CINVESTAV-Mérida, Borrador.

Daly, H.E., and Cobb, J.B., Jr., 1990, *Economy, Ecology, Ethics: Essays Toward a Steady State Economy*, W.H. Freeman, San Francisco, CA, USA.

ENIGH, 1992, Encuesta Nacional Ingreso-Gasto de los Hogares, Mexico.

Espejel, I., 1987, A phytogeographical analysis of coastal vegetation in the Yucatán Península, *Journal of Biogeography*, **14**:499–519.

Ewell, P.T., 1984, *Intensification of Peasant Agriculture in Yucatán*, Cornell University, Department of Agricultural Economics, Ithaca, New York, NY, USA.

FAO, 1991, Sustainable Development and Management of Land and Water Resources, Food and Agriculture Organization, Background Document No. 1, FAO/Netherlands Conference on Agriculture and Environment, FAO, Rome, Italy.

Freeman, I.M., 1986, Comment 1: On the valuation problem, in D.W. Bromley, ed., *Natural Resource Economics, Problems and Contemporary Analysis*, Kluwer Nijhoff Publishing, Boston, MA, USA, pp. 139–149.

Gallegos, G.E., 1981, 'La Milpa': Sistema Tradicional de Producción de Maiz Asociado en la Península de Yucatán, Instituto de Investigaciones Agrícolas (INIA), Mérida, Mexico.

García, E., 1973, Modificaciones al Sistema de Clasificación Climática de Koppen, Instituto de Geografía, UNAM, Mexico.

Gray, R., 1992, Accounting and environmentalism: An exploration of the challenge of gently accounting for sustainability, transparency and sustainability, *Accounting, Organizations and Society*, **17**:399–425.

Gray, R., 1996, Corporate reporting for sustainable development: Accounting for sustainability in AD2000, in R. Welford and R. Starkey, eds, *Business and the Environment: A Reader*, Taylor and Francis, Washington, DC, USA, pp. 173–196.

HABITAT, 1996, An Urbanizing World: Global Report on Human Settlements, United Nations Center for Human Settlements, HABITAT, Oxford University Press, Oxford, UK.

Howarth, R., and Norgaard, R.B., 1992, Environmental valuation under sustainable development, *American Economics Association Papers and Proceedings*, Vol. 82, No. 2, pp. 473–477.

INE and CONABIO, 1995, Reservas de la Biósfera y otras Areas Naturales Protegidas de México, Instituto Nacional de Ecología y Comisión Nacional de Biodiversidad, A. Gómez-Pompa and R. Dirzo, eds, Mexico.

INEGI, 1994, Censos Económicos 1994, Consulta de Información Económica Nacional (CIEN) y Sistema Automatizado de Información Censal (SAIC), Instituto Nacional de Estadística, Geografía e Informática, Presentación en discos compactos, Aguascalientes, Mexico.

Marín, L.E., and Perry, E.C., 1994, The hydrogeology and contamination potential of northwestern Yucatán, Mexico, *Geofísica Internacional*, **33**:619–623.

Maunders, K.T., and Burritt, R.L., 1991, Accounting and ecological crisis, *Accounting, Auditing and Accountability Journal*, **4**:9–26.

Ramírez, L.A., 1994, La política del desarrollo regional en Yucatán: Descentralización administrativa y empresariado, *Estudios Demográficos y Urbanos*, **9**:381–393.

Repetto, R., 1992, Accounting for environmental assets, *Scientific American*, June:94–100.

Ruiz Chiapetto, C., 1993, El desarrollo del México urbano: Cambio de protagonista, *Comercio Exterior*, *43*(8):708–716.

Sprague, M.A., Hanna, W.J., and Chappell, W.E., 1978, Alternatives to a monoculture of henequen in Yucatán: The agriculture, climate, soil, and weed control, *Interciencia*, **3**:285–290.

Glossary

Bajos – seasonal swamps.

Cenotes – sinkholes in the karstic geological foundation of the Yucatán peninsula.

Chicle – substance produced from the latex of a large tropical American evergreen tree, *Manilkara sapota*.

Chinampas – artificially raised fields primarily in the vicinity of Xochimilco near Mexico City.

Ejido – a form of collective land tenure that originated in the 1930s. Its main objective was to provide land to peasants. In the early 1990s, new legislation aimed at facilitating the attainment of economies of scale in agriculture allowed the sale of *ejido* land, a practice that was previously forbidden.

Encomiendas – royal licenses to collect tribute and labor from designated Indian communities given by the Spanish Crown to the *conquistadores* in return for services rendered just after the Spanish Conquest. The license did not include rights to lands. Encomiendas were gradually replaced by true landed estates known as haciendas.

Graben – an elongated trough of land produced by subsidence of the Earth's crust between two faults.

Haciendas – large rural estates that used extensive agricultural production systems and were largely based on the exploitation of the labor force. The term was first used in Yucatán in the 18th century to refer to estates producing maize and cattle. Later, the best-known haciendas were those cultivating henequen or sisal.

Henequen – a plant native to Yucatán from whose leaves fiber can be extracted. Used by the Maya in pre-Hispanic times, it was cultivated commercially by the Yucatán elite on a large scale from the second half of the 19th century until the middle of the 20th century, after which its production declined markedly. A close relative of henequen was stolen from the peninsula by the British and taken to Tanzania via the Yucatán port of Sisal, hence its African name of sisal.

Horst – a ridge of land that has been forced upward between two parallel faults.

Labor dependency rate – ratio of nonworking to working population calculated as [(population under 12 + nonworking population over 12)/working population] $\times$ 100.

Mecate – an area of land measuring 20 m $\times$ 20 m, or 400 m^2.

Maquiladoras – multinational assembly plants.

Maternity index – (population of 0–4-year-olds/female population of 15–49-year-olds) $\times$ 100.

Milpa – in Yucatán, *milpa* refers to traditional, long fallow slash-and-burn agriculture centered on the production of maize, beans, and squash. Forest land (*monte*) is cleared, burned, and planted for a couple of years (the first year is known as *milpa roza* and the second year is *milpa cana*) and then left to fallow, ideally for 15–20 years. In practice the fallow period is much shorter now, 5–10 years being considered "good."

Natural rate of population increase – percentage increase in a population over a year if there were no in- and out-migration.

Rancherías – housemounds, previously identified as *mainales* (*milpa* houses) by Folan (1975:46) and Folan *et al*. (1983).

Rate of urbanization – percentage of the population living in settlements of 15,000 inhabitants or more.

Sex ratio – male population $\times$ 100/total population.

Theoretical rate of migration – the difference between the real rate of intercensus growth in the population and the natural rate of population increase.