CHAPTER 11: FINDINGS AND CONCLUSIONS

11.1 RELATIONSHIPS AMONG INDIVIDUAL STUDIES

The individual study areas chosen by the participants included four from Asia, three from North America, and two from Africa. Searching for relationships among these studies is one way of seeking common issues pertaining to global changel. Thus, one might compare problems in China to problems in India when focusing on population size or on fossil fuel reliance, as Duderstadt did. Fosnight convincingly compares Senegal to Nigeria. On some dimensions India is also suitable to compare with Nigeria--both have burgeoning population problems and both have great cultural diversity. MacFarlane, from her spatially localized comparison of Haiti to the Dominican Republic relentlessly sought to expand the resource dichotomy she noted there, to more global scales. The focus one brings to making comparisons is important. Thus, student participants were asked to consider how their studies might link to those of the others. Here are some of their views.

Duderstadt--on China Related to Others

The study of population-environment transition theory in China can benefit greatly from the analyses presented in the other papers in this collection. China faces demographic, energy, and toxicity transitions common to countries worldwide.

One of the most interesting comparisons concerns Katharine Hornbarger's work on the energy crisis in India. China and India are at similar points in their demographic, energy, and toxicity transitions. Their populations are increasing at dramatic rates. However, China's demographic transition differs from India's in the effect of family planning policy on birth rates. India's population will continue to increase far beyond that of China's. Another comparison lies in both countries' dependence on coal. Both countries rely heavily on coal combustion and will continue to do so in the future. China's coal reserves, however, are of far higher quality than those in India -- suggesting that India may encounter an even more sever crisis through its toxicity transition. In order to deter drastic effects from simultaneous transitions, China and India will require policy implementation toward the use of alternative energy and more energy efficient technologies.

Hurng-jyuhn Wang's paper studying transitions in Taiwan provides another valuable comparison concerning family planning policies. Taiwan implemented family planning policies around the same time as China. Both countries were able to substantially control their birth rates through these policies. However, both countries are also undergoing rapid urbanization -- China possibly more than Taiwan because of the push toward rural industrialization. Increasing urban populations will lead to more air pollution in the cities, particularly sulfur dioxide and particle pollution. Wang also explores a factor in population growth only glance over in my paper, but worthy further study. This factor concerns female education.

China is also experiencing a resource crisis because of massive deforestatic and land use conversion. Eugene Fosnight, Cathy MacFarlane, Deepak Khatr Stephen Uche and Dawn Anderson provide detailed analysis of these issues in the respective studies. China faces similar difficulties in obtaining traditional fuel materia leading to an increased dependence on coal. This factor will aggravate the energy an toxicity transitions in China, by increasing the need for non-traditional fu consumption and elevating the amount of pollutants in the atmosphere. Furthermore increasing populations will require greater carrying capacity for the land, as Fosnigl points out in his study of Senegal. Deforestation leads to soil erosion and reduce carrying capacity for the land.

In order to provide adequate energy to sustain a growing population, China wi have to change its focus toward alternative energy sources. Nuclear power remains serious option. Gary Stahl's analysis of the environmental impacts of nuclea technology in the United States and the former Soviet Union, however, serves as frightening warning against indiscriminate neglect of nuclear wastes. Hopefully, Chin can learn from the mistakes of other nations concerning the implementation an development of nuclear technology.

The environmental problems facing China are present worldwide. It i necessary to recognize the global impact of individual transitions in each country. O significant interest is the threat of global climate change. Although it is difficult t prove the impact of greenhouse gas emissions on climate change, the national threats t public health and reductions of resources justify a serious push toward curbin pollution.

Fosnight--on Senegal Related to Others

Four of the papers in this series discuss the relationship between th demographic and land use transitions. These studies in Costa Rica, Haiti, Nepal an Nigeria described the effect of deforestation on sustainable growth. All of the countrie are struggling with the impact of an exponentially growing population. The pattern i consistent. The population is concentrating in a few urban centers causing increase impact of forested lands for fire fuel and detracting from the problems of agricultura production. Haiti is the most extreme example with only five percent of its foreste lands remaining and with severe land degradation taking place on the denuded soils. I Nepal the topography limits access to much of the country which effectively protect the less accessible areas, particularly as the rural population migrates to the urba centers, and concentrates the deforestation problems into the accessible areas. Nepa and Costa Rica have, perhaps, the greatest concern with urban areas expanding into th best agricultural lands even those this problem exist in all of the countries. Nigeria i the most similar to Senegal, but with even greater population pressures. In Senegal limited precipitation and drought is of greater concern than in Nigeria.

Khatry--on Nepal Related to Others

The sectoral transitions described in my paper have some similarities with other papers in this monograph. Although the demographic and forestry transitions occurring in the hills of Nepal are unique in many respects, these transitions show some similarities with the demographic and forestry transitions occurring in Nigeria, Senegal, Haiti, and Costa Rica as described in the papers by Uche, Fosnight, MacFarlane, and Anderson, respectively. In all these papers, there appears to be a direct relationship between an increase in human population with an increase in deforestation and/or forest degradation. The forestry transition in the hills of Nepal bears the closest resemblance to the one described by Fosnight in Senegal and MacFarlane in Haiti, where population growth, forest degradation, and agriculture appear to be intricately tied together. One major difference between Nepal and Haiti is that Haiti is almost bald due to deforestation, whereas Nepal still has substantial forest cover, even though the forests are degraded. The population increase in Nigeria is different from the one in Nepal's hills due to the fact that a substantial portion of population increase in Nigeria is caused by in-migration from neighboring countries, whereas Nepal's hill population growth is exclusively caused by a high fertility rate. The Nigerian deforestation can be partly attributed to colonial timber export policy, whereas Nepal's forest degradation in the hills is exclusively due to the demands of a growing subsistence population. A major difference between the forestry transition in Nepal and Costa Rica is that a substantial proportion of deforestation in Costa Rica can be attributed to cattle ranching and establishment of commercial plantations such as coffee and banana. Again, forest degradation in Nepal's hills is a direct result of the pressures created by a growing subsistence population.

The energy transitions described by Hornbarger in India and Duderstadt in China have a relationship with the forestry transition in the hills of Nepal. Forest degradation in the hills of Nepal is occurring due partly to the biomass fuel need of a growing population. In all the cases of China, India, and Nepal, there is a direct relationship with population growth and a growing energy deficiency. One difference is that the Nepalese rely almost exclusively on biomass fuels, and energy is used in the non-commercial sector. Although biomass is a predominant fuel in China and India, these latter two countries do have other significant energy sources such as coal, hydropower, and some ability to import petrochemicals. China and India also use energy in the commercial sector. However, the potential to develop hydropower in Nepal exists. Another major difference in the energy transition of Nepal with that of India and China is that part of the increase in energy need of China and India is due to rural-to-urban migration (per capita urban energy consumption being higher than rural consumption), whereas rural-to-urban migration is not a significant factor in the case of Nepal.

Stahl--on United States Related to Others

In contrast to the other papers, this paper focuses on the transitions within a very specific sector of human activity; Nuclear Weapons manufacture. This sector is salient in the extreme danger it poses to the earth, not only by its products, by its by products as well. Just as the nuclear weapons themselves represent unprecedented potential for destruction, the radioactive and toxic byproducts of their manufacture represent an immense toxicity problem. Until recently, the stockpile of wastes has been growing, behind a veil of secrecy, unchecked by public oversight, propelled by the imperative of national security. With the end of the cold war these pressures have reversed. Many of the plants that produced nuclear materials are shut down. Warheads are being disassembled, and nuclear powered warships are being decommissioned. A transition to peace is taking place that affords the opportunity to reverse the accumulating stockpile of toxic wastes and begin a process of remediation.

Uche-- on Nigeria Related to Others

A web of causative factors has been pointedly identified as the root and intervening force for the world-wide environmental deterioration, especially forest depletion. I have tried to analyze some of these as they concern the Nigerian situation. A rapid population growth stands out as a conspicuous driving force for the many other variables that interact to stimulate deforestation. A burgeoning population which thrives on a subsistence, rainfed agriculture depicts a bleak future for the land, rivers, forests and biodiversity. An extensive agricultural and livestock production method can only meet the food needs of the Nigerian society by a continuous expansion of agricultural and grazing land into the frontiers. Increasing fuel and industrial wood needs, and unsustainable use of the forests will continue to diminish what is left of the forests. Overgrazing, overcultivation, and deforestation are pronounced, and have individually or collectively contributed to visible environmental degradations, be they desertification, siltation or loss of water systems, massive erosion or reduction in agricultural productivity.

Similar trends of rapid population growth-driven environmental inharmonies have been implicated in other parts of the world in the course of our population-environment dynamics seminar. Deepak Khatry, articulating such dynamics in the middle Hills of Nepal identified the relationships between a rapid population growth, agricultural intensification, fuelwood energy needs. deforestation and forest depletion. He surmised that rapid population growth is the root cause of the environmental deterioration in Nepal. Similar observations were made by other workers. For instance, Katharine Duderstadt on energy needs in China; Gene Fosnight on the forestry and population situations in Senegal; Cathy MacFarlane on forestry and population changes in Haiti and Dawn Anderson on forestry dynamics in Costa Rica. All identified rapid population growth as the remote cause of the dwindling forestry and environmental trends in each of the cases. A projection into the future indicates even a worsening and frightening situation unless some conscious and aggressive steps are taken to stabilize population. Even if that is done today, the effects of population momentum will continue to generate high populations into the future.

From these various critical analyses from different parts of the world, it was established that different countries are in different stages of their population-environment transitions. It was equally recognized that there is a rising environmental consciousness among nations although each has different approaches towards addressing the problems. For instance, while some have adopted a stringent and coercive family planning program, e. g. The Peoples Republic of China, others have taken a laissez faire approach, e. g. Nigeria. Still, many have adopted different forestry policies with an intention of reversing the environmental trends. Unfortunately, not enough has been done by any one country. In general, there is the need for all countries of the world to continue to implement realistic environmental policies that will guarantee environmental-population harmonies.

Wang-- on Taiwan Related to Others

Nine countries were examined with regard to transitions; each country had a very different transition character. Among the countries studied, Taiwan has the highest income level (other than the U.S.). Taiwan's transitions are very difficult to apply to the others at the present time, although they may become the prototype for them when time and spatial situations change in the future.

However, in theory, the characteristics of transitions, in terms of policy implications and governmental administrative experience, might be transferred from developed countries to less developed countries. Taiwan's experiences in agricultural development and the demographic transition might play a useful role to third-world countries that choose to retrace those transitions.

These views of the interweaving of transitions, not only by type of transition but also by geographic region, suggest the richness of this sort of approach. In the next section we explore additional connections and finally suggest directions for the future.

11.2 COMMON FINDINGS

It is not unexpected that there are similarities among the papers in this volume. The researchers interacted heavily during the entire study and manuscript preparation period. In addition, each participant used a common framework, namely the notion of a family of transitions, for viewing the population-environment dynamic. What is surprising, however, is the similarity among both the findings in the studies and in the methodology problems encountered - even though they are studies varying widely in topic and region of the world. These similarities call out for explanation. We begin suggesting possible reasons for resemblances by reviewing the common themes among the papers. Table 11.1 presents the different sectors analyzed in each study. The last column indicates if longitudinal data were available and utilized in the analysis.

Table 11 - 1 Transition Studied by Country and Investigator

Chapter	Author	Country Studied	Transition Investigated	Longi-tudinal
2	D. M. Anderson	Costa Rica	Forestry: timber, reforestation Agriculture: farming, ranching Demographic: total population, fertility, death Urbanization Energy	yes yes yes yes no
3	K. A. Duderstadt	China	Demographic: total population, fertility Energy: community consumption, imports, per capita, requirements, by type Urbanization Industrial Toxicity	yes yes yes yes yes
4	E. A. Fosnight	Senegal	Agriculture: forest, agriculture (all by region) Demographic: total population Urbanization	yes yes yes
5	K. Hornbarger	India	Energy: commercial, non-commercial by type, consumption by type Demographic: total population Urbanization: urban and rural Toxicity	yes yes yes yes
6	Deepak Khatry	Nepal	Demographic: total population Agricultural: by geographic zone, fertilizer usage, soils, livestock Forestry: by geographic region Epidemiological Urbanization	yes yes yes no no
7	C. MacFarlane	Haiti	Demographic: total population, crude birth rate, crude death rate, total fertility rate, age distribution, over age 65, infant mortality rate Forestry: woodland area, fuel wood & charcoal	yes yes
8	Gary Stahl	United States	Toxicity (production of nuclear weapons) : by waste type at each stage of production Toxicity (retiring warheads and ships): by type of weapon and ship	yes yes
9	Stephen Uche	Nigeria	Demographic: total population, crude birth & death rates Urbanization: rural, urban, density Forestry: forest area, cattle population	yes yes yes
10	Hurng-jyuhn Wang	Taiwan	Demographic: crude birth & death rates, total population, female literacy Urbanization: urban & rural population, semi-urban population Rural Industrialization Agricultural: cultivated land by type, yield, fertilizer usage, farm families	yes yes no yes

A. PROJECTIONS OF TREND

This last month the U. S. Census Bureau sharply revised its view of Americas's future population. Rather than levelling off at 300 million by the year 2050, it is now expected to grow to 383 million by that same time and continue to grow thereafter. This change in the projection of population is due to changing patterns of age-specific fertility, immigration and longevity. Even though the United States has some of the best data gathering and analysis systems in the World, its projections have had to be modified radically from what was well accepted just a few years ago. What of countries that do not have as reliable longitudinal data? Yet, the basis of much public policy must be, and is, based on such projections.

During the course of this investigation, much effort was devoted to dealing with this problem. We accept that the projection of trends is important--be these trends those of population growth, deforestation rate, or a host of others. It is by looking at present and past data that one attempts to project trends into the future; indeed, to control the direction these trends might take. Thus, understanding how one might make these projections is critical. One way that is commonly employed, and that is quite useful in that it simplifies and clarifies, is the fitting of curves to observed, actual data. When the curve is extrapolated beyond the domain of current, actual inputs into the algebraic function describing the curve, the trend represented by the actual data is projected into the future. Because any curve may be extrapolated in an infinite number of ways, it is important to know ***both*** how a curve was fit to actual data and how it was extrapolated from actual data.

Anderson found, for example, that in Costa Rica, the logistic curve was a better choice to fit the actual deforestation than was an exponential. She found that when the obvious upper bound for the logistic, of q=4000 (the number of hectares possibly forested--the sum of current pasture and forest lands (suggested to her by Arlinghaus)), that the fitted curve overfit the actual data. However, when Anderson chose q=1270, the number of hectares under current protective status, she obtained a much better fit. Thus, she notes that "this suggests that the true limit of deforestation in Costa Rica is the amount of lands under protective status." Indeed, a thoughtful finding and one that suggests that government policy must enforce strict protective standards that add to Costa Rica's protected lands and refuse to allow any further depletion of forest stock.

Duderstadt also found a surprising situation when she fit a logistic curve to the actual population data for China. When she correctly fit a logistic curve to current data, using the stated upper bound of stability at 1.5 billion, her curve underfit the apparent logistic prediction of the World Resources Institute, although both fit the actual data from 1970 to 1990--with a slight discrepancy between the fits from 1950-1970. What this unexpected finding suggested to all was the importance of documenting for the reader (which WRI did not do, as far as we could tell) how projections of trends into the future are made. The slight variation between Duderstadt's fit and the WRI fit at the early end of the curve and the other end of the actual data close to the present, might be attributed to round-off error or some such numerical aberration. Again, it is not possible to ascertain if this is the case because WRI did not say, in addition to not telling the reader if the projection was made using the logistic curve, to how many decimal places their calculations had been made. By the year 2030 the Duderstadt fit and the WRI fit show a discrepancy of about 50 million people--enough of a difference to cause severe variance in policy decisions made years before either projected value is approached.

When Duderstadt used STELLA (allowing her great flexibility and ease in executing complicated dynamic modeling) to make a curve fit of the Chinese population data, the curve did not fit the actual data as well as her own estimate. It appeared to be some sort of a compromise between the projection of WRI and her own projection based on a tight logistic fit of actual data. Once again the importance of knowing the theory behind even dramatic technology became evident.

Fosnight looked at land use and land cover change, at the national level, in Senegal. He found quite naturally, as did others, that the forest and woodlands curve is symmetric about a horizontal line with that of agricultural lands. He observed that in some subnational units of Senegal the human carrying capacity had shot up exponentially while in others it had not. Disaggregation of national data in this manner is important to see where to focus policy efforts; Fosnight saw the possibility of using remotely-sensed data in Senegal as a means to supplement more traditional, and difficult to acquire, data.

Hornbarger (India) produced a graph of "Possible Futures for Coal Consumption," portraying alternative futures and explaining how they were obtained, reminiscent of the mop-like graphs in Meadows--those in which a number of different curves show a tight fit to current data and are woven together into a "handle" from which their stringy tentacles extend in disparate directions into the future. She used both a logistic curve and an exponential curve and fit them to coal consumption over a period of 100 years. Toward the far end of the projection the difference between the fits is of course quite large--the logistic damping of exponential growth becomes evident. Hornbarger once again underscores the importance of carrying out curve fits far into the future.

Uche's study of deforestation in Nigeria reveals the clear need for countries to have at least somewhat accurate monitoring of their own population; indeed, estimates of the Nigerian population in the two GISs used in this course range from 88 million to 122 million! Thus, as Uche points out, graphs that project an exponential population growth may be quite misleading, insofar as the last reliable benchmark was the 1963 census. Certainly it is easy to question the reliability of the evidence in the graph of fertility rates (Crude Birth Rate in Nigeria from 1950-2025) which shows a sharp drop projected after 1990--another case where it is important to understand that any of an infinite number of curves may be used to project from existing data.

Wang coupled some very careful use of fitting the logistic curve to his dazzling array of data in order to illustrate causal relationships in the population sector of Taiwan. He focused on the importance of the education of women as a way to continue to improve the management of the population stock in the years to come. In Wang's study, as in all of those above, there is an optimism (more in some; less in others). At present there are difficulties; growth appears to be logistic in nature, although of course one can't be sure. But there is reason to think that situations that signal dangerous depletion of critical resources might be reversed.

Stahl's study offers an important broad perspective to keep in mind when viewing how population might interact dynamically with the "natural" environment. He shows, how, over a short period of time (the span of the nuclear weapons build-up--a mere blip in the history of the creation of natural resources) the population of an affluent nation can become threatened by the byproducts of its own creations. This is an abstractly similar dynamic to the usual population-environment dynamic, although it is perhaps one not usually thought of within that context. Thus, Stahl's analyses for the U.S., and speculations for the former U.S.S.R. offer time-capsule type evidence for those looking at the sorts of opportunities of which economically-emerging nations might run afoul. At what price is defense of one's national territorial boundaries reasonable; what sorts of diminishing returns are there on the notion that one must have nuclear/atomic weapons for protection. Indeed, these returns are all the more the case as current projections of U.S. population suggest that the standard estimate of 299.7 million by 2050 may well be a vast underestimate coming from high fertility rates in recent migrants and from a surprising increase in babies born to women over 35 years of age. There are clear policy implications for countries with nuclear capability who either have, or are facing, a serious population problem. A global humanitarian cause is not served by the sale of weapons to the developing world.

Khatry (Nepal) has impressive evidence showing the difficulty, and therefore the danger, in making curve fits and consequent projections from questionable and scant data. He fits a wide variety of functions, linear, polynomial, exponential, and logarithmic to population and other data. He obtains a frighteningly good fit to population growth with exponential functions; he notes that the "logistic equation, which is commonly used to denote population growth...can be problematic, especially if one argues that subsistence lifestyles may change in the future as other opportunities for livelihoods may arise." Hence, he sees a severe difficulty in speculating on a reasonable upper limit or carrying capacity. However, it is important to do such speculation; without it, and if growth continues in an exponential fashion, depletion of forest resources and land denudation surge forward. A greater population has fewer and fewer reserves on which to draw; the exponential trend becomes irreversible and accelerates toward an eventual collapse of some part (or all) of the social and environmental system. Thus, it is critical to stem such a tide by determining when irreversibility becomes inevitable and then intervening with policy to prevent irreversibility. It is important that Khatry has empirical evidence to identify various trends in a nation just emerging on the global scene.

MacFarlane's graphs of Haiti also suggest exponential growth and an irreversibility evident not only in graphs but in comparative photos of lands along the Haitian and Dominican Republic side of the common border. The stripping of practically all vegetative cover has left the western half of the island of Hispaniola a nation with only a bleak future, if indeed it has one at all. The policy implications for industrialized countries seem clear--here is an island in dire need of humanitarian intervention.

B. FITTING CURVES TO DATA

Actual data, when graphed over time, can produce all manner of curves. There are many techniques for interpolating values between actual data points. There are also many ways of fitting curves to actual data so that curves fit to actual data can be extrapolated into the future to suggest alternative futures. Diagrams in Meadows (1991; reference in Appendix) reflect this sort of idea. Figure 11.2.1 offers a diagram of that sort and suggests the difficulty of choosing any curve as being representative of what is likely to happen in the future.

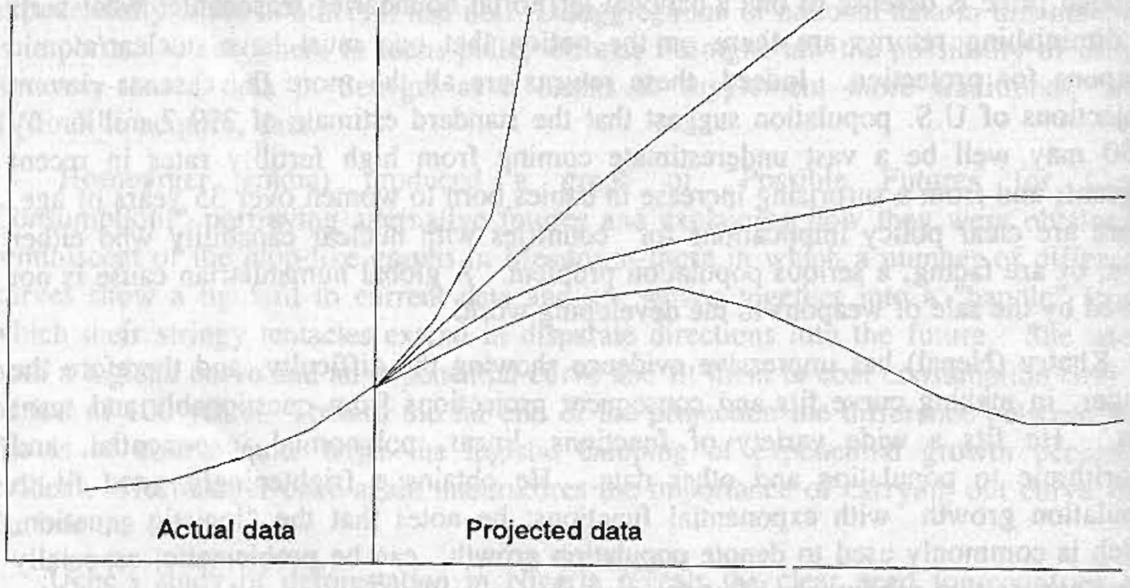

Figure 11.2.1. The curve to the left of the vertical line is a curve fit to actual data. The curves to the right suggest alternative futures. Each fits the actual data, yet each takes a vastly different path into the future.

The dynamic interaction between population and environment cannot be captured by a single, static curve. To have a notion of where to direct the application of policy to guide future development, it is thus important to consider the variety available in looking at alternative futures. When doing so and using a data set that has "future" data in it, it is therefore critical to know how this data has been projected from actual data: along a straight line, along an exponential curve, or along a logistic curve (to name a few)? Good data sets should tell the user how such projections have been made; if data sets do not so inform the user, then the user should feel obliged to determine this information and pass it along to future users. The only opportunity the user of a data set has to know if the projected data represents an extreme or a moderate forecast, is to know how the projection was made. In data as in maps, the method of projection is critical in understanding where distortion in meaning might occur.

Thus, we looked at families of transitions (Drake, 1992; reference in Appendix) in order to characterize various facets of the dynamic interaction between population and environment. Still, there remains a need to be able to compare, in some systematic and replicable fashion, the sets of curves generated by these families of transitions. One classical way to do this is to use techniques from the calculus. Another is to use a current geometric approach in which we attempt to make the dynamics of the geometry fit the dynamics of the real world (see Appendix).

Tangent lines and inflection points.

Often, transitions and issues involved with population dynamics follow an S-shaped curve (logistic, Gompertz, or other). Classical analysis offers tools for comparing different S-shaped curves to each other. The slope of the line tangent to a curve at a point measures the rate of change of y (the dependent variable) with respect to x (the independent variable). The steeper a positive slope, the greater the rate of change. Along an exponential curve, the slope of the tangent line is ever increasing as the independent variable increases--hence the devastating predictions that come from using an exponential curve to extrapolate from a set of actual data (Figure 11.2.2).

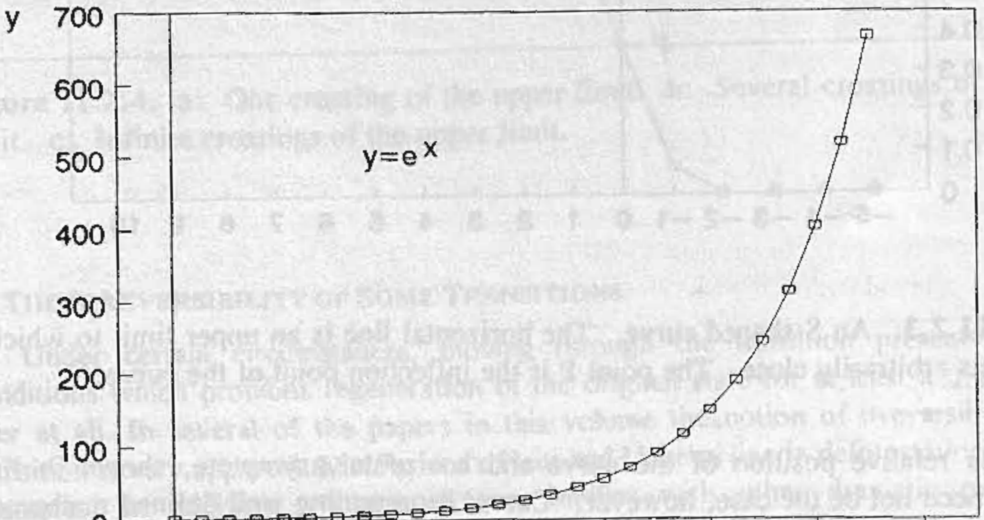

Figure 11.2.2. An exponential curve. The rate of change of y with respect to x, the slope of a line tangent to the curve, is ever-increasing as x gets larger.

When the exponential is tamed by placing on it some sort of upper bound as a "limit to growth" (Meadows 1992; reference in Appendix), then change in the slope of the tangent line is forced -- for a time it is increasing, but as the upper bound is approached the rate of change tapers off and control of the rate of change enters the picture (Figure 11.2.3). The point at which the slope of the tangent line ceases to increase is called the inflection point of the curve; it is also the point at which the curve switches from being concave up to being concave down. The slope of the tangent line at the inflection point is as steep as it will get; it is here that the rate of change of y with respect to x is at its largest. The coordinates of the inflection point are straightforward to calculate and have interpretations bearing on the real-world criteria that might have been used to select the upper limit (Arlinghaus 1991; reference in Appendix). Beyond the inflection point, the curve approaches the upper limit asymptotically--the larger the value of x, the closer y is to the upper limit. Generally, this idea is expressed as a simple approach by the curve from below the upper limit (Figure 11.2.3).

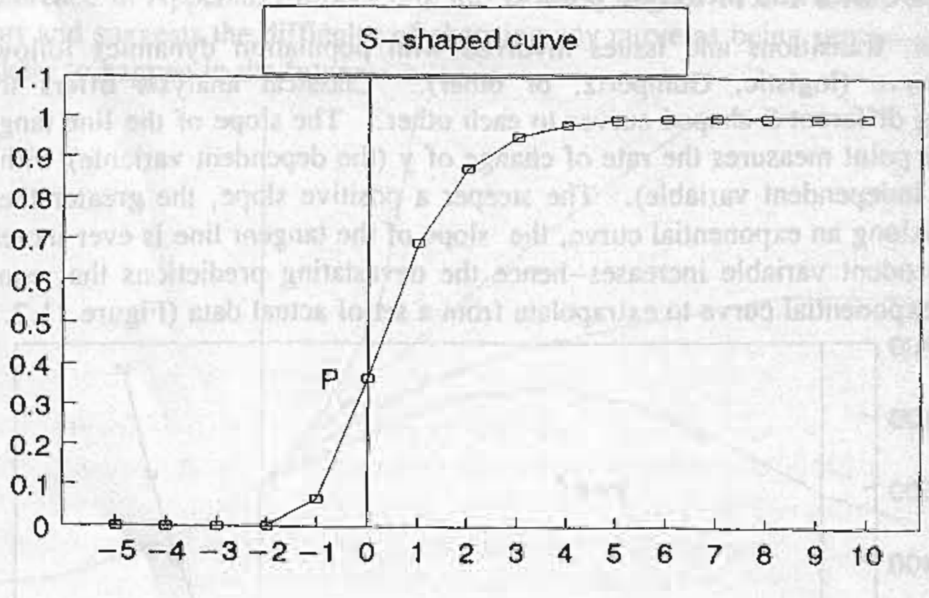

Figure 11.2.3. An S-shaped curve. The horizontal line is an upper limit to which the curve gets arbitrarily close. The point P is the inflection point of the curve.

This relative position of the curve and horizontal asymptote, shown in Figure 11.2.3, need not be the case, however. Curves representing well-defined mathematical functions can cross a horizontal asymptote, one, several, or an infinite number of times (and can be calculated) (Figures 11.2.4a, b, c). Thus, it is possible to go beyond an upper limit and yet still have that limit influence the ultimate behavior of the real-world process represented by the curve. Minor violations are tolerated; shattering of the limit sends the curve off exponentially, once again.

The ideas of slope of the tangent line, inflection point, horizontal asymptote (or upper bound), and intersection points of curves with an upper bound offer a set of concepts from the calculus that can be used to make quantitative comparisons of S-shaped (and other) curves that represent transitions. The insights they can offer are largely based on rates of change as the independent variable becomes large. They do not offer any strategy for suggesting geometric irreversibility; they are based on continuous methods in which one does not get geometrically trapped in geometric feedback. The Appendix shows a conceptual strategy as to how the geometric dynamics of Feigenbaum's graphical analysis might be used to capture feedback in order to suggest when irreversibility comes into play.

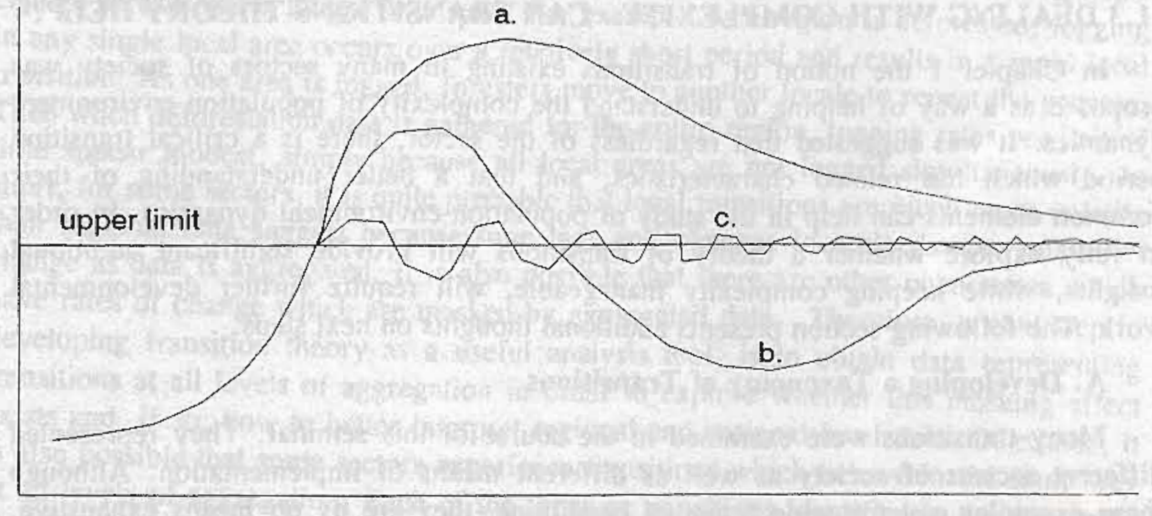

Figure 11.2.4. a: One crossing of the upper limit. b: Several crossings of the upper limit. c: Infinite crossings of the upper limit.

C. The Irreversibility of Some Transitions

Under certain circumstances, moving through the transition presents a set of conditions which prohibits regeneration of the original state for at least a millenium, if ever at all. In several of the papers in this volume the notion of irreversibility of the transition is very apparent. MacFarlane's Haiti and Uche's Nigeria deforestation papers are examples. In addition, we are all too familiar with other dramatic examples of irreversibility such as the demise of the Aral Sea of Russia. Even the lovely heather-covered moors of Northern England are examples of hardwood forests which transitioned to their "new" state during the eighteenth century when England needed wood for the tall masts and hulls of its naval fleet. During the course of the seminar this characteristic was discussed in relationship to specific settings, but perhaps there are conditions that could be identified which are general to many transitions. If so, there might be important policy implications in terms of intensity and timing of intervention. We did not have time to explore this topic fully, but consider it an especially important next step.The Appendix suggests one theoretical approach to characterizing irreversibility.

D. Importance of Urbanization

One of the more interesting results of this investigation is the importance of the urbanization transition. Table 11.1 indicates that almost all studies utilized this transition. Furthermore, the nature of the urbanization transition often was critical to the findings in the analysis. We suspect that a further examination of this transition, in relation to the others, is an important avenue for future research.

11.3 DEALING WITH COMPLEXITY - CAN TRANSITIONS THEORY HELP?[2]

In Chapter 1 the notion of transitions existing in many sectors of society was proposed as a way of helping to understand the complexity of population-environment dynamics. It was suggested that regardless of the sector, there is a critical transition period which has related characteristics, and that a better understanding of their common elements can help in the study of population-environment dynamics. In order to fully explore whether a theory of transitions will provide significant additional insights, while keeping complexity manageable, will require further developmental work. The following section presents additional thoughts on next steps.

A. Developing a Taxonomy of Transitions

Many transitions were examined in the course of this seminar. They represented different sectors of society as well as different means of implementation. Although these examples cover a wide range of conditions, they are by no means exhaustive. Therefore, an important next step is to develop a taxonomy of types of transitions and a nomenclature useful in their classification. For example, we have already suggested two broad categories: 1) transitions typifying different sectors in society and 2) those representing the means of change. Within each broad category in society, there are logical sub-groupings. For example, the toxicity transition is actually a grouping of transitions representing many different types of toxins or pollutants existing in air, ground water, surface water, and various types of solid waste.

As this taxonomy is developed, care must be taken to distinguish between the ever-present changes occurring in society and the specific change represented in a transition as defined here. The key aspects of transitions discussed here are, first, that the phenomenon under consideration starts from a condition of relative equilibrium, then shifts from slow to rapid change and returns again to relative stability, generally at a

[2] The material in this section has been condensed from a section by W. D. Drake in the concluding Chapter in *Population-Environment Dynamics*, Ann Arbor, University of Michigan Press, forthcoming in 1993.

different level and with different determinants. Second, a transition period is accompanied by an imbalance and/or change between key variables that is, in some way, unusual. Returning to relative stability after the transition does not necessarily mean that the determinants of the new equilibrium are the same as before the transition.

B. Obtain Empirical Evidence for Each Type of Transition

Longitudinal data on the population-environment dynamic is now becoming more readily available. However, this data often portrays transitions at the regional, national or international level and is obtained from secondary sources. We suspect that transition data of this type, which is aggregated to regional or higher levels of government, often masks the degree of change occurring at the local level. The volatility of change probably is much greater locally, but as local transitions are combined with others occurring at slightly different time periods the data appears to show a more gradual change spread over a longer time span. For example, as a region is deforested, logging in any single local area occurs over a relatively short period and results in a rapid local transition. As one area is logged, foresters move to another locale to repeat the process. Then when deforestation data is gathered for the entire region, logging rates per unit of time appear modest, simply because all local areas are not logged simultaneously. In short, for some sectors, it is quite probable that local transitions are much more volatile than regional data suggest because time lags and changes in scale dampen *apparent* change as data is aggregated. It is also possible that there are other phenomena which have rates of change which are masked by aggregated data. Therefore, a next step in developing transition theory as a useful analysis tool, is to obtain data representing transitions at all levels of aggregation in order to explore whether this masking effect exists and, if so, how to better interpret regional and national level data. Of course, it is also possible that some sectors experience transitions which behave in the same way at all levels of aggregation. Each of the types of transitions identified in the taxonomy should be explored empirically to see how universal the masking effect is.

C. Obtain Empirical Evidence on Geographic Regions Experiencing Multiple Transitions Simultaneously

One of the key arguments for viewing population-environment dynamics as a family of transitions is that transitions often occur simultaneously in several sectors. Therefore, it could be very useful to obtain empirical evidence on *geographic regions* which might be experiencing multiple transitions at the same time. In this case, an attempt should be made to identify changes in all the important sectors for each of several local settings. These locales then could be categorized by the degree to which they indicate transitional volatility. If earlier contentions about heightened societal vulnerability during transitions are valid, then there should be indication of such risk.

Because of the field-level difficulty in implementing such studies, it is unlikely that the status of all sectors could be determined in any single project. Furthermore, because the rich cultural and other local contextual characteristics are so varied, such geographically-bounded studies should be replicated many times. It is interesting to note that this type of study is similar to case studies done in many fields; including geography, natural resources, public health, anthropology, and public policy. Consequently, another possible approach to this inquiry would be to draw upon already existing studies in these fields, but recasting them in terms of transition theory.

D. Describe Transitions with Mathematics

The word "theory" has been used here to mean some sort of broad systematic strategy for linking similar observations concerning the behavior of different types of transitions in order to seek useful similarities among them. This real-world approach to theory shares with its mathematical counterpart the necessity of developing a logic for connecting related ideas. The mathematical approach typically consists of creating theory as a logically connected body of theorems. The real-world approach often does not prove theorems but seeks a similar style of connectedness.

Thus, another next step would be to find a way to hook real-world transition theory into mathematical theory. Mathematical models are an entry point to the latter theory much as evidence from the field or other primary sources can be entry points to real-world theory. Because curves of different shapes describe different transitions, a model that examines the geometric dynamics of the set of curves could be helpful. A tool which might be useful in this endeavor is Feigenbaum's graphical analysis from chaos theory. One curve might be well behaved (from the standpoint of geometric dynamics) while another, of just a trifle different shape, might be chaotic. Both might fit data from the real-world transition under consideration. Mathematics could offer reasons to choose otherwise equal choices by selecting the alternative most similar to real-world conditions.

A further step, with this mathematical model in hand, is to attempt to enter the world of mathematical theory and to characterize real-world transition theory as a mathematical transition theory (drawing perhaps from analogies with various transitions in the physical world). Then, with two parallel expressions of transition theory, the final step would be to align them and use one on the other to gain deeper insight.

Several mathematical formulations which could be useful in portraying transitions were presented. After getting empirical data, these functions should be fit to the data. It is hoped that by so doing, at least three benefits would be attained. First, if reasonably close fits are achieved, there may be new insights obtained on the character of the transition phenomenon resulting from knowledge about the mathematical function as discussed earlier. Second, comparisons across different scales within a sector and among different sectors would be facilitated. Third, providing unbounded functions are used, predictions about future rates of transitional change could be made by extending the time variable into the future.

E. Investigate Causes of Transitions

Perhaps the most important and potentially beneficial next step in the development of a theory of transitions is investigating the causes behind transitions. Understanding why a transition happens is fundamental to knowing how to modify its trajectory. If it is true, as we believe, that societal vulnerability is often higher during periods of rapid change, then in some circumstances, it may be prudent public policy to slow the transition. At other times, it may be more helpful to simply predict the timing of rapid change in order to plan for infrastructure needed to accommodate new conditions following the transition.

While much has been written about periods of rapid change in each of the major sectors of society, there is often little consensus about the underlying causes for this change. For example, even the widely studied demographic transition has adherents to different reasons for changes in fertility. Is reduction in fertility caused by improvements in education and affluence or is it caused by the clear identification of opportunity costs to the family in having additional babies? Education and affluence are traditional hypothesis, but recently there is mounting evidence favoring the opportunity cost hypothesis. It is quite probable that public policy which attempts to modify the trajectory of the demographic transition would differ depending upon the extent to which the competing hypotheses is true.

F. Studying Linkages Among Sectors

At the onset of this investigation, it was posited that there are linkages between different sectors of society which occasionally amplified each other's effects. We have seen such amplifiers in several of the studies in this volume. For example, high rates of urbanization occurring at the same time as severe toxicity transitions, overloads existing infrastructure and amplifies adverse effects in the epidemiological transition. As another example, historically, the deforestation transition is related to the agriculture transition because expansions in land under cultivation often came at the expense of forests. Now, however, as increases in agricultural production are coming from intensification of land already under cultivation, this linkage between agriculture and forests is less apparent. These two examples point out that while linkages exist, the strength of their relationship is by no means constant over time. In some cases connectedness between sectors is increasing and in others it is decreasing.

Another dimension in the development of a theory of transitions is to explore these linkages, perhaps on a case-by-case basis as has been done in this volume. And it is in this area that there may be fruitful policy implications. What are the circumstances under which these associations amplify adverse effects and when do they dampen impact? Which linkages between sectors are increasing in strength and which one are diminishing? Are there circumstances under which public policy can have a positive societal effect by encouraging joint development which either dampens adverse impact or reduces rates of change so that natural corrective processes can operate better?

11.4 FURTHER NEXT STEPS

What we seem to have learned is that transitions, and analysis using transitions, can offer far more insight when coupled with each other than when viewed, and applied, in isolation. As we knew, from the evidence, literacy is the inverse of population growth. What we found is that in all cases studied (with the exception the not yet urbanized Nepal) there was a surprising necessity of embracing the urbanization transition as the lifeblood of the analysis. Deeper probing of this necessity is clearly a vital next step.

There are a number of conceptual issues that remain--what types of curves reflect what patterns of irreversibility? How do these patterns tie to real world data and suggest a conceptual framework in which to guide intervention to keep curves from following projected courses to disaster? The theoretical approach of using chaos to find irreversibility thresholds is one step (Appendix).

A step in a different direction is the transmission of information: as MacFarlane, Duderstadt, and Wang have noted, education is a critical variable. So, too, it is in disseminating the results of these analyses and future work. This monograph is, itself, one step in that direction! Handbooks of data, that draw on global change data for examples, are another next step in the direction of education. People often integrate, into their general intellectual repertoire,the examples by which they learned techniques.

We have much more to say about next steps. But in the interest of producing this volume by the end of the term in which the course was offered, we shall stop here. During the next several months, in preparation for the next phase of development, there will be opportunity to reflect with more deliberation on what has been learned.