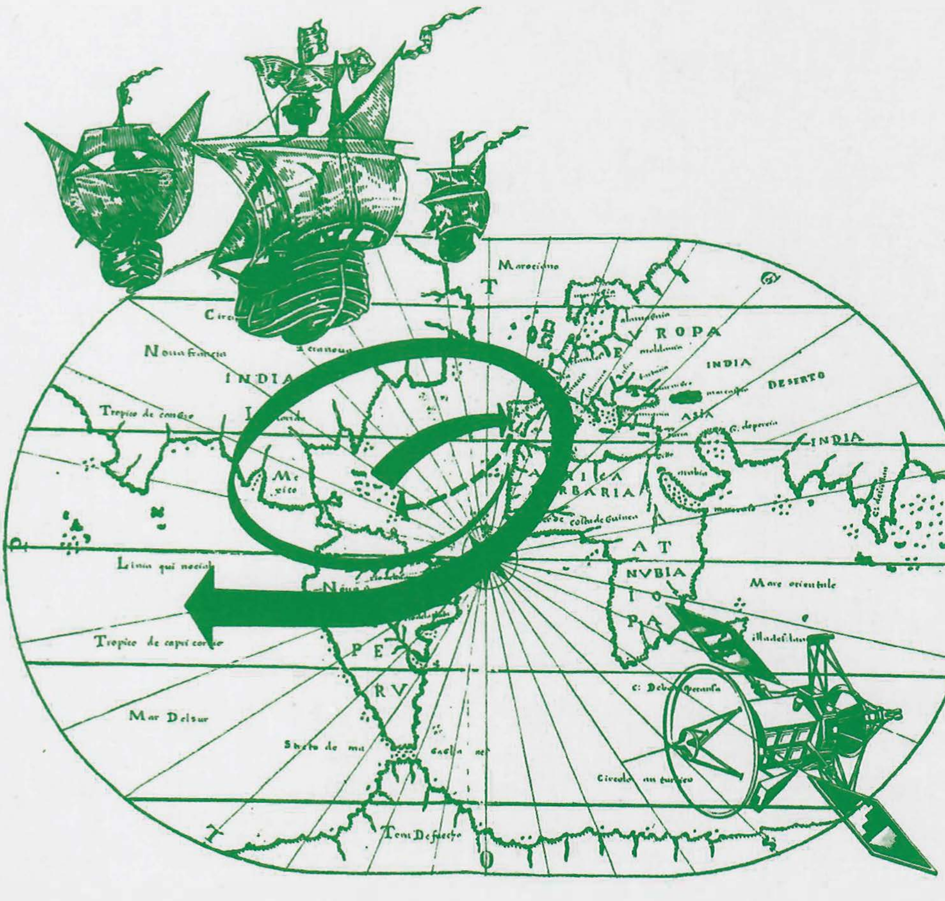
GLOBAL LAND USE CHANGE

A PERSPECTIVE FROM THE COLUMBIAN ENCOUNTER



Edited by

B. L. Turner II - Antonio Gómez Sal
Fernando González Bernáldez - Francesco di Castri

Consejo Superior de Investigaciones Científicas

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DEDICATION

This volume is dedicated to Dr. Fernando González Bernáldez. A noted scientist, teacher and mentor who was strongly marked the development of the Spanish Ecology. He was a co-organizor of the SCOPE scientific symposium on which this book is based, and a co-editor of the book. Dr. González Bernáldez was so keenly dedicated to the subject in question that he prepared and delivered his paper under conditions of poor health. He passed away on June 1992, during the editorial stages of the book's preparation.

PRESENTACIÓN

Hacia un análisis en perspectiva del cambio global en los usos del suelo.

El presente libro tiene su origen en la decisión del Comité Español de SCOPE (Scientific Committee of Problems of Environment) de presentar la candidatura de España para organizar la VIII Asamblea General de dicho organismo internacional. Como Secretario del Comité Español, dependiente entonces del CSIC, me correspondió efectuar la propuesta de candidatura en la VII Asamblea General que tuvo lugar en Budapest en 1988. Nuestras posibilidades eran muy exiguas teniendo en cuenta la limitada representación y actividad de nuestro país en SCOPE. Actuaban a nuestro favor dos circunstancias que resultaron decisivas: la elección de Francesco di Castri, buen conocedor de España y de los ecólogos españoles, como Presidente internacional en la VII Asamblea y la proximidad de 1992. Una adecuada valoración por parte de di Castri de la oportunidad que dicha fecha representaba, para analizar con perspectiva los cambios ambientales a escala global, así como de la importancia que se pretendía dedicar en España a la conmemoración del V Centenario del Descubrimiento o Encuentro en dos mundos, hizo posible no solo que nuestra candidatura resultase elegida, compitiendo con paises más cualificados por su mayor tradición en SCOPE, sino incluso modificar, como excepción, el ritmo trienal de celebración de las asambleas generales y retrasar un año la prevista en España, para que coincidiera en el 92. Con estas premisas resultaba sin duda necesario organizar en paralelo con la Asamblea alguna actividad que respondiese a las expectativas creadas: ofrecer una ocasión para analizar la evolución de los cambios ambientales a escala global, cuyo origen cabe situar en la fecha del Descubrimiento.

Para avanzar en la organización de la Asamblea General, asisto en julio de 1990 al simpósium regional sobre Desarrollo Sostenible y Uso del Suelo en América Latina organizado en Santiago de Chile con motivo de la reunión del Comité Ejecutivo de SCOPE. Es allí donde proponemos el contenido general del simpósium a realizar en España. Tendría por objeto analizar con perspectiva histórica, desde 1492 hasta la actualidad, los cambios en los usos del suelo que se iniciaron en Europa y en América a partir del encuentro entre ambos mundos, principalmente los debidos a los intercambios de especies que se propiciaron.

Mas adelante y con objeto de definir más claramente los contenidos del simpósium y las participaciones previstas, tiene lugar una reunión en París a la que asistimos los que seríamos responsables directos de la organización (Steering Committee), los profesores B. L. Turner II, Fernando González Bernáldez, Francesco di Castri y yo mismo. Participa también Veronique Plocq como Secretaria Ejecutiva de SCOPE. Se decide que la participación sea por invitación con objeto de reunir especialistas que hubiesen dedicado la mayor parte de su actividad profesional al tema propuesto. Se pretende contar con ponentes de probada experiencia en los temas definidos de antemano como de mayor relevancia. El objetivo es crear un documento que sirva como referencia, que analice y aporte datos sobre los cambios ambientales que tuvieron lugar desde el descubrimiento y del que puedan deducirse enseñanzas útiles para afrontar los retos que en la época actual plantea la gestión del desarrollo. Se encontraba próxima la celebración en Rio de la Conferencia de las Naciones Unidas sobre Medio Ambiente y Desarrollo y pensábamos que el Simposio de Sevilla, por la implicación de SCOPE y de varios de los científicos participantes en la preparación de aquella, podría servir para discutir algunos de los temas que allí se tratarían. El título propuesto: "Principles, Patterns and Processes: Some Legacies of the Columbian Encounter", recogía la idea de considerar los patrones y procesos del cambio en los usos del suelo como un reflejo de los fenómenos ecológicos que se desencadenaron a gran escala por la interacción de dos biotas que habían evolucionado aisladas desde los tiempos del continente único -Pangea-. Por su magnitud, la influencia de estos procesos biológicos, durante los años inmediatos y algo posteriores al Encuentro, sobre la cobertura vegetal y los usos del suelo en el nuevo mundo, fue muy superior a la de otras causas de cambio -sociales, políticas y económicas-. Con la perspectiva de cinco siglos, estas últimas actuaron como desencadenante de fenómenos -asilvestramiento y explosión demográfica de las especies importadas, extensión con virulencia desconocida de las enfermedades- que de inmediato escaparon al control de las poblaciones humanas protagonistas. Podria decirse que el encuentro entre ambas biotas provocó una fluctuación en la flora y fauna de América, que ha perdurado hasta nuestros dias. Con el paso del tiempo, el poder aportado por la revolución industrial y el cambio tecnológico hizo pasar a un segundo plano los procesos biológicos y ecológicos, en lo referente a su influencia sobre el paisaje y los usos del suelo. No obstante, en la epoca actual se vislumbra de nuevo como amenaza el que procesos ecológicos de dificil control recuperen una dramática actualidad a escala planetaria, con efectos negativos sobre la especie humana en su conjunto. Es lo que puede suceder si no somos capaces de encontrar soluciones que eviten el deterioro de los recursos y los desequilibrios que se derivan de ello, principalmente los relacionados con la alarmante deforestación de los bosques tropicales y la grave amenaza sobre la diversidad de especies.

El Simpósium y la Asamblea General de SCOPE (Enero de 1992) fueron uno de las primeros acontecimientos que tuvieron lugar en el recinto de la futura Expo92 de Sevilla. Por su trascendencia internacional, tal como hemos indicado fue un antecedente de la Conferencia de Rio, tuvimos el honor de contar en la inauguración con la presencia de S.M. la Reina. Los temas tratados recibieron un seguimiento informativo importante y tuvieron amplia repercusión pública a través de los medios de comunicación.

Para lograr la publicación final de la presente obra, hemos contado con la ayuda de numerosas personas e instituciones y una notable actividad del SCOPE París, SCOPE España, Comité Local Organizador de Sevilla y, en especial durante la fase de preparación del libro, el George Perkins Marsh Institute, Clark University. Aunque de todo ello damos debida cuenta en los agradecimientos que los editores realizamos conjuntamente, no he querido dejar de mencionarlo en esta presentación del libro y sus orígenes. Pensamos que su publicación en estas fechas, ya a cierta distancia del 92, es oportuna y responde a una demanda actual de análisis sobre cambios ambientales a escala global. Esperamos que, de acuerdo con la idea inicial, la obra resulte util, tanto por la documentación original que aporta, como por las visiones sintéticas y de perspectiva que se ofrecen en particular en los capítulos iniciales, sobre problemas ambientales de escala global. Respondiendo al deseo expresado por Fernando González Bernáldez, esperamos también que no solo suponga una visión sobre el pasado sino una valoración de sus enseñanzas para aplicarlas con perspectiva sobre la actividad futura. A Fernando quiero dedicar mi particular recuerdo; el agradecimiento por su contribución al presente libro y por su interés en que se llevara a cabo la publicación del mismo, aún en los momentos más graves de su enfermedad.

Antonio Gómez Sal

PRESENTATION

Towards an analysis in perspective of the global land uses changes

The origin of this book stems from the decision of the SCOPE Spanish Committee to present the candidature of Spain for the organization of the VIIIth General Assembly of this international institution. As the Secretary of the Spanish Committee I had to make the candidature proposal in the VIIth General Assembly which was held in Budapest in 1988. Our chances were scanty, particularly if we take into account the limited representation and activity of our country in SCOPE. Two circumstances, which turned out to be decisive, played in our favour: the election of Francesco di Castri, very knowledgeable of Spain and the Spanish ecologists, as the international President in VIIth Assembly, and the proximity of 1992. An adequate assessment by di Castri of the opportuneness that date represented to analyze in perspective the environmental changes at a global scale, and the importance pretended to give to the commemoration of the Vth Centenary of the Discovery, or the Encounter of two worlds, permitted not only our candidature to be elected, competing with more qualified countries with a greater tradition in SCOPE, but even exceptionally modify the triennial celebration of the general assemblies and delay one year the planned in Spain, in order to coincide it with the events of 1992. With these premises it was undoubtedly necessary to organize in parallel with the Assembly, some activities which responded to the created expectations: to offer an opportunity to analyze the evolution of the environmental changes at a global scale, the origin of which can be traced back to the date of the Encounter.

To advance in the organization of the General Assembly, on July of 1990 I attended the regional symposium on Sustainable Development and Land Use in Latin America, held in Santiago de Chile on occasion of the SCOPE Executive Committee meeting. It was there where we proposed the general contents of the symposium to be held in Spain. Its main objective would be the analysis with a historical perspective, since the Encounter until to now, of the land use changes that occurred in Europe and America mainly due to the species exchange.

Later and with the aim to define more clearly the symposium contents and to plan the participations, the Steering Committee, Professors B.L. Turner II, Fernando González Bernáldez, Francesco di Castri and myself, meet in Paris. Veronique Plocq also attended to the meeting as the SCOPE Executive Secretary. It is decided that participation would be made through invitation with the objective to assemble those researchers that have devoted most of their investigation to the suggested themes and have a demonstrated experience on them. The aim is the creation of a reference document, that furnishes with data and analyzes the environmental changes which took place after the Encounter and from which, some useful teaching may be inferred to face the challenges posed by the present developmental problems. The celebration of the United Nations Conference on Environment and Development was near and we thought that the Symposium of Seville -SCOPE and some of the members which were preparing the Spanish Symposium were implicated in the Rio Conference- could be a forum for the discussion of some of the topics that would be dealt there. The proposed title: "Principles, Patterns and Processes: Some Legacies of the Columbian Encounter" came across the idea to consider the patterns and processes of land use changes as a reflection of the ecological phenomena that occurred at a large scale due to the interaction of two biota which had evolved separately from the ages of the unique continent -Pangea-. Because of its great dimensions, the effect of this biological process on the vegetation cover and land uses of the new world during the years immediately and little afterwards the Encounter, was quite superior to any of the other changing factors -social, political and economical-. With a perspective of five centuries these latter triggered some phenomena that immediately escaped to the control of the involved human populations: establishment in the wild and demographic explosion of the imported species and a disease spread with an extreme virulence. As it is evidenced in the contributions of this volume it could be affirmed that the encounter between both biota originated a fluctuation of the flora and fauna of America that has endured until now. With the advent of the industrial revolution and the technological change, the biological and ecological processes which influenced the landscape and land uses, lost importance and were relegated to a second level. However, at the present a new consciousness about the danger of certain ecological processes which are difficult to control and may mortgage the survival of the human being, is arising. This mankind problem may occur if we are not able to find solutions to prevent the deterioration of resources and its resultant imbalances, mainly those related with the alarming rainforest destruction and the biodiversity threat.

The SCOPE Symposium and the General Assembly (January of 1992) were one of the first events to occur in the place of the future Expo 92 of Seville and we were honoured with the presence of Her Majesty the Queen in the inauguration. The topics under discussion had an ample public repercussion through the media. Many people and institutions have made possible the publication of this book. Special reference must be made to SCOPE Paris, SCOPE Spain, the Seville Local Organizing Committee and the George Perkins Marsh Institution, Clark University, which performed an important role in the preparation of the book. Although all this has been reiterated in the acknowledgments the editors we have made together I wouldn't like finishing without mentioning it in the presentation and account of the origins of this book. We believe that its publication now, when 1992 and all its commemorations have already passed, is the right moment and it responds to a present demand for a global scale environmental change analysis. In accordance with the original idea we hope that the book will be useful, both by the the original documentation provided as well as the synthetic and perspective views concerning with global scale environmental problems, particularly those given in the first chapters. In response to the wishes of Fernando González Bernáldez we also hope it would not only suppose a mere vision of the past but supply a knowledge applicable to the future activities. I want to dedicate my particular memory and gratitude to Fernando for his contribution to this book and his interest on it to be published, even in the worst moments of his illness.

Antonio Gómez Sal

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PREFACE

The quincentenary of the Columbian Encounter was met with an outpouring of concern about how this event and its repercussions were to be interpreted. Environmental impacts have ranked high among the concerns raised. Some professionals view the encounter as a significant antecedent of contemporary global environmental change, at least in the areas of land cover and land use. Current modelling of some environmental changes requires an understanding of changes associated with the encounter. Others seek to compare the nature-society relationships of European and Amerindian cultures, with revisionist interpretations vilifying the former and canonizing the latter. Of this discourse, however, little has been drawn on the evidence and interpretations available from the best and most up-to-date a large body of scholarly work on the environmental and land-use history of the periods and places in question.

This book addresses these same concerns, but it draws on the accumulated work of professionals who have spent much of their careers involved in field and archival research on the subjects in question. It is based on the Scientific Symposium "Principles, Patterns and Processes: Some Legacies of the Columbian Encounter" of the VIIIth General Assembly of SCOPE (Scientific Committee on Problems of the Environment), held in Sevilla, Spain, Janurary 20-25, 1992. This symposium was developed in a meeting held at SCOPE, Paris, in the spring of 1991 that included Francisico di Castri, Veronique Plocq, Antonio Gómez Sal, Fernando González Bernáldez, and myself. As the organizing hosts of the Sevilla meeting, Drs. González Bernáldez and Gómez Sal, representing SCOPE, España, sought to link it with the then forthcoming quincentenary of the first voyage of Cristobal Colón. They and Dr. di Castri believed that 1492 was indeed a good point at which to date the beginning of the globalization of sustained continental exchange of biota and land uses, an exchange that *entailed significant environmental transformation, particularly for land cover. An assessment of the kinds of land-use/cover changes that took place might offer important insights into many kinds of contemporary global environmental change. I strongly concurred.*

We agreed to develop a scientific symposium on the land-use/cover theme addressing three basic questions. What kinds of land-use/cover changes associated with the encounter were global, or at least transcontinental, in significance? What were the underlying processes that drove them? And were these changes direct antecedents of contemporary global land-use/cover change? Subsequently, a fourth question emerged: Was the "quincentenary" literature on environmental change relatively accurate? The first three questions required the symposium to address the actual land-use/cover changes occuring in the period in question and to assess the processes that led to these changes and the nature of the environmental impacts that followed. The fourth question addressed a larger concern that was swirling around the quincentenary, was revisionist thinking about the Columbian Encounter creating and reinforcing myths about nature-society relationships in the New and Old Worlds and about the environmental consequences of the encounter?

With these aims and questions in mind, we proceeded to identify those land-cover changes that may have been globally significant at that time and/or the antecedents of current global change. Here we did not have to rely on our own insights and work, but could draw on a large range of literature from the sciences, social sciences, and humanities (see Chapter 1). The potential topics are, of course, too numerous to have been handled in a two and one-half day symposium. We emphasized the Europe-America connection to remain consistent with the Columbian Encounter theme. But we also sought to balance this focus with several general assessments of hemisphere-wide conditions leading up to the encounter and through to the industrial revolution, and with brief examinations of the European and African land-use/cover conditions and impacts related to the encounter.

We were fortunate to entice an outstanding group of experts, most of whom have spent the better part of their professional careers engaged in field and archival research on various aspects of the symposium's subject. Additional experts were invited to participate in the symposium, serving as panelists and commenting on the papers. Several of these commentaries were so insightful that the editors felt they warranted publication and included them in volume.

The book consists of three parts. The first provides summary and overview papers. Chapter 1 by Turner and Butzer —previously published in Environment as a synthesis of the symposium's findings in the light of the research and experience of the two authors—introduces and summarize the themes in this volume. It outlines the supposed associations among contemporary global environmental change, the 1992 UNCED (United Nations Conference on Environment and Development, held in Rio de Janeiro), and the Columbian Encounter. It then reviews what the two authors see as the evidence for land-use/cover questions, drawing upon the symposium, the papers in this volume, and their own extensive research experience on the subject. It sets the tone for the volume through several basic observations: (i) that much of the conventional wisdom about land uses in Europe and the Americas before and after the Columbian Encounter does not stand the test of evidence; (ii) that the environmental consequences of the encounter were a mix of the positive and the negative; and that (iii) while much land-use change can be traced to the Columbian Encounter, (iv) much of what is considered contemporary land degradation is more the product of the rise of an industrial ecology and economy. Chapters 2 and 3, by Tudela, and Douglas and Hodgson respectively, descibe the broader global conditions (with various regional emphases) immediately relevant to land uses and cover and their changes before and after the encounter. In Chapter 4, Bifani discusses the importance of the decission making centers both the hierarchical level in which the decission is taken as well as the distance from the involved land. As the end of the first part, Di Castri (Chapter 5) establishes the ways of the globalization and analyzes their consequences from the times of the Encounter to the present days.

Part 2 collects the specific issue papers of the symposium. In Chapter 6, Bernáldez assesses the land-cover conditions and land-use systems of central Spain at the time of contact. He shows that, far from being ecological destructive and unsustainable, the agro-pastoral systems in Spain in 1492 were in relative balance with the environment and technology of the time. Continuing with the introduction and adaptation of livestock systems as to Mexico, Butzer and Butzer (Chapter 7) document the initial explosion of livestock and the processes by which the system was brought under environmental and production control.

The next three chapters consider the consequences of the encounter for the forests of teh New World. The first two deal with the tropical lowlands, an environment unfamiliar to the Spaniards but long used by Amerindians. Siemens (Chapter 8) and Smith

(Chapter 9) examine the Gulf Coast of Mexico and Amazonia respectively. Both authors document the dramatic changes in land use previous and subsequent to the encounter. Each indicates that the tropical forest regions encountered by the Spaniards and Portuguese had been significantly altered by previous Amerindian uses, albeit of different intensities and histories. In Chapter 10, Foster shifts our attention to the Anglo-Amerindian encounter in the northeastern United States, the deforestation of New England by European settlers, and the subsequent land-cover impacts of the industrial revolution.

Groves, in Chapter 11, takes us across the Americas and elsewhere in surveying some of the major consequences of the unintended transfer of weeds. The impacts of this transfer appear to have been much more localized in their scale than those of deforestation, re-forestation, and the extension and contraction of grasslands. Finally, Pieri (Chapter 12) searches for land-cover impacts in western Africa that may have followed from the depopulation of the area to supply slaves for the Americas. This cruel transfer was itself a product of massive land-use changes and Amerindian depopulation in the West Indies.

Part 3 takes us from the encounter to modern times, drawing in part on the excellent commentaries of the symposium participants. Fernández Alés, Martín and Merino (Chapter 13) take us through the transformations of a coastal area in southern Spain, not far from the harbor from which Cristobal Colón sailed, to its modern state as a national park. Ezcurra (Chapter 14), in turn, sketches the environmental history of the Basin of Mexico to its current problems associated with its massive growth in population and industry. Chapters 15 and 16 return our attention to the country side. Fuentes-Quezada, Miethke, and Avilés examine rural changes in the Mediterranean climates of Chile, and López-Hernández considers the modern impacts on the American tropics of livestock production, a land use that by all measures is exotic to this region of the world.

Finally, Ruttan (Chapter 17) discusses the lessons of the symposium for issues of modern land-use and development. He concludes that while the impacts of the encounter on biotic transfer are important for understanding agricultural land use their production (and environmental) consequences have run their course. Current important problems are the product of radical shifts to a new stage of land use history.

The papers by no means exhaust the range of environmental and nature-society issues associated with the Columbian Encounter. They do illustrate, however, what kind of understanding can be gained from linking current or recent past conditions to their *longer-term antecedents and what relevance this understanding has for contemporary global environmental change. Some of this understanding is essential for the global change community, some is not. It offers important data for testing and parameterizing global environmental models. It sets the cultural-historical context for modern land uses, such as the desire for cattle and grazing land in much of Latin America. It informs us that much of the Americas, from the mature forests of tropical Amazonia to the tall grass prairie of Canada, was not untouched or "pristine" at the time of the Columbian Encounter, that the Columbian Encounter significantly changed the land uses and land covers of the Americas and less intensively and directly modified other areas of the world, and that the encounter did trigger global land-cover changes associated with the transfers of biota and technologies. It is less clear that an understanding of the Encoutner helps to explain the magnitude and pace of current environmental changes or to address environmental and related land-use/cover problems that have arisen in the industrial and post-industrial political economies of today.*

B. L. Turner II
Worcester, MA

ACKNOWLEDGEMENTS

This book is the product of the efforts of many individuals and organizations. The editors thank SCOPE España, Consejo Superior de Investigaciones Científicas and SCOPE Paris for helping to develop and for sponsoring the symposium from which this volume was prepared. The organization of the Scientific Simposium "Principles, Patterns and Processes: Some Legacies of the Columbian Encounter", held in Seville on January of 1992, was supported by the Dirección General de Investigación Científica y Técnica del Ministerio de Educación y Ciencia, the Agencia de Medio Ambiente de la Junta de Andalucía, the Comisión Nacional para el Quinto Centenario, and the Sociedad Estatal Expo-92. We whish to thank Drs José Merino, Rocio Fernández Alés, Luis Clemente and particularly Pablo Arambarri from the local organizing committee of Sevilla for their effective colaboration to make possible the Simposium and General Assembly. Dr. Benito Valdés from the Sevilla University which also supported the symposium success and Dr. Antonio Cruzado, chairman of the Spanish SCOPE Committee for his invaluable help in the Symposium achievement. The George Perkins Marsh Institute, Clark University, and the Consejo Superior de Investigaciones Científicas, Spain, provided assistance in the preparation of this volume, including William B. Meyer, Heather Henderson, Heather Davies, Annie Allen, and Pedro Villar, and particularly Viola Haarmann, without whom we may not have completed the project. María Jesús Ramiro for her invaluable help in the preparation of the texts and unification in a definitive format. We are grateful to Karl W. Butzer and Catherine Lavassor for assisting in the preparation of the contribution by Fernando González Bernáldez who died during the editorial process of this volume. Finally, we thank *Environment* for allowing us to reprint a paper (Chapter 1) which first appeared in that journal.

The Editors

CHAPTER 1

THE COLUMBIAN ENCOUNTER AND ENVIRONMENTAL CHANGE[1]

B. L. Turner II and Karl W. Butzer

In June 1992, representatives from countries around the world assembled in Rio de Janeiro, Brazil, at the United Nations Conference on Environment and Development (UNCED). The establishment of UNCED and the attention surrounding it attest to humankind's recognition that people have transformed and continue to transform the Earth with serious implications for the physical well-being of the planet and its inhabitants. October 12, 1992, marked a significant event in humankind's history of global change: the passing of 500 years since Christobal Colón, or Christopher Columbus anchored his three small Spanish ships off the shores of the Bahamas, and opened the door to transcontinental contacts among all of the inhabitants of the world.

The two events, though separated by half a millennium are not unrelated. The 1492 "Columbian Encounter" set in motion the most dramatic changes in land use and land cover induced by human action up to that time. Within 250 years, virtually all land uses, land covers, and biota in Mexico, Central America, the Caribbean, and South America had been affected in some way by the encounter, in many cases dramatically (e.g. Crosby, 1986). The scale and pace of environmental change associated with the encounter foreshadowed similar changes associated with the colonization of other

1. This paper, slightly revised here, first appeared in *Environment* 34(8), pp. 16-20, 37-44, 1992. Reprinted with permission of Helen Dwight Reid Foundation. Published by Heldref Publications, 1319 18th Street, N.W. Washington, D.C. 20036-1802. Copyright 1992.

countries by Europeans during the sixteenth and seventeenth centuries and with the escalation of human impacts following the Industrial Revolution. Therefore, 1492 is a watermark not only for the emergence of the modern world but also for the beginning of the global change that UNCED addresses or, at least, that component of it related to land-use and land-cover change.

Because UNCED focused mainly on the state of current environmental change, its implications, and the actions needed to address the change, it is understandable why past events, such as the Columbian encounter, were not much considered[2]. It is less understandable, however, why the greater community of scholars and researchers concerned with human-induced environmental change has not given the association much thought to the association between past and present change[3]. After all, contemporary global environmental change consists of two broad types—systemic and cumulative (Turner *et al.*, 1992). Systemic change operates directly on the biogeochemical flows that sustain the biosphere and, depending on its magnitude, can lead to global change, just as fossil-fuel consumption increases the concentration of atmospheric carbon dioxide. Systemic change is largely associated with, but not limited to, the Industrial Age and thus has grown especially important over the more recent past.

Cumulative change, on the other hand, has been the most common kind of human-induced environmental change since antiquity and was dramatically exemplified in the Columbian encounter. Cumulative changes are geographically limited but if repeated sufficiently, become global in magnitude[4]. Changes in the landscape, such as changes in forest cover, cropland, grasslands, wetlands, or human settlements are an example of cumulative change. Some cumulative changes reached continental, even global, proportions long before the twentieth century (Kates, Turner and Clark, 1990; Thomas, 1956), including deforestation, the transfer of plants and animals between continents, modification of grasslands, and possibly, the extinction of a large number of animal species in the Quaternary period (Martin and Klein, 1984; Richards, 1990; Williams, 1990).

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2. Some of the major considerations of the research community in regard to UNCED can be found in: "Recommendations from Sigma Xi and ASCEND 21," *Environment* 34 (1992): 5 & 40.

3. For an exception, see the activities of the International Geographical Union's Working Group on the Historical Geography of Global Environmental Change led by V. Annenkov, Institute of Geography, Russian Academy of Sciences. Also see Clark and Munn (1986).

4. For a discussion of the relative roles of cumulative and systemic change see: Committee on Global Change (1988); Turner II *et al.* (1990).

In contrast to UNCED's interest in contemporary global change, research relevant to the Columbian encounter has a significant environmental heritage and has flirted with associations between past and present global change (e.g. Crosby, 1972). Such recognition, however, has been overshadowed by the contentiousness and polarization surrounding what some people see as a quincentennial celebration of European authority and superiority and a lack of attention to alternative viewpoints of the meaning of the events of 1492. The quincentenary celebration has become, like UNCED, a forum for a multitude of interest groups who demand consultation, consideration, and influence in setting policy and interpreting history.[5]

Tensions among the various groups have affected interpretations of the environmental consequences of the Columbian encounter, and have resulted in the creation of recurrent myths.[6] In the first Native Americans, or Amerindians are depicted as stewards of the land who operate under an ethos of harmony with nature, employ environmentally sensitive and sustainable agricultural practices — most notably swidden or slash-and-burn horticulture — and minimally change the wilderness of the Americas. In the second, often complementary, myth, colonial-period Europeans are shown to seek to control and exploit nature and to employ agricultural practices, in both Europe and the Americas, that are far less sustainable and usually degrading to the environment and lead to large-scale deforestation, destruction of croplands, and deterioration of grasslands (e.g. Sale, 1990; Weatherford, 1988).

The antecedents of these interpretations can be traced to Columbus himself, who described the island of Hispaniola (now divided into Haiti and Dominican Republic) as a terrestrial paradise (e.g. Butzer, 1992c). The modern tap root of these myths, however, is the depiction by nineteenth-century Romantic and primitivist artists of America as a pristine wilderness, an image that was carried almost uncritically into the second half of this century (Bowden, 1992; Denevan, 1992a). More recent roots stem from sources perceived to be outside the mainstream: Amerindians seeking to rectify misperceptions of

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5. See Auchincloss (1991). Despite the perception to the contrary, the academic community has been particularly diligent in exploring multiple and critical themes about the Columbian Encounter. Foremost among these is the long tradition of study of Amerindian depopulation and cultural destruction. Specific to the quincentenary, Spanish and American historians have studied issues of ethnic diversity, perceptions, and representations surrounding the Columbian Encounter, while geographers have probed the meaning of exploration in the Americas, European and Amerindian maps as text, the state of Amerindian landscapes at 1492, and the changes wrought by the European conquest. See Butzer (1992a).

6. The two myths can be found in a range of media, from scholarly to popular. See, for example, Butzer (1992b); Shelter (1991).

their heritage and cultures, environmentalists seeking alternatives to a mass-consuming society and high-input agriculture, and "critical theorists" who consider the seeds of most environmental damage to be sown by Western culture and capitalism.

Regardless of their sources, the two myths — the Amerindian as nature's steward and Europeans as its destroyer — and their implications for environmental change simply do not withstand scrutiny. They do not represent the views of the professionals steeped in the understanding of nature-society relationships and active in research on land-use and land-cover changes in pre- and post-conquest Latin America. Much information exists about the state of European and Amerindian landscapes at these times and the changes in both wrought by the Columbian encounter (e.g. Cronon, 1983; Harris, 1983; Meining, 1986; Parsons, 1966; Sauer, 1966; 1971; West, 1982). Little, if any, of this work, however, has been linked directly to contemporary environmental change, global or otherwise [7].

On the Eve of the Encounter

The Columbian encounter was not the first time Europeans reached the Americas. But, unlike the Viking landings, which occured approximately 500 years before, the Columbian encounter occurred at a moment when Europe was ready and able to take advantage of the "New World". By the late fifteenth century, the budding nation-states of Europe had developed the technological capacity for long-distance, trans-oceanic commerce and were beginning an intense competition with each other for the resources and wealth expected from trade with the Orient. The Portuguese, in fact, had just found a passage around Africa's Cape of Good Hope and were poised to break the Islamic domination of that trade by sailing into the Indian Ocean.

Land Use in Europe

The seafaring explorations that began in the fifteenth century were largely driven by a new exuberance for economic and political expansion, not so much by population growth problems [8]. It is important to understand that, from about 1350 until 1500, Western Europe witnessed an overall population decline and that the peak population of the early

7. This chapter draws upon some of the recent work directed to its themes, including the SCOPE symposium on which it is based (see Preface) and Butzer (1992a).

8. This statement differs slightly from that which appeared in the original article in *Environment*, but constitutes the meaning intended.

1300s was not reached again until the late 1500s (Butzer, 1990). Hence, the initial stages of Europe's "age of exploration" occurred at a time of population stagnation or loss, and the early Spanish colonization of the Americas occurred during a time of renewed population growth in Western Europe and a revival of agricultural systems. Only during the late 1500s was land stress apparent in various parts of Western Europe (Pfister, 1984; Girgg, 1980).

Large-scale land-cover changes had taken place in Europe over the past centuries, including the deforestation of more that 100000 km^2, the drainage of wetlands, and the continent-wide modification of biota (Darby, 1983; Williams, 1990). Such changes were necessary to sustain long-term occupation by a growing population and were apparently comparable to changes induced by other societies and cultures with similar needs. For example, only minimal difference in the scale of deforestation and landscape changes were found between feudal Europe and imperial China, though the cultures of each area supposedly operated under different views of nature-society relationships — mastery over, versus harmony with, nature (Tuan, 1968; Whitmore, *et al.*, 1990). Although managerial mistakes were made, overall it is difficult to single out European cultures as especially destructive to their environments when population size, technological capacity, and standards of living are taken into account.

The basic food production system in southern and central Spain in the late fifteenth century is a case in point. This system, which was similar to others of the western Mediterranean region, had been developed through the transformation of the natural woodland into a mosaic of agricultural and sylvopastoral land uses, and was based on native and introduced plants adapted to the seasonal rhythm of summer drought and winter rains. The agricultural system invoved a mix of cereal cultivation, olive groves, and vineyards; the planting of legumes or the use of fallowing to restore fertility during a two-course crop rotation; and the seasonal grazing of livestock on stubble. Except for some local use of marginal soils and topography for swidden agriculture, this sylvopastoral system was carefully managed by varying livestock mobility to avoid overgrazing and allow native legumes to maintain reservoirs of organic matter, nitrogen, and phosphorus in the soil. In some regions of the Iberian Peninsula, this mosaic of dry farming and controlled grazing was complemented by an often sophisticated irrigation system of orchard gardens or exotic commercial crops (Chapter 4; Butzer, 1988a).[9]

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9. Also see the papers delivered at the symposium "Arqueología: La Huella del Hombre en el Ecosistema Mediterráneo," Universidad Internacional Menédez-Pelayo, Valencia, Spain, 1-5 July, 1991.

Therefore, the systems of the western Mediterranean countries, far from being environmentally destructive, tended to involve careful modifications and transformations of the local environments. Of course, the landscapes were significantly altered, even in areas of marginal cultivation, and the Little Ice Age (A.D. 1560 to 1890) caused a series of land-use adjustments throughout Europe, as did the overall growth in population (Chapter 11; Butzer, 1998b). Yet, there is little evidence that the Columbian encounter was primarily stimulated by excessive land-use pressures or land degradation in the western Mediterranean or in Europe in general.

Land-Use in the Americas

On the eve of the landing by Columbus, North and South America contained a wide range of land types, from less disturbed wilderness to totally transformed landscapes. As in Europe, the degree of change on these landscapes was related to the length of human occupation and the level of environmental pressure as a result of population size and political and economic conditions. Unlike Europe, however, many of the more heavily occupied lands in the Americas were located in the tropics and therefore, offered different environmental opportunities and constraints to the inhabitants.

Probably about 54 million Amerindians lived in the Western Hemishere in 1492 (Table 1; Denevan, 1992b). They were distributed throughout a wide range of social and political structures, from small, kin-based groups to elaborate state organizations extending over very large areas, and were engaged in trade within and without their domains. Large populations and high levels of state development overlapped in central Mexico, the highlands of Central America from Chiapas, Mexico, to northern Costa Rica, and throughout the Andean realm. Substantial populations also were present on some of the Caribbean islands and in various parts of coastal Mexico and Central America, lowland South America, the eastern woodlands (including the Mississippi River delta) the northwest coast, and the southwestern region of North America (Denevan, 1992b).

In these and other areas, the Amerindians employed a variety of agricultural techniques: mountain slopes reconfigured into flanks of often irrigated terraces; gentle terrain sculptured into mosaics of open fields aligned with earthen planting mounds and ridges, gardens, and orchards; and wetlands reshaped into raised and drained fields (Whitmore and Turner, 1992). Even where occupation was less frequent, considerable modification of environments took place through such activities as agroforestry.

Table 1. Amerindian Populations, ca. 1492

Region	Population (in million)
North America	3 790
Mexico(including Yucatán)	17 174
Central America	5 625
Caribbean	3 000
Andes	15 696
Lowland South America	8 619
The Americas	53 904

Source: Denevan, 1992b

Although terracing was used throughout the Americas, this form of slope transformation was mostly prevalent in the area extending from the North American Southwest into the highlands of Guatemala and throughout the central Andes Mountains (Donkin, 1977). From southwest North America to Central America, Amerindians converted intermittent drainage channels to cultivated land through the use of weirs and check-dams (Doolittle, 1988). The use of nonirrigated, sloping terraces was prevalent throughout highland Mesoamerica (the region consisting of present-day Mexico and Central America), while slopes in the Andes Mountains had been reconfigured through the use of level, irrigated terraces.[10]

Open-field, rain-fed agriculture was commonly employed on gently sloping terrain and typically involved significant surface modifications in the construction of earth mounds or ridges. These labor-intensive features served multiple functions, depending on the environment and crops in use, and once constructed increased the value of land.[11]

10. No one has undertaken the formidable task of estimating the total area under Amerindian terracing in the pre-encounter Americas. This area was certainly in the many millions of hectares, however. Peru alone is estimated to have had 600000 ha, not accounting for the eastern Andean slopes where forest covers abandoned terraces and inhibits calculations (Denevan, 1988).

11. In the Basin of Mexico, open-fields were known as *acamellonada* or filled with planting mounds (Rojas Rabeila, 1988]). The precise form of field raising used and the functions performed varied by environment and crops used (e.g, Thurston, 1991; Wilken, 1987).

Also, the use of mounds and ridges suggests a land-intensive cultivation system based more on sustained field inputs than on the constant shifting of crop sites (Doolittle, 1992). The construction of mounds on well-drained fields was prevalent for potato production at the high altitude of the Andes, for manioc production in tropical locales — especially northern South America and the Arawak Antilles of Hispaniola — and for maize cultivation throughout Mesoamerica and the eastern woodlands of North America.

Amerindians used irrigation to expand cultivation or intensify cultivation on lands otherwise constrained by insufficient water supplies. Large-scale canal irrigation was used in the Andean-Pacific lowland region of South America and in certain places in the North American Southwest, some of which involved spectacular engineering feats (see, Doolittle, 1990; Knapp, 1987; Guillet, 1989). Elsewhere, especially from Mesoamerica into the North American Southwest, the use of runoff irrigation was particularly important (Doolittle, 1992). Regardless of the source of water, private gardens, orchard gardens, and orchards were also commonly irrigated, particularly orchards used for trade crops such as cacao in Mesoamerica and, perhaps, in the lowlands of northern South America (Bergmann, 1969).

Amerindians were particularly skilled in the art of wetland agriculture, from seasonal cultivation of the desiccating edges of wetlands to complete transformation of seasonal wetlands and shallow lakes (Denevan, 1970; Whitmore and Turner, 1992). Interestingly, the most extensive use of wetlands may have occurred long before the Columbian encounter (Siemens, 1988; Turner and Harrison, 1983), but the most impressive wetlands agriculture system known, the *chinampas* of the basin of Mexico (the area surrounding present-day Mexico City), was in full use in 1492. This system was based on the reconfiguration of the location of water within shallow lakes and marshes, without drainage, and the addition of large, artificial garden beds.[11] Use of wetlands for agriculture did not always involve the *chinampa* system. Almost invariably, wetland cultivation involved the digging of ditches or canals and, commonly, some form of field raising among the ditches. In the basin, the *chinampa* system was integrated with dikes and sluices to protect freshwater from mixing with saline water and to allow for multiple crop production. Although at different times, a considerable proportion of the wetlands in the Americas was modified for cultivation including wetlands in the Andes, the lowlands of South America, Mesoamerica, and the Mississippi River basin as far north as present-day Wisconsin (Plazas and Falchetti, 1988). As with terracing, no estimate of the total area of Amerindian wetland cultivation has been developed. However, 500 000 hectares of ancient wetlands fields, for example, have been located in the San Jorge River basin of Colombia alone.

Landscape modification also occurred in more sparsely occupied areas, particularly through the Amerindian's use of fire. For instance, Amerindians expanded, or at least maintained, grasslands in the plains of North America by burning them while on a hunt (Anderson, 1990; Sauer, 1950). Similarly, burning grassland for agriculture in Central America and portions of South America may have been responsible for the extended patchworks of grasslands and the extended distribution of pines trees into some tropical forest lands (Denevan, 1961; but see Chapter 8). In large part, the forests of the Americas, from Canada to Argentina, were so highly disturbed or modified by Amerindian use by 1492, that it is surprising that even the popular literature has missed this point. The evidence of ancient human occupation throughout the Amazon River basin, for example, is sufficient to warrant the speculation that the tropical forests existing at the time of the encounter (and, possibly today) had been significantly influenced by human use, an observation that can also be extended into regions of Central America and the humid lowlands of Mexico (Chapter 6 and 7). This disturbance stemmed from swidden, or shifting, cultivation and permanent cultivation and from forest culling and other activities involved in agroforestry (Denevan, 1991-92). The degree to which swidden agriculture in the Americas shifted is a matter of speculation. Stone tools, even with the assistance of fire, are not an efficient means of clearing forest lands; the extensiveness of swidden agriculture may have awaited the introduction of steel tools by Europeans. In the Yucatan, for example, orderly settlements were surrounded by orchard gardens and short-fallow open fields, which were separated from the next village by forests containing economic species that were probably the product of Amerindian selection and protection. Indeed, the composition of these forests, many long abandoned by the time of the Columbian encounter, reflected past land-use activities, relics of orchards and agroforestry systems, and overgrowth on the remains of ancient cities, towns, and villages (Gómez-Pompa *et al.*, 1987; Whitmore and Turner, 1992).

In New England, old forests prior to European settlement were repeatedly modifed by fires, hurricanes, and selective diseases. Initial farming by Europeans was small scale and low intensity, with little discernible impact on vegetation until the advent of forest clear-cutting and agricultural expansion in the late 1700s. Increased abandonment of farms and population nucleation in towns allowed the forests to regenerate after 1850, but today's New England woodland is dominated by white pine rather than the previous species — hemlock, beech, and chestnut — and reflects differential colonization rates, disease, and fire control (Heinselmand, 1981; Schoonmaker and Foster, 1991). In other words, contemporary "protected" forests also developed differently from the prehistoric "natural" forests, although both were modified by periodic catastrophes. Such insights are important to develop forest management and conservation strategies.

The evidence is clear, pre-Columbian Amerindians used a wide variety of agricultural systems, not simply swidden agriculture, and, in pursuit of these systems and other needs, they made extensive land-cover changes in the Americas. Palynological data demonstrate the magnitude of deforestation and other complex changes in land cover over time. Although many pre-Columbian agricultural landscapes were successes and sustained long-term occupation and societal growth, some were created and abandoned, while others were occupied at length and degraded. Furthermore, agro-engineering mistakes, such as inoperative canal irrigation, inhibited the use of some arid areas, and sustained intensive land use often led to soil loss and degradation and contributed to chronic famine (e.g. Farrington and Park, 1978; Hassig, 1981; Williams, 1982).

Some Impacts of the Encounter

In the first century and a half after the Columbian encounter, which largely involved the inhabintants of the Hispanic Americas, a number of socioeconomic events occured that had immediate or longer-term impacts of substantial significance for global environmental change (Chapter 2 and 3). Among these events were the plundering of the mineral wealth of the Americas and the destruction of the large Amerindian population.

An estimated $6.1 billion (in 1988 dollars) in precious metals were taken from the Americas to Europe during the first 150 years after the encounter (Barrett, 1990; Braudel, 1982). This wealth, immense for its time, not only helped to propel the reordering of land use and land cover worldwide through Europeans colonization but also helped to bankroll the development of the subsequent Industrial Revolution and, by extension, the initial stages of contemporary systemic global environmental change (Braudel, 1982).

The destruction of Amerindian populations changed the character of land occupancy in the Americas and ultimately creating the "wilderness" awaiting the arrival of the late European settlers. The pace and magnitude of the depopulation of the Amerindian peoples remain unprecedented in the annals of demographic history: an estimated 76 % of the population of the Americas south of the present-day United States was eliminated between 1492 and 1650 (Denevan, 1992b). By the time sufficient and relatively reliable censuses were undertaken in the Americas, Amerindian populations had been greatly reduced. Reconstructions of large Amerindian populations at the time of the encounter, therefore, were challenged because very little evidence existed of such large depopulations elsewhere, including the pandemics of medieval Europe. Models drawing on conservative mortality figures and other evidence indicate that the massive depopulation was highly possible (Whitmore, 1992). This cat astrophe resulted from a number of factors, including the European's harsh treatment of Amerindians. None was so devastating, however, as the devastating introduction of diseases from Europe (Cook and Lovell, 1991). Because they were isolated from the rest of the world, the Amerindian had little resistance to such exotic diseases as smallpox, measles, typhus, and the staggering population losses that occured triggered a number of systemic feedbacks that further reduced the population.

Land Uses in the Americas

The scale of depopulation in the Americas far exceeded the number of Europeans settling there in the sixteenth century. One hundred years after the encounter, in fact, only 175000 Spaniards had colonized the Americas in the wake of the precipitous decline in the Amerindian population (Butzer 1992b). A significant drop in land use, therefore, left many former Amerindian agricultural lands empty because the remaining population could not maintain them, particularly lands formerly sustained by labor-intensive systems. Land abandonment was particularly acute in the tropical lowlands, and forced resettlement of the remaining Amerindian population affected occupancy in most locales throughout the Spanish-held domain. The overall effect was not only a loss of productive agriculture and a diminishment of cultivation in general but also the afforestation of many tropical lowlands. Regions of the lower Gulf Coast of Mexico, the southern parts of the Yucatán Peninsula, lower Panama, and the eastern slopes of the Andes, among others, have retained the humanly modified, regrowth forests into modern times, though most of the regions are currently under heavy use. Sustained post-Columbian afforestation was not echoed in North America, however. Amerindian depopulation in the eastern woodlands was initially not as severe as that in Latin America, and, from the outset, European colonization in North America focused on further clearance of the forest for agriculture. Afforestation of the eastern woodlands did not begin until the nineteenth and twentieth centuries, when changing economies rendered agriculture less competitive (Chapter 11; Cronon, 1983).

Occupation in the Americas after European settlement differed in several ways from that before 1492. Although the initial Castilian settlers, for instance, preferred the cooler and relatively dry intermontane basins of the tropical Americas or the arid coastal lowlands of Peru, the Spanish eventually moved into the highland environments because they were somewhat similar to regions of the Iberian Peninsula, were amenable to Spanish agricultural technologies and biota, and, in a few cases, had existing infrastructures on which the Spanish could build, such as Amerindian irrigation systems. In short, the highlands offered land that was not only environmentally preferable but also more suitable for the Iberian agrosystem than were the tropical lowlands (Butzer forthcoming).

Because the agrosystem was based on the production of winter wheat, the Spaniards were prohibited from following this system, except in certain coastal areas in higher latitudes, such as in central Chile, because the tropical highlands of the Americas received mostly summer, not winter rains as in the Mediterranean region (Chapter 4). Thus, the Spanish were forced to develop a different system of winter wheat cultivation based on irrigation and to place a premium on lands that contained existing Amerindian irrigation systems or on those where such an infrastructure could be developed (Butzer, forthcoming). Furthermore, the use of the plow and draft animals, unknown to the pre-Columbian Americas, permitted favored irrigation on minimally sloped lands where plowing could be used most efficiently.

These changes in the rudiments of the system of cultivation in the highlands had two broad implications for land use and land cover. First, the changes concentrated settlement in the highlands and, thus, reduced the relative importance of the occupation of the tropical lowlands. Secondly, use of the plow allowed vast areas to be cultivated in the highlands with a small labor force and, along with irrigation of winter wheat, crops shifted the balance of cultivated lands to the well-drained soils of highland valleys and basins. This shift stood in contrast to the Amerindian's use of high slopes and bottom wetlands, which did not handicap their less discriminating horticultural tools. Furthermore, Spanish preference for highlands favored the drainage of valley bottom wetlands and contributed to the demise of many wetland agricultural systems (Whitmore and Turner, 1992).

Of the new biota brought to the Americas, none had such immediate impact on land use and land cover as did domesticated animals, of which the Amerindian had few. Large herd and draft animals — cattle, sheep, goats, horses, mules, and oxen — were particularly instrumental to early land use by the Spanish, including livestock production, which was oriented to trade in leather, wool, and cured hams. Also, use of the horse spread rapidly northward from Mexico and was adopted by the inhabitants of the North American Great Plains and altered their economy for several hundred years before the invasion of the Europeans (Dernhardt, 1975).

The production of livestock, especially in cattle and sheep, and the proliferation of semi-feral animal populations had large-scale, effected land use and land cover throughout the Americas, including the Caribbean Islands, Mexico, Colombia, and the pampas of Argentina (Butzer forthcoming). Hispaniola, the first land mass in the Americas to be occupied by Europeans, was significantly affected by the rapid and complete destruction of the native population and by the explosion of the cattle, hog and horse populations, much of which ran wild. By the later 1500s, lands may have been overgrazed and suffering from erosion by livestock trampling (Watts, 1987: 117-121). Unfortunately, the direct evidence is slim.[12]

But Hispaniola may have been an extreme case; only a modest expansion of open habitats can be inferred for the Gulf Coast of Mexico, because high-cellulose, "old" grasses were burned to improve livestock grazing in the tropical lowlands. Interestingly, some of the deforestation that may have been involved with the use of tropical lowlands for livestock producton probably involved lands that were formerly cultivated by Amerindians, calling into question how much, if any, old forest was cut to support livestock production (Chapters 5 and 6).

Livestock production, of course, was the pastoral complement to wheat production among the Spaniards in the highlands. Initially, the uncontrolled cattle grazing wreaked havoc on agriculture because of the large numbers, and it may have led to the deteriorating of pastures in Mexico (Chevalier, 1963). The Spaniard, however, brought this free-range production system under strict control by the 1550s, by moving the cattle production from central Mexico to the gulf coast and northward to the Bajío and beyond. Herds of sheep much larger than those of cattle were managed by seasonal migration of 250 km^2 or more by the 1580s and up to 800 km^2 by the 1640s. This mobility reduced pressures on dry season pasture, similar to livestock management in Spain, and explains the lack of evidence for soil erosion as a consequence of degraded soil cover until the late eighteenth century, despite the intrusive biomass of some six to

12. This paragraph has been changed in emphasis from the original in *Environment*. Despite the widely held view that the environments of Hispaniola were devasted by European livestock, the direct evidence is slim. De Oviedo (1535: 206), one of the few to record the impacts on Hispaniola refers largely to the loss of timber quality trees in the vicinity of Santa Domingo, owing to farms and immense numbers of livestock.

eight million sheep (Chapter 5).

Another biotic exchange that had consequences for land cover was the introduction of weeds and other non-economic plant species. A myriad of weeds were exchanged between the Americas and Europe, both intentionally and not, and the introducted species often flourished (Crosby, 1986; Mooney and Drake, 1987). Interestingly, more European species initially invaded the Americas than American species invaded Europe (Chapter 9). Despite the large number of weeds that were introduced, it is doubtful that land cover was significantly affected by them during the first 150 years. Subsequently, however, local ecosystems have been significantly modified by the introduction of weeds, though the degree of this change cannot be adequately quantified beyond the specific ecosystem.

Changes in the political economy of the Americas following the Columbian encounter also played an integrative role with technological and biotic changes to affect land use and land cover. Interestingly, these changes did not involve the introduction of commerce or, perhaps, profit. Amerindians had long engaged in major trade activities of both luxury and common goods, that brought differential wealth to both individuals and communities. The scale of trade varied by locale, but, in the Mesoamerican and Andean realms, a large variety of markets reflected active, professional long-distance trade associations — some sponsored by the state — and the tributes or taxes flowed to the controlling powers. On his fourth voyage, Columbus himself caught a glimpse of Amerindian commerce when he intercepted a vey large, fully loaded merchant canoe off the coast of present-day Honduras. The Aztecs, for example, accumulated enormous wealth through their state-sponsored merchants and their tribute demands. Extensive road networks were developed in some areas, particularly in the Andes, which assisted commerce and tribute payments (Sauer, 1966: 128-9; Trombold, 1991). Some areas even specialized in the production of long-distance trade products, such as salt on the Yucatan coast and cacao along the Pacific piedmont of Chiapas, Mexico, and in Guatemala (Andrews, 1983; Bergmann, 1969).

The political economy of the Spanish settlers, of course, changed the beneficiaries of surplus and created two economies, one for the Spaniards and one for the remaining Amerindians. The creation of two economies was evidenced spatially through a dual settlement pattern. The important point for land use and land cover, however, was that commerce per capita increased as a result of long-distance ocean transport, the introduction of new technologies and biota, and the Spanish control of Amerindian labor force and former Amerindian lands and resources. These circumstances sustained the various Amerindian land uses, despite the overall collapse of the population. Amerindian depopulation, first in the Hispanic Americas and later in the Anglo-Americas, created conditions in which enormous expansion of the new systems of land use were possible.

Among these new systems was the introduction of the plantation crops, particularly in the tropical lowlands. The plantation system, or the production of a single crop, particularly tree and shrub species, was not unknown to the Amerindians, who cultivated large cacao and other orchards in portions of the tropical lowlands. What was new, of course, was the Spanish control of production and labor on the plantation (Whitmore and Turner, 1992). Most important among the new crops was sugar cane, plantations of which spread throughout the Caribbean islands and much of the humid portions of the gulf coast (Del Rio, 1991). Small-scale plantations and livestock production replaced Amerindian agriculture in much of this area. The development of plantations in the Caribbean islands was achieved through the substitution of African slave labor for that lost through Amerindian depopulation. This change introduced the people of yet another continent into the post-Columbian encounter world. In this case, the people were experienced in tropical cultivation, and they developed a new system of land use that involved both open-field plow cultivation and intercropped, orchard gardens (e.g. Hall, 1991; Kimber, 1988).

The Amerindian was not completely eradicated, however, particularly in the highlands where the impacts of European diseases may not have been as harsh as they were in the lowlands. Amerindian agriculture not only survived the initial encounter, but it also became a source of exchange between Amerindians and Spanish farmers. Each borrowed from and experimented with the other's practices and, over time, a new set of hybrid landscapes emerged that integrated many of the crops and cultivation techniques of both systems. In this process, however, many Amerindian cultigens were lost or forgotten, as was expertise in certain systems of production, such as the construction of wetland fields (Gade, 1992; Whitmore and Turner, 1992).

Land-Uses Changes in Europe

The Columbian encounter had direct consequences for land use in Europe, primarily through the "Columbian exchange," or the biotic transfers from one continent to the other (Chapter 3; Crosby, 1972). The Spanish settlers were quick to send Amerindian crops back to Europe, and after a period of experimentation, many of these imported plants became central to European agriculture. Potatoes, for instance, became a mainstay of northern Europe, and corn became a major fodder crop. Tobacco and long-stemmed cotton also were readily adopted rapidly by Europeans. Other Amerindian plant imports include manioc, sweet potato, peanuts, beans, squash tomatoes, chiles, pineapple, and cacao (a source of chocolate).

The direct impact of the imported crops on European land cover was that they replaced the previous cropland cover. The major indirect impact was that they helped to promote demographic and economic change worldwide. The potato, for example, improved the diet and health of poor northern Europeans because of its high caloric yield and thus contributed to the population growth of the continent (Casanova and Bellinger, 1988; Hamilton, 1976; Foster and Cordell, 1991; Langer, 1875; Lunde, 1992). Long-stemmed cotton, on the other hand, was essential for the industrialization of the textile industry. The subsequent population growth and industrialization of Europe, of course, had major consequences for land cover there and abroad through the large-scale diffusion of European people, biota, and land uses and through the extraction of world resources to feed European industry.

From the Encounter to Global Change

The Columbian encounter set into motion a series of continental land-cover changes, almost all of which were initially driven by the rapid accumulation of changes in land uses. These changes, however, were not quite of the nature suggested by several currently popular "myths". Specifically, at the time of the Columbian encounter, the European landscape had not been excessively degraded and the agricultural systems used could have been continued — perhaps indefinitely. Also, Amerindian agriculture systems were not based solely or primarily on swidden agricultural systems, and the Americas at that time were not pristine wilderness. Moreover, after a period of adjustment, the new land uses introduced after the encounter were not unsustainable or exceptionally degrading of the environment.

Simply put, the land cover of both the Americas and Europe had been significantly modified by people prior to the Columbian encounter. These modifications varied in kind and scale according to local and regional levels of land use — pressures with the available biota and technologies — and the specific type of environment used. In both hemispheres, land-cover changes resulting from agricultural and environmental management had led to instances of agro-environmental collapse as well as to sustainable systems of crop production.

Land-use and land-cover changes after the Columbian encounter, however, were the most immediate, direct, and profound in the Americas and were exacerbated by the catastrophic depopulation of the Amerindians and the biotic, technological, and economic changes instigated by European settlers. The consequences of expansion of European land uses in environmentally unfamiliar regions led to some initial mistakes, but they were usually followed by sustainable management practices.[13]

The following themes from studies of the Columbian encounter are particularly important for the assessment of contemporary global land-use and land-cover change:

Land-Use and Degradation

• Significant land modification, even transformation, in the Americas is an ancient phenomenon and is not solely the product of post-Columbian encounter civilizations.

• The short-term land-use consequences of the Columbian encounter involved change far more than degradation.

• The land-use changes accumulated over time and resulted in significant, continent-wide alterations of land covers that ultimately would combine with similar changes elsewhere to contribute to contemporary global changes.

• The large-scale, sustained ecological degradation of the Americas is largely the product of the Industrial Age.

Deforestation

• Deforestation in all the Americas was probably greater before the Columbian encounter than it was for several centuries thereafter.

• Many of the primeval forests that were supposedly encountered by the Europeans in 1492 and that remain today, including forests with the highest biodiverstiy, were not "pristine" or "virgin" but were products of extensive use and modification by the Amerindians.

• The scale of deforestation, or forest modification, in the American tropics has only recently begun to rival that undertaken prior to the Columbian encounter.

Destruction of Grasslands and Grazing Lands

• The most radical land-use change in the Americas was the European introduction of large grazing animals, which dramatically increased native ungulate populations.

• Extensive areas of open or scrub forest and grasslands in the Americas were modified by the Europeans and Amerindians for herding by reducing ground cover or by impeding forest regeneration through the burning of grasses.

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13. Recent evidence from central Mexico demonstrates that the introduction of European plow agriculture led to no more erosion than that which had been created by Amerindian agriculture practices (O'Hara, Street-Perrott and Burt, 1993).

Decline in Croplands

• Excluding grazing lands, cultivated lands decreased in the America's subsequent to the Columbian encounter and probably did not return to their pre-encounter levels until the eighteenth or nineteenth centuries.

Understanding of these themes is essential for putting past and current land-use and land-cover changes in perspective and for connecting the Columbian encounter with contemporary global enbvironmental change. Research leading to and following from UNCED is intricately involved in modeling environmental change to improve understanding of both the processes of change and the assessments of the environmental and societal consequences they imply. Also, patterns of land-use are essential for establishing the numerical range of the various modeling endeavors.

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CHAPTER 2

LAND USE CHANGES BROUGHT ABOUT BY THE COLUMBIAN ENCOUNTER: TOWARD A SYSTEM APPROACH

Fernando Tudela

Introduction

The analysis of the evolution of land-use patterns faces huge difficulties stemming both from the complex nature of a process whose determining factors are as much social as environmental, and from lack of reliable and useful historical information. This paper presents a brief overview of the little we know about the major implications for land-use patterns surrounding the Columbian encounter. By means of a preliminary (but surely not exhaustive) bibliographic survey, the general layout of the research field is sketched. The sketch, however, requires much further work and consideration[1].

Latin American Land-Use Patterns and Demography at the Contact

As the Iberian *conquistadores* proceeded into the "new" continent, they were amazed at what they saw. Beyond any foreseeable eurocentric reaction, we must recognize that the Americas and its native occupation were highly original. Although some of the driest areas on earth are located in Latin America, this region is, on average, amongst the wettest in the world. Since biodiversity increases with precipitation, at least up to the 4 000 mm annual rainfall threshold, it is not surprising that the highest planetary biotic diversity is found in this region (Gentry 1982, 1988; Lugo, 1988).

1. This paper is based on previous work that led to the publication of Tudela (1990).

An Atlantic-side *tierra caliente* covered by tropical forest, nearly three times larger than the entire European Community of today, lies beside an eccentric north-south mountain axis whose length exceeds 7 000 km. While Amerindians occupied much of these tropical lowlands, even by means of "advanced civilizations", it was the geologically young (5 million years old) mountainous areas, at altitudes ranging from 3000 to 4500 m above sea level, that witnessed the apex of Amerindian occupation, societal achievement and civilization. It was in the high *sierras* of the Andes and the central Mexican plateau that the American counterpart to early river valley civilizations of India, Mesopotamia, or Egypt were located. Murra's (1975, 1979) account of the Inca strategy of use of multiple ecological zones, corresponding to different altitudes may be a better template for these cultures than irrigation-based ones based on the Old World experience. And yet, this pattern of human settlement and land use has been neglected since the conquest: four-fifths of the Peruvian terraced areas that were built with such hard labor are currently abandoned, subject to no cultivation at all (e.g. Denevan, 1988). The convenience of resuming an intense utilization of high altitude ecosystems gives rise to heated discussions amongst present-day planners.

Amerindians' staple food was no less original that their physiographic setting: maize (corn) in Mesoamerica, usually in combination with beans, squash (cucurbits), and chili; cassava (manioc) in tropical lowlands and islands; and potatoes, other tubers and maize in the Andean subregion. American food had almost nothing in common with its European counterpart. The domestication of maize, initially an insignificant gramineous weed, surely followed a long and difficult process, perhaps between 7 000 - 3 000 B.C. Maize or potatoes alone, both highly productive in terms of calories per hectare, allowed for intense occupation of the territory, almost as dense as that of the Asian rice-paddy regions[2]. In the tropical lowlands, slash and burn, orchard gardens, and other systems may have allowed for human densities of 40-50 inhabitants/km^2 on a sustainable basis (Denevan and Turner, 1985).

The two most powerful nodes of native American population and civilization, corresponding to the Inca and the Aztec empires, were both at their height in the late fifteenth century. With its nearly 300 000 inhabitants, the Aztec town of Tenochtítlan may have been, at the time of contact, larger than any other urban concentration on earth the exception of Paris (Hardoy, 1978). At the other center of pre-Columbian

2. The average caloric yield per unit of land cultivated with maize and potato (over 7 million calories/ha) is equivalent to that of rice. Wheat yields are barely 4.2 million calories/ha (Hemandez *et al.*, 1980; Montaldo, 1985).

civilization, the performance of the Incas as architects of infrastructure was no less impressive: their road network, 16000 km long, may well be considered one of the highest achievements of precapitalistic engineering (Trombold, 1991).

The European newcomers also found a populous and prosperous people with no "really big" domesticated animals, at least no better than Andean camelids. Native bewilderment when confronted with the very few horses brought by the *conquistadores* should not make us forget that America was the likeliest biological homeland of the horse at least the most complete series of *Equus* fossils has been found there.

The demographic dimension of human settlement as a process is an essential component for the reconstruction of the evolution of land-use patterns. Folk belief tends to assume a smooth demographic progression in preconquest America. Such a process is doubtful: the continent experienced a score of social and/or ecological crises that implied the fall of local populations, although none of them reached the proportions of the catastrophe brought about by European contact. The population of the valley of Mexico, for example, fell from a probable 150 000 near 500 A.D. to no more than 50 000 in 1 000 A.D. (McClung de Tapia, 1984).

Estimates of the probable magnitude of the native American population at the time of the European contact are commonly fraught with ideological and emotional overtones. The reconstruction of prehispanic population has a history of its own, with three distinct periods in the late twentieth century characterized by (1) gross underestimations (until the early 1960s), (2) awareness of the large population (1960s and early 1970s), and, most recently, (3) by the wariness of demographers of these lofty estimates (last fifteen years).

The step from the first to the second view is attributed to the "Berkeley School" and may well be conceived, in Kuhn's (1970) terms, as a scientific revolution or paradigmatic shift. The wide research program that was undertaken by Woodrow Borah, Sherburne F. Cook, Lesley B. Simpson, and William M. Denevan, among others, provided strong evidence for very large populations on the eve of the conquest, ranging from 50 to 100 million inhabitants for the Americas at large[3].

In recent years, some historical demographers have staged a strong reaction against the higher estimates. The wariness of professional demographers stems from a legitimate concern that appropriate demographic understanding and scholarship has not been

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3. A synthesis and discussion can be found in Denevan (1992), who estimates the following populations at contact (figures in millions): North America 3.8; present Mexico, 17.2; Central America 5.6; Caribbean 3.0; Andean area 15.7; South american Lowlands 8.6; total for Western Hemisphere 53.9.

applied, the lack of direct empirical evidence to support highly conjectural methods of creating estimates, and concerns about the nature of abrupt change (no parallel demographic catastrophe of such a magnitude has been documented elsewhere). Many demographers are more than skeptical of the now common idea that the encounter may be, as Crosby (1989: 665) stated, "one of the major discontinuities in the course of life on this planet."

Reducing the huge prevailing uncertainties has proven to be rather difficult, and has diminished some of the zeal applied to estimating the native American population of 1492. Nonetheless, the paradigmatic battlefield is still blazing. Fine tuning of the figures should not, however prevent us from realizing the order of magnitude of the phenomenon. What we already know allows us to state that in the late fifteenth century the native American population was larger than ever, probably at least equivalent to that of the entire population living in Europe at the same period. America's inhabitants might well have represented then about one fifth of all mankind (Chaunu, 1969). Since the Americas represent around 27% of the world's total land area, its density of occupation was not then too distant from the world's average.

The Demographic Collapse and its Aftermath

In spite of lengthy documentation, the role of disease and plagues in the depopulation of the Americas after 1492 was only recently fully realized outside specialized circles. *Conquistadores* and native Americans unknowingly fought the fiercest bacteriological war ever staged in history (Crosby, 1972; McNeill, 1976).[4]

In what seemed an obvious sign of divine partiality, the ammunition was entirely on the European side. The native American ancestors had crossed the Bering Strait, perhaps as late as 40 000-30 000 B.C., isolating them from the developing pool of some three thousand species of potentially harmful germs that had been coevolving with Eurasian and African populations during several millennia and had checked their population growth. Due especially to parasitic diseases, native Americans were not perhaps a healthy lot living in "paradise-on-earth" but, as far as we know, they were considerably healthier than their European counterparts,[5] albeit much more vulnerable with respect to most disfases than the latter. The encounter may then be thought of as a kind of global bacteriological short circuit with devastating effects.

4. See the work of Henige (1992) on what he refers to as the "High Counter numerology", which he dismisses as merely a discursive strategy.

Smallpox, reaching Hispaniola (present-day Haiti/Santo Domingo) as early as 1518, played an initial leading role in this catastrophe, causing within very few days the death of one third of the ill-fated populations, followed closely by measles (Cook and Lovell, 1992). Frequently, germs moved faster than the *conquistadores*, and epidemics developed before locals had even had a chance to see any bearded newcomer; Iberian conquerors could only meet the ailing survivors lost in bewilderment and despair. In some cases, this condition explains the lack of resistance to the small number of initial invaders into the Americas.

The results of the epidemic outbreaks were appalling. Towards 1548, no more than five hundred Indians, from an original population of over one million, survived on Hispaniola.[6] Extinction was absolute in many of the Antilles, where the labor force had to be subsequently ensured by slave trade. The 20 million inhabitants of central Mexico were reduced to slightly more than one million a century after the first contact.[7]

Cook (1981) has conducted extensive research on the demographic collapse in Indian Peru.[8] His estimates for the Peruvian contact population ranged from 5.5 to 9.4 million inhabitants. In 1620, less than 700 thousand people could be counted. Thus, in the century following contact, the decline in population amounted to 93%. Along Peru's coast, native inhabitants were completely wiped out. Highland Peruvians, especially those living form Cajamarca to Lake Titicaca, did much better and managed to retain a strong indigenous culture.

The demographic nadir was reached in most American subregions between the mid-seventeenth century and the first decades of the eighteenth century, when the total population of the continent, including those of European origin, may have amounted to less than 2% of all humankind on earth (Wrong, 1965). This human extinction, perhaps the worst ever experienced by our species, was markedly dissimilar depending on the various ecological contexts. Demographic slumps of 58:1 are considered possible in the

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5. The average life expectancy in central Mexico shortly before contact has recently been estimated within a range of 34 to 40 years, definitely higher than that of the English landlords in the mid-fifteenth century (Ortiz de Montellano, 1990).

6. Friar Bartolome de las Casas (1957-61) wrote about the presence of three million people in the islands, but his was surely a gross overestimation.

7. Just the 1545-48 smallpox epidemic may be held responsible for a death toll of nearly one third of the aborigines living in central Mexico (see Whitmore, 1992). Whitmore's work demonstrates that depopulation figures in the 70-80% range can be easily simulated for Mexico without any unusual assumptions. His work, then, is a direct challenge to those historical demographers who have attacked the Berkeley School.

8. Along with the work of other scholars, such as Linda A. Newson (1985). Cook's book may be representative of a "second generation" of the paradigm brought about by the Berkeley School.

tropical coastlands. Highlands, in spite of the liability of their higher human concentration, rated much better with average ratios of "only" between 3:1 and 4:1, which were, however, at least equivalent to the toll of the worst black plague in medieval Europe.

The specific reasons for these huge differences, that can be related roughly to environmental circumstances, are still a matter of guesswork. Warmer climatic conditions may have fostered a higher rate of germ conservation and reproduction. Yet tropical diseases thriving in hot lowlands and wetlands (e.g. malaria or yellow fever) could not be blamed for the higher mortality in lowlands, since most of these illnesses were brought from Africa and introduced to America at a much later period.[9]

Not even the most superficial account of land-use evolution in America could overlook this process: many American subregions were deprived of their land user. They had fallen victims to what Emmanuel LeRoy Ladurie (1981) called "the unification of the globe by disease". The Latin American population only reached its pre-1492 levels during the first or second decade of the present century.

Thus, as far as land use is concerned, the main global consequences of the demographic catastrophe was a selective dehumanization of American landscapes, especially in those areas with the highest rate of demographic decline. Many former agroecosystems were abandoned and gave way to vegetative successions. Although colonial land-use patterns and productive technologies were, perhaps, much more predatory than their pre-Columbian counterparts (but see Turner and Butzer, this volume), anthropic pressure on land decreased considerably in America as a result of the contact. Gómez-Pompa (e.g. 1987) has repeatedly pointed out that some of the seemingly "primary" rainforests in southeast Mexico showed an unusual presence of useful species that may be a hint of formerly managed ecosystems that were eventually left uninhabited. Depopulation was not the only cause of the abandonment of large American landscapes. In some cases, cultural and technological shifts may have led to the same consequences.

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9. Although its presence was documented in the Caribbean in the sixteenth century, brought by African slaves, malaria is thought to have reached the Amazon no earlier than the late seventeenth century. Yellow fever epidemics broke out in the Caribbean for the first time in 1648 (McNeill, 1976).

A Biological Revolution

As is now widely recognized, the European/Amerindian contact brought about a biological revolution at a global scale, unprecedented at least since the big Pleistocene transformations (Crosby, 1972, 1986). Some species seized the opportunity of an unchecked expansion in disturbed ecosystems. Among these situations, the extraordinary, spontaneous demographic boom of the cattle/horse population deserves special attention. Some of these animal allies of the European conquerors got loose, reverted to wildlife, and found in the American grasslands vacant ecological niches exempt from immediate predatory threats.

The Europeans could hardly realize the effect of the forces that they had unleashed. The freed animals staged what may be considered one of the strongest biological expansions ever to have taken place. Beef was among the cheapest foodstuffs to be bought in Mexico around 1540. Its price, at one eighth of the contemporary Andalusian levels, merely reflected transportation costs. In fact, cattle was usually sacrificed just for its hide, a valuable export commodity.[10] In the mid-sixteenth century, cattle ranchers could be found with more than 150 000 heads. At the beginning of the seventeenth century, wild cattle herds of more than 240 000 individuals were reported in Argentina.

Bernal Diaz del Castillo, the soldier/chronicler, could tell us about the name, sex, and conditions of each one of the 16 horses that Cortés brought to Mexico. A century later and four thousand miles further south, travelers in the Tucuman region in Argentina were stopped for the better part of a day by the passage of immense herds of wild horses. The way of life of Amerindians and mestizos was utterly transformed by the cheap availability of horses (as well as mules, donkeys, and oxen).

Cattle production is a sensitive problem in Latin America, owing to its current role in land-cover change. Less than one third of the present regional deforestation in Latin America is carried out for the purpose of agricultural production, much of the rest makes room for pasture development (Tudela,1990). Bearing this in mind, we might be tempted to think of the unchecked biological expansion of the horse, cattle, and sheep in the Americas that took place in the sixteenth century, as a most relevant process in the history of early colonial transformations of land-use/cover patterns in Latin America. But, arguably, it was not (see Butzer and Butzer, this volume . The long-term ecological impact of this process may not have been excessive. In sharp contrast with

10. Beef hides accounted for half of the total export values in Hispaniola in 1560 (Watts, 1987).

what has happened with cattle ranching in the last four decades, there was little deforestation involved in the sixteenth century cattle expansion, which took place primarily on existing savanna areas of the continent or in ecosystems that had been previously disturbed. Moreover, the initial cattle boom was short-lived, at least in Mexico and Central America, where it receded, beginning in 1570, as suddenly and unexpectedly as it started.

The New Colonial Organization

In the aftermath of the initial conflict of the conquest, a new colonial system evolved which sowed the seeds of the dominant contemporary patterns of Latin American land use. To understand the origins of this pattern, it should be kept in mind that the population of Latin America was certainly well below 30 million when independence was declared in the early 1800s throughout the New World domains controlled by Spain and Portugal. In spite of the vigorous demographic recuperation of the eighteenth century, the Latin sphere did not contain much more than the current population of Mexico City and its conurbation. Given that this population was scattered across 20 million km^2, remote-sensing technology would have had a difficult time identifying that the area was occupied.

We might view these domains as consisting of "two republics" -- the European and Amerindian social worlds -- which had their counterpart in the bimodal use of the land. From the point of view of the European settlers, there were a few basic forces that helped shape the colonial economic organization and its impact on land use. The most obvious ones were of a cultural and technological nature. Settlers looked for climates, landscapes, and products as similar as possible to those where their own culture had evolved. Their agricultural technologies and life styles were associated with biophysical requirements that could not always be met in America, (however see González-Bernáldez, this volume).[11] The Mediterranean climate is almost entirely alien to the American continent; only a few samples were to be found in California and Chile, far away from colonial centers of development. Adjustments and adaptations had to be made, and changing locations to one more akin to the Iberian Peninsula typically proved easier than

11. The absence of precise Old World items raised thorny issues with repercussions threading through most every fabric of life for the European settler. For example, contentious among theologians was the issue of the validity of catholic consecration without proper bread and wine.

abandoning their cultural heritage. New settlements in the tropics avoided as much as possible wetlands and tropical forests which were foreign to Iberian land use. Colonists systematically looked for hilly, drier locales, such as on the Mesa Central of México. The tropical lowlands would remain underpopulated, compared to prehispanic times, contributing to afforestation (see Siemens, this volume). Perhaps one quarter of the Amerindians of Central America and lower Mexico, for example, occupied the Atlantic watershed in pre-Columbian times (Denevan, 1992). Subsequently, this watershed was depopulated in favor of the Pacific watershed with its narrow coasts, higher altitudes, major dry season, and volcanic soils. In some cases, these shifts in relative population distributions have remained into modern times. In Nicaragua today, by way of example, the Atlantic coast has less than 9% of the total population of the country living in more than half of the national territory (OEDEC, 1977).

The Spanish penetration in South America followed the Andean mountain range, from which it departed to occupy the present northwestern region of Argentina. As the colonial regime established itself in western South America, the demographic center of gravity of the continent shifted toward the desertic Pacific coast: locations higher than 3 000 m above sea level in the Andes were as alien to European culture as the humid tropical plains. The Spaniard shunned Cuzco, which remained an Amerindian city, and settled in the coastland and lower mountains, although European sheep competed with llamas and alpacas for the existing pastures in the high sierra. While the Andean land had contained the largest concentration of Amerindians in South America previous to the Columbian encounter, it is becoming clear that substantial populations were situated throughout the immense tropical lowlands to their east (see Smith, this volume). This population largely disappeared (by disease?), while European settlement favored the coast. The immense Amazonian subregion and the Mato Grosso remained almost untouched by colonial administration. The humid Pampas in Argentina were also left unoccupied until the consolidation of the republican regime.

The European settlers developed new towns, the larger of which did not match with their biggest pre-Columbian counterparts. By the end of the colonial period, Mexico City was the largest city in the New World with about 100 000 people, smaller than Tenochtítlan, the Aztec capital, over which the European capital city was built (see Turner and Butzer, this volume). In fact, the economic slump that sealed the fate of the colonial system -which frequently had ecological crises- from 1630 onwards resulted in a striking decline of many of the existing cities.

Other processes affecting land use were strictly economic. During the early colonial period, a set of economic enclaves were organized and centered upon one valuable export product: what H. and P. Chaunu (1955-59) called the “produit moteur”. Three prerequisites had to be met: the existence of a stable market in Europe for the product; sufficient workmanship and labor force available for the exploitation; and compatibility with transport costs and technology, that is, a rate of weight/value as low as possible. Those conditions were initially met only by the mining activities related to precious metals. As mining towns evolved, their corresponding hinterlands suffered heavy deforestation to provide for the huge amounts of wood required for the activity. Eventually, however, other products took over as economic driving forces, particularly dye-producing species, such as indigo, cochineal, *palo de tinte*, and *palo de Brasil*. The technology for their exploitation was basically prehispanic (MacLeod, 1973).

Towards the mid-seventeenth century, the export activities to Europe ceased to be such a structuring force for the colonial land-use patterns. The tonnage of the exchanges between America and Europe dropped to half the level prevailing at the beginning of the century. The colonial economy became increasingly self-sufficient. A new organization emerged, based on the plantation economy and the haciendas. Commercial agroecosystems developed in certain dominant enclaves, which became highly specialized and suffered from increased take out vulnerability. Within this context, sugarcane was particularly demanding with respect to soil nutrients, and may have played a substantial role in the land degradation in northeastern Brazil (Sanchez, 1981). The evolution of the hacienda system and its long range implications has been very well described for the Mexican context by Chevalier (1976).

On the other side of the colonial system, surviving Amerindians, growing ranks of mestizos, and impoverished European colonists merged into a new peasantry in Latin America, whose function was to provide workmanship and stability to the local food system. Basic diet remained rather unvarying. In spite of the deepest cultural and political changes, in many Latin American countries, staple food for the bulk of the population is not, even today, too different from what it was five centuries ago: maize, beans and chili in central Mexico, and “chuñu” (freeze-dried potato) in the Andean highlands. In colonial times, the general food system was thus based in the persistence of some pre-Columbian technologies and agroecosystems, combined with a very interesting hybridization with European agricultural inputs and know-how (Whitmore and Turner, 1992). This combination was usually sustainable and ecologically friendly.

Induced Changes in the Iberian Peninsula

Land-use changes related to the American colonization were much less conspicuous in Spain, Portugal, and the rest of Europe than in their colonized areas across the Atlantic. No biotic revolution, as experienced in the Americas, was unleashed in Europe as a consequence of the encounter. In the old world any related transformation, such as the introduction of American cultivars, remained under anthropic control and were shaped by strong economic and political influences. European frost checked the expansion of most plants from tropical America. The quite complex demographic and economic trends that affected the Iberian Peninsula in the sixteenth and seventeenth centuries were modulated by American circumstances, but few of them could be explained as a pure result of American colonization (García Sanz, 1985).

At the time of the encounter, the Spanish population was mainly concentrated in the Kingdom of Castile, where 80% of the nearly five million Spaniards lived. The Portuguese population amounted to no more than one million people. Spain experienced a demographic stagnation during the first three decades of the sixteenth century. Subsequently, the Spanish population experienced a notable expansion, particularly in urban areas, until the late 1580s, when a total count of nearly 7 million people is considered probable.[12] Rural-urban migration was intense during this expansion phase. A demographic slump followed that lasted throughout the mid-seventeenth century. The subsequent recovery was rather sluggish, since at the beginning of the eighteenth century the Spanish population probably did not exceed 8 million (Bustelo, 1989).

The Spanish economy expanded greatly in the sixteenth century. This economic growth cannot be explained only by means of the colonial windfall. It had its roots in the preconquest fifteenth century, when the Castilian economy established links with European markets where it sold wool from the Mesta herds (see González-Bernáldez, this volume),[13] agricultural products from the Guadalquivir valley (Fernández Alés, Martín, and Merino, this volume) and metal artifacts from the Basque region.

The economic boost provided by the early arrival of American precious metals

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12. The population of the Iberian Peninsula at the end of the sixteenth century was considered to be higher by Elliott (1963): Crown of Castile (65% of all peninsular area), 8.3 million; Crown of Aragon, 1.36 million; Kingdom of Portugal, 1.5 million; Kingdom of Navarre, around 0.2 million.

13. Merino sheep were introduced from Africa around 1300. The Mesta was a powerful social organization of transhumance that was established in the late thirteenth century and dominated land use in the possessions of the Crown of Castile. (Note that nomadic pasturing of livestock in Spain is typically referred to as transhumance).

bolstered Castilian urban expansion on the basis of a new emphasis on commerce and manufacturing. The emerging empire required a heavy administrative infrastructure, for which there was no precedent in the western world. When Madrid became a capital city in 1561, it was little more than an outgrown village with less than 20 000 inhabitants. Towards the end of that century, its population soared to over 90 000, and reached a peak of 130 000 in 1630. Seville, the southern city that monopolized American commerce, grew from 25 000 inhabitants in 1530 to over 75 000 in 1591 (Chandler, 1987).

During the sixteenth century, the Castilian economy developed a growing dependence on the colonial input. The latter, however, represented at its best (during Philip II's reign) no more than 25% of the state's income. The economy fell victim to endless unproductive investments, heavy indebtedness, inflation, and deficits. In the case of Spain, the unprecedented military effort required to stage subsequent wars in Europe sapped the stamina of the country. An army of at least 65 000 men was permanently mobilized, with peaks reaching over 350 000 soldiers during the campaigns (Elliott, 1989). In the late sixteenth century, up to 60% of the silver consignments from America left Spain at once, right after its registration, in a desperate attempt by the debt-ridden Spanish crown to keep its European armies in pay and its banking creditors at bay (Elliott, 1989).

Although a score of powerful structural factors accounted for the Spanish decline, the colonial circumstances may have acted also as a catalyst for the unprecedented depression that set off in the late sixteenth century and lasted throughout the following one. Castilian lower classes experienced one of the hardest times in their history. Commerce with America, which had grown at a constant pace until 1610, suffered a steep decline in the period 1610-60. The transhumance system run by the Mesta began to disintegrate. At the time of the encounter, almost three million transhumant sheep could be counted in Castile. A century later, those herds amounted to less than two million (Klein, 1979).

The economic slump brought about heavy demographic consequences. The population loss of the late sixteenth century and first half of the next century, was extreme in many of the existing towns in central Castile, with the notable exception of Madrid, the administrative center that managed to come out more or less unscathed. As of 1650, Castile's population was reduced to less than 4.5 million inhabitants (Garcia Sanz, 1985).

There is no general agreement on the relevance of migration to America with respect to the Spanish demographic decline that was already noticeable in the late sixteenth century. The volume of migration was not impressive in quantitative terms: some 30 000 westward crossings were estimated for the entire century (Boyd- Bowman, 1976; Mörner,1976).[14] The bubonic plague that raged in 1598-1602 inflicted losses of nearly half a million lives. Migration was, however, a highly selective process in terms of age (young people, mainly in their twenties), and geographical distribution (more than 40% of all sixteenth century emigrants to America were Andalusians, while native "Sevillanos" accounted for nearly one fifth of the total emigration) (Boyd-Bowman, 1976). The demographic recession of the first half of the seventeenth century was followed by stagnation during the second half of that century, everywhere except in the northern regions, whose economies and populations were much enhanced by the cultivation of an American product, maize.[15]

There is still considerable confusion about what American product was cultivated where and at what time, but Europe at large benefitted from the increase in carrying capacity derived from the introduction of American plants, especially maize and potatoes. The main European land-use transformations, however, are certainly due to more systemic effects. The research of Immanuel Wallerstein (1974), among others, put forward the idea that America's precious metals played a leading role in the expansion of western capitalism and its related productive changes. This claim has been, however, challenged by further research which tried to establish that American gold and silver played a marginal part in that development, or even that capitalism emerged in spite of the colonial mining revenues, which were mainly utilized to fuel destructive warmongering (Flynn, 1984). This argument holds that little European accumulation of silver took place in the sixteenth century: most of the American silver influx entered complicated Mediterranean commercial circuits and ended up in the far east.

Methodological Considerations

Scientists have not always been prone to accept the possibility of radical changes in natural or social processes, or even to identify a discontinuity. The Columbian encounter was certainly one of those cataclysms or discontinuities that challenge the human mind as framed within prevailing paradigms. There is an utter lack of proportion between the

14. Interestingly, figures for migration in the seventeenth century are even more hypothetical than those for the previous one.

15. Gonzalo Anes (1978,1984) has carried out extensive research work on the beneficial effects of the introduction of maize on the economy and the quality of life in northern Spain.

triggering process and the staggering effects or consequences that this process unleashed. The transatlantic transfer of a few tons of biomass triggered transformations of enormous magnitude and spatial reach, many of which are still active. The change of land-use patterns that created these land-cover changes operated in ways that are far from clear. Further research work should be carried out in order to get a clearer picture of this dynamics, whose systemic nature calls for an interdisciplinary approach.

As this brief overview attempts to convey, changes in the occupation of the territory and the utilization of its resources depend on processes affecting social factors such as demographic, political or cultural features, economic factors such as new productive orientations, and biophysical or ecological factors. The relationships between these factors determine the structural properties of the system, including its stability, vulnerability, and resilience. A structural analysis may thus explain why most land-use changes were so disproportionate with respect to the initial process that elicited them.

A theoretical framework has evolved recently which might be useful to deal with complex, interdisciplinary problems, such as the ones raised by deep changes in land-use patterns in areas undergoing similar processes. The roots of this approach are to be found in Jean Piaget's constructivist epistemology and Ilya Prigogine's open systems thermodynamics, or "dissipative structures."[16] Most recent work on "chaos" strives in the same direction. Within this context, complexity is thought of as a "self-regulating heterogeneous" property of a system, which should not be confused with "complication". A hydraulic model, or an econometric one, may be technically complicated but still not complex in the context of the assumed theoretical framework.

The methodological problems to be addressed include the following:

(1) construction of the object as a reality which is heterogeneous, unassignable to any specific discipline; delimitation of a complex system and consideration of its interactions with external reality or boundary conditions;

(2) articulation of different scales and levels of analysis; specificity of every spatial/temporal scale;

(3) structural and functional characterization of the system studied; sets of relations between biophysical, social and productive elements;

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16. A general view of the "dissipative structures" approach may be found in English in Prigogine and Stengers 1984). A compatible development in Spanish may be found in García (1986); also García et al., (1981).

(4) detection of changes in the elements and their interactions; a complex system may evolve through phases of stability or undergo sudden destructuring disruptions, according to the range of fluctuations of its internal elements and changes in the boundary conditions.

Such a complex systems approach to land-use changes seems promising in so far as it would combine considerations of both structures and processes.

Before the Columbian encounter, different biological worlds, not to mention cultural realms and trends in civilization, coexisted on this planet. As a forerunner of present-day globalization, the encounter set off a biological unification whose effects ran deeper than the concomitant political and military clashes.

The unification of the social and natural sciences, both academically and culturally, has proven to be much more difficult. As a research field, the analysis of changes in land-use patterns brought about by the Columbian encounter is an excellent opportunity to enhance interdisciplinary efforts and foster the unification of "natural" and "social" approaches.

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CHAPTER 3

WESTERN EUROPE AND THE WESTERN HEMISPHERE, 18th-20th CENTURIES: MAGNITUDES AND IMPACTS OF LAND-COVER CHANGES

Ian Douglas and R.I.Hodgson

An Overview

The Columbian encounter set into motion a series of social forces with environmental consequences that can be traced beyond the seventeenth century. Indeed, some of the more dramatic environmental changes associated with the encounter were delayed some 200 years as settlement developed beyond the Hispanic Americas, first in North America and much later in the southern parts of South America. By the eighteenth century, individual farmers in New England, following a European view that the forest was an obstacle to be cleared in order to make a farming landscape (Williams, 1989), were clearing about one hectare of forest annually (Foster, 1992). In South America, in the second half of the nineteenth century, British companies in the Gran Chaco were investing in timber processing for tannin, while others were speeding the transformation of the Pampa into a great wheat-producing area. The eighteenth to twentieth centuries witnessed the heyday of colonialism and the beginning of the rise of industrial capitalist society in Europe, leading to a North-South division of wealth and power which had great implications for land-cover stability and change.

The period saw unprecedented population expansion and transatlantic migrations, with the European population growing from 100 to 600 million, while those of North and South America together expanded from around 8 to 350 million. The upsurge came first in the European countries in the late eighteenth century, in the United States in the nineteenth century, and in Latin America in the twentieth century (Figure 1). Expansion

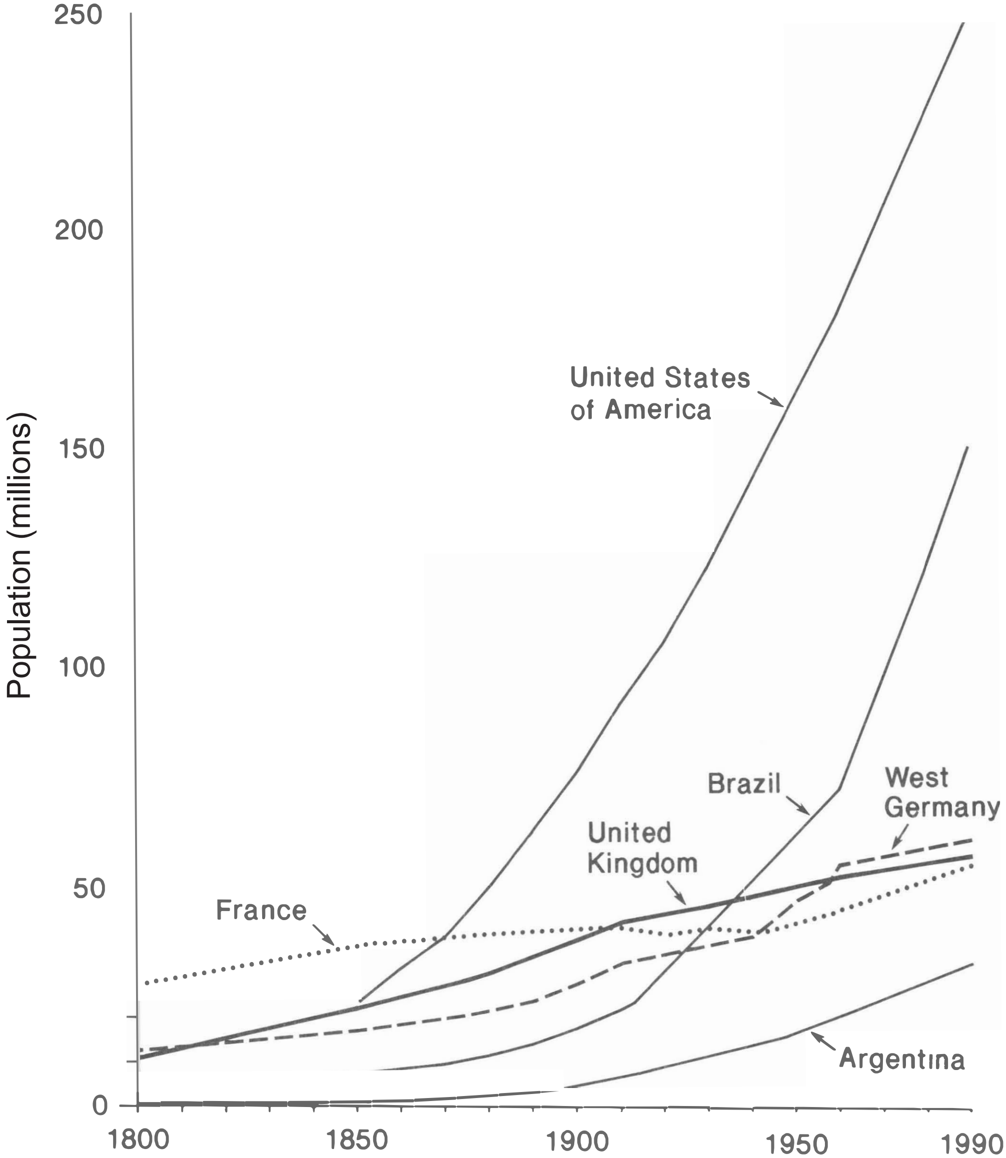

Figure 1. Population growth in Great Britain, France, Western Germany, Brazil, Argentina and the United States from around 1800 to 1990 (compiled by the authors from various sources).

from the European core over the past five centuries has involved the transcontinental movement of about 95 million people; most of this migration occurred in the nineteenth century. About 33.5 million Europeans went to the United States and seven million to Latin America between 1820 and 1920 alone (Hennessy, 1978) (Figure 2); the forced movement of Africans, especially to the American tropics and subtropics, accounts for some 19 million.

This enormous population expansion was sustained by the rise of a capitalist world economy, in which commercial considerations and the needs of urban-industrial societies were to the fore (Figure 3) and whose most striking characteristic was the import of primary products from the frontier or periphery in exchange for the manufactured goods of the metropolis or core (Table 1; Figure 2). The primary producers spread into the new lands of the middle and high latitude Americas, especially the temperate forests, prairies and pampas, further displacing the indigenous peoples (Tudela, this volume). In the eighteenth century, American lands began to meet European needs: cotton and tobacco from Virginia and the Carolinas; and timber, pitch and tar from New England for British ships. As industrialization grew in Europe, land passed out of agriculture and reafforestation was encouraged, while in the Americas, more and more forest was cleared so that land could be put under the plough and extractive industries expand. Eventually, the emphasis of land-cover transformation shifted to Latin America, where the twentieth century is still witnessing massive land clearance and vegetation change to meet both local and international, especially United States, market demands, while European forests, and to a lesser extent, those of North America, are being saved and expanded. Here too, popular movements have led governments to protect wetlands, mountains, and coastal zones.

At the beginning of the eighteenth century the development of the Americas was still essentially focused on the ties between southern European states and their colonies in Peru, Mexico and the Caribbean. A century later the political relationships had changed dramatically: the American War of Independence, 1775-83, saw the United States loosen its ties of colonial dependency, while in the wake of revolutionary fervor in Europe, notably in France, the 1820s were to witness the independence of much of Latin America. New political relationships were formulated by wave upon wave of immigrants who brought with them their strong sense of ethnic and class identity and, in the case of many of those from Western Europe, the economic ethos of free trade which emanated from the "Manchester School" (Disraeli's famous phrase for the forces which triumphed in England's great industrial city in the 1840s). Changes in transport technology, most notably the application of steam power to railway engines from about 1840 and

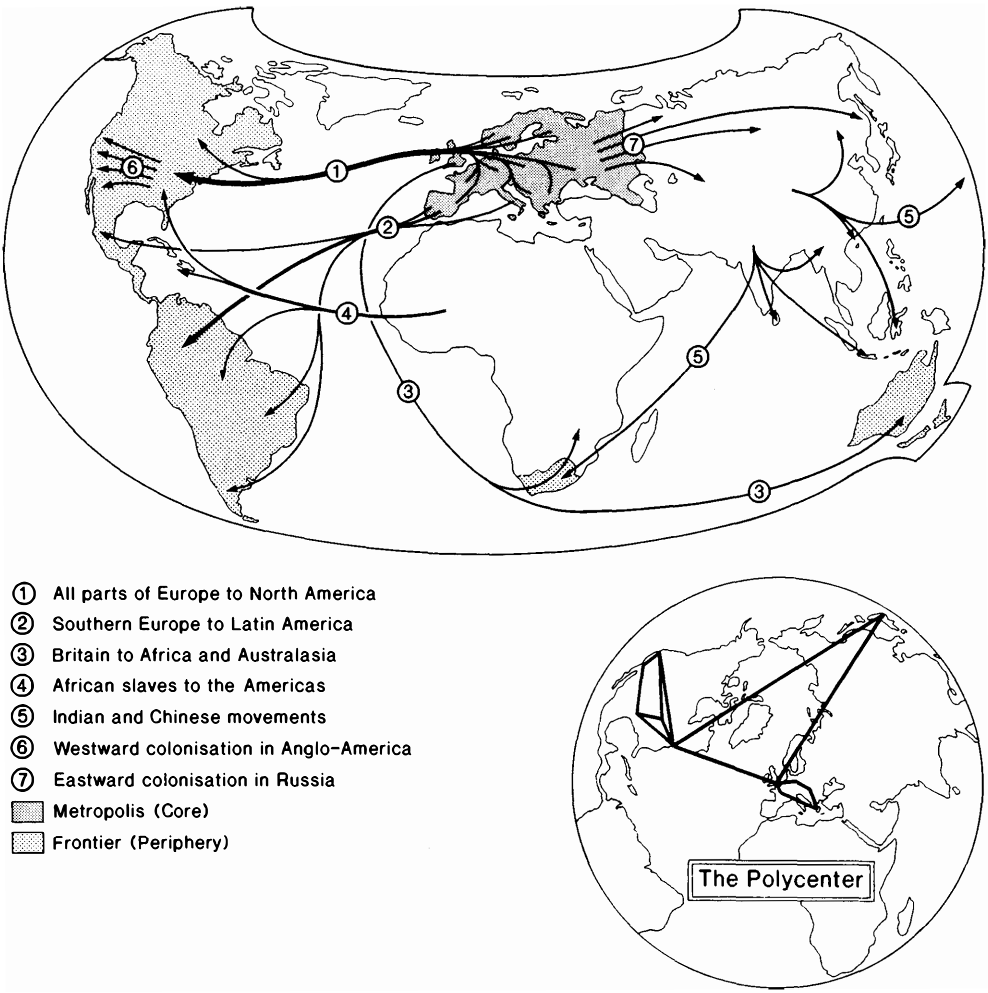

Figure 2. Migration paths during the eighteenth to twentieth centuries (after Haggett, 1979), indicating the metropolis/heartland and frontier (core and periphery) of Europe and the associated American, African and Oceanic new lands (after Webb, 1952). The inset indicates the late twentieth century polynetwork at the core of the modern world economy (after Berry, 1990).

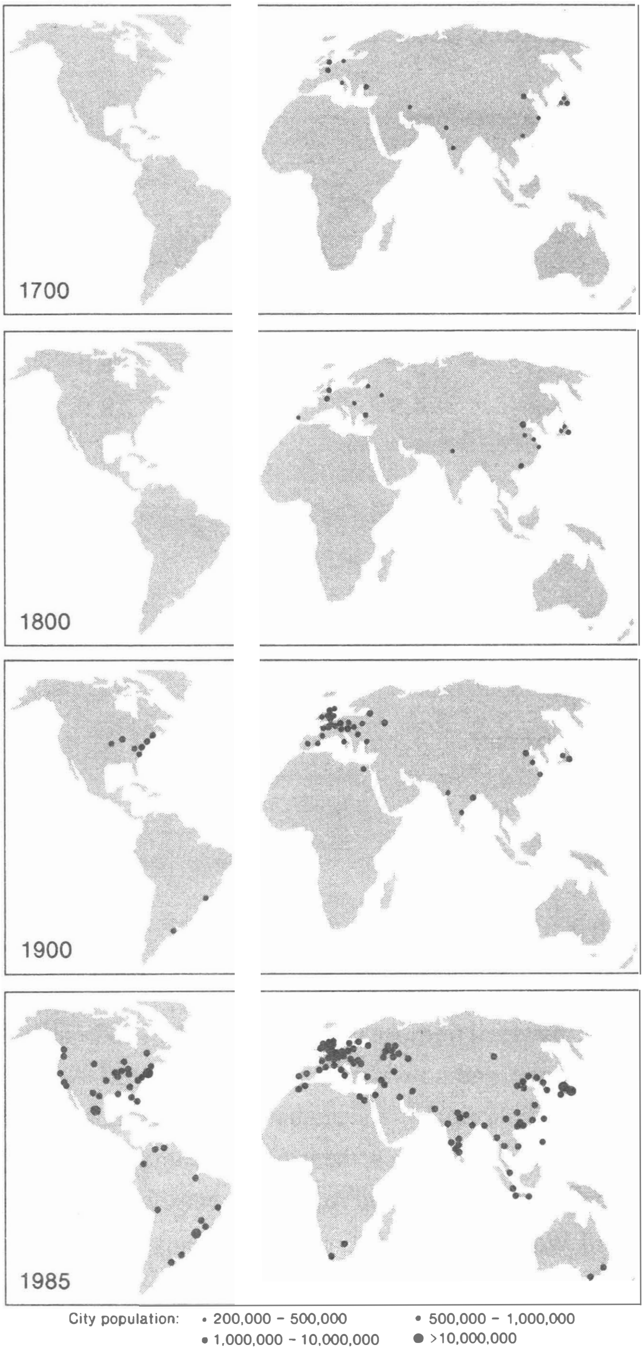

Figure 3. Growth of world cities from 1700 to 1985. Note growth in North America after 1800 and in Latin America after 1900 (after Berry, 1990).

Table 1. Percentage of British imports and exports linked to the Americas in the eighteenth century (after Darby, 1973)

	England and Wales			Great Britain	
	1700-01	1750-51	1772-73	1772-73	1797-98
Percentage of domestic exports from:					
To:					
North America	5.7	10.7	25.3	26.0	32.2
West Indies	4.6	4.9	12.0	12.0	25.2
Percentage of import to:					
From:					
North America	6.4	11.2	11.6	14.5	7.1
West Indies	13.5	18.9	24.8	23.7	25.0
Percentage of re-exports from:					
To:					
North America	5.0	11.2	9.0	8.7	3.1
West Indies	6.2	4.1	2.9	2.5	4.1

faster,cheaper, steam-powered transoceanic ships from the 1860s, shrank space in terms of time and cost-distance, and so widened the availability of American resources to European consumers. While eighteenth century resource exploitation had focused upon the tropical goods of Hispanic America, the late nineteenth century saw producers in the temperate latitudes of North America and Argentina competing with European suppliers.

The First World War saw much of Europe's economy devastated and the focus of political and economic power shift firmly to North America whose links with and controls over Latin American development grew as those of Western Europe, particularly Britain (Tables 2 and 3), diminished. The Great Depression of the 1930s, which began in North America but soon spread its tentacles far and wide, triggered an era of protectionism which distorted production factors and international trading relationships.

With European countries again torn apart by war between 1939-45, the Americas had once more to adjust. Reinforced by the need to manage their own economies, Latin American countries turned to manufacturing industries for their salvation and afforded less protection to their stagnating agriculture. Meanwhile, North America, with the aid of advanced technology, was becoming the bread basket of the world.

Over the past 40 years or so, the economies of the United States and Europe have been subjected to the attentions of a strong farming lobby which has induced policies favorable to agriculture, a feature absent or low on the political agenda in most Latin American countries. North America, and most especially Western Europe via the protectionism of the Common Agricultural Policy (CAP), continue to distort national patterns of development while all Latin American countries favor free trade, a feature most evident in the recent impasse over the General Agreement on Tariffs and Trade (GATT) talks. Meanwhile, Japan and other Pacific Rim countries, and the new market economies of the desperately impoverished Eastern European states, challenge the Americas and Western Europe with new relationships.

The immense changes in land cover and land use are one expression of these momentous demographic, commercial, and political changes. In the Americas they were initially spurred by the search for mineral wealth but from 1800 onwards it was huge new demands for agricultural produce which transformed the landscapes, altering vegetation and changing the quality of the soil resource. At the same time in Europe, industrialization changed land uses and massively altered air, soil, and water quality. The primary concern of this paper is these land use changes and the ways in which they were brought about by the Columbian encounter and its aftermath.

Land Transformation as a Consequence of the Columbian Encounter

The contacts and transfers involved are not solely those of agricultural products and technologies, but involve the whole range of resources, industrial products, and technologies, right up to computer software and hardware and the nuclear industry. In such an analysis both the direct and indirect land-use and land-cover consequences of the Columbian encounter may be envisaged. The direct consequences are the immediate impacts on land cover and soil conditions, whereas the indirect consequences are those which feed into urban and industrial activities which in turn bring about huge demands for food supplies, materials for urban construction and consumption, and space for waste disposal, transportation facilities and recreation.

The basic task in addressing the impact of the Columbian encounter on land is to

Table 2. Nineteenth century expansion and twentieth century decline of British dominance of trade, especially with South America (based on Braudel, 1984; Christopher, 1985; Hobsbawm, 1987).

1825	Rush by British capitalists to invest in newly independent South American states. ("Bound hand and foot to the City of London, Latin America would remain on the periphery of the world economy" Braudel, 1984: 424).
1851	British cotton industry accounts for 46 % of country's total exports and is equal in size to that of the rest of Europe together.
1881	Britain is now buying almost 50% of the world's meat exports and more cotton and wool than anyone else.
1883	German exports are only half those of Britain but are beginning to expand rapidly.
1887	Acts by American Congress and 13 western states restricting ownership of land to U.S. citizens; decrease in British owned land area in North America and expansion of holdings in South America and Mexico (Christopher, 1985).
1905-9	Britain extremely dependent on imported food, taking 50 % of all cereals, 76 % of all cheese and 68 % of all eggs from overseas producers (Hobsbawm, 1987).
1913	German exports exceed those of Britain.
1914	Britain has 44 % of world's overseas investments and a merchant fleet 14 % larger than all the other European merchant fleets put together.
1938	Britain still takes 33 % of Argentina's exports.
1954	Britain's share of Argentine exports falls to 18 %.

Table 3. Changing proportion of European trade in the commerce of the Americas.

a) Percentage of world commodity exports by region

	1913	1928	1937	1955	1958
World	100	100	100	100	100
W.Europe	47,2	41,6	39,3	37,0	38,4
N.America	14,2	19,7	16,8	22,0	22,1
Latin America	8,1	9,8	9,9	10,0	9,1
Africa	3,9	4,2	5,2	5,9	5,2
Asia	9,4	13,7	17,4	11,9	11,1
Oceania	2,4	2,9	3,3	2,8	2,4
Planned economies	14,8	8,1	8,1	10,4	11,7

b) Percentage of world commodity imports by region

	1913	1928	1937	1955	1958
World	100	100	100	100	100
W.Europe	56,4	49,5	48,1	40,3	39,9
N.America	11,5	15,0	15,3	17,9	17,9
Latin America	6,9	7,6	7,1	9,2	9,0
Africa	3,3	4,7	5,7	6,9	6,7
Asia	8,7	11,9	14,5	12,4	12,2
Oceania	2,4	2,7	2,5	3,2	2,5
Planned economies	10,8	8,6	6,8	10,1	11,8

Source: Dewhurst *et al.*, 1961.

assess changes in the state of the land and its biological productivity, whether under natural conditions or varying states of management, through the impacts of new crops, technologies, resource uses and market demands stemming from the encounter. Assessment of this involves knowledge of: (a) what was removed from the land; (b) changes in land cover; (c) introduced plants and animals; and (d) the impact of new technologies. The effects of these changes on soil stability, erosion, and the sustainability of production then has to be evaluated. The results are inevitably going to differ on either side of the Atlantic, but will also vary regionally and locally within the continents. The differing dependence of small and large communities on transatlantic ties was evident from the outset of the Columbian encounter, but became more marked in the eighteenth to twentieth centuries. To work solely at the continental, or even the nation-state level, might obscure communities totalling millions of people that were brought into being and remained largely dependent on their transatlantic links for most of the three centuries here considered.

Removal of Material from the Land

The acquisition of precious metals, which had been the prime motive for the initial Spanish settlement in Middle America, led to persistent changes in the land cover in the countryside surrounding every mining center. For example, the present barren windswept landscape of the hills around Zacatecas, Mexico, arises from the removal of acacia and oak stands before the end of the sixteenth century (West, 1989). In the same way, following the 1849 gold discovery in Nevada and California, forests were depleted, pine being cut in the Sierra, while pinon trees around the camps were exploited for fuel (Kersten, 1964).

Although large countries have come to dominate the mining statistics of the Americas, many smaller countries are major world producers of certain ores, such as Jamaica for bauxite and Peru for lead and zinc. United States interests have generally taken over the European initiatives of earlier centuries. This change in markets is well illustrated by Peru, which initially supplied Spain, but in the nineteenth century turned mainly to the British market, only to see the United States replace Britain temporarily during the 1914-18 war and finally become the major trading partner after 1939 (James, 1959).

Throughout much of South America in the nineteenth century, Britain came to dominate trade, particularly through: (a) the role of London markets in fixing commodity prices; (b) investment in land (Table 4), mining, railways, urban transport, trade, and banking; (c) negotiation of loans with London banks; (d) British control of marine transport; (e) investment by private British individuals in mining companies; (f) technological dependency for imported machinery; and (g) emulation by Argentine and Chilean society of British (and French) cultural and educational patterns (Garcia, 1989). Perhaps in the mining industries of the Americas, the role of European investment and European market decisions has lingered the longest.

Table 4. Companies involved and areas of land owned by British companies in the Americas, 1885 and 1913 (after Christopher, 1985).

	1885		1913	
	Companies involved	Area 1000 ha	Companies involved	Area 1000 ha
North America	79	16 895	113	4961
Central America	6	135	76	11602
South America	17	3274	139	15140

Colonial relationships always played a part in the exploitation of mineral resources. When Royal Dutch Shell drilled the first productive oil well in Venezuela, they built their refinery on the neighboring Dutch island of Curaçao, and Creole Petroleum (Standard Oil of New Jersey) located theirs on Aruba. Only after 1945 did Venezuela legislate for a higher proportion of home refining of local production. Mineral resource extraction over much of the Americas is still dominated by European interests and markets and remains the explanation for many settlements in unattractive, difficult environments, from the oilfields of the Alaskan north slope, to the high altitude mines of Bolivia and the desert nitrate workings of Chile.

Meanwhile, in Europe, the great expansion of coal, iron, salt, limestone, sand, and gravel extraction created a whole series of derelict landscapes of mine waste tips, abandoned quarries and gravel pits, surface depressions, and water bodies resulting from subsidence due to underground mining. So severe had these problems become by the mid-twentieth century that large-scale efforts were made by both national governments and local authorities to transform derelict lands such as those of the German Ruhr, the Belgian Sambre-Meuse coalfield, and the coal and salt mining areas of Staffordshire, Cheshire, and Lancashire into new woodlands, meadows, housing and recreational areas.

Changes in the Plant Cover

Population growth led to an increase in cropland (Table 5), in Europe largely before 1850, in North America prior to 1920, and in Latin America mainly since 1920. These differences in timing indicate the way in which both spatial land-cover change and intensification of land use operate to maintain food supplies to a growing population. The ability of soils to respond to intensification depends on their inherent biophysical characteristics and their technomanagement. A major factor in the way the Columbian encounter has influenced soil productivity and the sustainability of agriculture has been the degrees to which different groups of settlers have had the skill and material technology (or adopted them from the Amerindians) to manage the soils of the areas into which they migrated.

Exploitation of the tropical forests of the Americas has a long history, English privateers and traders taking timber along the coast from Yucatán to southern Nicaragua after about 1600, eventually concentrating on mahogany from Belize (West, 1989). While the Amazon basin (Selva) was virtually undisturbed by non-Amerindians until the mid-twentieth century, the coastal and southern forests of Brazil were felled from the beginning of European settlement (Figure 4) (James, 1953). A tradition developed, not found elsewhere in Latin America, of moving on to new forest areas once soil was exhausted, Brazilian society sharing a mobile migratory nature with North Americans, unlike Hispanic Americans (Hennessy, 1978); this can be seen today with the migration into provinces like Rondônia. Exploitation of the quebracho (break-axe) hardwood forests of the Gran Chaco began in 1850 and spread rapidly, with British investments playing a major role at the turn of the century (Christopher, 1985), reaching a rate of 200 000 ha a year by 1950. Conversion of forests to cultivation in South America is very much a twentieth century phenomenon, driven by internal, national, or regional economic forces rather than European market demands.

Introduction of Plants and Animals

It would be wrong to think of the agricultural impacts of the encounter as having been unidirectional, that all of Europe was under plow and little of the Americas were cultivated. Sophisticated systems of cultivation were maintained throughout the Americas by Andean and Mesoamerican Amerindians among others; and mound cultivation was widespread even in the Carolinas (Doolittle, 1992; Whitmore and Turner, 1992).

Table 5. Land use data: Europe and the Americas 1700-1980 (after Richards, 1990). (Note: The forest areas include reafforestation and plantation forestry).

Region and vegetation type	Area (million ha)					
	1700	1850	1920	1950	1980	1980 (% of 1700)
Europe						
Forest and woodland	230	205	200	199	212	92
Grassland and pasture	190	150	139	136	138	73
Croplands	67	132	147	152	137	204
North America						
Forest and woodland	1016	971	944	939	942	93
Grassland and pasture	915	914	811	789	790	86
Croplands	3	50	179	206	203	6766
Latin America						
Forest and Woodland	1445	1420	1369	1273	1151	80
Grassland and pasture	608	621	646	700	767	126
Croplands	7	18	45	87	142	2029

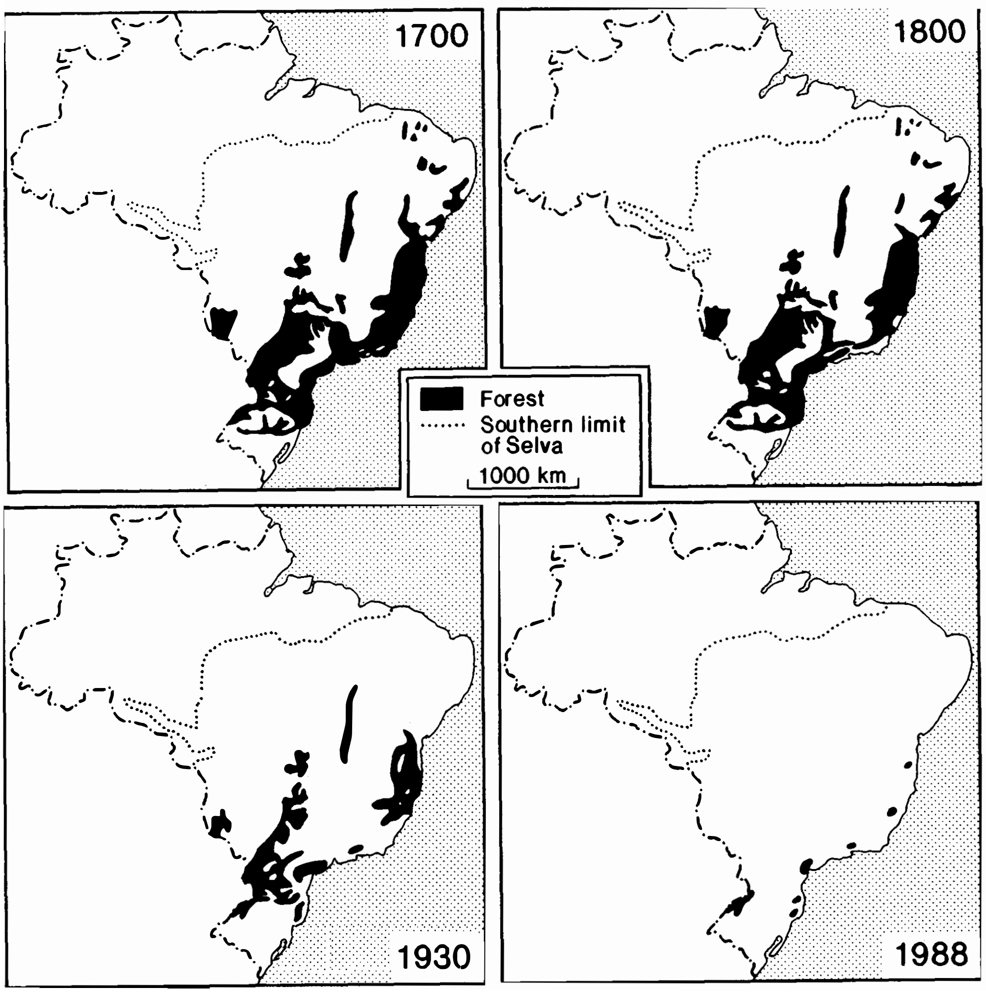

Figure 4. Depletion of the forests of Brazil south of the Amazon basin (Selva) (after James, 1953 and World Resources Institute, 1990).

On the other hand, at the beginning of the seventeenth century, much of Europe was still "waste," uncultivated, little modified natural landscape: the proportion of France under cultivation expanded from 35.5 % in 1600 to 60 % in 1890 (Braudel, 1990). Landscapes on both sides of the Atlantic have been transformed by the exchange of crops (Table 6).

Introductions from the Americas to Europe

Maize (corn) and potatoes were probably the two most important crops introduced to Europe. Both helped sustain the great increase in population after 1700. The two crops were complementary, maize being confined to the Mediterranean and Balkans, while potatoes spread in northern Europe. Up to 1914 maize was among the two most important cereal crops in Hungary and Italy (Figure 5), the plains of both countries undergoing considerable drainage and reclamation to cope with the crop.

In contrast to the rapid success of maize in Europe, the potato took longer to become widely adopted. Initially regarded as an exotic luxury when introduced to Spain in about 1570, the potato began to be a field crop in Germany and Austria and later in Italy, Switzerland, France, and the Low Countries in the seventeenth century; yet it was long regarded as food only for animals, or the poor or desperate (Braudel, 1990). Such was its status still in England and Wales in the 1760s and 1770s when English agricultural writer Arthur Young recorded its increasing availability and cultivation, especially in the industrializing districts (Figure 6). Its value as a food was finally recognized by Scottish and Irish peasants in the mid-eighteenth century, when three-quarters of Ireland was owned by English or Anglo-Protestant landlords and the peasantry was driven either to a precarious subsistence on a potato patch, or migration to the United States, often under conditions little better than slavery. "The potato kept the Irish alive and allowed them to multiply" (Plumb, 1950: 179).

Early in the nineteenth century the potato was highly successful on well-manured dry light soils in Lancashire and Cheshire (Prince, 1973), including newly drained moss land close to Liverpool and Manchester. By 1815 a typical rotation in Lancashire consisted of wheat, then oats or barley undersown with clover, followed by a grass ley left for up to four years and then potatoes. Farm produce fed horses and cows kept in towns, and manure and night soils were brought back to improve soil fertility (Fletcher, 1962), helping to transform waterlogged wastes into prime agricultural land. This major nineteenth century expansion of European potato production (Figure 6) was not even stopped by the blight which successively wiped out the Irish and French crops in 1846 and 1847.

Table 6. Introductions of tropical and temperate plants to and from the Americas (in part after Watts, 1971).

Crop	Area of origin	Area of current maximum production
Tropical crops		
Sugar cane	S.E.Asia	W.Indies and S.America
Rubber	S.America	Malaysia
Pineapple	C.America	Hawaii
Coffee	Ethiopia	Brazil, Mexico, Indonesia
Cocoa	S.America	W.Africa, Brazil, Malaysia
Citrus	S.E.Asia	USA.
Banana	S.E.Asia	Mexico, Brazil
Nutmeg	Moluccas	Grenada, W.Indies
Sisal	Mexico	E.Africa
Temperate crops		
Potato	S.America	USSR, Poland, China
Tomato	S.America	USA, USSR, Italy, Turkey
Tobacco	C.America	China, USA, Brazil, India
Maize	C.America	USA, Brazil, France
Wheat	S.W.Asia	China, USSR, USA, France
Barley	S.W.Asia	USSR, Canada, France
Oats	S.W.Asia	USSR, USA, Canada
Soybean	N.China	USA, Brazil, China
Runner bean	C.America	China, Turkey, Spain, Italy

European Introductions to the Americas

Sugar grew rapidly in demand in the eighteenth century, becoming a necessity for the masses (Bowle, 1974). Reintroduced to Barbados as a commercial crop in 1637 (Watts, 1966), sugar cane came to dominate the landscape in 1665 when almost all the forest had been removed. Not all land clearance for sugar on the Caribbean islands was as drastic.

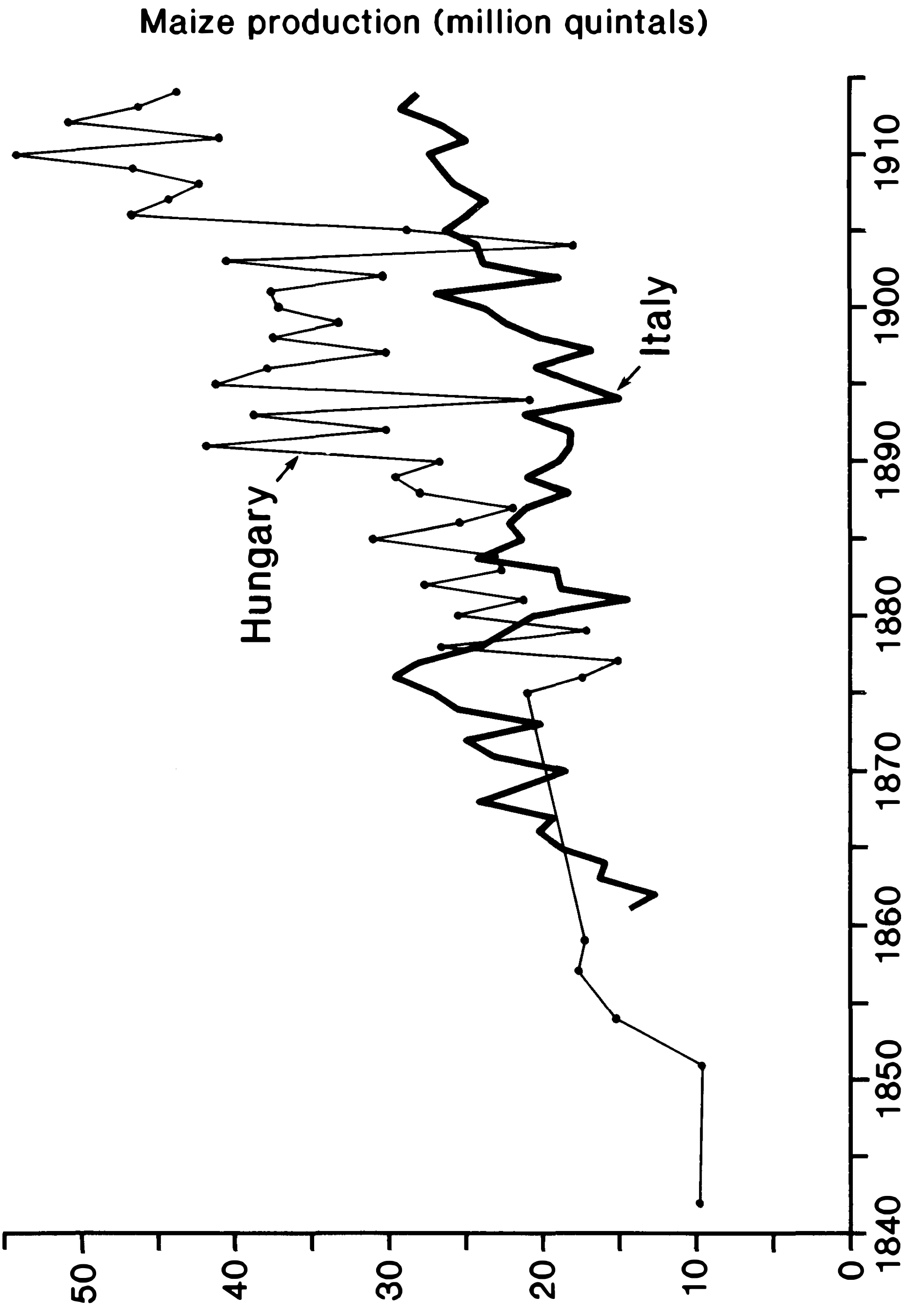

Figure 5. Expansion of cultivation of maize in Italy and Hungary, 1844-1914 (based on data in Mitchell, 1971).

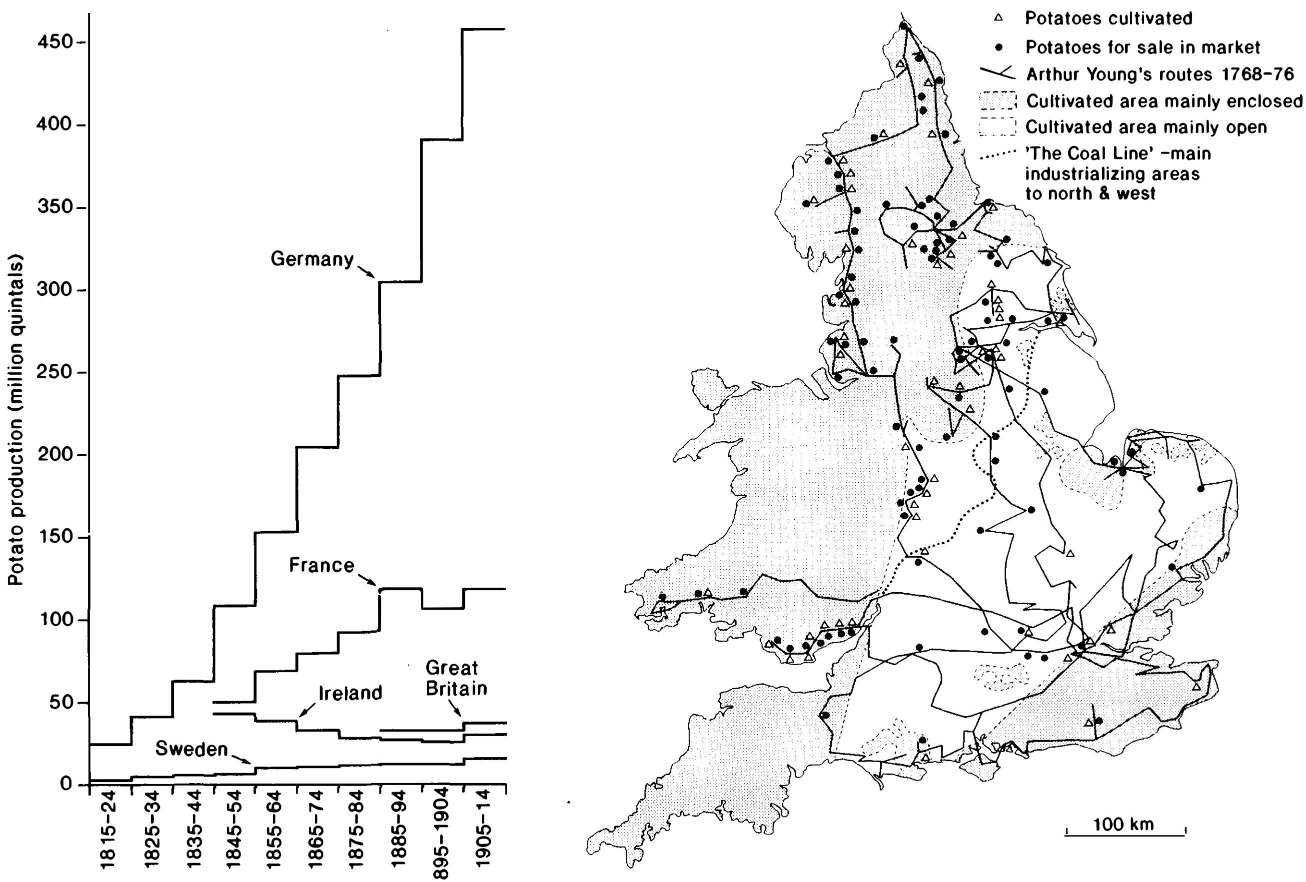

Figure 6. Growth of potato cultivation in Europe, 1815-1914, and areas where Arthur Young found potatoes being grown or sold in eighteenth century Britain (graph from data in Mitchell, 1971; map after Salaman, 1949).

The Government of Trinidad restricted the sale of forest land "to preserve the natural vegetation" (Richardson, 1975). Elsewhere, islands were relatively untouched until the mid-eighteenth century, Dominica being left as a "neutral" island in the hands of the indigenous Caribs. Soil deficiencies of calcium and magnesium made this island unattractive even when the sugar business was thriving elsewhere (Welch, 1968).Beet sugar was introduced to the United States from Europe by 1838, following the establishment of the industry in both France and Germany around 1812. American production was quite small until the end of the nineteenth century (Loeffler, 1963), but it is now important in the middle west, Great Plains, and Pacific Coast areas.

Grain crops, however, represent the most significant introduction from the old world leading to a vast transformation of prairie and pampa landscapes. The pace of transformation following railway construction was rapid; wheat output in the United States grew from 7.28 to 23.8 million m^3 from 1860 to 1900 (Nevins and Commager, 1945), while in the 54 years from 1875 to 1929, the Argentine area of grain and forage crops grew from 34 000 ha to 25 million ha (Ferrer, 1967). New crops suitable for the Great Plains had to be sought outside western Europe, such as Kubanka wheat from the Turgai steppes west of the Ural River and Kharkov wheat from the Ukraine (Nevins and Commager, 1945). Land came under the plow, lying bare for part of the year and exposed to all the deleterious effects of monoculture.

The unintended introductions of weeds also had serious consequences. By the 1920s, only a quarter of the plants growing in the pampas were natives, while 60 % of the more important farmland weeds in Canada and 35 % of those in the United States were said to be of European origin by about 1950 (Crosby, 1986). Although many weeds were simply a nuisance, others served a useful purpose, colonizing bare land and protecting it from water and wind erosion, often also providing feed for cattle. Following the flooding and drought in California in the early 1860s, introduced plants quickly responded to the first rains, recreating the grasslands and saving large areas from severe soil loss.

Introductions of New Technologies

Although irrigation and drainage existed on both sides of the Atlantic previous to the Columbian encounter, the major transatlantic difference was the lack of a plow, cattle, and horses in the Americas. The expansion of North American cropland by 258 % from 50 million to 179 million ha in the period 1850-1920 (Table 5) and that of Argentina and

Uruguay by 800 % from 0.4 to 32 million ha in the period 1870-1970 (Grigg, 1974a), were made possible by industrial innovations of which John Deere's steel plow and the McCormick reaper of the 1830s were crucial, and the production of cheap wire for fencing by the 1860s extremely helpful (Simmons, 1989). Although existing technology moved westward, the need to find some local, American, solution to physical and market conditions brought innovations which later improved European agriculture.

The expansion into the Great Plains forced farmers to adapt to new environments:

"The adaptation came, in time. Railroads provided transportation; barbed wire was made available for fencing; deep-drilled wells and windmills supplied water; dry farming and irrigation solved, in part, the problem of farming where rainfall was inadequate for the kind of cultivation to which the farmers had been accustomed". (Nevins and Commager, 1945)

In Argentina, too, agriculture depended on windmills, and on Australian water tanks (Ferrer, 1967). In the twentieth century the use of tractors (Table 7) became a powerful instrument of land transformation as fields had to be enlarged to permit laborsaving equipment to be operated. Mechanization gave economies of scale and saved labor. In Europe the pressure grew for fragmented land holdings to be amalgamated to achieve areas of land large enough for economic operation of the new machines. In England, hedgerows were uprooted in some areas to create a few large fields from many small ones. In this way farming technologies that had proved so advantageous on the broad plains of the Americas had an impact on the very different landscape of western Europe (Peel, 1978).

Major industrial innovations moved from Europe to America in the eighteenth century. The first Newcomen engine was exported to the United States as early as 1755 (Briggs, 1979). The upsurge in iron-making in places like Pittsburgh, a fourteenfold increase in the twelve years before 1815, and the advent of the steamship which revolutionized traffic on the Mississippi were the forerunners of the industrial growth in North America. Railway technology took hold at least as quickly in the Americas as in Europe (Figure 7), United States track length growing from 4830 km in 1840 to 48 300 km by 1860 (Nye and Morpurgo, 1965). In North America railways were the key to the settlement of the Great Plains, while in South America they fed a European-oriented trade. Both the Canadian Pacific Railway and the Northern Pacific Railroad were instrumental in opening up new land, the latter flooding the European markets with advertisements about the land along its route. Investment in railway technology served the needs of the merchant-capitalists, who were frantically plundering natural resources and agricultural products of the hinterland for the rapidly expanding new core areas of the northeast of the United States and the Toronto-Montreal area of Canada (Eliot-Hurst, 1976).

American technology, however, fed back into European development. In Britain, the prodigious expansion of cotton manufacturing,"the most extraordinary phenomenon in the history of industry" (Harris, 1973), caused imports of raw cotton to quadruple from 1790 to 1810 (Prince, 1973). The British industry, in 1851 equal in size to that of all the other European countries combined (Table 2) (Briggs, 1979), gained from the Whitney cotton gin (modified and improved with saw teeth) which facilitated cotton cultivation in the American Piedmont (Prunty and Aiken, 1972).

Table 7. Growth in the use of tractors in France, Germany, the United Kingdom and the United States of America.

Date	Number of tractors (thousands)			
	UK	France	W.Germany	USA
1910				1
1920				246
1930				920
1940	50	36	30,3	1545
1950	325	144	139	
1955	435,9	330	441	
1957	450	535	600	
1980	512	1484	1467	4768
1988	518	1518	1460	4760

Sources: Dewhurst *et al.*, 1961; Barger and Landsberg, 1942; FAO, 1989.

Drainage and Land Reclamation

Both Dutch techniques of land reclamation to reclaim swamps and wetlands from seas and lakes, and the Scots' technique of tile drainage of wet rain-watered land have been major agents in transforming parts of the Americas (although Amerindian use of wetlands was extensive; Turner and Butzer, 1992). Land drainage in the United States began in 1835 with handmade tiles, and the first tile drainage machine was imported from England in 1848 (Ayres and Scoates, 1939). Both the drainage of wetlands, particularly around the growing industrial centers linked to transatlantic trade, such as Lancashire, which had little mossland left by 1880 (Coppock, 1973), and the reclamation and enclosure of uplands, such as the Rossendale moors of Lancashire (Harris, 1973), progressed rapidly in the nineteenth century.

Irrigation

At the end of the seventeenth century, the world's irrigated areas were largely in Asia, with only scattered parts of southern Europe and North and South America having significant irrigated areas as a percentage of the global total (Table 8). But by the twentieth century, surface and groundwater resources were extensively exploited, the High Plains (Ogallala) aquifer, for example, supplying 20 % (5 million ha) of the irrigated land in the United States. Although initially pumped by windmills, energy became cheap enough for turbine pumps in the 1940s. Late United States center-pivot irrigation systems allowed hitherto unsuitable areas to be used, the technology being transferred to many other countries.

Impact on Soil Stability and Erosion

Mining not only led to the major vegetation changes described earlier but also had significant impacts on erosion and the sediment yields of rivers. Gold placer deposit workings may cause river sediment loads to increase to twelve times natural levels (Guyot and Herail, 1989). Most new crops involved forest clearance, such as the wave of land-cover change and associated erosion which spread over the American Piedmont Region from 1700 to 1830. Erosion was most severe in areas where clean-weeded cash crops were grown and slaves managed the land, reaching a peak before 1850. Soil loss from cotton plantations peaked around 1870, while all the southern Piedmont had high erosion from 1860 to 1920, with sediment filling many streams and covering floodplains

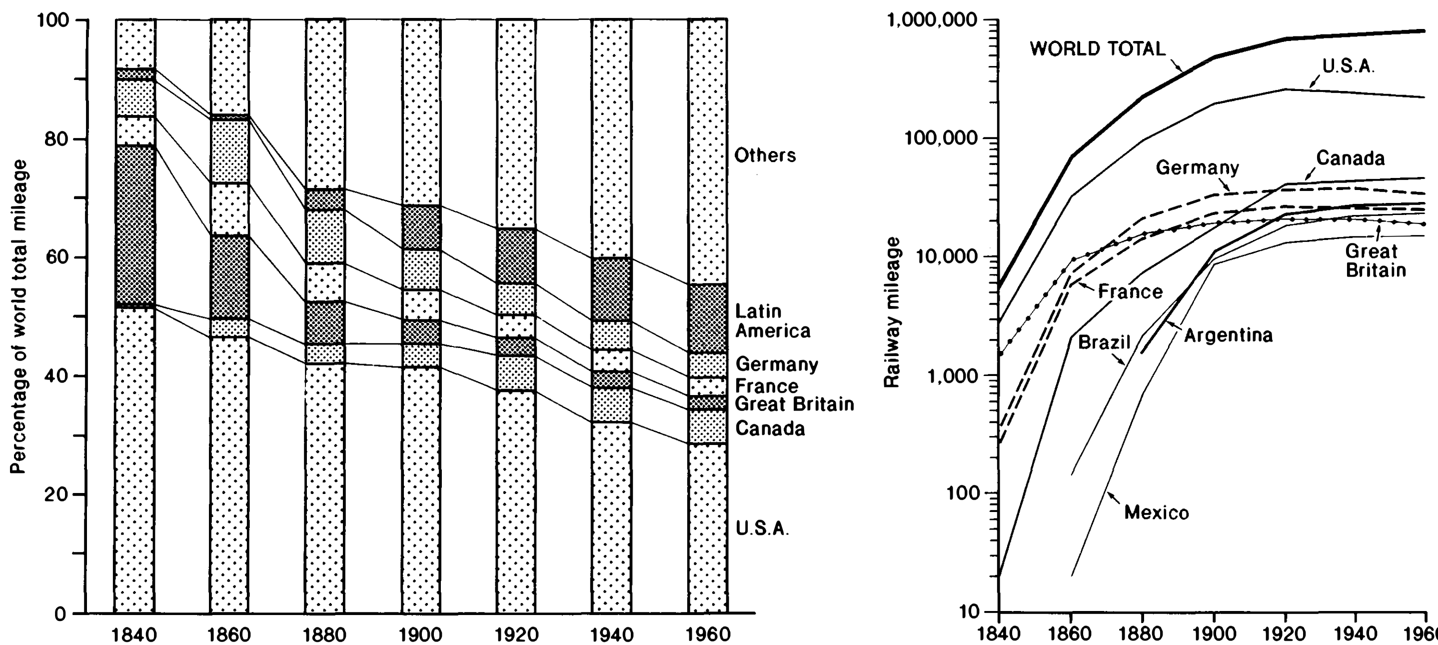

Figure 7. Expansion of railways, 1840-1960, showing the changing proportion of world mileage in various countries (after Woodruff, 1966).

Table 8. Estimated annual water withdrawal, consumptive use, and return flow for irrigation (after L'vovich and White, 1990).

Area	1680	1800	1900	1950	1985
			$Km^3 y^{-1}$		
Europe					
Return water	0	1.0	3.0	5.0	25.0
Consumptive use	2.0	4.0	17.0	40.0	160.0
Total withdrawal	2.0	5.0	20.0	45.0	185.0
North America					
Return water	0	1.0	5.0	10.0	38.0
Consumptive use	1.0	3.0	35.0	85.0	262.0
Total withdrawal	1.0	4.0	40.0	95.0	300.0
South America					
Return water	0	0	3.0	2.0	10.0
Consumptive use	1.0	2.0	7.0	18.0	55.0
Total withdrawal	1.0	2.0	10.0	20.0	65.0

(Trimble, 1974). Erosive land use declined during the twentieth century as some land reverted to pasture and forest, and soil conservation practices, such as crop rotation, cover-crop planting, contour plowing, terracing, and conservation planting of close row crops were adopted after 1930.

Coffee cultivation in Brazil caused similar erosion, initially around Rio de Janeiro, by 1850 around the Paraiba River, and then around 1880 in Campinas and Ribeirao Preto (Haggett, 1961). Sediment built up on valley floors during the nineteenth century and is now being washed back into the rivers during storms and may possibly produce problems for water supply and hydropower reservoir projects further down valley. The late twentieth century land clearance in the Brazilian Amazon produces similar erosion but is driven more by the internal dynamics of Brazil than by the European market.

The replacement of prairie and forest in southwestern Wisconsin with cropland and grazing (Figure 8) led to a four- to fivefold increase in runoff during a period of poor

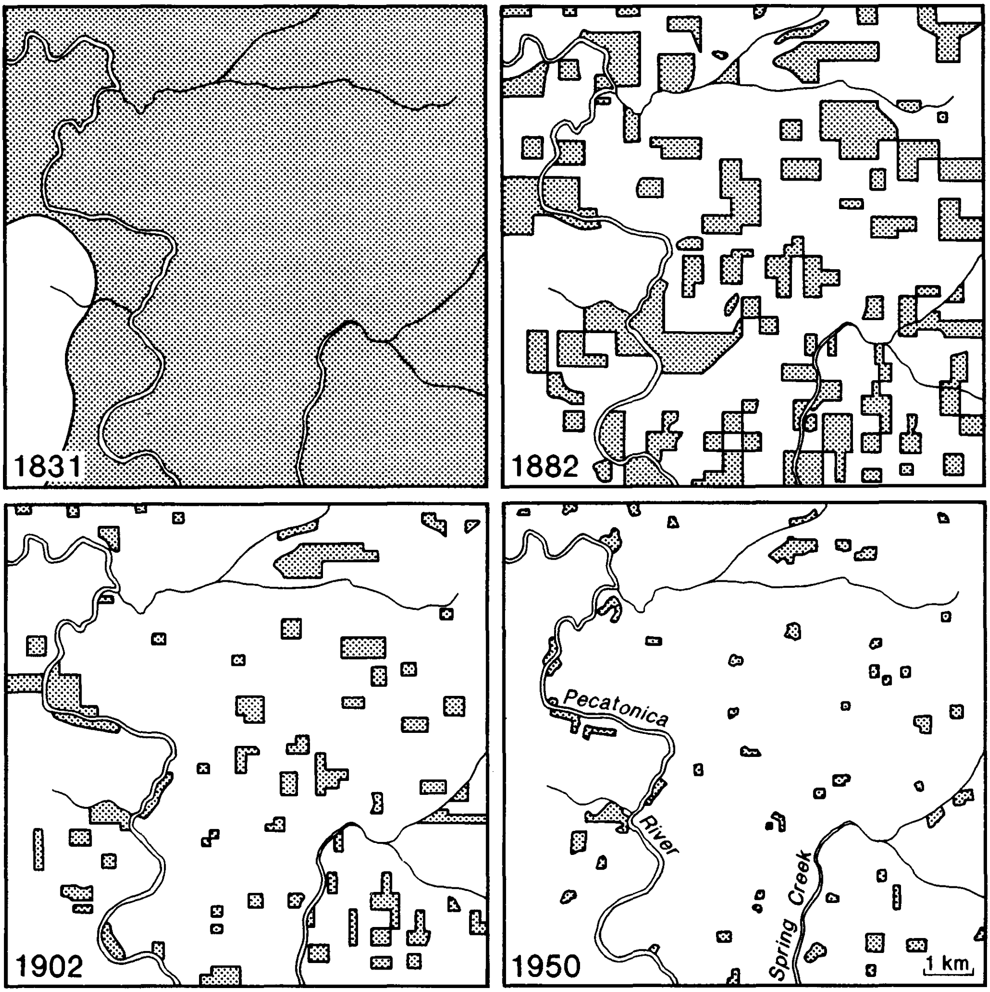

Figure 8. Clearance of forest in Cadiz Township, Green County, Wisconsin during European settlement; the township has an approximate area of 10 km x 10 km (after Curtis, 1956).

land practices from about 1870 to 1945 (Knox, 1989). The intensity of erosion was higher in the period 1900 to 1930 than in the previous decades (Trimble, 1983). Since then, soil conservation measures have reduced erosion rates (Trimble and Lund, 1982). The successful adjustment of many parts of the humid and semihumid areas of the United States to the erosion and associated modifications of drainage density and runoff regimes does not appear to be so closely paralleled further south in the Americas, where many landscapes still show old ravines and badlands topography associated with export-demand oriented exploitative plantation agriculture.

Soil structure in many areas has been affected by cultivation, especially through the development of a tillage (or plow) pan in the subsoil. Such impervious, compacted layers disrupt root growth, impede water percolation, and reduce the effectiveness of fertilizers. About 50 % of the American Great Plains may be affected by this condition.

From the sixteenth to the nineteenth century, Europe saw a great increase in the use of mountain pastures and an increase in population density. The middle pastures on fragile slope deposits (screes, valley-side moraines, and glacial terraces) suffered the most disturbance, severe erosion occurring in some Alpine and Pyrenean valleys in the nineteenth century (Metailie, 1987). In the high Cevennes in the southeast of the Massif Central of France, sheep numbers increased tenfold leading to severe overgrazing and gully erosion (Muxart et al., 1990). Numbers of sheep in the Commune de Dourbies grew from 640 in 1774 to 6600 in 1874. This mountain overexploitation represented the continuing effort of Europe to feed itself during the industrial revolution. The need arose from the great expansion of population which was in turn partly dependent on the accumulation of wealth resulting from the Columbian encounter.

Conclusions and Comments

The environmental impact of the Columbian encounter on the Americas was profound, pervasive, and persistent well after 1700. The impact on Europe was less evident, more ephemeral, and more spatially episodic. The countries of the western seaboard of Europe (Spain, Portugal, Britain, and France) gained the most from this encounter, mainly through accumulation of wealth through exploitative relationships, but also through the expansion of their cultures into the Americas. The facades of Lisbon and Liverpool speak volumes for the past triumphs of overseas trade, while the Europeanization of most of the Americas, albeit integrated strongly in places with Amerindian and African legacies, testifies to the impacts of European migration.

Importantly, the industrial capitalist society that followed from the encounter, coupled with large population growth, expanded and exacerbated the land-cover changes begun earlier. Both the scale and pace of these changes have been profound and led to human-induced land degradation of a kind that has been unparalleled in history. Interestingly, however, some land covers have been improved and forests and grasslands regrown (Foster, this volume), particularly in the more affluent areas of the North whose resource needs can be met by imports from elsewhere.

Perhaps a key to understanding the impact of the Columbian encounter on the environment is this: that while the initial emphasis was on major land-use and land-cover change, it led, ultimately, to escalating land degradation, although highly variable by area. In some cases, it promoted afforestation.

The speculative questions of what would have happened in terms of an industrial revolution in Europe if there had not been the transatlantic connection, or what would have happened to the exploitation of the Americas if there had been no contact with Europe, remain. The Mediterranean might have remained the center of European trade and culture and the industrial revolution may have been later and more continental in flavor. The Americas may have seen a flowering of the indigenous culture and technologies before Polynesian voyagers guided Chinese traders to the Pacific shores. Would the two continents have moved to their present European Community and Pacific Rim outlooks more rapidly without the Columbian encounter?

It is hard to say, for example, whether the Lancashire cotton industry would have developed the way it did without American cotton found in the Columbian encounter. The triangular trade from Britain to west Africa to America and back to Britain set up an enormous interdependence between the cotton mills of Lancashire and their American suppliers, reaching a peak in the mid-nineteenth century. The cotton industry not only created a vast new urban complex whose emissions and waste contaminated the surrounding air and rivers, but also led to the transformation of the surrounding countryside, with drainage of wetlands and reclamation of moorland. The huge urban population then began to exert demands on the countryside for recreational use. The ensuing social upheaval eventually led the affluent aristocratic owners of grouse moors to recognize the right of public access to open countryside, and to the creation of National Parks, an idea developed initially in the United States. Surely, a different circumstance for the encounter would have led to a different set of stories of change, but the ultimate differences for global-scale land-cover impacts cannot be known.

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CHAPTER 4

GLOBALIZATION, SPATIAL SCALES, AND DECISION MAKING: IMPLICATIONS FOR LAND USE

Pablo Bifani

Introducción

The origin of the present international trade and economic system can be traced to the structure of international economic relations opened in 1492 and further shaped by the advent and expansion of industrialization. The driving forces of the post-Columbus economic expansion were mercantilism and industrialization. The former was propelled by geographical expansion, by the discovery, conquest, and colonization of new areas; technological progress was the engine of the latter. The mercantilist epoch lasted from about 1500 to the middle of the eighteenth century, while the era of industrialization had begun by the end of the eighteenth century.

Crucial to this evolution were access to and control of: i) natural and environmental resources; ii) the sources of surplus and accumulation and of financial resources; iii) markets; iv) technology; and, v) cheap labor. The emergence of dominant economic doctrines was also important. Behind the changing structure of economic international relations governments, institutions, and economic agents defined and implemented policies and adopted decisions concerning the allocation of resources, the choice of technology, and the distribution of the output and of the revenues generated by economic activities.

Directly or indirectly these decision-making centers determined how land was used. The increasing complexity of international economic relations has been associated with the changing character and locus of the decision-making centers.

Two set of dynamic factors are relevant. The first concerns the consequences of the changing international economic structure for the functioning of national economic systems and the consequent use of natural ecosystems. The second set involves the international economy, more specifically the behavior, planning, and coordination capabilities of the decision-making agents together with their economic and political power and legitimacy. These factors determine how and where resources are used and for what purposes.

Basic considerations about decision making

The interactions of land uses at various spatial and temporal scales occur through decision making. Changes in land use are the result of decisions adopted at given places and times. Decision making refers to mechanisms that attempt to rationalize and optimize system performance in the achievement of pre-defined goals. Often it includes discretionary power to choose between different courses of action. In this process of rationalization and optimization, decision making is in fact a resource allocation mechanism.

Socio-economic actions are purposeful. They are adopted in order to achieve goals, but they also involve the control needed to assure the attainment of the objective. The aim of control is to detect, avoid, or regulate unwanted deviations from the goals in order to optimize the movement towards their attainment.

Controls can have purely spatial or space-time dimensions. A restricted spatial control establishes boundaries. That is, it defines a space inside of which certain rules and actions are applied. A typical economic example is the establishment of tariff barriers to foreign goods and services.

The decision maker in executive regions can implement control in the space-time domain through direct intervention or by granting different degrees of autonomy to the dependent area. Three general levels of such control can be identified: i) direct intervention, which by passes local-level control through administrative action backed by legal, executive, and even military powers; ii) establishment of "control action" at lower levels, meaning the granting administrative authority to dependent areas as long as the outcomes are consistent with those of the decision-making center; and iii) granting autonomy to the dependent areas in administrative and even legal aspects, while the goals and objectives are established by the dominant center.

Decision making differs in its temporal and spatial scope: day-to-day versus long-range, small and large geographical area or population affected. The degree of organization in any system depends upon its scale. At larger scales, the decision process is more complex. Decision making is largely governed by the extent of knowledge about the effects of the decision and the degree of interaction with other decision makers. If the latter is complex, the role of socio-economic and political bargaining is enhanced.

Decision makers are not easily described, for they include persons in a wide variety of situations: elected officials, agency representatives, managers, department heads, field operators, local leaders and so on. At the time of the Columbian encounter the decision maker may have been easier to identify: the King or the governor, for example. Today, however, decisions are adopted by groups of individuals acting as representative of larger groups sharing the same or similar interests. The complexity of decision making systems means, among other things, important a tendency to conceal the real decision maker, giving rise to erroneous perceptions concerning "who" and "where" takes decisions.

Land as a basic resource has been allocated to different uses according to changing objectives defined by dominant decision-making centers. These centers, at every specific historical moment and on the basis of prevailing political and economic doctrines, have defined administrative machineries and legal principles to support their decisions concerning land uses. The dominant decision-making centers have imposed their rationality and have had the capacity to change the economic and natural context in which they act.

The different spatial and temporal dimensions of the scale issue are directly related to the levels at which decisions are adopted. Land use can be decided at a local level like the family or the farm household, or at a higher one: the community or village, the region, the state, the country, or beyond national boundaries in the case of colonial powers, supranational organizations such as the EC, and powerful economic agents like transnational corporations. The higher the level of the decision making, the larger are likely to be the spatial and temporal implications, the larger the distance between the *locus* of decision and the geographical space in which it is implemented, and the broader the geographical area in which it can be implemented.

Whenever the use of land and agricultural practices depends on huge and costly land and water management works that go beyond the technical and economic capabilities of individuals, a higher and centralized level of decision making is indispensable. This is so whether land is privately owned or a common property regime prevails. The Inca agricultural system is a case in point.

The issue of the level of decision making is associated with basic questions: "who decides? where?" At first glance, a neat correlation seems to exist between spatial scale and decision making. Second thoughts reveal that although at a local and low level of decision making there exists some such correspondence, it is much more difficult to establish at higher levels and in larger spaces. Inside the farm space, the family or the farmer makes decisions, but at a regional scale, and within the national geographical space, the identification of the decision maker is harder. Additional difficulties arise in those cases in which the results of a given decision materialize in the long term. The problem becomes more complex if to the questions of "who" and "where" is added a third one: “how?”

Although decisions are adopted by individuals or groups of individuals, they are moreover, made within, and indeed conditioned by, a network of social, economic, technological, institutional, and political relations. So decisions concerning land use even at the local level are affected by the characteristics of land tenure, by the spatial consequences of national policies concerning taxes and incentives, regional development, sectoral priorities, infrastructure investments, and agricultural inputs and outputs, by local or national programs, and so. This network is not restricted to national boundaries. The international environment exerts an important and increasing influence through for example the functioning of markets for commodities, the structure of commercial routes, international agreements concerning standards, prices, and stocks, and through the supply of agricultural inputs.

So the decisions adopted by the direct user of the land --the peasant, the farmer, or the manager at the site of production-- should be dishnguished from those factors that determine the range of options available to the direct user. In other words, the range of options offered to the direct land user is narrowed by a set of social, economic, technological, institutional, and political parameters. These "external" parameters are the result of decisions adopted by others in different places and frequently in different epochs. These "external" parameters have played an increasingly large role in land use, to the extent that in fact they have become more important than the direct, *in-situ* decision making. This is to contend that land use is mainly decided *exsitu,* steered by forces spatially distant from the site where a concrete intervention materializes.

The changes in land use derived from increasing interdependence have followed various patterns, taking place at distinct dates and at dissimilar speed, depending on the characteristics of prevalent economic and political relations. Although interdependence of countries and regions was already evident in the ancient empires, there is no doubt that the real global interdependence started with the age of discoveries and since then has greatly affected land-use patterns.

A crucial element of the changing spatial scale of land use has been the incorporation of new areas into an agriculture inserted in the world economy, making them vulnerable to international markets, patterns of demand, and price fluctuations and dependent on access to financial resources and technology. A second important element has been the transfer of germplasm from its regions of origin or of domestication to faraway areas. The new imported varieties, or their progeny, become major crops covering large acreage, often making the importing country a world production leader in a particular commodity.

The Columbian Encounter at the end of the fifteenth century and industrialization by the mid-nineteenth mark two turning points in the history of land use.The former made new land available for European agriculture to establish itself overseas, while new species, indigenous to the Americas, begin to be used and disseminated all around the world, at the same time that the New World was receiving varieties from the Old. By the end of the nineteenth century, industrialization started to permeate agricultural activities, paving the road toward the era of modern agriculture, characterized by the increasing use of out-of-farm technological inputs and the intensification of production. In both cases, the prevailing use of land was subverted and decision making concerning land use increasingly separated from the physical space in which decisions are implemented.

Mercantilism and land use in the colonies

The enlargement of economic space initiated by the Columbian encounter was a major impetus for the formation and evolution of mercantilism. The primary objective of this school of thought was to augment the wealth and power of the nation-state. Precious metals, particularly gold and silver, were for the mercantilist the most important form of wealth. Gold and silver represented a means of paying for imports and building up power. Their regular and abundant supply was a pre-condition for national welfare and strength. Following this principle the prime function of international trade was to augment the stock of precious metals by facilitating access to their sources. The first role of the colonies was to provide gold and silver. Only later trade in food, fibers, and raw materials come to be appreciated: "We live not so much from trade in raw materials as from gold and silver" [1].

Mercantilism promoted the integration of the world economy, opening new markets for the expansion of the emergent European manufactures, increasing and capturing

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1. Assertion by Monchrétien, quoted by: Heckscher, A. (1936) Mercantilism, page 187.

the surplus generated in the Americas and promoting the growth of the core economies. It prompted the opening of new trade routes and thereby facilitated and stimulated further trade, as well as the incorporation of new areas into the international economy.

The discovery of the America gave rise to an increased flow of international trade. Industrialization itself was made possible by more than two centuries of trade expansion. Geographical discoveries provided unique opportunities for specialization and improvements in productivity boosting the generation of surplus.

In the course of two centuries, new routes were opened, cartography was improved incorporating the changes brought by the new discoveries, new sea transport and nautical techniques were developed, and shipbuilding was expanded and modernized. The opening of new trade flows and routes required heavy initial seending on research, technological development, infrastructure although and so on. These developments were slow by modern standards. Although the new sea route between Europe and Asia around the Cape of Good Hope was opened by Vasco de Gama in 1498, a century elapsed before its economic exploitation. Once triggered, however, trade expanded very rapidly, prompting the development of ports and entrepots. Innovations in transport systems brought diminishing costs. Maritime freight rates started to decline continuously by the middle of the seventeenth century.

The importance of this traffic was so evident that in order to control the transatlantic trade a trade board, the Casa de Contratación, was set up in Seville in 1503. During the same epoch the Merchant Adventures Company had a monopoly over British trade with its colonies. The growing magnitude of trade led in 1600 to the creation of the East India Company, to which Queen Elizabeth I granted a 15-year monopoly together with customs concessions for trade beyond the Cape of Good Hope. These privileges were renewed and expanded by subsequent royal decrees. From the point of view of decision making, this represents a clear case of space-time form of control of the core economy over the dominions.

The expansion of international trade coincided with the ascent of particular economic agents able to exploit the opportunities created by the enlarged economic space. It was the time not only of such explorers and conquerors as Columbus, Vasco de Gama, Cortés, and Pizarro, but also of the rise of the merchant class. The merchant captured the surplus generated by overseas economic activities, becoming the most important investor, lender, and entrepreneur. Merchants became crucial decision makers in the organization of production and the allocation of resources.

The mercantilist doctrine was highly nationalistic, promoting the regulation and control of economic activities, particularly foreign trade. In order to assure national wealth and power it subordinated individuals to national objectives and regulations. The growing trade between the metropolis and the colonies was undertaken chiefly by state-chartered monopoly trading companies, such as the Casa de Contratación, the Merchant Adventures Company, the British East India Company, the Hudson's Bay Company, and the Vereenidge Oostindische Compagnie (VOC), (Dutch United East India Company), which were the embryonic form of transnational corporations.

Despite an early domination of maritime routes by Spain and Portugal, England and the Netherlands expanded rapidly and particularly at Portugal's expense. Trading companies established control over particular routes and areas: VOC operated in part of Africa and Asia and British companies in India and in Hudson's Bay in North America. A papal decree of 1493 allocated the trade with the Americas to Spain, legitimating and helping to consolidate its position in Central and South America. It was a clear example of space-control mechanisms negotiated between dominant decision makers. To make the control more effective, trade was subjected to strict inspections and innumerable regulations, while merchandise was carried in royal ships. In addition the Spanish Crown confined the colonial trade to "monopoly ports" on either side of the Atlantic: Sevilla and Cádiz in Spain; Veracruz in Nueva España (Mexico) and Portobello in Tierra Firme (Panama). All America-bound vessels sailed only twice a year, as part of large fleets protected by warships. In this way, the decision maker created a system of global space-time controls.

During the first half of the seventeenth century, the main concern of the East India Company and its Dutch and Spanish counterparts was with the shipping trade without any involvement in direct production. Later on, they became directly or indirectly engaged on decision making concerning production, with a fundamental role in the allocation and reallocation of land to different uses.

The increasing trade of raw materials and manufactures fostered specialization and the international division of labor in accordance with classical economic principles. The flow of food and new plant species, from the Americas helped to feed a growing, particularly urban, population, making possible the reallocation of European land resources and their accommodation to the needs of the emerging industries. In turn, the New World absorbed the excess population of the industrializing countries and provided raw materials and markets for the new industries in the metropolis. Of foremost importance was the New World's role as a source of surplus, laying the basis for the following capitalist expansion.

Specialization and division of labor were governed by the demand pattern of the metropolis. New areas were inserted in the world economy according to their capacity to supply the goods demanded by Europe. The productive system of the New World thus evolved not only following the pattern suggested by the economic potential of its endowment of resources, but mainly in response to an increasingly diversified international demand, and in accordance with strategic decisions adopted in the metropolis concerning land use. The economic expansion of the New World has been a reflection of the vigorous demand of advanced countries and their fight for the control of markets and international trade flows.

Land-Use Changes in the New World

Whenever given systems come into contact with others, they act and react upon one another. The more powerful system tends to impose its own form of occupation and use of nature.

The Disruption of the Pre-Columbian Land Use Pattern.

Although by 1500 European agriculture was starting to spread overseas, its major expansion occurred under colonial domination, which modified dramatically preexisting local socioeconomic and environmental relationships. Colonial domination imposed everywhere commercial, political, and institutional structures to serve the interest of the metropolis. The West African Federation: "was created to serve French interests and only indirectly those of separated colonies" (Skurnik, 1967). The same can be said of all colonial systems that organized the local societies and used the natural environment in order to produce, at low cost, the goods required by the metropolis. It was a system of direct intervention involving the overriding of local levels of decision making by an administrative machinery hierarchically linked to the decision-making center in the metropolis.

During the first century of colonization, the main economic objective was to export precious metals, which were in fact the only commodities that got a merchant value in Europe. Whereas Oriental countries produced commodities of high value per unit of weight like spices, muslin, carpets, and silks, in America the conquerors found nothing to support lucrative trade but precious metals. Those found in America were needed to pay for the expensive spices and merchandises coming from the Orient.

Until the middle of the Sixteenth century, Spanish efforts were largely aimed at the discovery of precious metals and the exploitation of alluvial gold. The exploitation of silver in Potosí and Mexico and mercury in Peru began by 1554. The value of the metals exported by private entrepreneurs was estimated at more than four times the value of the imports coming from the metropolis, a good indicator of the importance of the colony as a surplus generator. In this period, land was used mainly for food production to supply the local communities, playing little or no role in the insertion of the Americas into the global economy.

The generation of large surplus was possible not only because of the land's natural potentialities, but in addition because natural resources were not priced and labor was compulsory or cheap. Conventional analysis emphasizes the availability of cheap labor, but it rarely refers to the fact that the natural system was not priced, therefore undervalued and prone to overexploitation favoring the creation of surplus[2].

The pre-Columbian American system did not have a monetary economy. Private property in land and natural resources was nonexistent, and the concept of salary was missing in societies that either were organized as communities or where compulsory work was a common practice, as in the Inca or Aztec empires. This missing economic elements on one side facilitated the appropriation of resources; on the other, they made difficult the transfer of surplus to the metropolis.

At the time of the encounter, land in the Americas was not a salable commodity but common property. For europeans, however, ownership of land was associated with power, although until few decades before the discovery of America it was associated with military power. Although the prime motive of the conquest was the obtain gold and precious metals in accordance with mercantilist doctrine, the importance of land was not ignored. "For three and a half centuries after the discovery of America, appreciation of the strategic role of land gave it an even greater role in history....religion went hand in hand with real property conveyancing, somewhat disguising the role of the latter. Spaniards considered themselves commissioned by God to win the souls of Indians; Puritans believed themselves primarily under the obligation to find a favorable environment for their own. for Catholics and Cavaliers the Lord was believed to favor rather large acreages with the opportunity these accorded for the spiritual custody of aborigines" (Galbraith, 1972).

The Crown, considering the land a free good, allocated it as *mercedes de tierras* (land grants), *conucos* (Caribbean smallholdings), *chacras* (orchards), *haciendas* (country estates or large farms, or ranches), *estancias* (cattle ranches), and *caballerías* (parcels of about 42 ha). Only in the seventeenth century, in order to overcome economic problems

2. Probably the few exceptions can be found in the marxian literature particularly in Rosa Luxemburg: Accumulation of Capital, (Chapter XXVII).

faced by the Crown, was land sold at public auction, the final step toward the complete metamorphosis of land as common property into land as merchandise, a commodity, and an object of speculation. The collective system was replaced by private property and the land granted on a hereditary basis. It was the origin of one of the most typical features of Latin American agrarian structure, one of enormous influence on land use: the *latifundio*.

The control and the private ownership of land are of scarce usefulness without labor that can exploit it. This concern was clearly reflected in Queen Isabel is edict of 1503 that established the *encomienda*, that is the allocation of a number of indios to the settler in order to overcome their resistance to work for him. Private property in land was this complemented by measures oriented to the creation of the needed labor force. To reinforce the *encomienda* and to foster a wage-earning system, other compulsory measures were the adaptation and redefinition of indigenous customary measures such as the *mita* (Inca) or *cuatequil* (Aztec) and the *yaconado* · The mita, an Inca coercive measure for the allocation of labor force, was adopted in 1570.

The importance of compulsory labor measures is twofold: first, they provided cheap labor for mining and agriculture, and second, they contributed to the ejection of the local population from the land needed for growing the new imported crops: alfalfa, wheat, grapevines[3]. The effect was the depopulation of the Peruvian-Bolivian highlands and the agglomeration of people in shanty towns on the mining sites [4].

The granting of land by the crown and compulsory labor were the two crucial measures that broke the pre-Columbian environmental-socioeconomic relationship and drastically changed land use. They were decisions based on the discretionary power of the geographically distant highest decision maker and had long-lasting and widespread implications for land use.

Mercantilism, International Trade, and Land Use

By the middle of the seventeenth century, as a consequence of the weakening of Spanish political and economic power and of changes in the world economy, trade between Spain and America declined and the Spanish monopoly was broken by the entry

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3. It is interesting to note that the colonization of Africa also adopted labour compulsory measures. This was one of the reason for the enforcement of head or hut tax. See: Giovanni Arrighi: Sviluppo Economico e Sovrastrutture in Africa. Einaudi Milano 1969.

4. The mita was fundamental for the exploitation of silver in Potosi and a main factor of the decimation of the indigenous population. When the mita was established the indigenous population of the 16 provinces of the highlands was estimated at about 81,000 people, after 100 years it was scarcely 10,000 (Bifani op. cit.).

into the trade of French and British interests legitimated by the treaty of Utrecht. England, during the reign of Elizabeth and later on under Cromwell, and France, under Colbert, expanded their maritime power and simultaneously incorporated the colonies into their economic system, promoted industry, and regulated every aspect of economic activity internally and externally. Spain failed to apply mercantilist principles in their external and internal complementarity. Internally it faced increasing land erosion as a consequence of sheep overgrazing, while the merchants and artisans (Jews and Moors) were expelled from the country and its manufacturing activity was clearly behind that of other European countries.

To counter these trends, the Crown initiated a process of economic liberalization. Private trading companies were created in order to assure the Spanish presence in the transoceanic trade and the regular supply of overseas commodities: the Compañía Guipuzcoana had the monopoly of the trade of cocoa from Venezuela to Spain, and the Compañía La Habana was granted a monopoly of the tobacco trade. The liberalization of 1765 lifted the ban on trade between the colonies and allowed the **criollos** to enter into trade activities. It also abolished the port monopolies of Seville and Cádiz in Spain and Veracruz and Portobello in the Americas. Control based upon direct intervention and the overriding of low-level of decision makers began to give way to a more lenient type of control that allowed some decision- making power to local administrative, although retaining the responsibility for the definition of global goals and the overall control of the process.

As the links with the metropolis grew looser, power passed to the landowners. In this context the institutional mechanisms created by the colony, like the encomienda, or those adopted from the Incas and Aztecs such as the mita and the cuatequil, lost relevance while the land tenure system created through the mercedes de tierras and the comunidades indígenas become important. The former originated the latifundio and the latter the minifundio, the two most noticeable characteristic of the Latin American agrarian structure.

The properly mercantile productive system was formed by commercial haciendas cultivating imported crops such as rice, wheat, sugar cane, coffee, and bananas or local species, like potatoes, for which market was opening in Europe. The production centers were located near the coast, facilitating the shipment of the output to the metropolis, or in the mining sites.

Trade in New Species and Land Use

One of the most important phenomena fostered by the Columbian encounter was the explosion in the international transfer of germplasm. The economic implications of this large transfer of native crops between the New and the Old world, or Columbian Exchange (Crosby, 1972), have scarcely been analyzed. Although interest in plant diversity can be traced back to ancient times, with the discovery of America it acquired enormous implications. Columbus brought maize back from America and on his second trip carried to the New World chick-pea, sugarcane, citrus fruits, grape vines, olives, melons, onions, and radishes, with which the colonization of the American ecosystems started.

This colonization gained momentum in the late seventeenth and early eighteenth centuries. Sugar arrived in Brazil and Barbados in 1640. Rice spread in Latin America, particularly Brazil, after 1650. Coffee plantations started in Brazil only after 1727 when coffee trees were introduced from the French Guiana, ending a long journey that had taken them from Ethiopia to Ceylon (Sri Lanka), Java, the Amsterdam Botanic Garden, and Suriname.

The particular importance of the Columbian Exchange was not so much in the discovery of new plants nor even in their spread. As a matter of fact, crops had been diffusing outward from their centers of origin for thousands of years. In 2000 B.C. The Sumerians and Egyptians were sending expeditions to collect exotic plants such as figs, roses, and incense trees. What was new was the economic exploitation of biodiversity. This led first to the definition of particular uses of land and second to the building up of strong government support, including naval forces, not only to protect the cargoes but also to impose specific crops and land-use patterns.

In 1708 the United East India Company (formerly East India Company) used British military force to adapt the cotton and silk production to the requirements of British industry. Its competitor in the Indian Ocean, the Dutch governmental sponsored Vereenidge Oostindische Compagnie (VOC, or Dutch United East India Company), was empowered to make treaties, acquire land, build forts, and even institute slavery in the Moluccas and Java to compel the shift from traditional food crop production to crop plantations for export. The VOC eventually cut down 75% of the clove and nutmeg stands in the Moluccas and concentrated spice production on three strongly protected islands, regulating production, establishing monopolistic high prices, and impeding foreign access to the island. The administrative machinery for the implementation and control of decisions was backed by legal and military power.

During the seventeenth century, the trade of indigo from India was under the control of the British East India Company and the Dutch VOC, but by the eighteenth century the French government introduced indigo in the French Antilles. They the technology for the processing it secret and exported the dye cakes. To defend its monopoly, France established an embargo over the trade, and those who dared to steal indigo plants from Antigua were sentenced to the guillotine. Nevertheless the governor of nearby British Antigua managed to smuggle seeds to London, while after three years South Carolina, in the US, began to export indigo cakes. The British Parliament voted a bounty to prompted the production and export of indigo in the British colonies, breaking the French monopoly. This struggle for the control of a very valuable commodity involved a series of decisions concerning land use and the design of mechanisms to control the use of land, the crop, and the output in the colonies, on route to market, and in the market itself.

The transfer of germplasm permitted the colonial power to develop plantations in those geographical areas that were the most convenient for their economic and political interests. The objective were to minimize risks and instabilities, reduce costs, and augment the surplus. Cotton originally from Mexico and Peru initiated cotton plantations in Africa, Asia, South America, and the Caribbean. Sugar cane from Southeast Asia is at the origin of plantations in Africa, the Caribbean, and Latin America. Coffee, originating in Ethiopia, was grown with plantations in the Caribbean, Central America, Africa, and Asia; the banana, from Southeast Asia, on plantations in Africa, South America, and the "Banana Republics" in the Caribbean. Seeds of Brazilian rubber smuggled by the botanists of the Kew Gardens in England were used to establish disease-free rubber plantations in Malaysia and Liberia and are at the origin of such transnational corporations as Dunlop and Firestone. The smuggling from Peru and Bolivia of cinchona by the botanists of the Dutch Buitenzorg Garden and the British Kew Gardens initiated the plantations of cinchona in India and Ceylon, which were the basis of the British and Dutch quinine industry. Cocoa was transferred from its original Latin America to initiate plantations in Africa, while the German plantations of sisal in its Tanganika colony (Tanzania) contributed the collapse of the original mexican production.

Free appropriation of germplasm and its transfer by colonial powers to different regions has two, scarcely examined, implications. First, it helped increase the flow of surplus to the metropolis, along with the export of food, species, precious metals, and raw materials; second, it was accompanied by modifications of land use. Today more than half of the Latin American area planted with industrial crops is with a foreign species brought in the second Columbus trip: sugar cane.

International transfer of germplasm is a unique type of trade. First of all, germplasm has been a free good. There are no property right systems for it [5], which moreover would be very difficult to enforce. Therefore anybody with the knowledge and technology to use germplasm can do it without payment. It was (and still is) not priced. Germplasm can be moved internationally at virtually no cost. The free and priceless mobility of germplasm - associated with the control of technology - creates dynamic comparative advantages stronger and more important that the static advantages associated with fixed resource endowments. The economic relevance of crops was such that governments at the same time implemented policies to gain access to them while making efforts to keep control over those existing on their territories or that they had already appropriated and to block the access of others to them. Given the state of knowledge about biodiversity, the only way to keep control of a crop was to appropriate or to establish full control over the entire species. But this is an almost impossible task. Species are spread over large areas: how to establish control over the complete territory covered by a species?, how to know the boundaries of the area?, how to prevent species from crossing the boundaries? Moreover smugglers do not need to carry the plant with them, only the seeds or the propagation material. The problem is even more difficult when, as is frequently the case, the output (the fruit) is identical to the means of production (the seed) and the former cannot be traded without the latter.

Most countries passed laws to combat smugglers, but at the same time supported their own nationals in smuggling activities. So while anti-smuggler laws have been difficult to enforce, officially sanctioned smuggling has been a common practice everywhere. Measures like the French embargo on indigo, the law enacted by the Spanish Council of Indies in 1556 preventing foreigners from exploring for plants in the Spanish colonies, and those that conferred ownership rights over all newly discovered varieties on the King were of limited efficacy and of very short life.

Other policies were oriented to the collection and incorporation in national natural systems of crops original to other regions. The important role of the Kew Gardens in Great Britain in the transfer, control, and dissemination of botanical material was imitated by others, such as the Dutch. By the end of the seventeenth century, the colonial powers, particularly Great Britain, the Netherlands, and France, established gardens along the commercial routes to Asia and the New World to facilitate the flow of plants, seeds, and seed material. It is said that Thomas Jefferson smuggled rice sewn into the linings of his coat out of Italy in order to introduce to South Carolina and that he used to say that "the

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5. There are nowadays property right for modified varieties of plants such as the: the Plant Breeders'Rights and the UPOV system for sexually reproducing plants and the traditional utility patent systems, which has been extended/adapted to this specific purpose by some countries.

greatest service which can be rendered to any country is to add a useful plant to its culture".

By 1819 the US Treasury Department requested American consulates to send seeds to the US. Ships of the U.S. Navy used to return from Japan and Asia with large varieties of plants and seeds such as roses, barley, and fruits. By 1842 a greenhouse in Washington was receiving the imported plants.

To sum up, the appropriation, control, adaptation, and transfer of plant varieties has been, an important strategy for modifying ecosystems and for exploiting them according to the interests of the metropolis.

Spatial Structure and Organization.

Every spatial structure results from the dynamic interaction of a socioeconomic organization with its physical surroundings. The city is a particular form of space occupation. In the traditional agricultural civilizations, like those of pre-Columbian America, it was the residence of the people who did not participate in the productive process: the aristocracy, the priests, the military, and the bureaucracy, who appropriated the surplus generated in the hinterland. Cities depend upon their ability to usufruct the surplus generated in rural areas, for which they were the centers of decision making.

The urban-rural pattern of the new areas was shaped by the form of their insertion into the global system. Colonial cities had two basic functions, administrative and commercial. The first was oriented to strengthening political control, the second to channeling raw materials, first precious metals, then food and the generated surplus, toward the metropolis. It was a distinctive pattern of urbanization. In Europe industrialization was the main dynamic factor behind the expansion of cities. Latin American colonial cities, having the particular role of linking the dominions with the metropolis, were concentrated in the coastal areas. They were the equivalent of the gateway cities created by the British Empire on the route towards Asia[6]. The colonization of the New World by Spaniards shows very clearly this preference for the coast. Although in Mexico the crown took over the already developed Aztec urban area in the valley of Mexico, it also set up the new settlement of Veracruz on the Atlantic coast. The conquerors of the Inca empire instead of occuping Cuzco created new settlements on the coast. As Mariátegui observed, the colonists feared and distrusted the Andes, of

6. Samir Amin summarizes the case of Africa; "L'Africa, la cui geograffa, come la storia, imponevano uno sviluppo continentale, organizato attorno grandi assi fluviali, sará condannata ard esser valorizata solo nella sua sottile zona costiera...".

which they never really felt themselves masters[7]. It was their desine for precious metals, gold and silver, that pushed them to the mountains where the mines are. Otherwise, the colonization of the sierra would have been even more fragmentary[8].

Thus one of the most remarkable spatial characteristics of Latin American colonial areas, still noticeable nowadays, is the abandonment of the interior geographical space and a urban hierarchical structure with a communication network converging from different and disconnected production points of the hinterland towards a single or few coastal points. The coastal settlement pattern was particularly evident in Latin Americal well into the twentieth century, by the late 1950s, nearly 87% of the Latin American population was concentrated in the coastal area. In Argentina all communications ran through Buenos Aires. The political strategy was to divide the interior of the country, while the economic rationale was to facilitate the transit of products to be exported. It was the physical-spatial dimension of the decision- making machinery in the dominions that induced a particular use of land.

The Impact on the Old World

At the time of the encounter, European agriculture was becoming more and more integrated with the market. The destruction of feudalism and the rise of towns and cities were making agricultural products, particularly food, articles of commerce. The situation, however, was not uniform across Europe.

In England the encounter coincided with a growing trade of wool with the continent, particularly with the Netherlands and Italy. It was the epoch of the Tudor monarchy, which imposed internal peace and created a situation in which land "began to be seen as a source of wealth rather than of the command of tenantry to arm and lead to battle. Sheep were more valuable than men" (Robinson, 1970). During the sixteenth century, the lords of manors, propelled by the prospects of profits, were enclosing the land over which the population had had common rights. Peasants were deprived of their rights to cultivate in open fields, to use the common pasture for their cattle, and to gather wood fuel. Customary rule was replaced by private property and the feudal lord by the landlord,

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7. "Me he referido a la inclinación de los españoles a instalarse en la tierra baja. Y a la mezcla de respeto y de desconfianza que les inspiraron siempre los Andes, de los cuales no llegaron jamás a sentirse realmente señores". Mariátegui (1976).

8. "Sin la codicia de los metales encerrados en las entrañas de los Andes, la conquista de la sierra hubiese sido mucho más incompleta." Mariátegui (Op. cit. pag 13).

more similar to a merchant for whom land was a resource from which profit can be obtained.

Land enclosure facilitated, during the eighteenth century, the introduction of intensive labor techniques based on crop rotation, stall feeding of cattle, the elimination of triennial fallow, and the use of nearly all cultivable land every year. Agricultural productivity was rising. On the continent, however, the increasing commercialization of agriculture seems to have had less impact on productivity. In France, "except for the introduction of maize during the sixteenth century as a forage crop for animals, which increased greatly the amount of wheat that could be marketed, there were no important technical innovations. Agriculture continued to be carried on in fundamentally the same technical and social framework as had existed during the Middle Ages.." (Barrington Moore, quoted by Robinson op. cit).

One of the most important impacts in land use in the Old World resulting from the Columbian encounter involved to the adoption of new crops. Although the domestication of plant and animal species is an old practice, it gained momentum after the encounter. Species indigenous to the New World gave rise to radical changes of the agricultural and land-use patterns of the Old, though they did not become evident until the eighteenth and even nineteenth century.

Maize, originally from Latin America, was first noticed in China after 1550 but only spread in southern Europe in the eighteenth century. It became together with cassava, also originally from Latin America, an African basic crop during the nineteenth century. Other crops from the New World that spread and became part of the European diet were tomatoes, beans, sunflower, and squash. Potatoes started to spread in Europe during the second half of the eighteenth century and became a major food crop during the nineteenth associated with the increasing use of fodder crops, particularly turnip, alfalfa, and clover. This crop combination during the eighteenth century fostered the integration of livestock and arable husbandry, favoring the fertilization of soils and so contributing to increased food production.

The integration of livestock with arable husbandry modified land use, for it incorporated arable cultivation of legumes for fodder in rotation with traditional crops, allowing the reduction of bare fallow periods, increasing the availability of land for agriculture and making possible the enlargement of herds. Increasing use of nitrogen-fixing food and hay crops such as beans, peas, clover and alfalfa together with larger livestock population, hence larger production of manure, had positive effects on land productivity and conservation.

New cultivars also allowed a higher productivity per unit of surface at lower cost than traditional european cultivars. The species and varieties imported from Latin America, having a higher protein content than the European varieties, were more efficient in terms of calories produced per hectare. They thus helped to feed a population in rapid expansion, which indeed doubled between 1750 and 1850. Some authors even affirm that German industrialization would have not been possible without potatoes, whose relevance in the diet of European countries is well known: the share of bread and potatoes in the French intake of calories was estimated at 70% in 1880 (Toutain, 1971).

Another effect relates to economic accumulation. In the analysis of world capitalist expansion, only few authors mention the free appropriation of germplasm. The new species contributed to keep salaries low, for higher productivity means less labor to produce a similar volume of protein. This together with rapid population growth, depressed salaries and contributed to expel workers from the countryside. At the same time it contributed kept low the prices of popular foodstuffs. Cheap food such as maize and potatoes helped to keep wages close to the subsistence level, favoring therefore the generation of economic surplus and the process of accumulation.

Although the impacts on the European diet and on food production, are probably the best known, the importance of the new species went beyond changes in food habits, for the imported varieties were concomitant with the development of the textile, the dye, and even the chemical industry. Among industrial crops originally from the New World are cotton and cottonseed, tobacco, rubber, and cocoa.

The incorporation of alien varieties from the New World developed rapidly in Europe, reaching important percentages of the total acreage and drastic ally modifying the use of land. Nowadays more than 46% of the food crop production of the European Mediterranean area is of species originally from Latin America, a percentage that rises to almost 52% for the north european and Euro-Siberian region. The percentages for industrial crops are 32% and 17% respectively. Crops originally from Latin America and West Central Asia represent together more than 85% of the total food crop production of the European Mediterranean area and 87% of the north European and Euro-Siberian region.

Because of the transfer of germplasm and its adaptation in other regions, there exists today no coincidence between the centers of origin of diversity and the dominant production centers. The capacity of developed countries to incorporate alien species or varieties into their ecosystems and, through technological innovations, to reach high levels of productivity was crucial in making them the production leaders of today. It has been reported that the larger producer of agricultural commodities in the world, the U.S.A, is 100% and 84.7% dependent on alien germplasm. European figures are similar: 90% and 80% (Kloppenburg, 1988).

Industrialization, technological innovation, and land use

The basic inventions in spinning between 1769 and 1779 are often considered the beginning of the industrial revolution, but the invention that really triggered this revolution was the advent of steam power between 1769, when James Watt registered his first patent, and 1800, when the displacement of water power by steam was becoming widespread. Coal, iron and machinery replaced wood as material and fuel and water, animals and humans for power. The industrial revolution gave society an enormous control over the quantity and the intensity of energy to be applied to economic activities, allowing transformations -often irreversible- of natural systems at hitherto impossible scales. This crucial revolutionary factor -the control of energy- of the Industrial Revolution, did not really reached agriculture until the second decade of the present century, however, with the large-scale introduction of tractors by Henry Ford[9].

Industrialization also induced changes in agricultural patterns, and therefore in land uses, by affecting the demand for agricultural commodities, by providing inputs that affected the agricultural supply, and by creating structural conditions that modified agricultural activities.

Industrialization, Urbanization, and Agriculture

Though population growth has been a main driving force for increasing agricultural production, with industrialization changing consumption patterns became prominent. Industrialization prompted income increases leading to new, more diversified patterns of consumption and increasing demand for more expensive foodstuffs. Of particular relevance has been the move, particularly in the current century, from vegetable to animal protein, indirectly reorienting the allocation of land to suit the changing characteristics of the dominant pattern of demand. Today livestock products represent between 55% and

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9. Gasoline tractors were in fact first produced in 1892, but market penetration was relatively slow.

85% of the value of the total farm output of developed countries.

A similar phenomenon occurred with the demand for raw materials and fiber. Textile manufacture was the first dynamic sector of the industrial revolution. It created a growing demand for cotton and wool, which was satisfied by the expansion of cotton plantations in the US and subtropical areas and the development of sheep farms in Australia and New Zealand. Industrial development also created a dynamic demand for vegetable oils, lubricants, paints, and other industrial uses. The development of the energy sector with the concomitant development of electrical engineering and the automobile industry created an important demand for natural rubber, whose importance as an organic raw material led large areas of Southeast Asia and Africa to be converted to its cultivation.

Agricultural relations with the market go back to ancient times, and wholesale marketing of agricultural products dates at least from the Middle Ages. Rapid industrialization *cum* urbanization, however, required an increasing share of agricultural output to be channeled to urban markets. Agricultural activities became increasingly market-oriented with the slow decline of subsistence farming. This phenomenon was facilitated by the improvement of transport and the mechanization of agricultural activities.

A most important impact of industrialization was on transport, with significant implications for agriculture in at least two ways. First, because agricultural raw materials are frequently bulky and of low added value, the transport cost tends to be high in relation to the value of the transported commodity. Second, because most agricultural products and particularly foodstuffs are perishable, their consumption far away from the site of production requires rapid transport and techniques for their preservation. Before industrialization, distances were a major impediment to the specialization and internationalization of agriculture. Relatively little agricultural production entered international trade. Each region was supposed to produce as much as possible in order to satisfy local needs; land was allocated to the growing of a diversity of crops.

Maritime transport costs started to decline much earlier than land transport costs, which explains the early location of agricultural activities near the cities and the ports. During the mercantilist period, important reductions were achieved in maritime freight rates. The declining trend accelerated after 1800, with the incorporation of new power systems. A real decline in land freight rates started only with the development of railway after 1820, and it was a crucial element for the expansion of the agricultural frontier and the incorporation of new land into agriculture and international markets, such as the Argentinian *pampas*. The development of refrigeration systems fostered the international trade of agricultural outputs.

Diminishing transport costs also affected agriculture and land use from the supply side. They facilitated the import of fertilizers such as *guano* from Peru in 1840, sodium nitrate from Chile, which by 1860 reached important dimensions in European agriculture, and, later on, phosphate rock. Between 1830 and 1880, British imports of fertilizers rose almost thirty-fold (Thompson, 1983).

Industrialization, Technological Change, and Land Use

Important effects of industrialization on land use operate through technological innovations used in efforts to raise agricultural productivity. Land-based economic activities have been always considered backward, their productivity lower than industry's[10], and their development and adoption of the technological innovation sluggish.

The stumbling block to the incorporation of agriculture into the vigorous pace of industrialization was the subordination of land-based activities to nature: to its biological, spatial, geophysical, climatic, and temporal variations. The constraints imposed by nature hindered both the disaggregation of the productive process and the modification of the period of production. These factors prevented agriculture from attaining the levels of capital and labor efficiency achieved in industry.

Industrialization has affected land use among other ways by the efforts to increase agricultural productivity and to reduce the deterministic influence of nature, forcing it to adapt to socio-economic requirements. With the exception of hybridization and new biotechnology, the most important technological innovations applied to agriculture are either extensions of innovations already successfully applied in industry or by-products of industrial innovations.

The successful development of manufacture suggested that inducing the same development in agriculture required its "capitalization and industrialization". This effort involved the replacement of food crops and self-sufficient agriculture by cash crops, the commoditization of land, and the disengagement of land-based activities from natural constraints. To the extent that these efforts were successful, land use patterns were modified.

Overcoming of the spatial obstacle to increased agricultural productivity has been a

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10. Adam Smith noted at the very begining of the Industrial Revolution that: "the improvement of the productive powers of labour in agriculture does not always keep pace with their improvement in manufactures"; Adam Smith (1930): The Wealth of Nations.

permanent goal. In industry, resources can be transferred from one place to another and concentrated in a single place: the factory. But land is immobile and cannot be concentrated in a particular site. To use it if is necessary to move along it. Such a movement, moreover, must be done at a given and very short period of time: when sowing or when harvesting. Thus the use of large acreage required a large labor force.

In the early 1800s, horse-drawn machines and steel tools like harrows, seed drills, corn planters, horse hoes, two-row cultivators, hay mowers, and rakes replaced labor and wooden instruments based on human and oxen power. This technological innovation implied the transformation of such basic agricultural operations as soil preparation, sowing, tillage, and harvesting. The era of agricultural mechanization thus initiated multiplied the acreage that could be cultivated by one person, accelerating the conversion of land to agriculture.

The plow is, no doubt, one of the most important implements in land use. It was indeed a major technological innovation when introduced to the New World and therefore a basic element in land use change. Until well into the last century, and even during the present one, plows were made of wood and normally by the farmer. Only after 1850 were lighter cast-iron plows introduced Danhof (1969). Much lighter than the wood plow, they favored the replacement of oxen by horses and sped up the basic task of soil preparation, making it possible to cultivate larger areas. Technological innovation in the steel industry towards the second half of the nineteenth century allowed John Deere to introduce the one-piece steel mouldboard plow. It could be produced in series, thus benefiting from economies of scale, which lowered prices and laid the basis of one of the world's largest agricultural machinery firms. A similar trajectory can be traced with other agricultural machinery. The development of harvesters led to the creation of another giant: International Harvester Company.

Once the advantages of self-propelled machinery were recognized, their development was relatively rapid. Before World War II, the large machinery firms were already well established, including John Deere, Heinrich Lanz, Allis-Chalmers, International Harvester, and obviously Ford, which that by that time introduced the hydraulic Ferguson automatic control system allowing the reduction of tractor size and weight, giving them more stability and greater traction (Kudrle, 1975).

Cost reduction in the manufacturing of agricultural equipment requires, among other factors, standardization of the product and its production on a large scale. Yet soils differ across the world, and agricultural machinery has been developed mainly for use in the temperate zone. When transferred to tropical, subtropical, or semiarid areas it frequently proves inappropriate, leading to soil degradation. The plow and mechanization designed and produced for soils of temperate zones have, when introduced into certain areas of Africa, Latin America, and even Asia, led to deterioration of soil structure and increased erosion with the consequent loss of organic material and nutrients. Plouwing in drylands, moreover, has initiated a process of degradation of the light soils, which in turn leads to the plouwing of additional areas and the spread of the problem.

Mechanization, or the replacement of animal power by self-propelled machines, made it possible to organize agricultural and industrial processes on a common energy base. For agriculture, which used to rely on its own produced energy, it has meant an increasing dependency on external factors: energy and industrial machinery. Decisions on land uses become conditioned not only by market requirements concerning the agricultural output but in addition by the conditions brought by the new technology.

From the perspective of land use, these technological changes imply more acreage cultivated and important increases in output per man-hour in cereals production. It has been estimated that between 1840-60 and 1900-10 output per man hour in the US increased four-fold (Parker and Klein, 1966). The diminishing reliance on animal energy reduces livestock and consequently the need for pasture and feed crops allowing land to be reallocated to food or industrial crops or soil conservation. For each adult working horse replaced by tractors, between 3 and 5 acres were released (Bogue, 1983).

Productivity per unit of land area, however, remained largely unchanged. Machines are substitutes for labor, so they allowed the area under cultivation to expand and to be cultivated with less labor, but increases in production remained a function of increasing acreage. Increases in yields per unit of land cultivated area were made possible by the Haber-Bosch process in 1915 for the industrial synthesis of ammonia and the further development of the fertilizer industry during the 1920s. This innovation was complemented with the development of pesticides and hybridization . They constitute what has been named biological and chemical technology (Hayami and Ruttan, 1985). Their joint application is the basis of the green revolution, whose impact on land use is well documented. Biological and chemical innovations are the main factors in the intensification of agriculture, which indeed has been the most important force behind the increase of agricultural production of the last 30 years, and a fundamental force in changing land use.

The growing yield per unit of land motivated new advances in mechanization. Mechanization increases the speed with which each operation can be executed and expands the area that can be covered. To maximize speed and to undertake a unique task over a large area requires that the culture be as homogeneous as possible. So to maximize the efficiency of mechanization requires the minimization of variability: uniform plant size and architecture, uniform shape of the harvesting fruit, uniform and simultaneous maturity, dwarfing characteristics, and high plant population are among the crop features required. "Machines are not made to harvest crops; in reality, crops must be designed to be harvested by machine" (Webb and Bruce, 1968). The industrialization of agriculture has been an important motivation for plant breeders and research into new varieties, a scientific and technological effort that has required the collaboration of biologists, plant breeders, and engineers. The final objective, contrary to what many people believe, was not to develop machines conforming to plant attributes, but rather to adapt plants to the requirements of an efficient mechanization: "The effective approach is to modify the plant to reduce the degree of selectivity required in harvest and to place the harvested parts on a predictable position in relation to the harvest machine" (Barnes and Anderson, 1975).

Genetic material is a highly valued resource. Not only is it able to reproduce itself, but each variety contains traits that permit responses to different economic and environmental demands, being the raw material for the creation of new cultivars. Germplasm has been displaced from its centers of origin to other regions that eventually become the dominant producing centers. At the beginning of the current century, the laws of inheritance developed by Mendel were rediscovered and genetic science started to develop. The manipulation of diversity and the combining of genes led to creation of new customized varieties. The technology of hybridization and more recently modern genetic and biotechnology gives the trade and appropriation of germplasm an enormous economic importance.

Germplasm mobility coupled with technological innovation not only gives comparative advantages to the center of reception of the germplasm, but also creates a new product. The exclusive monopoly over the new product, supported or not by international property laws, gives the receiving areas an edge in international markets. This new product is, in addition a substitute for the original resource (germplasm). So, the dominant production center is able to use more efficiently the imported varieties, acquiring comparative advantages over the original center, and in addition has monopoly control over the substitute.

The development of breeding varieties during the current century allowed the extension of maize and other crops to cooler areas, defining new uses of land. It has also removed from the farmer the traditional responsibility for the production of seeds and plant material. It is necessary to have the control or the ownership over a plant material and to be able to enforce protection of such ownership. The economic value increases with technological progress, while its property is protected by legal, economic, and institutional instruments. The out-farm control over the seed is reinforced by the creation and adaptation of intellectual property rights. So technological innovation together with new institutional mechanisms transfer the control of genetic resources from the farmer to the scientists and the firms that produce the new varieties.

Hybridization has permitted an unprecedented expansion of food production but has been accompanied by the increasing homogenization of cultivated land. This homogenization has several dimensions and implications. The best known is a particular form of land use: monoculture, in which one or few varieties predominate over the others. Uniformity implies greater vulnerability of cultivars, that is, greater exposure to losses due to epidemics or unexpected environmental changes, losses having a higher probability of occurrence and a larger potential magnitude. To reduce the risks of homogenization, specific pesticides were developed. The issue of pesticides has given rise to great debates for their environmental and health implications. Much less has been said about their implication for land use. They can, for example, facilitate the incorporation of new areas to agriculture that were until then unsuitable for agriculture because the existence of pests. From the perspective of decision making, it should be noted that pesticides constitute, together with plant varieties and fertilizers, a technological package, in which the use of one of the elements is largely conditioned on the use of the others, thus narrowing again the range of alternatives available to the farmer.

The introduction of the new varieties was accompanied by important developments of irrigation schemes and economic incentives to promote the application of agrochemicals. The reluctance of farmers to adopt innovations and the need of adequate management led to the development of diffusion schemes. Farmers were instructed what varieties to plant and the dosage of fertilizers to be utilized and in which period to apply them. The fact that agrochemicals were highly subsidized was a powerful incitement to use them. Thus the combination of incentive policies, technological packages, and diffusion programs contributed to reduce the decision capability of the farmers. In other words, the strategy withdrew from the *in-situ* decision maker elements of decision making, control, and management, placing them at a higher and often *ex-situ* level of decision. This strategy also facilitated the entry into agriculture of the seed and agrochemical transnational corporations, which, by offering to peasants and farmers diverse arrangements for the buying of industrial inputs, got access to the decision-making process concerning land use.

The Industrialization of Agriculture or Agro-industry

The increased linkage of agriculture with the market and with the industries that supply the basic inputs has been associated in the last decades with the transnationalization of agricultural activities, that is, the penetration of agriculture by large transnational corporations.

Throughout recorded history, core decision-making systems adopted a variety of mechanisms to open up the new economic space suitable to their expansion, to implement decisions, and to control their evolution. The final objectives have been always to maintain or increase their pace of expansion, to adapt and to survive in an increasingly competitive world of changing character, and to increase production and benefits. Firms expanded outside of their home countries for different reasons and in diverse ways in each historical period. In some cases direct control over natural resources was the main mechanism for capturing surplus. In other situations the development of industrial activities -and or commercial operations complementary to the extractive activities has been dominant; the control of the market was the leading mode in still other situations.

In this effort to control agricultural activities a main element has been the process of farm re-organization and integration with industry. One form was the *in situ* establishment of interrelated activities of resource exploitation, such as refineries near mineral and oil extraction activities, refrigerating plants near exporting ports, and processing factories near farms.

Another strategy was the control of the marketing process. International integration was oriented to secure the surplus generated throughout the chain of activities of extraction, transformation, transport, marketing, and distribution. Frequently one of these forms replaced a previous one. In epochs of strong nationalism, for example, the control of market mechanisms was safe and more secure than the direct ownership of the natural resources.

The establishment of affiliated business concern in the countries of the New World has been a frequent mechanism of control. Affiliated firms or subsidiaries acted either to open the market for the new manufactured goods produced in industrializing countries or as local branches for the local exploitation of the resources to be exported to the metropolis. When the buyers of the agricultural output are state corporations or when one or few firms control the market of the product, mechanisms such as the advancing of credit scheme transfer elements of decision from peasants and farmers to commercial enterprises or financial institutions.

An example is the gradual control of the Peruvian milk market by Carnation, and later on by Nestle, which led to the sowing of large areas with alfalfa. The steady removal of elements of decision in the dairy industry is a main characteristic of the western European cooperatives, one that has been facilitated by governments through marketing boards. This case also illustrate the subordination of the decision-making process to a supranational level, here the CAP.

Farms everywhere in the world are generally now contracted either to suppliers of inputs or to dealers, who are in turn linked to wholesalers, supermarkets, or food processors, often transnational chains, that set quality and quantity standards, places and dates of delivery, prices, conditions of payment, and so. Through these mechanisms what, where, how much, and will be produced are almost totally predetermined, and indeed denote a higher, centralized and out-of-site level of decision concerning land use. The places of decision making concerning land are today the headquarters of large transnationals such as United Fruit Company, Del Monte, Pioneer, Bookers, Guthries, Unilever, Nestle, Harrison and Crossfield, Dole, Cargill, Monsanto, and the like. According to the United Nations Center on Transnational Corporations, transnational corporations control 80% of the world's land cultivated for export oriented crops (Shrybman, 1990) .

Conclusions

Land is a very distinctive resource because of its immobility. To use it requires that other factors of production be moved. Land use, moreover, has been always associated with a particular economic actor, the farmer or the peasant traditionally linked to its geographical space by cultural, social, institutional, ethnic, or even religious reasons. This two aspects tend to give the impression that land use is an issue locally decided.

Since the Columbian encounter, however, land use has increasingly been determined by factors and decision makers far from the area concerned. The globalization of the world economy, the process of industrialization, and technological progress have been the main causes of the increasing geographical separation between the land and the *locus* where decisions are adopted. The decision making process concerning land use has moved away from the site, towards higher levels and more distant spaces.

With the advent of industrialization, the farm ceased to produce its own mechanical inputs. Chemical innovation, hybridization, and finally new biotechnology removed the the production of biological inputs and of seeds and planting material from the former. These innovations have incorporated agriculture in the process of industrialization and at the same time have increasingly conditioned the decision of what to produce and how.

The transnational corporations, as well as their precursors, sometime alone, but most often within the framework of governmental strategies and policies and/or an oligopolistic structure, have allocated resources, innovated, administered prices, transferred resources, captured surpluses, and, through the manipulation of market mechanisms, been able to mold consumer habits. They have been, and certainly they are, economic agents able to modify economic and natural environments. Yet this fact does not necessarily imply an overall control over the economy or even over the geographical area of the activity concerned. Such control is only achieved by the identification of common interests and the coordinated activities of the different economic centers, which indeed suggest the presence of an hegemonic power.

In this decision-making structure, the decision center confers autonomy on the dependent areas in administrative and legal aspects, but the goals and objectives are established by the center, which tends to control the associated parameters: e.g., the market channels, the supply of inputs, the processing factories, and the distribution system.

Together with this evolution the process of decision making has become increasingly complex. The amount of information-technical, financial, legal, commercial, political, and so-required for the design, evaluation, adoption, implementation, and control of decisions has increased enormously and goes beyond the capacity of individuals. So concomitant with increasing complexity there was a movement from the individual to the group as a decision maker. The identity of the identity decision maker has become increasingly unclear.

This evolution is very clear in the plantation system, which also illustrates the above -mentioned trends toward the adoption of industrial forms of organization by agriculture. The early slave system evolved into plantations initially operated by their owners and later on by managers employed by absentee owners.They in turn were replaced by foreign firms and finally by trading companies or their subsidiaries operated as production units on a vertically integrated chain, starting with production and moving along processing, transport, and marketing.

Out-of-site decision making seems always to have affected the patterns of land use. With the Columbian encounter, however, the *locus* of decision making started to move away from the production site to spatially distant decision making centers, that have had the capacity to change the use of both newly discovered and old land.

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CHAPTER 5

1492-1992 : SEARCHING FOR SIGNALS AND CONSEQUENCES OF GLOBALIZATION

Francesco di Castri*

The Encounter: A Premonitory Globalization

The five hundredth anniversary of the Columbian encounter ("El encuentro de Dos Mundos") has been marked - quite understandably - by a proliferation of publications on this unique and far-reaching event. It would be beyond the scope and limits of this article to provide a concise bibliography of papers and books on this subject, which have been elaborated with very diversified purposes.

Many of them have taken primarily an historical approach, even directed at the general public (see Attali, 1991), but they have tried to analyze the discovery also from the viewpoint of the "discovered" - the local "Amerindian" populations and civilizations (see, e.g., Federació Catalana d'Associacions/Clubs UNESCO, 1990, León Portilla, 1992, PNUMA-AECI-MOPU, 1990, Tudela, 1992). Admittedly, up until now, an Old World one-sided vision has permeated and biased most of the textbooks and teachings of history.

It is true that several books have also attempted to draw conclusions and generalizations from the lessons of the Great Discoveries. In particular, two of them are worth mentioning here, because they have strongly influenced biological and socioeconomic thinking in this aspect. Crosby (1986) coined the expression "Ecological Imperialism" to define the biological expansion of Europe and the invasion of European biota. Above all, the formidable and pioneering work of Braudel (1979 a, 1979b, 1979c) on the emergence of capitalism from the 15th to 18th centuries, wherein key attention is given to the Columbian Encounter, evokes problems similar to today's with its references to "the structures of everyday life", "the wheels of commerce", and "the perspective of the world". Current hot debates on how to harmonize changes in our daily life with the internationalization of trade and traffic had a premonitory treatment in the "long-history" approach of Braudel.

I have been deeply involved in the launching and/or implementation of most of the so-called global programs of international research of the last 30 years, namely the International Biological Programme (IBP), the Man and the Biosphere Programme (MAB), and the International Geosphere-Biosphere Programme on Global Change (IGBP). I have realized in retrospect how much they failed (or are likely to fail) in adapting and applying their strategies to face complex global problems characterized by new steps, new interactions, new scales, and, accordingly, new emerging properties (di Castri, 1983a, 1985a; Price, 1990). It became, therefore, a priority and a leitmotiv of my research and operations to identify and detect signals, consequences, and possible regulatory processes of globalization.

It is noteworthy that the two very large United Nations Conferences where the overall planet was taken as a symbol, that of Stockholm in June 1972 on the Human Environment with the motto "Only One Earth", and the Rio Summit in June 1992 on Environment and Development with the motto "The Planet in our Hands", neglected (as in Stockholm) or underestimated (as in Rio, with the exception of the discussions on climatic global change and global biodiversity) aspects of globalization such as the rules of an interdependent world market economy, current and forthcoming human migrations (and related demographic concerns), increased inequalities, marginalizations, and unemployment rates, and cultural blending and homogenization. These were almost "taboo topics" in Rio, and it can be wondered how new development trends can be discussed and responsibly proposed without consideration of such issues (di Castri, 1983b, 1991a,b, 1992a,b,c, 1993a).

To have a benchmark against which to compare patterns of globalization, a prospective as well as a retrospective view is required. With this in mind, the Columbian encounter represents such an essential benchmark, as the first globalization (di Castri, 1989a and 1989b; di Castri and Hadley, 1988) where the encounter of the "known" and the "unknown" worlds implied the “opening of new man-made routes across biogeographical realms; intercontinental human migrations and colonizations, driven by strong economic and social pressures, and made possible by new transportation and communication systems; progressive globalization of trade and exchanges; enlargement of the scale of space and acceleration of the scale of time” (di Castri 1989b). Some of the terms used above regarding the Columbian encounter could be applied even now to describe patterns of the current globalization. If the winning ideology behind the first globalization, the Columbian encounter, was the Christian belief and the colonial attitude of the Westerners, at present the worldwide encounter - since the collapse of the Soviet Empire - entails widely accepting and practicing the rules of a global (almost) unrestricted exchange of goods, capital and information. This exchange often threatens the very foundation of the nation-state, which in historical terms is a relatively new construction in its present form.

Admittedly, the "acceleration" of change is much greater at present than at the time of the Columbian encounter, because of two main factors: new information and communication technology (e.g., computers, satellites) allowing instantaneous transfer of information and capital from one country to another anywhere in the world; and the fact that the world population is more than six times larger now than a few centuries ago, and is likely to become 10-12 times larger in a few dozen years. This implies even greater social pressure, massive world-wide urbanization, large-scale and intractable migratory movements at both continental and intercontinental levels, and unacceptable inequalities conducive to widespread marginalization in economic, geopolitical, and societal terms. Overall global security is undermined.

In some 40-50 years time, all biota of the world, including man, are likely to face another new kind of globalization, that of human-induced climatic change. Nevertheless, if present trends continue with no adequate regulations, by that time massive deforestation, desertification, landscape and agricultural simplification, distant impacts of megalopolis and declining biological diversity will have destroyed most of the natural resources for development and even for subsistence, at least in the countries of the South (di Castri ,1991c, 1992c; di Castri and Hansen, 1992).

In order to study the signals of globalization, particularly related to the Columbian encounter, I first concentrated my research on biological invasions by alien species. During the workshop on "History and Patterns of Biological Invasions in Europe and the Mediterranean Basin" held in Montpellier (France) at the CNRS in 1986, and later during the synthesis workshop in Honolulu in 1987 at the East-West Center, it was recognized in particular that: a) 1500 AD was a key turning point marking the breakup of the biogeographical realms; as regards invading plants, it defined the borderline between archaeophytes and neophytes; and b) that the flow of invasions was much greater from Europe to the Americas than in the opposite direction; this uneven trend was produced by historical chance and background as well as by biological necessity and opportunities (see di Castri, 1989b, 1990a). In any event, human kind has played a key role in facilitating this biological globalization.

A main conclusion is that pervasive human action, even in the distant historical past, cannot be disregarded as a major factor in phenomena that have been traditionally understood as being caused by geological, climatic, and biological events. When studying the evolutionary convergence and divergence of disjunct ecosystems under the same mediterranean-climate influence (di Castri and Mooney, 1973) in California and Baja California (Mexico), Chile, South Africa, southwestern Australia and the Mediterranean Basin (including Portugal, Morocco and part of the MiddleEast), it quickly became apparent that many similarities and dissimilarities can only be attributed to human influence, in spite of the large discontinuity in space and time of these mediterranean-type ecosystems. Furthermore, in a multi-factoral typology of them (di Castri, 1981, 1991d) many similarities between ecosystems of the Mediterranean Basin, California and Chile are a direct consequence of the Columbian encounter. Other affinities between South Africa and Australia depend on later Great Discoveries when British explorers played a major role.

It is primarily for this reason that, during the workshop held in the Vatican City in 1987 (di Castri 1989a), I tried to combine processes and effects of a potential globalization due to climatic change with those of the already existing globalization spurred by the international and interdependent market economy. To disassociate the two, as was done during the early phases of the International Geosphere-Biosphere Programme on Global Change (IGBP), would have been a far-reaching mistake from both a scientific and a managerial viewpoint.

Undoubtedly, defining globalization is not an easy task (see Price, 1989; Buttel *et al.,* 1990) because of the quantity of factors that need to be considered and because there is room for likely confusion among causes, signals, processes, and effects of globalization (see Table 1). I certainly accept the definition of Turner *et al.* (1990) of two types of global environmental change, including a) "systemic changes that operate globally through the major systems of the geosphere-biosphere" and b) "cumulative changes that represent the global accumulation of localized changes".

My only warning is to point out that global changes do not imply equal effects everywhere in the world. In the absence of regulatory processes throughout the institutional setting, the contrary is often true, and globalization is likely to lead to major world fractures and massive marginalizations and powershifts. This happened after the Columbian encounter, with the marginalization, segregation, and often genocide of the existing populations of the "New World" and in Europe with the decline of Venice as the

Table 1a: Patterns of the globalization process.

CAUSES	EMERGING PROPERTIES	SIGNALS
◆ Increased exchanges • capital and goods • people • biota, including pathogens • information ◆ Homogenization • cultural • food habits • industrial • urban way of life ◆ Increased interactions • competitiveness • transnational connectedness of policy measures ◆ Change of scale • larger scale of space • accelerated scale of time	◆ Systems complexity • non-linear behavior • discontinuities • bifurcations • thresholds • surprises ◆ Increased unpredictability ◆ Likely conflicts and incompatibilities	◆ Turbulences ◆ Extreme events ◆ Disruption of boundaries dynamics • ecotonal (under tension) situations ◆ More permeable frontiers

CONSEQUENCES
◆ Winners and losers incidence • increased gaps • segregations • magnified migrations ◆ Fractured world and fractured societies • likely occurrence of local wars • unemployment • marginalization ◆ Powershifts and shifting governance • declining of Nation-State concept and role • transnational delocalization of industrial and economic centers ◆ Institutional lack of adaptation • lack of focus of decision-making processes • non-operational consensus because of a too low common denominator • biased or ill-defined priorities • inadequate education and training • biased academic career system • increased corporatism and sectoralization ◆ Revival of cultural and ethnic identities, from greater regional attachment to fundamentalism and rejection of other cultures

Tabla 1b: Patterns of the globalization process.

REGULATIONS
◆Preventive world-wide measures to limit the excess of unrestricted and instant circulation of speculative capital ◆Trade adjustments founded on true prices, and evolving towards non-abrupt elimination of subvention-based sectors ◆Co-development partnerships between countries of the North and of the South, as applied to specific projects ◆Global conventions, agreements, principles and programs, to be elaborated taking into account existing national and regional specifities: - flexible and evolving in nature - concrete and problem-solving oriented - with proper adequation between available resources and proposed goals so that countries at a different level can progressively participate in a more than formal way ◆Planning and management policies balancing both local specifities and global connectedness ◆Decision-making processes taking place at the appropriate hierarchical level as related to the nature and extent of the problem •harmonization of national and regional networking through global coordination ◆Reshaping, remodeling and reconstructing institutional structures, in order to increase their adaptive capacity, and injecting more flexibility, creativity, innovation and care for people •changing the control and evaluation systems of international organizations •promoting partnerships among universities, industries, governmental bodies, media and civil society •reintroducing "relevance" as a key criterion of training and in academic career ◆Education and public information highlighting the fact that viable world-wide development and solidarity are survival factors not only for the South, but mostly for the small part of the human population living in the North ◆Conceiving and applying ways and means leading ultimately to a more participative and cognitive democracy

economic center of the "known" world, to the benefit of Amsterdam and later of London, as well as with massive disruptive migrations in Central Asia, the slave traffic from Africa, the Chinese migrations, and the successive waves of different European populations to the Americas (di Castri, 1989b).

Migration is likely to be the leitmotiv of globalization, as for instance that which could now happen from the south to the north of the Mediterranean region, because of soil degradation, desertification, and social and demographic pressures in the south (di Castri, 1990b).

It is almost unnecessary to emphasize the unprecedented marginalization of the contemporary world, not only between rich and poor countries in geopolitical terms, but even more in the new patterns of segregation and unemployment within each country. No solutions are responsibly viable within the context of any single country, but through new regulatory principles adopted on worldwide or widely regional scales.

My second methodological warning is precisely on the importance of scales (and hierarchical theory) and the emerging or vanishing properties of the system at any given scale (di Castri, 1985b, 1986a, 1986b; di Castri *et al.*, 1988a, O'Neill *et al.*, 1986; Salthe, 1985). I refer not only to the scaling of space and time, but also to scaling human perceptions, decision-making processes, economic production systems, and institutional structures (di Castri and Hadley, 1988; di Castri and Hansen, 1992). Zooming up and down hierarchical scales, according to the nature of the problem to be solved, is the only viable scientific and managerial policy.

Patterns of a globalized world

I have already presented an overview of the perspective of a globalized world in the allocution of the President of SCOPE (di Castri, 1992d) in the opening of the General Assembly of SCOPE in Sevilla, in the presence of her Majesty the Queen Sophia of Spain. I have already drawn attention to the paradoxes of this crisis (di Castri, 1990c, 1991e). More detailed information concerning the geopolitical aspects can be found in Badie and Smouts (1992) and on the economic ones in Beaud (1993), Muñoz Cidad (1992), and Petrella (1993), while Chesnaux (1993) analyzes globalization from a different angle.

I would like now to offer some generalizations on causes, emerging properties, signals, consequences, and regulations of the globalization process. I have already said that it is very difficult to differentiate, for instance, a signal from a consequence. This fact, in addition to my intention to merge biological, climatic, economic, environmental, agricultural, industrial, and communication globalizations, makes my typology a simple preliminary framework where, admittedly, debatable overgeneralizations will appear much too often. It will serve as a kind of explanation of the terms used in Table 1a and 1b.

The paradox of my conclusions is that we are dealing at the same time with centripetal forces conducive to trends of an uniform world and with centrifugal forces opening the way towards a fractured world and a fractured society. The centripetal forces refer mostly to the causes, signals and emerging properties. The centrifugal ones apply primarily to the consequences, which in reality are often feedback mechanisms counteracting the former ones. It is the role of the regulations to take into account and to harmonize both. It is ironic to see in this post-Marxist era how applicable an almost Marxist language would be. One goal is, as a matter of fact, to achieve a dialectical synthesis between the antagonistic terms of the centripetal and centrifugal forces.

As regards causes, I refer particularly to the following four aspects: increased exchanges, trends towards homogenization, increased interactions and connectedness, and change of scales (Table 1a).

Exchanges are of a very diversified nature: exchanges of capital and goods leading to worldwide economic interdependence, including the relocation of factories by multinational companies to countries where labor is cheaper; controlled and uncontrolled human migrations searching for regions that are supposed to have a better standard of living, or simply escaping famine, war and political repression, a trend likely to increase in a massive way because of demographic pressure; the new kind of seasonal migrations on a worldwide basis because of the rise of tourism; biological invasions, including those of pathogens and vectors of diseases; and massive exchange of information, simultaneously transmitted everywhere via satellites.

The trend towards homogenization covers different aspects of our daily life: cultural blending because of the overwhelming flow of news, information, and cultural products emanating from sources sharing the western way of life and the ideology of competitiveness and market economy; homogenization not only of agricultural practices and food customs (which was also a very important aspect just following the Columbian encounter), but also of technological and industrial patterns, as well as those of a worldwide urbanized life in great megalopolis, with steady disappearance of the rural way of life.

Increased interactions and close connectedness are certainly related to the increased exchanges. They can be viewed in positive or negative terms, but they are not neutral.

For instance, interaction can lead to increased efficiency of production or to a reciprocal cultural enrichment, but more often it is a starting point for wild competitiveness or an attempt to impose a given cultural or ideological pattern. Connectedness on a worldwide scale may be necessary for the creation of a more desirable global consciousness and awareness, but it usually imposes great constraints by linking all countries together in economic terms, for better or for worse, thus preventing a search for more creative, relevant and root-based solutions.

Emerging properties appear, according to hierarchical theory (Salthe 1985), as a result of change in scale - much enlarged - and increased interactions. The system - economic, geopolitical, climatic, and biological, with interactions among all of them - becomes more complex. High complexity of a system necessarily implies non-linear behavior, with discontinuities, thresholds, bifurcations, surprises, and greater incidence of extreme unexpected events. The predictability of the dynamics and evolution of the system is low, and the emergence of conflicts and gaps is more likely. This is recognized and generally accepted in regard to the physical (ecological and climatic) behavior of the earth system, as well as the patterns of biological evolution (di Castri 1991c), including the emergence of the human species and of the human condition.

Yet it is, psychologically and almost unintentionally, rejected or not accepted by today's "man in the street", the politicians, and the "institutional fortresses", mostly in the Northern wealthy countries. Having grown accustomed to a long period of stability, growth, and relatively high predictability (at least in the short run) since the Second World War - a very unusual and almost unrepeatable period in historical terms - and having been detached from the historical roots of cycles, extreme events, and instability, they find the new situation intolerable.

Moreover, institutions created with features adapted to a world situation that no longer exists are stagnant, resistant to change, and non-reactive; they lack the fitness (adaptive capacity), suppleness, and creativity to find - as a survival stimulus - new ways, a new language, and a new deal for action. From a biological evolutionary standpoint, these large bureaucratic machines, rigidly fixed and unlikely to be exposed to new adaptations, should become extinct to give way to more adaptable and flexible human constructions. But too many political interests and too much inertia in the North and in the South as well, and admittedly the intrinsic resistance to change of the majority of the human population, will keep alive our "man-made dinosaurs" for a long time to come. Accordingly, in a few years time, the overall human organization and governance will not correspond at all to the selective forces and pressures, economic and biological, prevailing in the world today. We can see even now the premonitory signs of this dysharmony and dysfunctioning.

Concerning the signals, mention should be made of the *turbulences* (di Castri, 1989a) -geopolitical, monetary, economic, social, biological, and institutional disorders- preceding the phase of adaptation to globalization, or the *stress* insofar as it is rightly considered as a syndrome of adaptation, the higher incidence of *extreme events* (droughts, killing frosts, etc.) examined mostly as precursors of global climatic change (Wigley, 1985), and the worldwide *disruption of boundary dynamics* (landscape boundaries, inter-state frontier boundaries with greater permeability, cultural boundaries). Disruption of boundaries leads to an ecotonal-like world, that is to say, a world under tension and with intermingled patterns (di Castri and Hansen, 1992; di Castri *et al.* ,1988b).

In terms of consequences, I contend that similar global forces acting upon very diversified regions and zones of the world (from the physical-biological to the socioeconomic and geopolitical aspects), with no regulatory processes, should inevitably provoke unequal and iniquitous effects. In other words, the same rules of the game applied to players of different calibre increase injustice and widen gaps. There will be "winners and losers" on both the geopolitical and the biological levels (see also The Times, 1989, with a map of the world's winners and losers). Marginalizations, segregation and, above all, migrations (and perhaps regional wars) are likely to be magnified. As with the paradox already discussed between centripetal and centrifugal forces, a "globalized world" can easily become a "fractured world" that still has a close connectedness between its uneven pieces so that chain reactions of implosions and explosions may occur.

There may be a shifting or lack of governances, as well as a lack of focus on decision-making processes. Unemployment and social disruption in one part of the world can produce in another part - through unarrestable migrations - marginalizations and segregations as well as a newly emergent racism. As already stated, the concept and the power of the nation-state is undermined. Biologically and epidemiologically speaking, biological invasions can take the shape of the almost forgotten plagues, in particular with respect to vectors, pathogens, and the uncontrolled release of bioengineered organisms.

It is even more complex to analyze the consequences of globalization for cultural diversity and identities. Ineluctably, there is a worldwide homogenization in certain regards and the total collapse of some local and regional identities. This has, in my view, a more serious and far-reaching impact on global diversity and the stability of the biosphere than does the so widely publicized extinction of some species of plants and animals. Nevertheless, and perhaps as a feedback mechanism to globalization, there is a healthy worldwide revival of cultural identities and ethnic cohesiveness, the need for a sense of belonging to a given people and a specific land, the necessity of "returning to breathe his own roots", to paraphrase the Chilean Nobel Prize poet Pablo Neruda. And it is true that the cultural products of a more universal character and coverage usually originate from artists and thinkers with strong specific and identifiable attachment.

There are different steps or levels of this cultural revival: for instance, a new regional awareness and attachment in France, the deeply-rooted regionalization in Spain, the feeling of independence of Quebec in Canada, the newly independent Eritrea in Africa, the non-negligible support for a federal-based government in Italy as proposed by the "Lombardy League", some independence movements in Scotland and Corsica, up to the extremes of Islamic fundamentalism in several Moslem countries, the regional series of wars in the ex-Soviet Union, and the very regrettable and multifaceted situation of ex-Yugoslavia. Of course, in the above gradient, from very desirable trends of cultural attachment and identity, there is a progression towards unacceptable aspects of intolerance and rejection of other identities.

Regulations of the effects of globalization

To avoid the trap of suggesting the ineluctability of the consequences of globalization, it is very important to highlight possible regulations. In spite of the tremendous inadaptation of our institutions, I see no reason why globalization should not be visualized as a "founding crisis" that leads in the end to a better society, a more adequate geopolitical setting, and new institutions to replace the anachronistic ones. Regulation processes are of three kinds: those aiming at the prevention to any possible extent of the adverse effects of globalization, those addressing the limitations of the impacts, and - above all - those leading to adaptation to the globalizing forces, including feedback mechanisms (di Castri 1989a).

A word of warning is needed: if the preventive measures can be global and similar to a certain extent, the fact that the same force produces quite different responses according to local and regional situations implies more explicitly that the same regulatory process can have very positive results in one context and be very negative in another. In spite of globalization, or more appropriately, just because of it, no miraculous worldwide prescription, convention, or strategy is applicable, but only measures and operations that are strictly adapted to a specific situation, while taking into account the connectedness derived from the global forces (see Table 1b).

Accordingly, global governance ("Haute autorité"), large governmental conferences and Summits (like the Rio Summit), global conventions, or the pretentious global agendas for the next century (Agenda 21, see Centre for Our Common Future, 1993) or the next millennium, should be cautiously taken as sources of general guiding principles to be progressively modified when faced with the changing realities of people's lives. A blind application of them could only lead to inefficiencies or disasters.

Furthermore, it has always been evident that oversized political conferences, inevitably lacking a proper knowledge-basis, can only lead to a very low common denominator of consensus, not irrelevant as a kind of wide platform, but whose all-embracing recommendations cannot be translated into concrete operations. Unfortunately, this is not usually the belief of cumbersome organizations, whether they be global, as the agencies and bodies of the United Nations system, or regional, as the Commission of the European Community.

There have been attempts, periodically revived, to prevent some aspects of globalization. A few years ago, a so-called New Information Order, equivalent to a certain extent to national filters to internationally emanating information, was proposed by the majority of the Member States of UNESCO (those of the former Soviet bloc and most developing countries), in an attempt to avoid a Western cultural bias and homogenization. In addition to the unethical aspects of this Order, above all it would have been absolutely inefficient given the current mechanisms and tools of communication.

As for the filtering of goods and capital, that is to say protectionism, in order supposedly to prevent the gaps from widening, it is no longer a viable solution in its classical form within the current world patterns, as exemplified by the collapse of the Soviet Empire and other centralized and State-centered economies. Nevertheless, it appears increasingly evident that some worldwide regulations are urgently needed, even if the policies of the International Monetary Fund (Chossudovsky, 1993), of the World Bank (see McNeely, 1992), and of GATT (General Agreement on Tariffs and Trade) deserve at least an indepth debate, to use only a euphemism.

As in the Middle Ages, an appeal is made to undefined and demagogic "magic words", the three most popular ones being "Global Change", "Biodiversity", and "Sustainable Development". Even for the most tangible of them, biodiversity, its functional role remains still unknown (di Castri and Younès, 1990). As a matter of fact, most of the key issues are handled in an amazingly amateurish way by instant and extemporaneous experts, with slogans, messianic statements, and media-palatable attitudes replacing a much needed professional and responsible behavior. Among the highly visible "eco-bluffers" (see Wachtel and McNeely, 1991) are the most conspicuous and influential personalities, listened to by politicians and the media.

There is an urgent need for a greater commitment on behalf of science and scientists to counteract the prevailing myths and demystify the current catastrophic beliefs as magnified by most of the media (di Castri, 1991f). This is the main merit of the Heidelberg Appeal in 1992, in spite of its ambiguities (di Castri and Spiroux, 1993). Yet I have already pointed out the institutional constraints on scientists, particularly in terms of their academic career system (di Castri, 1990c). Scientific institutions are by no means better, or less anachronistic, than the political ones.

Regarding scientific programs, particularly concerning the environment, I prefer to quote myself through Price (1990): "In 1984, at the first international symposium to discuss the IGBP, di Castri noted 'a complex proliferation of environmental programmes....Even for a scientist familiar with research in this field, it can be difficult to find a way through the labyrinth of acronyms of such programmes which often use similarly complex semantics of loosely-used neologisms, and, in the end are addressed to essentially the same research workers. To make matters worse, repetitions, overlaps, inter-institutional and even intra-institutional competition constitute all too often the foggy leit motiv of these programmes. Noteworthy as well, is the enormous and widening gap...between their overambitious goals and the resources (both human and financial) available to achieve them. Moreover, the complementarity or cooperation among these programmes (whether in a formal or operational sense) is often lacking....Another challenge facing scientific programmes today is how to function in a period of economic crisis and of geo-political unpredictability. Even more important is to anticipate how the understanding of trends of global change can be 'absorbed' and used within existing organizational frameworks and policy-making procedures'. In 1990, di Castri's comments still ring true". I would like to add that in 1993, after the Rio Summit, the proliferation is magnified and the quality and relevance of many programs have further diminished.

I should mention also, among the regulations, the emergence of many non-governmental organizations (NGOs) on the environment, and to a minor extent on development, as well as the emergence of political ecological movements. They can play an useful role as feedback mechanisms against an excess of productivism. With few exceptions, however, they lack real competence on these matters and are mostly emotionally and ideologically driven. In addition, they are not exempt or protected from the fundamentalism of so-called deep ecology (see also Ferry, 1992). I certainly cannot visualize them as an alternative governance.

Furthermore, too much emphasis is given to the protective and preventive aspects of the environment sensu stricto in a way that can only increase the divisions between the North and the South. Ecology is rarely perceived as a tool for viable development, as it once was and as it should still be (di Castri, 1993b). Environment is essentially, in my view, a very important symptom or signal of good or bad development, and should be treated in developmental terms.

Philosophically speaking, the roads leading toward solutions and regulations seem to be clear and far-reaching in the minds of authors such as Jonas (1990), Morin (1982), Morin and Kern (1993), Serres (1990). While admiring their thinking, I fail to perceive the application of their proposals on a real-world level.

I have myself made, as many others have, the statement that no long-lasting solutions can be envisioned without individual responsibilization and commitment, together with the acquisition of a planetary consciousness and awareness (di Castri, 1991g). This is certainly true, and public information and education are the key factors. But this can only be acheived in the longterm, even more so if consideration is given to the inadequacy of the media as awareness-raising entities; because of understandable economic reasons linked to the great daily competition in this field, their strategy is rather to deliver to the audience what the audience is most eager to receive, from idyllic unrealistic views of some parts of the world to the unrestricted catastrophism of ecological disasters. None of these aspects is conducive to an individual responsibility and action. Concerning education - the most important function of a society - educational, training, academic, and research institutions are, in most countries, among the most anachronistic, stagnant, and conservative organizations of the overall gloomy institutional panorama.

Several regulatory processes are suggested, in very sketchy terms, in Table 1b.

The lack of institutional fitness

Institutional inadequacy and resistance to adaptation has been the leitmotiv of this article, and I will conclude with some final considerations of institutions. Institutions are also at the basis of the decision-making process, but, in their current form, they represent the main obstacle to the "necessary utopia" of a knowledge-based, more participative democracy.

Many students have recently been struck by the inefficiency of our institutions to organize our future (see, e.g., Calame 1993, Decornay, 1993, Sérieyx, 1993). Since 1982, at the 10th anniversary of the Stockholm U.N. Conference (di Castri, 1982), I have been shocked by its poor follow-up and by the further worsening of the world situation, which continued to deteriorate up to the U.N. Rio Summit in 1992 and is unlikely to readjust constructively as a result of Rio (di Castri 1993a).

I wrote in 1982 that "most existing institutions, governmental and academic, national or international, in industrialized and in developing countries, are not adapted either to face the complexity of environmental protection and resource management problems, nor to react in time when an unexpected difficulty or a new crisis arises. Institutions are often subdivided in sectoral, inward-facing compartments; they tend to generate....increasingly heavy machinery for management, and to self-impose planning procedures that are too rigid....for such an unpredictable world.....Organizations seem to be powerless to solve global issues, and too big to even envisage solving everyday problems. Furthermore, they are not conducive to being evaluated or else have such a cumbersome management procedure that they prove impossible to evaluate".

I repeated later (di Castri and Hadley, 1988) that "By their very size and structure....institutions are able to resist efforts to change their ways of working. Attempts to promote interaction along and across disciplinary hierarchies have to confront many obstacles....Too large to tackle small day-to-day problems, while lacking the power to bring about real change, many institutions find themselves in a sort of limbus, hovering between the daily and the global, and powerless to affect either".

The above statements derive from some "incursions" into hierarchical and organizational theories, but primarily from the direct experience of having worked for many years in key positions in university, academic, research, technological, and production institutions, national and international, governmental and non-governmental, in the North and the South, and of having been involved in several restructurings and launched a number of research and development programs. The overall results were modest and unsatisfactory from my own evaluation, but have led to a relevant and still valid learning experience. And there has been a continuous "trial and error" exercise between proposals and attempts of solutions.

It would be beyond the scope of this article to extend a discussion on more desirable institutional patterns and structures to face the management of the unpredictability of globalization (see also Table 1b). In addition to the already quoted papers, reference can be made, among others, to di Castri (1989c, 1990d, 1991b,h,i, 1992e,f,g, 1993c) and di

Castri and Hadley (1986, 1992).

Briefly, two main institutional requirements are an increased decentralization at least of the decision-making process, and many measures to be taken in order to inject into the institutional functioning more flexibility, creativity, innovation, care for people, and conviviality.

Decentralization and regionalization, to the extent that they do not imply a "steeplechase" of successive obstacles to overcome often opposite centers of decision-making, are most appropriate measures for increasing the spectrum of possible solutions and promoting a responsible involvement of the users (di Castri, 1989d, 1993d). It is interesting to note that federal states and structures seem to be more resilient to the negative effects of globalization than centralized societies. Above all, a balance between local specificity and global connectedness should be the ultimate goal.

Conclusion

In summary, globalization is an ineluctable fact that is not good or bad per se, but depends on the human response, which should be both timely and appropriate. It is to be expected that, according to catastrophe theory, human awareness and reaction will be accelerated by forthcoming increased turbulences and impacts of extreme events.

A magnificent challenge lies in front of us, and the non-deterministic and non-linear nature of the processes involved increases our space of freedom and creativity. If the Columbian encounter was the meeting moment of two delimited Worlds, it is now the interaction and connectedness of every single place of the planet. The new universality cannot be achieved through a melting pot of uniform supposed "citizens of the world"; this melting pot would be of an unstable and explosive nature. Universality should be founded on the acceptance and respect of the inalienable right of individuals and people to their own diversities.

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CHAPTER 6

WESTERN MEDITERRANEAN LAND-USE SYSTEMS AS ANTECEDENTS FOR SEMIARID AMERICA

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Traditional Land-Use Systems and the Western Mediterranean

Traditional land-use systems (Di Castri, 1981) are the result of an historical process in which the interaction of cultural innovations and biophysical components results in specific solutions aimed at self-sufficiency and fluctuation buffering (Montserrat and Fillat, 1991; Bernáldez,1991a/b). Most of the lands of the world once were or currently are under some form of traditional agricultural and pastoral use. Consequently, an understanding of such traditional systems is critical to interpret the present landscape and environmental state of the land, even when these systems have been replaced by "modern" counterparts.

This is true for the western Mediterranean Basin which has a long history of agropastoral land use, adapted to the particular climatic conditions of the area: severe water stress during the growing season of "normal" plant species; low temperatures during the wet part of the year; and relatively erratic rainfall patterns during the cool season. Human adjustments to these conditions required adaptation and manipulation of preadapted biological material; transformation of the natural forest into orchards (*frutalización*, Bernáldez, 1991b); introduction of field crops long ago evolved from annual grasses and legumes; periodic movements of livestock (different scales of transhumance, Ruiz and Ruiz, 1986); and complex sylvopastoral systems (Montserrat and Fillat, 1991). In addition, sophisticated irrigation schemes (*huertas* or irrigated gardens) were developed for extra-Mediterranean plants (Grigg, 1974).

Preadapted Biological Material in Western Mediterranean Land-Use Systems

Traditional land-use systems in the western Mediterranean Basin must be understood in terms of the environment, particularly its natural vegetation which coevolved as an adaptation to water stress and the manipulation of this vegetation for human use (Table 1):

• Lauroid forest and preforest elements characterized by deep rooting, efficient stomatal control, hard leaves and very frequent adaptation to frugivory (e.g. *Olea*, *Ceratonia*, *Pistacia*), giving rise to olive, carob and pistachio groves, and even to edible acorn oaks in western Iberia.

The efficiency of rooting and stomatal control prevents excessive water stress during drought intervals since transpiration remains very low. However, plant water potential, as an appropriate thermodynamic measure of water tension (Chapman, 1976), can occasionally reach values as low as -50 bars or less with no apparent damage (Sánchez Díaz, 1989). Lauroid communities are typically regressive and their vestiges are incapable of significant expansion (e.g. *Pistacia, Arbutus*, *Quercus*, *Oleaceae, macchia*, *monte noble*, *monte de cabeza*). They probably represent an old pre-Mediterranean background challenged by invaders as a result of ancient climatic change.

• Chamaephytic invaders, with shallower rooting, varnishes and hairy covers; large entomogamous flowers and dry fruits are common (e.g. *Cistus*, *Thymus*, *Lavandula*); not converted to cropland, but encroaching on disturbed areas and providing inferior firewood or charcoal.

These communities tend to multiply from seeds, readily invading disturbed, nutrient-poor sites. Although endowed with various xerophytic adaptations, they are subject to considerable water stress and tolerate passive water deficits (Sánchez Díaz, 1989).

• Winter hardy, drought-resistant Mediterranean therophytes (e.g. *Triticum*, *Hordeum*, *Vicia*), domesticated as critical cereals and legumes, or semidomesticated as pasture plants.

Mediterranean therophytes tend to colonize open, disturbed, and generally nutrient-rich sites. Their drought-adopted characteristics keep water stress at very low levels. They are also well adapted to cold; and many species are able to grow at temperatures close to 0°C (e.g. rye, wheat and many clover and vetch species). This adaptation to a cool growing period was a reason for the failure of many Mediterranean crops in America (Del Río Moreno, 1990), much to the dismay of early Iberian colonists.

Table 1. Preadaptation of Western Mediterranean Agricultural Plants

TYPE	DROUGHT ADAPTATION	ECOLOGICAL CHARACTERISTICS	EXAMPLES	AGRICULTURAL USE
Lauroid forest and preforest elements (paleomediterranean)	• deep rooting • hard leaves • efficient stomatal closure • moderate to large water potential	• frequent frugivory • anemogamy • regressive communities • vegetative planting	• *Olea europea* • *Pistacia vera* • *Ceratonia siliqua* • *Quercus ballota* (*Q. rotundifolia*)	• conversion of natural forest to orchards • olive, pistachio, carob, sweet acorn oak
Chamaephyte invaders (steppe origin)	• varnish and hairy covers • passive water deficits • shallower rooting • high water potential possible	• multiplication from seed • entomogamy • invaders of disturbed, nutrient poor sites	• *Cistus* spp. • *Lavandula* spp. • *Thymus* spp.	• no agricultural conversion • woody "weeds" • poor quality firewood and charcoal • important landscape components
Winter hardy, drought avoidant therophytes	• drought avoiding • cold resistant • low water potential	• invaders of disturbed, nutrient rich sites	• *Triticum* • *Hordeum* • *Vicia* • *Trifolium*	• ancient conversion to cereals and annual rotation legumes • semidomesticated pasture legumes
Phreatophytes	• deep rooting • efficient water conducting system • low water potential	• adaptive to riverine forests • frugivory	• *Vitis vinifera* outside the Mediterranean area; also *Phoenix dactylifera*	• converted to crop in deep soils by manipulating shoot/root ratio

• Less common, phreatophytes (*Vitis vinifera*) adapted to deep soils with proximity to the water table; unimportant owing to pruning or selection that create a low shoot/root ratio.

In addition to the adaptations of the vegetation, domesticated animals were used in different types of transhumance systems, adapting their ability to move in response to seasonal changes in water and vegetation. Of particular importance were the Merino sheep, Iberian pig, and *avileño* and *retinto* cattle (Ruiz and Ruiz, 1986; Bernáldez, 1992; Bernáldez *et al.*, 1991).

At least three pastoral systems can be identified: (1) Micromigrations within the same area; (2) short-range transhumance[1]; and (3) long-distance transhumance. Micromigrations involved the winter use of well-drained uplands (*cerrillo*, *altos*) and south-facing slopes (*solana*, *adret*) followed by summer use of low-lying meadows benefitting from groundwater seepage (*baén*, *bajos*), or north-facing slopes (*umbría*, *ubac*). Short-range transhumance involved *travesío* livestock, moved from the mountains to neighboring lowlands, such as in the case of the Maritime Alps of southern France and between the Pyrenees and the Ebro Valley in northeastern Spain. Finally, *cabañil* livestock were used in long-distance transhumance in treks of hundreds of kilometers, for instance from the northern Iberian Peninsula (maritime climate of the western coasts at middle latitudes) to the valleys of Andalusia or Extremadura.

Livestock movement was one of the most important methods of buffering the production impacts of climatic oscillation in the Mediterranean area. Complex transhumant systems needed political stability and a well-policed countryside, achieved in Spain with the "Santa Hermandad," a rural police created at the end of the fifteenth century.

Landscapes as an Outcome of Traditional Land Use

The typical western Mediterranean landscape of today can be seen as the consequence of various traditional land-use systems, used from about the sixteenth to the twentieth centuries and themselves adapted to the physical environments of the region. Those of Spain are exemplary.

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1. Transhumance is a European term with a specific meaning that has commonly been applied to all types of pastoral movements. Its original meaning was and remains pastoral movements that involve altitudinal shifts from upland to lowland pastures or grasslands.

Rain-Fed Arable, Rotation and Fallow Lands

Olive groves, vineyards, and cereal fields with a fallow period and rotation with different legume species (approximately 12 species for fodder and 5 for food) were the most important components of traditional land use. Fallowing was used not to restore soil moisture (as is frequently stated, confusing Mediterranean conditions with the dry-farming practices in summer rain climates), but to reconstitute soil fertility, since no nitrogen-binding rotation crop could be grown during the dry summers.

Plowing-under of legumes (especially *Vicia* and *Lathyrus* spp.) at the flowering stage, to create a green manure, was used since at least Roman times to help maintain fertility. Rotation with various legumes has also been very important in fertility maintenance. The number of legume species used in rotations or characterizing extensive fallow land in Mediterranean Spain is impressive. Rain-fed species rotating with cereals and used for fodder or green manure included: *Vicia sativa* L., *V. articulata* Hornem., *V. villosa* subsp. *villosa*, *V. ervilia* Willd., *Lathyrus sativus* L., *L. cicera* L., and the fodder variety of *Cicer arietinum* L. The fodder legumes *Ornithopus sativus* Brot., *Onobrychis viciifolia* Scop., *Hedysarum coronarium* L., *Trigonella foenum-graecum* L., *Vicia fava* L. subsp. *minor* and *Medicago arborea* were less dependent on rotations. Legumes often used as human food, such as lentils, chick pea, broad bean, and the edible pea species were also important in rotation. Beans imported from America required irrigation, as was the case with other legumes, including alfalfa, *Trifolium resupinatum* subsp. *suaveolens* (from Persia), *Trifolium alexandrinum* (from Egypt), and "ladino" clover (Eastern Europe and Middle East).

Semidomesticated legumes diffused slowly by means of livestock movements from *majadal* pastures enriched with nitrogen and phosphates to the rest of the peninsula, providing important components of pastoral systems and arable land with long fallow periods. Notable here are the clover *Trifolium subterraneum* and related species, but improved western Iberian swards may contain almost 30 annual clovers, such as *Trifolium glomeratum* L. or *T. striatum*, which adapt to a variety of ecological conditions. *Biserrula pelecinus* and other legumes also are important in areas of oligotrophic soils. More neutral and alkaline soils are favored by many annual *Medicago* species and other legumes, such as *Scorpiurus* spp. and *Coronilla varia*, that may also be included in the semidomesticated category. Many of the *majadal* forms are characterized by their resistance to close, dense sheep grazing, in contrast to other legumes and pasture plants, so, for example, in the Mediterranean environments of the New World. These differences may explain the absence of adaptation to the overstocking typical during some stages of *majadal* formation outside of their bioecological core areas. Even in cases where the western Mediterranean legumes were introduced, mainly by accidental and haphazard dispersal, population pressures and soil properties probably prevented the development of multispecific swards resistant to overstocking.

Periodic and systematic spacing of sheep enclosures (*redileo*) was practiced both in pastures and arable fields. *Estante* (non-transhumant) sheep have been a more important asset of traditional western Mediterranean agriculture than is generally believed. After the Middle Ages, they almost outnumbered the famous transhumant *mesta* flocks (Iradiel Murigarren, 1988; Ladero de Quesada, 1988). Some large *estante* sheep breeds, such as the castellana and the manchega were "arable land" specialists, and their importance only decreased in modern Spain following the virtual suppression of fallowed land.

Pastoral Systems

Sylvopastoral systems frequently relied on two overlaying strata of vegetation. In western Iberia, they included a tree layer, normally live oak with improved fruits (probably developed by selection for larger fruit, low tannin, few male catkins), and a herbaceous ground cover in which annual legumes (about 30 species of *Trifolium* and various *Medicago*) were prominent (Bernáldez, 1991b; Gómez Gutiérrez, 1991). Some of these legumes are semidomesticated, deliberately spread by means of livestock movements from areas of high fertility *majadal*. Dissemination outward from special, intensively managed "cores" is a characteristic of traditional grassland management in Spain (Montserrat and Fillat, 1991), as was the spread of fertility from improved central areas in oligotrophic agricultural land of northern Spain and Central Europe (Sigaut, 1975).

The most original silvopastoral land-use system is the *dehesa* (from Latin: *defessa* = protected, excepted from common pastoral use), which allocates pasturage for migrating sheep in their wintering areas or for the *estante*, non-migrant sheep and farm animals of local villages. In Spain, the *dehesa* system still occupies about 1.5 million ha in the southwest, while in Portugal similar systems (*montados*) are distributed in the southern half of the country. In most cases, the tree layer consists of improved *Quercus ilex* subsp. *rotundifolia* that has probably been subjected to selection since Neolithic times. Tree planting and the pruning of scrub to favor arboreal form has been aimed at increasing acorn quality and production. The tree has also been extended much beyond its natural area. Palynological studies have revealed the consistent presence of deciduous

Quercus spp. under the present *rotundifolia* woodlands (Reille *et al.*,1980). It is not clear, however, whether this substitution was always the result of deliberate introduction or an indirect consequence of land use involving fire, browsing, shifting cultivation, and higher radiation levels favoring *Q. rotundifolia*. Nevertheless, there is considerable historical evidence of the deliberate expansion of this tree, as shown in the frequent presence of straight, artificial borders with other species, e. g. in the regions of Salamanca and Madrid. Highly competent and respected rural planters and managers of *Q. rotundifolia*, *Q. faginea*, and *Q. suber* were active until very recently (Bernáldez, 1991b). The density of approximately 60 trees/ha from this activity encompassed 20% to 40% of ground cover. The improved trees were periodically pruned according to specific techniques aimed at increasing acorn production.

In Spain and Portugal, Iberian strains of pig and sheep were the most important grazing animals, with pigs playing an important role in transforming rough vegetation into improved *majadal* (Bernáldez, 1991b, Gómez Gutiérrez, 1991). The absence of the pig in the Mediterranean environments of northwest Africa created a very different woodland structure. Trees were not pruned to increase acorn production, resulting in quite different shapes and densities. The main goals in Morocco were timber and sheep or goat production. Intensive acorn production was also absent from eastern Spain (on limestone soils), while the *Quercus ilex* woodlands of southern France (with bitter acorns) additionally have a very different aspect. Firewood, charcoal, and browsing for goats were important objectives, but the *dehesa* system remained absent from these areas (Hubert and Thiault, 1989).

The tree canopy acted as a buffering mechanism and the acorns (producing about 600 kg/ha) complemented grazing; during periods of stress, branches were also used as fodder for goats, sheep, and cattle, the oaks contributing 90%, 30%, and 50% of the daily requirements of these livestock genera, respectively (Bernáldez, 1991b). The massive, well- adapted oak trees were less affected by drought and cold periods than the herbaceous layer and also served as a microclimatic sheltering mechanism, to reduce wind speed and radiation at ground level (Bernáldez *et al.*, 1969). The calcium, magnesium, and potassium inputs from oak litter to the oligotrophic soils dominant in the *dehesa* significantly improved soil nutrient levels and inhibited leaching (Bernáldez *et al.*, 1969).[2]

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2. More details on complex Iberian sylvopastoral systems can be found in specialized papers: Bernáldez, 1991a, 1991b, 1992; Campos Palacín, 1984; Elías and Muntion, 1989; Gómez Gutiérrez, 1991.

The Huerta Systems

The irrigated *huerta* allowed the survival of plants not adapted to the Mediterranean climatic rhythm, such as fruit trees of the *rosaceae* and horticultural plants derived from outside the Mediterranean ecozone. The impressive *huertas* of Granada, Murcia, Valencia and other areas of eastern Spain seem to represent expansions and improvement of Roman schemes during the Islamic period (Butzer *et al.*, 1985). The water supply was commonly supplied by a sophisticated system of irrigation canals, leading from piedmont areas to the lowlands through a combination of tunnels, excavated within the aquifer (*mayrat*, *foggara*), and waterwheels (*norias*) or a variety of wells. The larger *huerta* complexes required highly complex engineering and management systems supported by a traditional body of conflict-solving rules, specific maintenance officials, and enforcement authorities.

Many of the Old World irrigated crops that have been of importance for the Americas, such as lemons, rice, and sugarcane, were first cultivated in Spain during Islamic times. Only bitter varieties of oranges were known and were used as garden ornamentals and medicinal plants. The sweet orange was introduced much later, probably brought from the Far East by the Portuguese. Irrigation also was the only effective way to produce most New World crops, such as beans, tobacco, maize, and potatos, in the dry Mediterranean areas of Europe and North Africa. Although incompatible with the pre-Columbian systems of wetland agriculture, the experience of irrigated Mediterranean systems was important in initiating or expanding irrigation tracts in the Americas, especially in the territories characterized by Mediterranean-type climates, of which the contemporary Californian schemes are outstanding examples.

Seral and Mature Shrub and Preforest Communities

Old, abandoned, or long fallow fields were often invaded by the forementioned chamaephytes (*Cistus*, *Lavandula*, *Thymus*), while encroaching *jaral* (*Cistus* shrubs) was an endemic problem in areas of marginal agriculture. In the Mediterranean uplands, non-domesticated lauroid elements (e.g., *Arbutus*, *Pistacia*, *Phillyrea*) were used by domesticated and wild browsers (goat, red deer) as well as for charcoal production.

These uplands with their excellent anti-erosive and infiltration qualities, played and important role in aquifer recharge (Bernáldez, 1985).[3]

Some Historical Patterns of Change in Land Use

The historical evolution of western Mediterranean land-use systems can be illustrated with Spanish examples. The most important components of western Mediterranean agriculture (olives, grapevines, and cereals with legumes and fallow land) were already accurately depicted by the Andalusian-born Roman agronomist Columella (about A.D. 60). In contrast to northern European agriculture, the patterns described by Columela remained remarkably constant in central Spain from Roman times until the beginning of the twentieth century. One reason for this is that water, not chemical fertility, was the most important limiting factor for rain-fed agriculture. The large proportion of Columella's text devoted to the grape, coincides closely with the importance given to this crop in medieval and modern Mediterranean times (Herrera, 1513).

The indigenous Iberian element is especially notable among livestock raising techniques, e.g. sylvopastoral systems, transhumance, special animal breeds. Agricultural changes during the Islamic period seem to have been limited to the improvement or expansion of certain irrigation systems or techniques, already known and operative in Roman times, and the promotion of some irrigated crops of oriental origin such as sugarcane and rice.

The fifteenth century initiated a period of demographic recovery in Spain. Vast tracts of land opened up by the wars of the Reconquest were put under cultivation. Wheat was increasingly cultivated, and became the dominant cereal. Olive groves were an important land-use component in warmer localities such as Andalusia and the Ebro Valley. Vineyards expanded considerably after the withdrawal of the Islamic populations (Iradiel Murigarren, 1988; Ladero de Quesada, 1988).

Both long-range transhumance and the *travesíos* (predominantly vertical, short-range shifts) underwent enormous expansion. Long-range transhumance organized by the powerful Mesta association reached record figures of about three million sheep in 1464. Non-transhumant sheep totalled about two million at the end of the fifteenth century, and the fine merino wool industry became a very important and profitable activity (Gerbet, 1991).

In the sixteenth century, Spain and other European countries became deficient in wheat and dependent on exports from other parts of Europe. From 1500 until 1600 there

3. With most of the forest and preforest vegetation in non-arable uplands still remaining, Spain now has one of the highest proportions of forest land (about 25%) in the European Community.

was significant population growth, also in Spain. Cereal production increased with the population, and field crops were produced in rotation systems involving annual legumes. The sixteenth century was a period of confrontation between the peasants and the aristocratic powers, the *mesta* stockraisers, and other users. Various crown documents regulated the use of common land in an attempt to alleviate these tensions (Fernández Albadalejo, 1988; Gerbet, 1991; Huetz de Lemps, 1986).

The seventeenth century coincided with an important agricultural crisis leading to land abandonment in some sectors of central Spain. This decline is often attributed to the increase of taxes of different kinds (e.g. *pechos, tasas, alcabalas, millones, embargos de pan, alojamientos de tropas*). Wheat production in central Spain may have declined by 40%, and since this mainly affected the driest and coldest sectors of central Spain, it has been suggested that climatic changes (Little Ice Age) could have been at play (Font Tullot, 1988; Pfister, 1985). However, the chronology of harvest failures compiled by Hamilton (1934, 1947) does not show a concentration of severely cold years or major droughts in central Spain from the 1470s until the 1780s, although their incidence was more common in Andalusia during the 1600s. Thus the decline of the interior is better attributed to changing economic patterns in the peninsula.

The late sixteenth century was one of population decline in central Spain, that accelerated during the 1600s. At the same time, however, there was a significant increase in both agricultural production and population in the northern, non-Mediterranean part of Spain, possibly due to the introduction of maize and potato from the New World. The coastal Mediterranean areas were not particularly affected by the crisis. The *huertas* successfully developed rice cropping, multiplying its hectarage by 100 at the beginning of the eighteenth century, at the expense of extensive wetland reclamation and with the unintended consequence of malarial infestation. The transhumance system organized by the *mesta* collapsed from about three million sheep in 1464 to about 1.8 million in 1621 (Huetz de Lemps, 1986). Both the eighteenth and the nineteenth centuries were characterized by a steady expansion of arable land, olive, wheat, and grape production, finally leading to practical self-sufficiency in wheat production and considerable exports of wine, olive oil, and *huerta* produce. The transhumance system declined correspondingly rapidly.

Environmental Consequences: Landscape Conservation and Biodiversity

Old Migration Patterns

The high proportion of woody crops (olive trees, carobs, almonds, live oak *dehesa*) and woody seral communities are characteristic of western Mediterranean land-use systems. These natural and artificial woodlands were compatible with a relatively high biodiversity, maintaining very old migration patterns of central and northern European birds. Almond and olive groves and *dehesas* provide important wintering areas for insectivorous birds nesting in central and northwestern Europe (e.g. *Sylvia atricapilla, Erythacus rubecula, Phylloscopus collybita, Turdus philomelos*) (Bernáldez, 1985).

Biodiversity

Pastoral systems are very complex. As indicated, they frequently include a tree layer that offers microclimatic shelter and soil protection. These systems may be endowed with high biodiversity by combining both forest and grassland elements. This heterogeneity allows the coexistence of open area species such as certain birds (e.g. *Anthus pratensis, Motacilla alba, Galerida* spp.) with forest species (e.g. *Fringilla coelebs, Certhia brachydactyla, Sitta europaea, Parus caeruleus*) (Bernáldez, 1991a/b, 1992). The same effect explains the presence of forest insects (for instance many moths living on oak as do oak butterflies, such as *Quercusia quercus, Nordmannia ilicis*), open woodland butterflies, such as *Fabriciana niobe, Euphydrias aurinia,* and even open plain species (*Zegris eupheme, Chazara briseis*). In the Casa de Campo, an area near Madrid traditionally managed as *dehesa* (Gómez Bustillo and Fernández Rubio, 1974), 75 species of rhopalocera have been recorded in approximately 2500 ha.[4]

The great age of many of the oaks encourages the presence of a fauna specialized in tree holes, including saproxylic insects which are becoming rare in other areas (Council of Europe, 1989) and larger animals, including *Strix aluco, Athene noctua, Coracias garrulus, Genetta genetta, Martes foina,* and *Elyomis quercinus* (Bernáldez, 1992).

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4. Compared, for example, to the less than 60 rhopalocera species in the United Kingdom.

Soil Erosion and Fertility

Although some Mediterranean land-use systems are quite efficient in soil and water protection, agricultural practices have resulted in considerable erosion. One little mentioned reason for this is the mainly downslope orientation of traditional agricultural furrows, aimed at draining excess water of the Mediterranean winter. As indicated above, legumes have played an extremely important role in maintaining fertility, not only through atmospheric nitrogen conversion but by maintaining organic phosphorous pools as well, thus preventing both irreversible fixation and leaching (Gómez Gutiérrez, 1991).

Interstitial Land

Seasonal livestock migration on a broad range of scales from tens to hundreds of kilometers has also resulted in an increase of landscape and biological diversity. *Cañadas*, *veredas*, and interstitial pasture areas within cereal fields (*entrepanados*, *longares*) provide examples of landscape diversity.

Perhaps the important point is that these landscape changes, while involving some environmental degradation, were maintained in a relatively sustainable state until the nineteenth century. The traditional land-use systems served the large majority of the population without significantly undermining its environmental base of production.

Maladjustments of Mediterranean Land-Use Systems in the Americas

Cropping Systems

With the exception of irrigated Mediterranean agriculture, there was a certain incompatibility and lack of intercommunicability between most of the pre-Columbian land-use systems and those of the western Mediterranean after 1492 (with the exception of irrigated Mediterranean agriculture). Opposite climatic rhythms and other physical characteristics were the reasons for the lack of adaptation of most western Mediterranean crops to the conditions in New Spain and Perú, and their early failures are now well documented.

The first failures were experienced in humid tropical climates and they may have influenced later behavior and even habitat preferences of the Spanish colonists (Del Río Moreno, 1990). The maladjustment of the early wheat cultivars, which responded poorly to a constantly warm climate and to fungal diseases is well known, but the other two main components of western Mediterranean agriculture in 1500, grape and olive, were similarly affected. Even when transferred to the highlands of Mexico, these crops did not do well, owing to wet summer/dry winter seasons there (Butzer and Butzer, this volume).

At the same time, crops brought back from the Americas such as maize, beans and potatos also underwent adaptative difficulties in the dry Mediterranean areas of Spain. Maize and potato were finally adapted in irrigated coastal areas and in wetter regions of southeastern or northwestern Europe, as late as the seventeenth century. Until very recently, they have had almost no influence on the agricultural patterns of central Spain, however.

Wheat and other crops central to Mediterranean-style agriculture proved inappropriate for large areas of tropical America, and it took a long time before the typical Mediterranean land-use systems became adapted to the more suitable environments of central Chile and California.

Pastoral Systems

The most striking maladjustment, however, was that of the traditional pastoral systems, so well adapted environmentally in Spain and other western Mediterranean regions (Bernáldez, 1991a/b, 1992; Butzer, 1988, 1990). Climatic suitability is a requisite for full adaptation of the traditional Mediterranean systems, which only central Chile and California could be expected to provide. A reasonable degree of adjustment was found to exist outside the Mediterranean climate, in some transhumance and long-distance systems of the Mexican uplands in particular (Butzer and Butzer, this volume), while the failure of adaptation to central Chilean conditions and the very late adjustments in California are puzzling (USA MaB Committee and Comité Français MaB, 1989; Aschmann, 1991).

The lack of natural legumes adapted to heavy grazing probably prevented the development and functioning of the *majadal* and similar methods based on brief overstocking. Some Mediterranean pasture legumes (from the semidomesticated group), such as *Triolium subterraneum* and *Medicago* species were introduced, probably by accident, but these scanty and impoverished populations probably only reached the mediterranean environments of the New World after much damage had already been done and the traditional systems were forgotten.

Overgrazing

Overgrazing and other abuses in the Americas triggered different processes and resulted in different phenomena than in the old Mediterranean pastoral areas. Heavy sheep grazing of the indigenous vegetation in both Mediterranean and non-Mediterranean areas of Latin America have generally resulted in considerable damage leading to severe soil erosion. In contrast, the *majadal* systems -- based on legume-rich, short sward plants with very low growth points -- are practically insensitive to overstocking. Extremely heavy grazing leads to a change of facies in ground cover, replacing palatable annuals with scarcely palatable nitrophilous plants that create a feedback mechanism which normally prevents soil damage (Bernáldez, 1991a, 1992; Bernáldez *et al.*, 1991; Gómez Gutiérrez, 1991).

The different effects on perennial, indigenous swards in Argentina, Chile, and Australia have often had disastrous outcomes. In Australia, however, the annual legume grazing and rotation system was reinvented at the start of this century, using and improving adventitious *Trifolium* and *Medicago* species of Mediterranean origin. The success of these innovations was enormous, facilitating soil protection and an increase in fertility of huge areas of wheat and pasture. These methods are being extended to other Mediterranean climatic areas in the world, such as California and central Chile, although the adaptation is not always easy since it involves many soil and fertilization problems.

Dehesa Trees

No true equivalent of the Iberian *dehesa* was established in America, although *Acacia* species in Mediterranean Chile, mesquite (*Prosopis*) in certain other parts of the New World, and *Quercus* and pine in Mexico and California may have played similar roles. But many of the resemblances between stockraising in Mexico and, for instance, the western Mediterranean pastoral systems may be only superficial. The lack of adapted legumes and the rhythm of the predominantly C-4 grasses are very different from those of the western Mediterranean Basin. In Mediterranean America, mycorrhyza problems and the extreme length of life cycles may well have posed obstacles for the introduction of sweet-acorn *dehesa* oaks.

Livestock Activities

Relatively sophisticated transhumant systems have been known to work satisfactorily in Mexico (Butzer and Butzer, this volume) and more recently in California (USA MaB Committee and Comité Français MaB, 1989). It seems that in these cases the degree of stocking and grazing pressure is relatively low. Livestock droving along transhumance paths is not likely to cause irreversible damage to plant cover or soil if prolonged grazing is avoided. The situation is similar to nomadic herding in Anatolia (in areas with very similar climates to those of central Spain), where true transhumance is much less developed than in Castile. Thus continuous herd movement with adequate stocking can be relatively harmless to native, non-adapted vegetation. Only preadapted sward, *majadal*, and *dehesa* techniques are environmentally compatible with heavy and persistent grazing in central Spain, and this is probably the case for the semiarid Americas.

Woody Vegetation

The differences in the high proportion of rain-fed woody crops (e.g. olive trees, carobs, almonds, live oak *dehesa*) in the western Mediterranean and in equivalent areas in America are striking. In the case of central Chile, the differences may be explained by the very early failures when introduced legumes were rare and grazing was at the expense of the indigenous plant cover; consequently the system collapsed. In California, where very similar oak species are present (although with a relatively high tannin concentration in the fruits), the lack of adjustment may be explained by the relatively late and short-lived presence of the Spanish colonists (USA MaB Committee and Comité Français MaB, 1989). As indicated, the Australian annual legume pastoral and rotation system, inspired by the western Mediterranean is now being introduced in both central Chile and in California. But there are no systematic attempts to develop the corresponding tree layer.

It is known, however, that *Quercus* acorns were an extremely important food for coastal Californian Amerindians, representing one of the rare centers of acorn harvesting other than those of prehistoric Iberia. According to some descriptions, the whole Amerindian population in parts of California was busy collecting acorns for special granaries during the maturation period. The method used to free the fruits from the noxious tannin, however, was not genetic selection but meticulous washing of the daily, acorn flour rations (Margolin, 1978).

Research Needs: A Comment

It would be worthwhile to systematically study the reasons for different degrees of adjustment of western Mediterranean pastoral systems in different parts of the Americas. In many cases their application was a failure, and the system was disrupted and degraded, resulting in an unbalanced proliferation of feral animals.

Although a reasonable degree of sustainability may characterize land uses involving indigenous crops and intensive agriculture in arid and semiarid Iberoamerica, grazing and browsing by livestock in marginal and wooded environments continue to reflect the lack of adjustment of the Mediterranean systems, thus resulting in ecological imbalance. Research is needed to achieve sustainability and reduce adverse environmental impacts by combining appropriate solutions and seeking information from balanced, traditional land-use systems. In this respect joint research programs involving American countries and Mediterranean areas of the world, especially southwestern Europe and Northern Africa, may be of enormous benefit.

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CHAPTER 7

TRANSFER OF THE MEDITERRANEAN LIVESTOCK ECONOMY TO NEW SPAIN: ADAPTATION AND ECOLOGICAL CONSEQUENCES

Karl W. Butzer and Elisabeth K. Butzer

Introduction

The Columbian encounter had many short- and long-term consequences. But human and biotic ecosystems have complex feedback loops, so that the eventual outcome of any one "input" derived from this great, intercontinental exchange could not be predicted. Commonly, the relation of cause and effect took generations, if not centuries to understand. One of the most momentous and problematic features of this exchange was the deliberate transfer of Old World domesticated livestock to the Americas.

Due to a fortuitous set of Cenozoic evolutionary and biogeographical processes, the New World had few wild animals that, in terms of temperament, ecology and economics, were suitable for domestication. Whereas distinct trajectories of agricultural coevolution on both hemispheres produced different but equivalent repertoires of cultigens, the New World lacked a counterpart to domesticated cattle, sheep, goats, and pigs. These animals enriched the prospects and quality of life in the Old World with meat, milk, and fiber, while increasing crop productivity through their indispensable fertilizers. One such system of livestock-raising that has enjoyed great longevity was practiced in the Mediterranean world (González Bernáldez, this volume).

Yet despite its known viability, Mediterranean pastoralism has long been under attack, both as prejudicial to agriculture and as ecologically destructive. These two issues should be sharply distinguished, as they always were in the past. Cultivation and pastoralism in the Mediterranean world have always been combined, as a complex subsistence strategy to (a) use different kinds of environmental resources in heterogeneous landscapes, and (b) minimize subsistence risk by providing animal foods that complemented cereals and were commonly susceptible to different climatic hazards. But herd animals require constant supervision in a mosaic of cultivated fields and upland pastures, and their propensity to forage on crops assures a constant tension, as a result of periodic and inevitable damages. Such tensions come to a head during times when agriculture expands, encroaching on traditional pastoral preserves, as was the case in Spain around 1450-1600 (Butzer, 1988a).

The standard historical study of long-distance sheep transhumance in Spain -the *mesta* - was unfortunately written by an American scholar with no agricultural background (Klein, 1920), who took a very narrow view of pastoralism, that has had inordinate influence. In dealing with Spanish pastoral activity in Colonial Mexico, Chevalier (1952, 1963) and Simpson (1952) failed to appreciate the built-in dialectic of agropastoral systems and used the substantial evidence for crop damages to Indians out of context, much as if modern crime statistics in America were grounds to assume total lawlessness and a lack of law-enforcement. More recently, a host of political ecologists have broadened the charge against Colonial pastoralism to assume that it was, by definition, environmentally destructive.

The introduction of a suite of domesticated animals to a new environment will inevitably reduce biodiversity and increase ecological fragility. As disturbing as that reality is, the subjugation and dispersal of selected biota by humankind can no longer be reversed. Two, more productive questions concerning the transfer of Spanish livestock to the Americas are:

(1) Did such introductions lead to acute environmental degradation, and if so, immediately (within a century) or with a notable lag (after several centuries), and at a local scale or over wide areas?

(2) Was the net impact for the indigenous population positive, negative, or disastrous, when weighing resource destruction, or infringement on arable land, versus benefits in regard to subsistence risk, nutrition, and fertilizer?

In order to reach even partial answers to such complex questions, archival research must be combined with field study of the biophysical evidence, to focus directly on land use and environmental history. One of the most detailed sources of potential information on Spanish pastoralism in early Colonial Mexico is provided by the land titles or *mercedes* preserved in the Archivo General de la Nación in Mexico City. Together with two "stray" volumes now in Chicago and Washington, these materials comprise some 25 000 folios, and include over 10 000 land grants from 1542 to 1643. These deeds, when studied systematically -- rather than selectively or on the basis of the marginal indices -- serve to document both the processes and regional patterns of land acquisition, livestock management, and related problems. But they must also be evaluated in the context of the resolutions (*actas*) of the *cabildo* of Mexico City (Orozco y Berra, 1859) and the royal decrees (*cédulas*) of the period (Puga, 1563; Bentura, 1787; Dusenberry, 1963; Solano, 1991).

This paper is based on detailed study of some 6000 *mercedes* from selected areas of New Spain, and provides a first outline for the origins and evolution of the Spanish livestock economy in Colonial Mexico based on systematic and primary research. Comparisons with Iberian antecedents (Butzer, 1988a) are emphasized, and the implications of livestock for the Indian population and for the environment are examined. Finally, the expansion and regional developments of this increasingly autochthonous economy, to the frontiers of New Spain and beyond, are briefly sketched. An overview such as this cannot be accompanied by an appropriate, scholarly apparatus of documentary citation. Such supporting data must be deferred to a book-length presentation currently in preparation.

Evolution of the Livestock Economy 1526-1643

Precedents for the allocation of lands to new settlers in Mexico are provided by the Christian repopulation of the Iberian Peninsula during the Medieval Reconquista. Good documentation exists for the *repartimientos* of Valencia and Sevilla in the 1240s, when lands or incomes from lands were assigned by the kings of Aragón and Castilla to their political supporters and soldiers, according to rank and merit (González, 1951; Cabanes and Ferrer, 1979). This concept of *repartimiento*, as distinct from the later requisitioning of Indian labor in Hispaniola, was again applied, immediately before discovery of the New World, during the reconquest of the last Moorish kingdom in Granada (1486-92) (Ladero, 1968; López de Coca, 1977). In the resettlement of Granada, an important distinction becomes apparent, between personal awards or *mercedes* given by the king, and the allocation of vacant lands to new settlers, made at the local level. But the fundamental goal of both types of awards was to resettle abandoned or vacant land, not to displace existing inhabitants.

Another critical precedent was the principle of landholding in Mediterranean common law, as reflected in the Visigothic law code of the sixth century (King, 1972), and the several competing legal alternatives, such as the *Siete Partidas*, of the thirteenth century (see López, 1555). The holding of land was ultimately based on usufruct, so that uncultivated or abandoned land (*tierra baldía*) could be assigned by the king. The *vecinos* of most municipalities had additional claims to communal lands, used to graze animals and collect firewood, while other tracts were under *señorial* jurisdiction (Gerbet, 1982; Vassberg, 1984). The remainder constituted public domain (*realengo*), open to grazing by all herds--although commonly at a fixed fee per head; unimpeded passage from one pasture zone to another was carefully safeguarded (Butzer 1988a, with references).

These institutions had profound implications in the New World, by opening up all uncultivated land to Spanish livestock. In particular, since the Indians did not initially own livestock, they lacked effective claim -- in Hispanic eyes -- to communal lands that were vital for the collecting of wild foods and fuel. Thus the 1533 *cédula* (Puga, 1563: f.85v) affirming commonage (*montes comunes*) guaranteed free access to woodlands, pastures and waters, but this was to stop Spanish infringements on the *ejidos* of Mexico City, not to express parallel privileges for the Indians. The first reference to Indian *ejidos* is from 1540 (see Orozco y Berra, 1859: III, 199).

The initial introduction of cattle and sheep to New Spain is linked to Cortés (Prem, 1992), but the *cabildo* of Mexico City first awarded licenses for sites -- *sitios* or *asientos* -- to keep sheep in 1526. Although most *mercedes* made by the *cabildos* of Mexico City (Orozco y Berra, 1859) or Puebla de los Angeles (Fernández de Echevarría, 1780) until 1537 were for small tracts of irrigated land, in keeping with the precedents set in Málaga and Granada, a handful of grants for sheep *sitios* were given out in most years. The uncertainty of the authorities can be seen from those grants of 1530 that were specified for grazing only, not for property rights. Yet a series of royal *cédulas* -- authorizing *cabildo* awards (in 1531), encouraging Spanish settlement and farming (1533), and legalizing *cabildo* grants of multi-use farm land (old-style *caballerías*) to conquistadors and qualified settlers (1535) (Puga, 1563: ff.37, 86, 108v) -- failed to evoke a systematic distribution of land.

Indian protests in regard to land usurpation or damage by animals to crops had begun promptly in 1524, but in regard to pigs (Orozco y Berra, 1859: I, 7, 79), and the indecision regarding land distribution may have been the result of intervention by the missionary orders on behalf of Indian rights, an instance of which is documented in 1533 (Orozco y Berra, 1859: III, 41). Part of the initial problem seems to have been the question of disregarded Indian claims to commonage. A second issue was that, in Spain, herds from elsewhere (*ajeno*) were allowed to graze on stubble (*rastrojo*), but by prior arrangement, in the harvested fields of a community, and only until the new crop emerged. The Spaniards in Mexico insisted on this traditional right, at times too early in the harvest season (Sarabía, 1978: 269), and the Indians were incensed by such an incomprehensible privilege--as well as initially unaware of its benefits in terms of manure.

The interminable delay in formal land distribution -- from 1527 to 1542 -- had major repercussions because herd expansion, livestock dispersal, and management patterns developed spontaneously, rather than in response to official policy or control. This becomes evident from: (a) the formal organization of a stockman's association or *mesta* in Mexico City in April 1539 (but functioning informally since at least 1529), designed to deal with open-range cattle and sheep raising, with its attendant problems of ownership claims, theft, and damage to cropland (Orozco y Berra, 1859: II, 1; IV, 313-16); and (b) a *cédula* of November 1539 on the collection of episcopal tithes (*diezmos*) from herds that -- seasonally or in the short-term --moved regularly from one diocese to the other (Puga, 1563: f.119; Orozco y Berra, 1859: V, 27). These events demonstrate that a completely mobile, local or long-distance pattern of mobile stock management had emerged during the 1530s. Even formal sheepwalks (*cañadas*) are recorded as early as 1544 (Orozco y Berra, 1859: V, 63, 65). Great herds of cattle and sheep moved around what were seen as public lands, migrating from one region to another, following Castilian customary law.

After six years of prevarication, Viceroy Mendoza finally issued a flood of land titles in 1542-43, almost 1000 of which are preserved. These grants distinguished *sitios,* for large or small stock (almost exclusively cattle versus sheep), on which a nucleus of animal sheds and *corrales* had to be built within one to several years. No units of size are specified in the grants, but a critical document of July 19, 1538, now in a private archive in Mexico City (Escobar, 1984: 281, n. 23), specifies a tract of 3000 *pasos* square (1 *paso*=1.397 m) (1750 ha) for cattle and horses and 2000 *pasos* square (780 ha) for sheep, evidently the same measures for *sitios de ganado mayor* or *menor* formally specified after 1560. Nonetheless, the cumulative evidence shows that a *sitio*, a term gradually replaced by *estancia*, was nothing more than a seasonal headquarters for a particular (but mainly implicit) number of animals. By contrast, agricultural land was given out in units of standard size, specified as 115 by 230 *pasos* (5.2 ha) in 1537 (Orozco y Berra, 1859: IV, 72); this remained the practice until 1563.

In the meantime, the mobile livestock economy threatened to go out of control. Mendoza and his successor, Luís de Velasco (1550-64), not only had to cope with countless, routine infractions of the rules governing dry-season transhumance (*agostadero*). They were also compelled to take decisive actions by a number of notorious incidents in Oaxaca and the Llanos de Ozumba (1540s), Tequizistlan (1543), Cuautitlan (1551), the valley of Toluca (1555-60), Tepeapulco (1555), Tlaxcala (1550-63), Aculman (1563), and especially the outrageous rape of Jilotepec by 300 African slave herders with up to 30 000 head of stock in 1551. Each of these gross infractions involved members of the *cabildo* as negligent owners, and the Jilotepec debacle included a list of 29 of the most powerful citizens of Mexico City, forcing the king in 1555 to appoint an independent adjudicator from Guatemala.

The viceroys, however, persevered in asserting the rule of law and, backed by the Council of the Indies, expelled cattle from Oaxaca, Jilotepec, and Tepeapulco for good, and brought the sheep barons of Puebla and Tlaxcala to heel (see Sarabía, 1978: 269-70, notes). Subsequently cattle raising was restricted to the tropical lowlands, the Chichimec frontier, and Toluca (Muñoz, 1592: 261-62; Torquemada, 1610: I, 610) -- where the cattlemen were eventually forced to pay for extensive protective fences covering areas of Indian cultivation. The existing literature fails to grasp that livestock transgressions were quite rare from 1563 to 1591, because the viceroys had indeed brought the system under control.

Before his death in 1564, Velasco modified land grant policy by enlarging the agricultural *caballería* to a unit of 400 by 800 *pasos* (42.8 ha), and explicitly defining *estancias* in measured units with prescribed stocking rates: 500 cattle or horses on 1750 ha, or 2000 sheep or goats on 780 ha.[1] Systematically appearing in the awards after 1563, these precisions were formalized by Viceroy Falcés in 1567. Instead of running three to five times that many head, and at large, the number of allowed animals was drastically reduced. Even so, mobility remained the practice. But estates could finally be delimited with boundary markers (*mojones*), as the public domain was systematically

1. These stocking rates for cattle (28.5 head or 17 000 kg/km^2) versus sheep (256 head or 10,240 kg/km^2) give a biomass ratio of 1.7:1, that is in no relation to the ratios of relative body weight (600 to 40 kg, 15:1) or market value (5:1) of cattle and sheep. This suggests that stockmen were well aware that sheep, unlike cattle, crop grass down to its roots, creating a far more serious problem with overgrazing. But such biomass figures are very high, comparing with those for wild ungulates on lush, nutritive grasses in East Africa (10 000-20 000 kg/km^2) and exceeding those for the northern Great Plains during the buffalo era (3000 kg/km^2). To accommodate such seemingly impossible densities of livestock to the quality of browse and the modest, native grama grasses (*Bouteloua* sp.) of Central Mexico (A. Gómez-Pompa, pers. comm., 1989) -- which originally had an ungulate biomass of about 100 kg/km^2 (white-tailed deer and pronghorn) -- transhumance and other forms of mobile herding were indispensable. The estimate of biomass in Central Mexico is based on the number of ungulates taken during a traditional game-drive near San Juan del Rio in 1542 (Torquemada, 1610: 611-12).

converted into private property in most of central Mexico. Rapid settlement now becomes apparent in several regions, centered on areas of better land along the main *caminos reales*, as the process of land granting accelerated.

During the 1580s, reports and notarial records serve to detail the scope and scale of sheep transhumance: 200 000 head moving 250 km and more from Querétaro, westward to Lake Chapala and central Jalisco, accompanied by the sons of the owners and by a crew of Spanish *pastores*, who lived around that town as *transeuntes* during the rainy season (Butzer, 1989a). Even larger herds moved from Puebla into the lowlands of Veracruz, where the herd owners began to acquire formal land titles to winter pastures. By 1596, at least 750 000 sheep (and probably twice that many) annually streamed across the mountains from Jalapa to Orizaba, to winter on assigned *estancias* in the foothills or near the coast (Figure 1). In the Bajío, the situation remained more fluid. In 1588, *estancias para agostar* began to be requested around Lake Cuitzeo. Then, after 1597, relative peace on the northern frontier led to great treks of sheep northward, pasturing around Río Verde, later expanding into the more productive Huastec lowlands. A veritable land rush ensued in 1613-15 between Santiago de Valles and Tanchipa (Ciudad Mante), with a total of 140 winter sheep *estancias* awarded, and an additional 200 applied for beyond the limits of Spanish control. By the middle of the seventeenth century, at least 500 000 sheep wintered in these regions, up to 400 km from the Bajío.

Momentous changes were also taking place in agricultural settlement. About 1590, roughly a third of the cultivable land of the Basin of Mexico was occupied by Spaniards, and as the Indian population plummeted with the great plague of 1575, more and more Indian land was bought up, or claimed as deserted. Sheep *estancias* were awarded on the rougher piedmont slopes, for animals that were wintered on the warm plains of Morelos. Much the same happened on the other side of Popocatepetl, along the foothills of Huejotzingo (Prem, 1992). By 1615, although the *chinampas* around Lake Xochimilco remained in Indian hands, Spanish ownership had been imposed on the irrigated Indian *huertas* of Tlalnepantla, Cuautitlan, and Texcoco (Figure 2), as well as on other such tracts from Jilotepec to Jalapa. In the Bajío, on the other hand, the Spaniards found several almost empty areas -- beyond the limits of traditional Indian agriculture -- for new, Spanish irrigation development. These included San Miguel after 1555, Celaya after 1563 (Murphy, 1986), Salvatierra after 1583, and Salamanca after 1608 (Urquiola, 1990). Here Spanish canal systems, field patterns, and water rules were implemented, in contrast to the Basin of Mexico, where little more than Spanish ownership was superimposed on existing systems.

By 1630, the rural economy of Central Mexico had been transformed. Spanish wheat farmers with unirrigated land either converted to maize or abandoned their grants, since wheat suffered serious blight problems when grown in summer (Murphy, 1986), while rainfall was insufficient for winter wheat. Others requested permission to shift to goats or sheep in order to provide milk, cheese and butter for urban markets. Holders of some sheep *estancias* applied for permission to introduce dairy cows. A process of intensification is evident, as the pastoral economy appeared increasingly inappropriate in an urban hinterland. In the eastern Bajío, some 200 000 cattle in about 1580 had been reduced to 45 000 by 1630 (see López Lara, 1973), as the rural sector focused on production of wheat and maize, with sheep raising increasingly limited to the rougher uplands. By 1600, the large estates had coalesced, and there was no more land available for the continuing flow of Spanish immigrants to the eastern Bajío that began about 1590 and only ended about 1640 (Super, 1983; Butzer, 1989a; Urquiola, 1989: 29-197; Barroni, 1990). Such new settlers were forced into urban occupations or to work on large estates, where they began to assume leaseholds on small plots. The western Bajío, by contrast, was still in the process of development; here, extensive cattle grazing continued, with 140 000 head verified in 1630 (see López Lara, 1973).

The marginalization of sheep raising was accelerated after 1633, when the first 800 km transhumance trek reached Nuevo León (Chevalier, 1952), a frontier area sparsely settled by new Spanish colonists in 1626. Its governor offered vast grants to the *agostaderos*, and the number of sheep from Central Mexico on its winter pastures swelled from 300 000 in 1648 to a million in 1715 (Cavazos, 1961; Hoyo, 1972). The scale of operation and holdings by the sheep barons who dominated this massive transhumance is illustrated by the last will of Don Juan Caballero y Ocío of Querétaro in 1689 (Rincón Frías, 1984). He left 195 000 sheep and 271 *sitios de agostadero*, including 17 in San Miguel, 57 north of San Luís Potosí, 113 in the Huasteca, and 84 in Nuevo León, with a work force that comprised 140 African slaves.

Patterns of Spanish Land Use during the Early Seventeenth Century

In New Spain proper (here termed Nueva España), the process of land granting came to a close in 1643, as the majority of the holders of deeds paid a relatively small sum in order to secure permanent title (*composicíon*). Although grants continued to be awarded by local authorities in Nueva Galicia, Nueva Vizcaya, and Nuevo León the later *mercedes* of Nueva España consist mainly of licenses, adjustments, and transfers of property, with only a trickle of new land grants. It is still not possible to delineate the

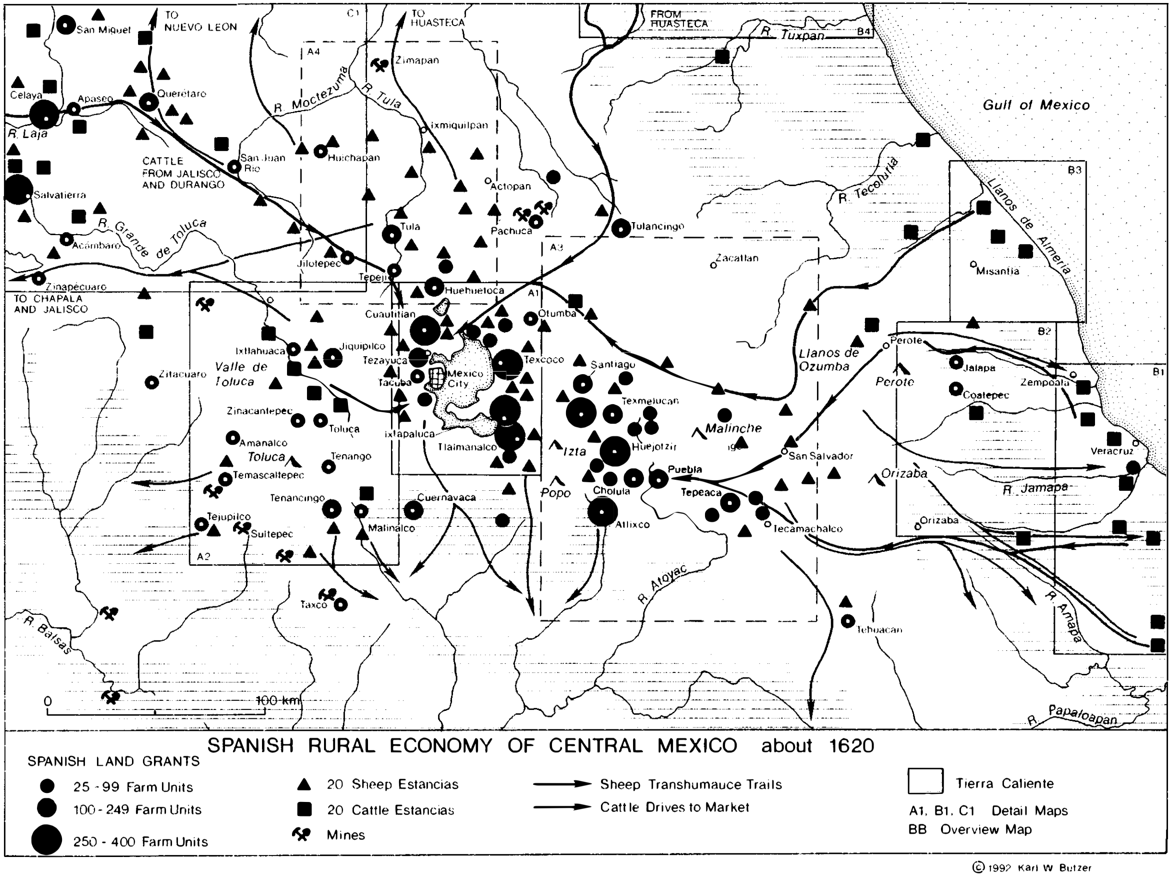

Figure 1. The Spanish rural economy of Central Mexico about 1620, as based on land-grant records and other documentary evidence. The complete frames indicate areas for which semidetailed mapping has been completed; the dashed frames are areas in which preliminary analysis has been initiated, in part based on other studies.

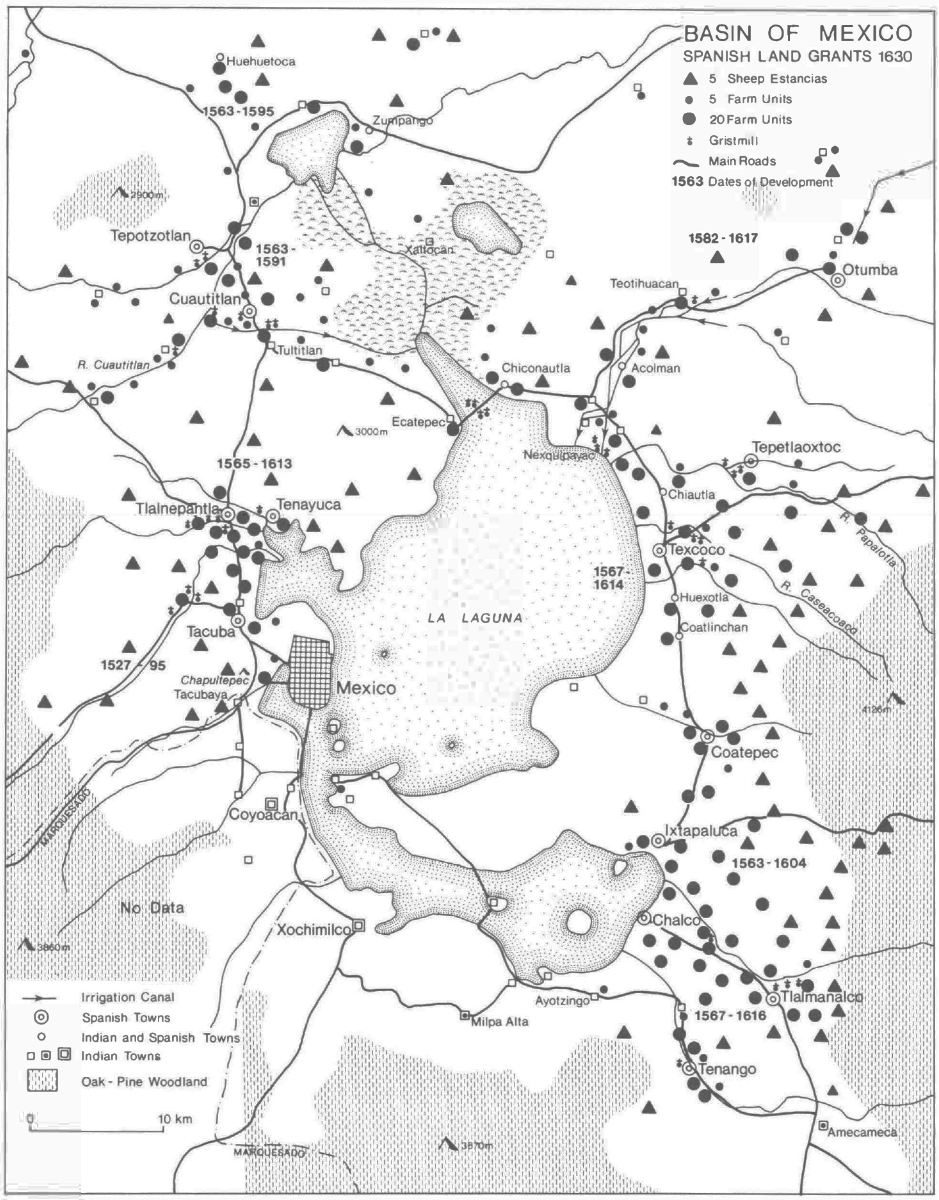

Figure 2. Patterns of Spanish land grants in the Basin of Mexico by 1630 (see A 1, Figure 1). No data are available for the area southwest of Mexico City, controlled by the Cortés family and known as the Marquesado, since any land titles here would be in another archival repository. The absence of awards to Spaniards around Xochimilco is, however, significant and indicates that this region was off-limits. The location of sheep *estancias* near the edge of the forest is very approximate since such titles provide few useful landmarks.

picture of cumulative Spanish landholdings in Nueva España as of about 1640, but a partial overview can be offered for most of central and eastern Nueva España (Table 1; Figures 1-3).

(a) In the rural economy of the heartland of the colony, centered between Mexico City and Puebla (Figure 1), Spaniards held some 1500 km^2 of agricultural land, almost 40% of the total of this quality awarded in New Spain. When the less nucleated but contiguous areas of Toluca, Tula, and Cuernavaca are included, this central nucleus accounts for 58% of the agricultural land. Most of the remainder (20%) was concentrated in the secondary heartland of the eastern Bajío.

(b) Most "home-base" sheep *estancias* were also found on the plateau, between San Salvador de los Llanos and San Miguel (Figures 1 and 2), around the fringes of the agricultural grants, mainly on rougher lands. This belt accounts for some 80% of perhaps 2000 home-base grants. Roughly another 1000 sheep *estancia* titles within Nueva España, and many more beyond the northern border, were *agostaderos* for dry-season grazing. Nominally, 2000 *estancias* represent about 4 million sheep, although the true number may well have been in the order of 6 to 8 million or more. As a result of the well developed transhumance patterns, these animals ranged through a territory of some 500 000 km^2. Figure 1 shows the major axes of long-distance transhumance: towards the lake basins of Chapala and Jalisco; Nuevo León; and the piedmont below Jalapa and Orizaba. Based on less substantial evidence are the short-distance transhumance routes suggested in Figure 1 from Puebla, the Basin of Mexico, and Toluca south into the adjacent foothills within the *tierra caliente*, the tropical ecozone that provided fresh pasturage at the onset of the cooler and drier part of the year.

(c) Cattle *estancias* are conspicuously absent in the Mexico City-Puebla area, although there was a small cluster in the Valle de Toluca. The major concentration of such grants was along the Gulf Coastal Lowlands (Figure 3). Whereas the Gulf cattle *estancias* continued to be active in 1640, the second cluster, in the Bajío, had demonstrably declined, with fewer cattle verified in 1630 than would have theoretically been allowed. We tentatively estimate 400 000 cattle in the Gulf Lowlands, 200 000 around Toluca, 200 000 in the Bajío, and perhaps 150 000 in both Michoacan-Jalisco and the Pacific Lowlands. Altogether this represents 1.1 million cattle, although that number may well have been as high as 1.5 to 2 million. It is possible that these animals

Table 1. Lands Granted to Spaniards in Central and Eastern Mexico, 1526-1643

Region	Agricultural Units	Sheep Estancias	Cattle Estancias	Horse Estancias	Grist-mills	Total Land Units
Basin of Mexico[1]	2112	416	---	2	32	2562
Puebla (incomplete)[2]	1534	255	19	3	7	1818
Gulf Lowlands (without Guazacualco)	391	593	733	144	5	1866
Valle de Toluca[1]	798	190	96	5	12	1101
Valle de Tula (approximate)[3]	700	400	6	---	5	1111
Bajío (to 1591 only)	966	333	407	4	47	1757
Provisional Totals	6501	2187	1261	158	108	10 215
Square kms	2782	17 059	22 143	2774	---	44 758

[1] In part, after Colín (1967).

[2] In part, after Prem (1978, 1984) and Licate (1981).

[3] In part, after Melville (1983).

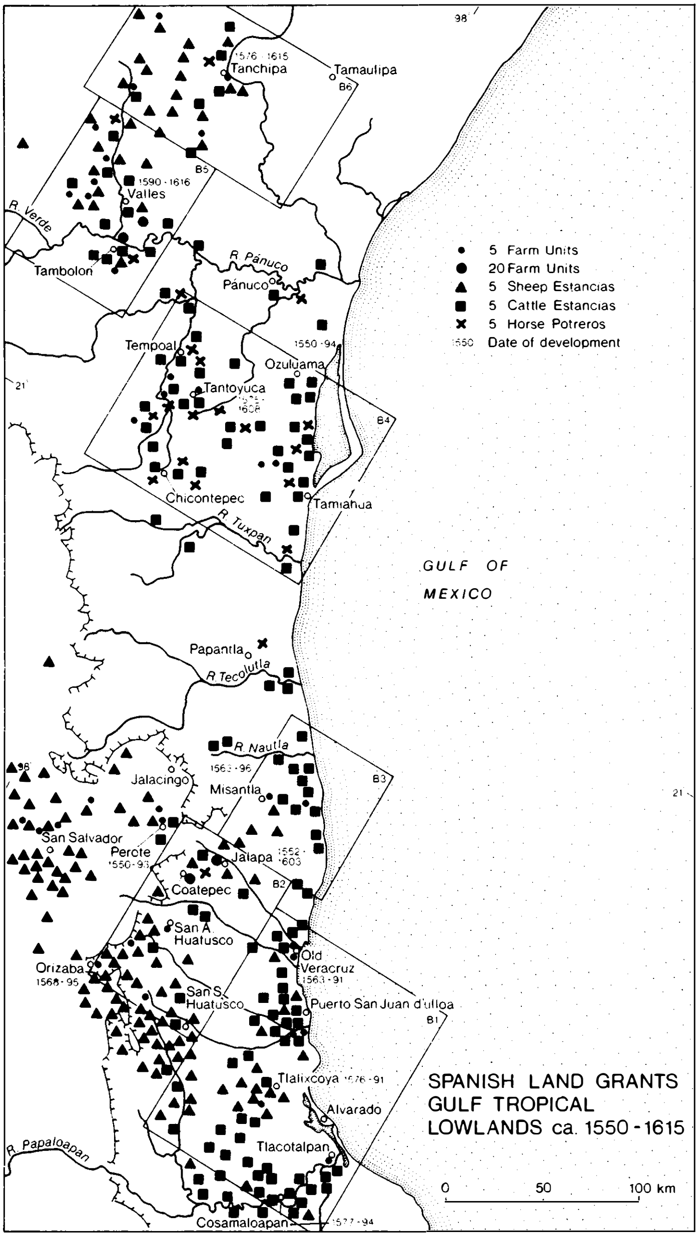

Figure 3. Overview map of Spanish land grants in the Gulf Tropical Lowlands, as awarded about 1550-1615 (see B 1 to B4, Figure 1). The different clusters were opened up for Spanish acquisition at various times, and only after these districts were almost totally depopulated as a result of epidemic disease. Indian settlement and land use continued without interruption in the "blank" areas of the map.

also ranged through an immense, thinly populated area of as much as 150 000 km^2, with a stocking rate as low as one head per hectare.

It should not be assumed, however, that feral cattle could multiply indefinitely in the *tierra caliente*. For one, there were effective feline predators for calves, and various parasites, especially along the Pacific littoral, that substantially undermined bovine health (see Acuña, 1987: 459). More important, perhaps, is that mature tropical dry forest (*selva baja*) provided very poor browse and only on a seasonal basis. Alternative, grassland settings were limited to the Gulf Lowlands, but these were dominated by coarse, tall grasses that became unpalatable and only minimally nutritional without fire management (Paso, 1905c: 195). Figure 1 identifies the important centers of cattle-raising that emerged in the Gulf Coastal Lowlands. It also shows the key, documented trails used to drive cattle from distant breeding pastures in the Gulf Lowlands or Nueva Galicia to the great urban meat markets of Mexico City and Puebla.

(d) *Estancias* for horse and mule breeding (*potreros para yeguas*) were found mainly (over 60%) in the tropical Huasteca. About 200 such titles suggest a minimum of 100 000 equines on such stud farms, although a figure of 150 000 is more probable.

According to our tallies, over 10 000 *mercedes* were awarded up to 1643, totalling perhaps 17 000 units of land. Table 1 details 10 000 such units, representing almost 45 000 km^2. Extrapolating to the remaining areas, we estimate that 23% of the 250 000 km^2 of what are now the seven states of Veracruz, San Luís Potosí, Guanajuato, Querétaro, Hidalgo, Mexico State, and Puebla had been formally awarded to Spaniards. With considerably less confidence, we further estimate that some 15% of the 500 000 km^2 territory of Nueva España had been legally converted into Spanish holdings. Considering that the records are incomplete and that many properties were initially acquired without proper titles, these values were probably closer to 40% and 25% in reality.

The larger picture of Spanish land grants in Nueva España suggested by Figure 4 shows that they were notably clustered around an axis extending from Veracruz to Mexico City, Zacatecas, and beyond. Many of the remaining areas were forested mountains or less attractive tropical lowlands. But other sectors with few land grants remained populated by relatively intact Indian groups: the Tarascan heartland of Michoacan, the Mixtec and Zapotec regions of Oaxaca, or the great mosaic of Totonac, Nahua, Otomí, and Huastec landscapes between Jalapa and Valles, to mention major regions with minimal Spanish intrusion. The *mercedes* are unambiguous for the woodland environments of the Sierra Madre Oriental, where Spanish *estancieros* were systematically expelled by the viceroy. On a more detailed scale, it is apparent that land was only opened up for settlement when the Indian population had dwindled away, to the point that residual populations of less than a dozen or so families were moved to larger nuclei (*congregaciones*). Thus a substantial part of the unawarded land was deliberately reserved as *patrimonio primitivo* (traditional Indian lands). We hazard a guess that some 45% of Nueva España remained *patrimonio*, in the viceregal vision of things. That leaves perhaps 30% non-agricultural domain or *tierras baldías*, mainly forested mountains or semidesert, thinly settled by more mobile Indian groups.

A semiquantitative estimate for Spanish land allocations and livestock raising in Nueva España is presented in Table 2, as representative for the period about 1620-50. We emphasize that this is an estimate, since our completed documentation covers only 40% of this area, but almost 60% of the titles awarded. In depicting this information as a map (Figure 4), we move into a more impressionistic arena, particularly for the southern and western parts of Nueva España, and for the delimitation of the *patrimonio primitívo*. This cartographic assay is nonetheless based on a substantial body of hard data, leading us to conclude that the map of Chevalier (1952, 1963) is unreliable.

In order to provide a broader picture for preliminary comparison, Figure 4 has been extended to include Nueva Galicia, Nueva Vizcaya, and Nuevo León, based on the district compilations of Gerhard (1982), as well as on a variety of sixteenth to seventeenth century primary reports, and a first inspection of the Monterrey Municipal (Ramo Civil) records (see also Cavazos, 1961). For these areas the map represents no more than a second approximation, rendered particularly difficult by the widespread conversion of cattle *estancias* to sheep pastures in Nueva Galicia during the 1600s. Bounded by vast *tierras baldías*, Spanish livestock will also have grazed far beyond the limits shown, which demarcate areas with seventeenth century *estancias*.

The Indians and the Spanish Livestock Economy

Whatever its flaws in detail, Figure 4 gives a representative overview of the patterns of dominant land use and land allocation among Indians and Spaniards by the mid-1600s.

These patterns can be examined at different scales, with different levels of resolution.

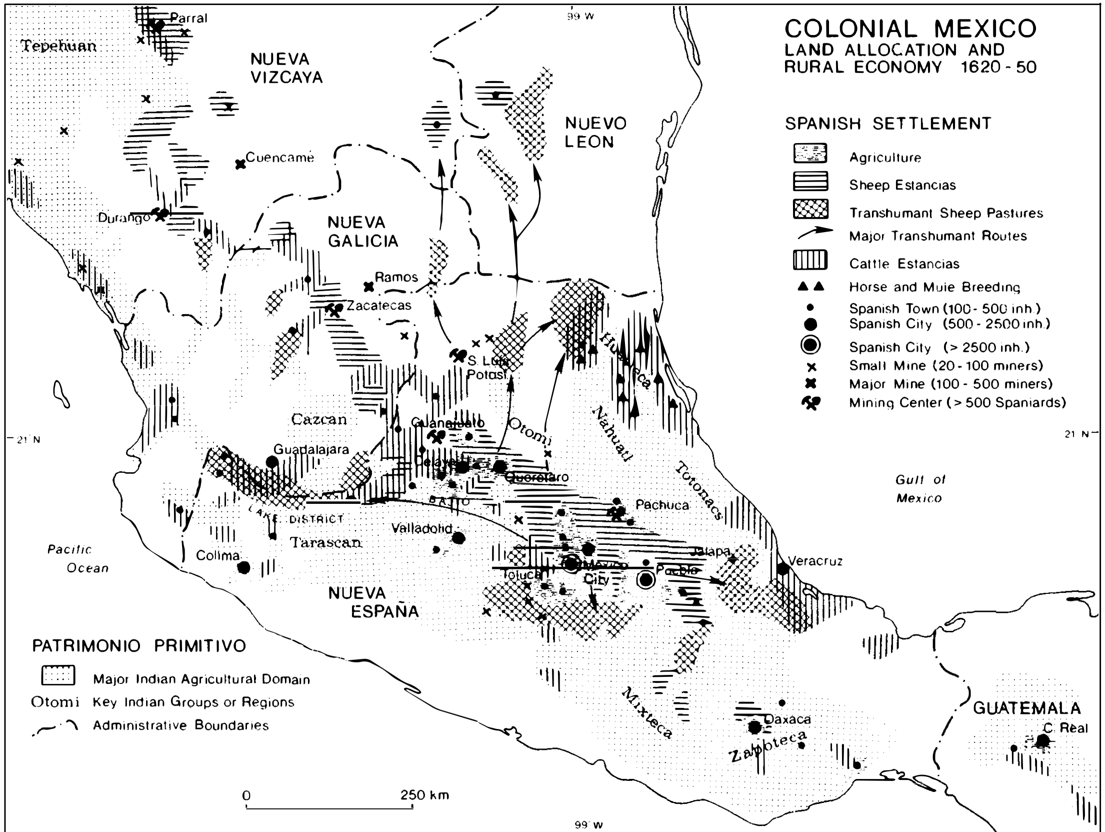

Figure 4. Land allocation and rural economy in Colonial Mexico, about 1620-50. The boundaries for agricultural areas and pasture zones are impressionistic, and the data base for Nueva Galicia and Nueva Vizcaya is minimal. The several regions of relatively undisturbed Indian agriculture are significant, and the channelling of Spanish economic activities reflected both policy and choice.

(a) At the macro-scale it is striking that vast areas of traditional Indian agricultural settlement in Nueva España remained almost undisturbed by direct Spanish intrusion. With the demise of the *encomienda* system and its labor demands, these areas were reorganized and dominated by the missionary orders, to be converted into a kind of theocracy.
(b) A substantial part of Spanish settlement spread beyond the margins of agricultural settlement, which in 1519 lay south of the Bajío. Almost all settlement expansion after 1700 was directed to the *tierras baldías* of the north.
(c) Most of the concentrated Spanish settlement in Central Mexico coincided with the core of the former Aztec state, although there was encroachment on the lands of Spain's Tlaxcalan and Otomí allies.

At a smaller scale the documentary record shows unambiguously that, at least at the level of viceregal policy, Indian farmland was not to be dispossessed. Despite the pressures to create a hinterland of wheat-producing farms in the Basin of Mexico, less than 15% of the land titles eventually granted here had been awarded before the mid-1560s. Even in 1640, only 75% of that region had been legally allocated to Spaniards, although the true figure was certainly higher. Although the absence of preserved land grants during 1545-49, 1557-59, and 1569-72 is commonly interpreted as a matter of lost record books (e.g. Simpson, 1952; Prem, 1992; Melville, 1983), these years also coincided with demonstrable shifts in viceregal policies (see Hanke, 1976-77; Sarabía, 1978), made in response to spates of livestock infringements on Indian lands, during the tenure of Mendoza and Velasco, and in the last case reflect the deliberate caution of Viceroy Martín Enríquez (1568-80), during his first five years of office. So, for example, Mendoza during 1544-47 was preoccupied with seeing to it that cattle *estancias* in Oaxaca and the Llanos de Ozumba were sold and converted to sheep raising, because of the flagrant damages caused by uncontrolled cattle herds. Velasco faced more universal problems and, after receiving several, increasingly impatient, royal *cédulas*, 1555-56, simply stopped granting land until matters were again under control. How successful he was can be judged by the fact that around 1580 the only cattle left in Puebla state were a few wild herds, hiding in the forests of Malinche and Popocatepetl (*relaciones* for Tlaxcala and Tetela del Volcán, see Acuña, 1984: 72, 1986: 269).

The grants were indeed issued in "waves", until the 1630s, reflecting fluctuations in policy, and the flood of titles awarded between December 1560 and early 1568 must be interpreted in such a fashion.

The conditional clause attached to each title, that the award not be prejudicial to the Indians or other third parties, were not mere formalities. Before a title was actually granted, the prospective owner was required to submit a petition describing the land parcel desired. This prospective area had to be visited by the royal magistrate of the nearest town, and if not in evident conflict, the request was proclaimed at the local church before Sunday services. Only if there was no protest was the award actually made, typically a year or two later. Land could not be awarded if already cultivated, or if within 500 *varas* (yards, later 700) of the outermost house of an Indian settlement. This did not protect Indian commonage, but if the impact of introduced herds was indeed deleterious, months later the matter did come up for renewed adjudication, and not infrequently the title was declared void. In some outlying areas, the Indians were probably cowed by local magnates and did not protest a potential award, as advertised; but the fact is that fully a third of the petitions made for land, especially in the years 1590-1620, were never granted. In general, therefore, the policy did work, despite innumerable cases of fraud, intimidation, or illegal "purchases" for ridiculously low prices (see Prem, 1978, 1992).

The acceleration of land granting in the Indian heartland after 1560, and especially after 1590, primarily reflected the Indian demographic collapse. As populations declined, especially after the epidemics of 1545 and 1575 (Prem, 1991), traditional cultivated lands were increasingly abandoned, and many grants were explicitly made for such *tierras eriazas*. Eventually, communities that had almost disappeared were consolidated in new locations by the missionary orders. Villages were also abandoned for various reasons, but primarily to escape *encomienda* work demands. The lands of an abandoned community would then be "opened up" for a spate of new titles and new settlers. But the viceroys were very clear about reserving agricultural land for agriculture, and abandoned farm lands were never awarded to stockraisers.

Some clusters or regions of Indian settlement remained viable, while others did not. As a result, outside of the Basin of Mexico, the Spanish land grants are noticeably clustered, with large areas devoid of grants between several such nuclei in the Valle de Toluca, southeast of Puebla, or along the Gulf Coastal Plain (Figure 3). In some cases, those areas without grants still show strikingly different field and land use patterns today, for example in the Huasteca. Such cases bear testimony to the basic efficacy and sincerity of viceregal policy during the sixteenth century.

Given the hundreds of recorded appeals to the viceroy to redress livestock damages to Indian lands, the question remains whether -- as already alleged by contemporary Spanish writers such as Zorita (1585: 269-71) and Torquemada (1610) -- village depopulation or abandonment was indeed caused by a lack of government intervention, to stop persistent grazing and trampling of standing Indian crops. The record of such appeals that reached the viceroy's office is primarily preserved in the *ramos mercedes* and *indios*. The language generally follows a formula, that without redress a particular village will be abandoned. It is important to recognize that livestock depredations are inevitable with open-range grazing, and that the *mesta* organization in Mexico, as its counterparts in Spain (Marín, 1987) or Italy (Marino, 1988), was designed to adjudicate, and where necessary, arrange for payments against damages (Dusenberry, 1963; Bentura, 1787). Only those cases that were not satisfactorily resolved came to the higher court of the Audiencia. If that court decided in favor of the Indians, the stockowner was severely fined, beyond the damages that had to be paid through the offices of the *mesta*. Some such claims were spurious, and even Velasco, who was a stickler in regard to Indian rights, is on record that it was not uncommon for Indian villagers in some areas to deliberately plant new fields in designated grazing areas in order to collect damages. But litigation was expensive and often took years, facts which inevitably worked against the Indians.

An examination of Indian claims for damages to the Audiencia shows striking temporal and spatial patterns. A wave of Indian complaints followed the spate of land grants in 1542-43 and again 1550-56. These were indeed adjudicated, and resulted in years of land-granting freezes. That the stockowners were effectively disciplined by Velasco can be gauged by the paucity of Indian complaints following some 1500 awards during 1561-67. Problems only resurfaced in 1590, under Luís de Velasco the Younger, who issued almost 2200 grants during his five years in office. The younger Velasco, himself a major livestock owner, evidently was an ardent advocate of settlement expansion, and titles no longer included the explicit condition of not being prejudicial to Indian rights. But even if we allow that Indian protests had become subdued, it is striking that the great majority of such appeals to the high court came from a very few outlying areas, such as Michoacan, probably reflecting the disinterest of local or regional authorities in resolving cases that favored the Indians.

We do not contend that open-range grazing was without negative consequences for Indian livelihood, settlement continuity, or demography. But government policy in the matter was benign and basically effective, and damages were contained. This is an important point to which we will return in discussing land-cover change. Indian demographic decline was overwhelmingly due to epidemic disease (Whitmore, 1991; Prem, 1991), and it was that decline which made possible the expansion of Spanish livestock and agricultural activity, not vice versa. Spanish colonial administration, once established, was one of rule by law, by laws that applied relatively consistently to all peoples. In this, Spain was centuries ahead of Britain, France, or Portugal, or for that matter, the European colonial powers in Africa around 1900, not to mention the United States during the nineteenth century.

In focusing on the negative impacts of introduced European livestock on the aboriginal populations of the New World, it is easy to overlook the potential benefits. Since the beginnings of agriculture in the Mediterranean Basin, agriculture and livestock have been complementary strategies that reduce subsistence risk (Butzer, 1988b). Climatological anomalies that impair productivity for one of these components commonly do not affect the other, and adult goats, for example, were only slaughtered during years of harvest failure or extreme scarcity.

In the Americas, the first and most enthusiastic adoption by the Indians of domesticated stock was of Old World chickens, which were hardier and more productive than indigenous poultry. In South America, pigs and sheep were also adopted early, particularly in the Andes (Gade, 1992), where the indigenous population had the requisite experience in dealing with domesticated llamas. By 1600 cured hams and cheeses were produced by Indians of Ecuador and Peru on a large scale for commercial purposes (Vázquez de Espinosa, 1629), providing a source of cash income or for tribute payment. More importantly, perhaps, sheep provided an opportunity to utilize high-mountain pastures that were too cold for cultivation, in order to produce meat, milk and its by-products, as well as wool. Pigs, on the other hand, could process domestic garbage in settlement areas, to provide a regular source of meat for home consumption. Without any doubt, these were significant benefits.

In Mexico, the transfer is more ambiguous. Many of the *relaciones geográficas* of about 1580 do not mention pigs, sheep, or goats as standard livestock kept by Indians, suggesting a delayed transfer that might be attributed to Mesoamerican lack of experience with larger domesticated animals. However, ordinances by the *cabildo* of Mexico City in 1526 repeatedly interdicted bringing pigs into town to sell at market or to raise in the city; since only one of three such zoning laws mentions a monetary fine (see Orozco y Berra, 1859: I, 72, 106, 108), Indians evidently were among the offenders. Viceroy Mendoza urged the Indians to run livestock (Torquemada, 1610: I, 611), and already in 1544 Indians were ordered to pay tithes on their livestock (Puga, 1563: f. 149). Encouragement to keep all kinds of livestock were reaffirmed in 1550 and 1551 (Solano, 1991: Nos. 56, 59). By 1560 some Indian communities or dignitaries were receiving licenses to run flocks of 12 000 to 28 000 sheep (Simpson, 1952: 14), and Muñoz Camargo, the indigenous chronicler of Tlaxcala, tells us (about 1579; see Acuña, 1984:

88) that in ten years his own herd of merino sheep had expanded from two animals to 10 000. In Nopaluca, Indian sheep owners eventually came into competition with their Spanish counterparts, requiring annual visits by officials of the *mesta* in the 1570s. Although Indians acquired land titles to many sheep *estancias* in some areas (Llanos de Ozumba, Valle de Tula, Mixteca), this does not seem to have been a prerequisite to them keeping substantial numbers of small stock. Although Indians rarely kept cattle, Ciudad Real (1591: I, 57) implies that most Indian towns had busy, illegal slaughterhouses for "stray" cattle, providing cheap beef.

In effect, the *relaciones geográficas* appear to have misrepresented the wholehearted acceptance of Mediterranean livestock by the indigenous population, perhaps because their management techniques were informal and, in most regions, implemented on a domestic scale. Quite apart from the reduction of subsistence risk, the nutritional impact of abundant meat for societies probably suffering from protein shortage in pre-Conquest times must have been highly significant for the Indians of New Spain.

There also were other important benefits. The Spaniards introduced the first transport animals to Mexico. Previously all heavy land cargo had to be carried on human backs, a practice gradually made unnecessary as the Spaniards built a network of wagon roads for mule trains. Eventually *burros* became cheap enough for Indians to buy and breed, greatly reducing labor requirements. In a similar vein, the rapid dispersal of the domesticated horse among the Plains Indians of the North America beyond Mexico after 1720 is credited with the rapid florescence of the Plains Hunting Cultures, that ended with the demise of the buffalo after 1865, as a consequence of American or American-sponsored overkill.

Last, but not least, domesticated livestock provide large quantities of manure, vital to replenishing soil fertility on a much larger scale than any available prehispanic technique (see Rojas, 1988). In the Mediterranean world, grazing on stubble is very much a reciprocal arrangement, welcomed by the traditional farmer as an indispensible means to maintain crop productivity. The impact of animal manure on indigenous fields, beyond the kitchen garden, must have been enormous in terms of increased crop yields, certainly compensating for episodic crop losses to uncontrolled herds.

In evaluating the overall impact of the introduction of Mediterranean livestock to the New World upon indigenous lifeways and quality of life, there evidently were serious problems in regard to competition for land, but the clear benefits for reduced subsistence risk, improved nutrition, and greater crop yields (see Rincón Mautner, 1988) must have outweighed the drawbacks.

Environmental Impacts of the Livestock Economy

The theme of ecological change or destruction by Mediterranean livestock is one that continues to be argued more as a matter of principle than in the arena of empirical evidence. Two different assumptions are commonly invoked in such presentations, both ultimately shaped by ethnocentric preconceptions.

(1) *An old and deep-seated bias by North European scholars and travellers against Mediterranean pastoralism*. Since the eighteenth century Enlightenment, visitors from France, Germany, Britain, and the United States noticed that the topography of the Mediterranean lands is more angular; that soils are thinner and of different color; that woodlands are few, open, and have low canopies; and that smaller streams almost disappear during the dry season. Unable to understand that the Mediterranean world represented a different environment, with a different earth history, they tended to assume that this was an impoverished landscape. Later archaeologists would assume that all monumental ruins in the Aegean world or North Africa had once graced a green, garden landscape reminiscent of a Berkshire estate, but that nomads had subsequently plundered the land of its natural richness, so much so as to change climate for the worse. Next came the Colonial or Unesco agricultural specialists, who identified sheep and especially goats as an environmental curse, and their efforts to eliminate pastoralism have recently been emulated by regional government agencies.

Today the animals are gone, and the open woodlands are suffocating in an undergrowth of thorny *matorral,* waiting to explode in periodic fires that destroy more timber than any army of voracious goats ever did. Pollen evidence shows that after distinctive, Neolithic to early Bronze Age experimentation, the Mediterranean woodlands have been more or less continuously managed as an artificial ecosystem that, on the whole, was sustainable (Harrison, 1985; Butzer and Martí, 1991; Boyazoglu and Flamant, 1992; González-Bernáldez, this volume). Cumulative damage to the soil mantle was no greater than in northern Europe, as studies of alluvial sediments show. But the pastoral sector of the economy continued to reduce subsistence risk, while providing the fertilizer critical to sustained crop productivity (Halstead, 1987). The acute risk to the Mediterranean ecosystem today has nothing to do with Bronze Age goats or Medieval sheep. It is first and foremost a matter of water contamination by industry and sewage. Livestock can indeed be very destructive to the environment, when poorly managed. But the mounting biophysical evidence shows that, historically, equilibrium management was the rule, rather than the exception. Over 200 generations of sedentary peoples were thereby sustained, quite successfully.

(2) *The implicit or explicit premise that the precolumbian Americas were ecologically pristine, and that introduction of the European agrosystem drove New World ecosystems to disequilibrium*. For centuries it has been assumed that, prior to 1492, New World populations were small and lacked the technology to significantly transform their environments. Recently, some militant ecologists and Native American activists have refashioned the Renaissance myth of an American Eden, to claim that New World peoples lived in harmony with nature, deliberately refraining from altering their environments, and that they somehow succeeded in maintaining an idyllic ecological equilibrium (e.g. Sale, 1990). Europeans, by contrast, had a ruthless land ethic, were driven only by materialistic goals, and introduced an agrosystem that was, by definition, harmful. The result was environmental destruction of apocalyptic proportions.

This picture is simplistic and flies in the face of two generations of research that has verified teeming populations in some parts of the New World (Denevan, 1992) -- real people whose nutritional requirements demanded that priority be placed on survival, rather than an abstract ideal of ecological integrity.

All forms of subsistence technology change land cover and *potentially* can degrade the environment, both New and Old World. The technologies introduced by Columbus or the Pilgrims were potentially destructive or wasteful, but they were puny compared with those of the Industrial Era. When and where and to what degree such new technologies fundamentally altered, let alone destroyed the environment of the New World must be determined empirically. Did such alteration attain regional significance in the first century after settlement, or only during the nineteenth century, with the aid of far more powerful, industrial technologies? Finally, is there a statute of limitations for blaming everything on "Europeans"? Livestock, for example, were introduced 500 years ago and, in the meanwhile, many different adaptive strategies for their use have long been developed, in the New World, by peoples who by any criteria deserve, let alone claim to be indigenous. As much as we lament the tone of the Columbian polemic, we are enthusiastic about the impetus it will surely provide for a new generation of active research on the environmental history of the Colonial Americas. Much has been done during the last decade, but it tends to be isolated, sometimes incidental, and commonly is published, if at all, in relatively obscure media.

Large parts of central and southern Mexico had been converted to agricultural landscapes before the arrival of the Spaniards (Whitmore and Turner, 1992). Archaeological evidence further verifies long periods of fairly dense settlement during the middle of the first millennium A.D. ("Classic") in several areas, as well as a few earlier nodes of agricultural activity dating back a millennium further ("Formative"). Various lines of paleoecological work confirm this, verifying land-cover change, at times quite substantial, back to at least 3000 B.P. The question then is whether Spanish land use was qualitatively and quantitatively different than that of the prehispanic occupants, possibly expanding or intensifying land-cover changes.

Both qualitative arguments and semiquantitative estimates can be offered that the aggregate area of land use in Nueva España *decreased* substantially after 1519, despite Spanish colonization efforts and land acquisition. This was entirely a result of Indian population decline, the full implications of which for land abandonment -- and changes in land cover --have to be considered:

(a) Archaeological and paleoecological evidence (as discussed further below) is consonant with the high population estimates extrapolated back to 1519 on the basis of Spanish records of the mid- to late 1500s. These estimates vary from about 10 to 25 million, depending on the author and the assumptions used, for the area here defined as Nueva España (Figure 4). We favor the lower end of this range, which approximates that of the region in 1910, after initial industrialization and completion of the railroad network. That would compare with a total population of perhaps 1.5 million around 1620-50, when the indigenous population was at its nadir and Spanish and mixed-race numbers still were small (about 200 000) (see Cook and Borah, 1974: Table 2.1B).

(b) In the Basin of Mexico the archaeological evidence indicates a sustained population growth at an annual rate of 1.0% during the 150 years or so prior to the Conquest (Butzer, 1992a). This is a veritable demographic explosion that would have required a considerable expansion as well as intensification of agricultural land use. The cultural landscapes of central Mexico in 1519 bear this out, with extensive agricultural landforms (such as *chinampas*, semiterracing, and terracing) and an expansion and greater complexity of irrigation networks (Whitmore and Turner, 1992). Presumably this would also have put considerable pressure on adjacent woodlands on rougher terrain used for fuel and timber. To support even a conservative population figure, marginal and unirrigated cropland would have had to be cultivated on a perennial basis (Williams, 1989). Not surprisingly, excessive pressure on sloping, marginal land led to prehispanic soil erosion (Werner, 1986; Carlos Córdova, pers. comm., 1992).

(c) Indian demographic collapse 1519-1620 as a result of epidemic disease led to widespread abandonment and sale of indigenous cropland (Prem, 1992), and presumably also to disintensification in those areas not abandoned. As a small minority, the Spanish settlers were almost totally dependent on indigenous labor, which remained in short supply well into the eighteenth century. Consequently Spanish agricultural activities could not possibly pick up the slack, from which it follows that areas of earlier indigenous agriculture could not all be kept in cropland, and even areas of persistent farming would have been subject to some disintensification. This can be illustrated by the hypothetical scenario of Table 3, which assumes an indigenous population of 10 million in 1519 and 1.3 million in 1620-50; further assuming 4.0 persons per family in 1519 (with demographic expansion) and 3.3 per family in 1620-50 (with demographic regression), the number of households would have declined from 2.5 million to 0.4 million. Setting an arbitrary figure of 10 ha of land permanently or periodically cropped by one household, and assuming that urban families without farm plots would need to be similarly supported, the total area directly affected by agricultural activities would have declined from 250 000 to 40 000 km^2. Yet only 4000 km^2 of cropland were awarded to Spaniards, including the new agricultural districts of the Bajío (Table 2). Even if this figure is incomplete, and is rounded up to 10 000 km^2 to include occult purchases, it implies that cropland was reduced by about 80% in less than 100 years. Changing any of the initial assumptions, within broadly acceptable limits, would only increase the estimated decline. In effect, this conservative scenario argues that the abandonment of cropland (or the implied conversion of cropland to pasture) was catastrophic, and the Spanish colonists were not even remotely capable of making up the difference.

(d) If the high estimates of sheep, cattle, and horse pasture land of Table 2 are used in Table 3, the total area of Spanish effective land use is increased by 125 000 km^2, but that still leaves 75 000 km^2 (30%) unutilized or underutilized, by the standards of 1519. The implication is that substantial areas, especially outside of the Basin of Mexico, were allowed to revert from cropland or fallow to woodland or scrubland, presumably used seasonally as off-site pasturage. A corollary inference is that, despite Spanish interdictions against giving *estancia* titles for former cropland, most of the *estancias* granted outside of the environs of Mexico City and Puebla (and within the former sedentary zone) must have been located on abandoned indigenous farmland. That would certainly be the case in the *tierra caliente*, where vegetation specified in the land grants (in area B1, Figure 3) after 1575 suggests a "cultural savanna" with characteristic *coyole* palms, and local clusters of prehistoric mounds (*cués*) or of agaves and prickly pear (*maguey*, *nopal*).

Table 2. Summary Estimates for the Spanish Land Allocation in Nueva España, 1620-50

Area of Veracruz, San Luís Potosí, Guanajuato, Querétaro, Hidalgo, Mexico State, Puebla	- about 250 000 km^2.
Agricultural Land *Caballerías* awarded to Spaniards	- about 9000 titles (close to 4000 km^2); - 58% within 120 km of Mexico City; 20% in Bajío.
Sheep Grazing (*Estancias*)	- about 2000 titles for home-base *estancias* (15 600 km^2 recorded, but probably closer to 25 000 km^2); - almost exclusively on plateau, eastern Puebla to eastern Bajío; - about 1000 titles for winter pastures (*agostaderos*) (7800 km^2, but probably closer to 25 000 km^2); - representing 6 to 8 million sheep.
Cattle Grazing (*Estancias*)	- at least 2000 titles awarded (35 000 km^2, but probably closer to 70 000 km^2); - mainly in Gulf Lowlands, Toluca, western Bajío, and Jalisco lake district; - representing 1.5 to 2 million cattle.
Horse and Mule-Breeding (*Estancias*)	- about 200 titles awarded, mainly in the Huasteca (3500 km^2, probably representing some 5000 km^2); - representing perhaps 150 000 equines.
Area of Nueva España	- about 500 000 km^2.
Land Controlled by Spaniards	- about 130 000 km^2 (26% of Nueva España).
Indian Agricultural Domain (*Patrimonio primitivo*)	- perhaps 220 000 km^2 (44% of Nueva España).
Non-Agricultural Domain	- perhaps 150 000 km^2 (30% of Nueva España). (*Tierras baldías*)

Table 3. Scenario for Land-Use Change in Nueva España after the Conquest[1]

Period	Indigenous	European		Total	Total
	Cropland/Fallow	Cropland/Fallow	Pasturage	Agropastoral	Population
Before 1519	250 000 km^2	---	—	250 000 km^2	at least 10 million
Ca. 1620-50	40 000 [2]	10 000	125 000	175 000	about 1.5 million

[1] Based on assumptions listed in text.

[2] Implies disintensified use, by smaller families.

In effect, early Colonial land use marked a significant retraction compared with that during the decade or two prior to 1519. The next question is whether the new component of Spanish land use had a different or greater environmental impact than indigenous activities did before 1519. That can only be answered in part because the methods of environmental history do not provide the type of resolution that a biologist would require to assess range management or contemporary environmental impacts.

What we can do at this point is discuss the different categories of paleoenvironmental information currently available, and then amplify this specific information by sketching out some general inferences in regard to changing land cover. Contributions to the environmental history of the Spanish colonial era in Mexico include palynology and limnology, travellers descriptions, vegetation described in land-title deeds, soil erosion and changing hydrology recorded by alluvial geology, and documents referring to tree-cutting and the use of fire to modify vegetation.

(a) Detailed pollen cores have been studied from the Gulf Coastal Plain (Tuxtla, southeast of Veracruz), the Basin of Mexico (Tlapacoyan, Teotihuacan), Tula, Michoacan (Lakes Zacapu and Patzcuaro), the Bajío (Parangueo), and a number of shorter cores further north and west. These materials have been presented, reviewed, or discussed by Brown (1985), and also Butzer (1992a), Butzer and Butzer (1993). In each case, the major periods of ecological disturbance predate the Spanish Conquest, most pertaining to the Classic or Early Post-Classic, but some also to the Formative. The Colonial period, as recorded by very few samples in such profiles, saw only moderate levels of disturbance, in part with some degree of forest regeneration or improvement of grass versus compositae, in part with subsequent evidence of increasing disturbance, during the eighteenth or nineteenth centuries. In no case does the historical segment of these profiles include any early phase of weed explosion and arboreal decline. The available pollen cores do not, therefore, record significant environmental disruption after the Conquest, and at least not until the eighteenth century.

(b) A comprehensive limnological study from Lake Patzcuaro (O'Hara *et al.*, 1993) now provides a three-dimensional picture of a catchment and its changing soil landscape over time. Three protracted episodes of soil erosion are indicated, the first beginning before 3000 B.P., the last approximately A.D. 1200. Neither mineral sediment nor charcoal increased after the Conquest, despite considerable Spanish settlement and seasonal stockraising in the basin since the 1540s. The results of this compelling study do not stand alone: lakes next to Classic Maya sites in northern Guatemala also show sustained accumulation of clays, organic matter, and phosphates in lake cores during the period of indigenous occupance (Rice *et al.*, 1985). These cases imply that the burden of proof now lies with those who claim that cumulative Spanish land use was more environmentally destructive than its indigenous counterpart.

(c) Spanish officials of the sixteenth century were excellent environmental observers, leaving numerous good route descriptions or district reports. Our evaluation of this record --including the *Suma de Visitas* of about 1550 (Paso, 1905a/b), the parish reports of about 1570, over 200 *relaciones geográficas* of 1577-85 (e.g. Acuña, 1984, 1986, 1987), the Ciudad Real (1591) diary of 1585-89, and the Mota y Escobar (1605, 1623) descriptions of Nueva Galicia (around 1605) and the diocese of Puebla-Tlaxcala (about 1608-23) -- permits a comprehensive overview of vegetation during the period 1550-1620. Large-scale patterns of physiognomic vegetation recorded on the aerial photography of ca. 1970 (and its derivative topographic maps) are quite similar to those of the earliest Spanish reports that date within a few decades of the first livestock grants. Several Indian maps accompanying the *relaciones* also represent vegetation well, including complex communities of succulents and agaves that require many decades to establish (e.g. for Zempoala, see Butzer and Williams, 1992), in the same places they are found today. This all supports the pollen evidence, that the basic distribution of forest, live-oak steppes, and *matorral crasicaule* observed today was already established in prehispanic times, and that there is no apparent evidence of degradation during the late 1500s. By contrast, travellers of 1765-1830 (Ajofrín, Morfí, Berlandier) describe examples of patently degraded vegetation north and northwest of the Bajío. Relevant here is that the intendant of Guanajuato in 1796 was ordered to inaugurate a program of afforestation, to revitalize timber growth, protect the water supply of the town, and prevent erosion (Dusenberry, 1963: 170-71).

(d) For the Bajío we have assembled some 250 descriptions of local vegetation and hydrology, recorded in title deeds dating from 1542-91, and compared these with the same settings today (Butzer and Butzer, 1993). They show that woodland was slightly more expanded; that unlike today, rivers were accompanied by dense riparian forests of mesquite or *Taxodium*; and that there was no tangible evidence for disturbance after 50 years of stockraising in areas of Spanish settlement. Some of the riparian forests have only been destroyed since the 1830s. In some areas of traditional Indian agriculture, however, the vegetation was degraded, and in one case a Spanish observer interpreted a forest clearing with disturbed vegetation as *prima facie* evidence for an abandoned Indian settlement. Melville (1983, 1990) has assembled evidence from the *mercedes* for the Valle de Tula, claiming significant degradation after 1590. We disagree with some of her criteria (Butzer, 1992a), and our ongoing analysis for 1592-1642 for the area where our studies overlap does not support her conclusions.

(e) The most sensitive indicator of ecological change across a watershed is provided by floodplain sediments, because degraded vegetation and soil erosion lead to accelerated alluviation by higher peak floods. In the Laja drainage near San Miguel, there was no change in hydrology from before 1500 until about 1750 or 1800 (Charles Frederick, pers. comm., 1992). The earliest destructive floods in the Bajío (Guanajuato, Celaya) are recorded from the mid-1700s. Similar alluvial studies are currently underway in the Basin of Mexico and in Oaxaca by C. Córdova, C. Frederick, and C. Rincón Mautner at the University of Texas.

(f) The *mercedes* also include licenses to cut trees and interdictions against burning pasture. It is well known that 6000 timbers were cut shortly after the Conquest to provide beams for the government palace in Mexico City. This is not excessive in light of data from Medieval Europe, that 500 to 600 beams were required for an average church roof, and ten times that many for a monastery (Haas, 1990), values identical to those cited from Mexico City during the 1500s. The *cabildo* of Mexico City directed that timbers should be cut in the mountains, so as not to eliminate shade trees and windbreaks for pasturage in the foothills (so in 1533, Orozco y Berra, 1859: III, 56-59). During at least the 1540s and 1550s timbers for construction could only be cut by license. The accelerated building of churches and monasteries from 1560-90 must have led to considerable deforestation in limited areas that were also used to graze sheep. The mountain streams of the Basin of Mexico nonetheless continued to provide a reliable source of water for irrigation, grist and fulling mills, as well as sawmills, at least through the 1630s, judging by licenses granted. The voracious demands of towns for timber and fuelwood was not a uniquely Hispanic trait: the steep uplands around Classic Copan (Honduras) were more or less totally deforested (Abrams and Rue, 1988), and in the Guatamalan Classic Maya region, the Petén rainforest was completely removed during the same period (Vaughan *et al.*, 1985). It evidently does not require iron axes or sheep and goats to denude commonage!

(g) Whereas the Indians did not use fire in hunting drives (see Torquemada, 1610: I, 611-12), after the Conquest Indian or African herders burned pastures to improve grazing for their employers' livestock. The practice was severely fined by the viceroy, based on early *mercedes* from Toluca and Michoacan; yet Ciudad Real (1591: II, 128-29) in 1587 described such deliberate burning of transhumant sheep pastures in Jalisco. The Spanish practice to periodically burn *matorral* must have been transferred to the New World, and apparently was difficult to stop.[2] In 1571, the parish priest of Veracruz also described how fire was used to remove old, non-nutritive savanna grasses every two years (Paso, 1905c: 195). These isolated examples suggest that fire was used, perhaps commonly so, in pasture management. That would favor grass over *matorral,* and inhibit the expansion or regeneration of arboreal vegetation. Curious enough, despite the contemporary impact by *carboneros* on Mexican forests, we have not yet found early

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2. The expanded ordinances of 1574 for the Mexican *mesta* included a paragraph that declared setting fires in woodlands (*montes*), fields (*campos*), and savannas as disadvantageous in general and in particular, especially because it damaged livestock pastures (Bentura, 1787: II, 62, item 81). Other ordinances of 1579 stipulated that anyone setting a fire in the *monte* or around it, in a manner that might damage that *monte*, would be severely punished; other prohibitions in the same set included the cutting of trees, and the gathering of fuelwood by cutting a tree at the base, rather than its branches (Bentura, 1787: II, 68). In regard to the comparative advantages of burning in the Mediterranean Basin, see Trabaud (1991) and Lewthwaite (1981).

Colonial documentation referring to charcoaling activities.

This summary of a substantial body of information on potential vegetation and land cover change in early Colonial Mexico shows that the questions initially raised are difficult to resolve. We suggest several tentative conclusions:

(1) Prehispanic land use in some regions, and at different times, had profound environmental impact. This suggests that high population densities lead to significant biotic change and local degradation. Spanish settlement intruded on an environment already extensively used for agriculture, with partial removal of woodland.
(2) Spanish livestock raising and related management practices did not immediately lead to ecological deterioration, neither in areas beyond the agricultural frontier of 1519, nor in old settlement areas, where Indian demographic collapse simultaneously reduced population pressures. Whether the switch from indigenous farming to Spanish stockraising led to qualitative changes in the ground cover, such as shifts from grasses to compositae or woody shrubs, cannot yet be ascertained.
(3) In at least some areas, Spanish livestock practices eventually did lead to biotic degradation and soil erosion, probably during the eighteenth century, when overall population density increased rapidly. It is by no means certain that this was a general phenomenon; more probable is that landscape histories varied considerably from place to place.
(4) In at least some areas, soil erosion dates to Post-Colonial times, possibly the late nineteenth century. Most of the soil erosion conspicuous in several parts of Mexico today, such as badlands, gullying, or shoestring erosion, is quite recent. As often as not, it is the result of injudicious cultivation efforts.
(5) Despite such cases of ecological disturbance during the last 2500 years, in most regions the basic patterns of residual, natural vegetation probably continue to reflect climate, topography, and substrate as much as they do cultural intervention. Thus the Río Tula floodplain from well above Ixmiquilpan down into the deep gorge to the Moctezuma River confluence continues to be fringed by an unbroken riparian forest of ancient *Taxodium* trees, documenting long-term systemic equilibrium and landscape stability, in one of the bleakest environments of Central Mexico.

In sum, introduction of the Spanish livestock economy to Nueva España did not lead to dramatic ecological repercussions. There was land-cover change, but it was subtle and long-term, possibly remaining insignificant until two or three centuries after the

Conquest. The explanation for this apparently counterintuitive conclusion should probably be sought in the mobile, extensive management practices introduced to Mexico and derived from many centuries of Mediterranean pastoral experience. The Spaniards were evidently well aware of the dangers of overstocking animals on fixed, dry-season pastures, and adhered to a highly mobile management strategy, in order to limit environmental impact. That strategy happened to be detrimental to Indian farming, because of periodic trampling or devouring of crops. But the viceregal government made serious efforts to assure that damages were recompensed, by the same method of adjudication applied in the case of the Castilian *mesta*. In the meanwhile, the Indians profited from the subsistence security, balanced nutrition, and invaluable fertilizers provided by the much-maligned Old World livestock.

The Northern Livestock Frontier: 1650-1890

After 30 years of economic recession, with falling mine production and sales tax receipts (*alcabalas*), new silver strikes and fresh capital revived the economy of New Spain during the late 1660s. Thereafter, with exception of the crisis of the late 1690s, the economy continued to grow until the eve of insurrection in 1810 (see annual revenue data in TePaske, 1976). This process favored urban growth, proto-industrialization, and agricultural intensification in Nueva España. Further north it led to continuing settlement expansion, that shifted the center of livestock production toward the new and still unstable frontiers (Trautmann, 1986).

In Nuevo León, the number of transhumant sheep increased from 300 000 in 1648, to 555 000 in 1680, and one million in 1715. From its beginnings, the great *mesta* treks to Nuevo León had only been possible for wealthy owners, who sent individual flocks with an average size of 25 000 to 30 000 head into hostile Indian country, accompanied by up to a 100 *pastores* (Cavazos, 1961; Hoyo, 1972). The major attraction of modern Tamaulípas, Nuevo León, and northern Coahuila was the combination of winter rains and only sporadic frosts. While other pasture lands of Central and North Mexico were parched and dormant, those of the Northeast were green, and water was abundant (see Alonso de León in Cavazos, 1961). Flocks were pastured here from late November to late April. Then, after they had lambed, the endless lines of ewes and their young returned, to be sheared in the eastern Bajío, or driven on to the meat markets of Mexico City.

Owners of smaller flocks only drove their sheep intermediate distances, to safer *agostaderos* in the valleys or foothills on the Pacific or Gulf slopes--the Huasteca, Michoacan (Morin, 1979: 37-38), or Jalisco-Nayarit (Serrera, 1977). Whatever their targeted pastures, the transhumant sheep had to be very hardy to survive long trails etched through thorny or succulent scrub (*matorral e nopaleras*), with widely spaced waterholes (see Alonso de León in Cavazos, 1961). The fine-fleeced merino sheep of the sixteenth century had disappeared by Humboldt's time (1811: 299), leaving only the all-purpose meat and wool breed (*raza churra*). The hard plant debris embedded in the fleece was almost impossible to remove, with the result that textiles were generally woven from coarse and dirty wool.

After 1700 the trend was towards permanent stocking of the northern pastures. A small wool center developed in Saltillo, and both large and small owners of sheep or cattle began to establish themselves in Nuevo León. During the 1750s Tamaulípas, until then controlled by mobile or semisedentary Indians, was "pacified" by an elaborately planned military occupation and settlement program. In 1757, 914 000 sheep belonging to eight individual or corporate owners in Querétaro were wintering here. By 1795, there were 112 000 cattle, 389 000 sheep, and 141 000 goats resident in Tamaulípas, while in Coahuila one great estate ran over 200 000 sheep. On the eve of independence, there were a million cattle, 5 million sheep, a million goats, and 35 000 pigs in northern Mexico (see Florescano and Gíl, 1976), with perhaps another 5 million sheep in Nueva España (Humboldt, 1811). The era of long-distance transhumance in Mexico was drawing to a close, and much like in Spain, more local movements of animals (*travesío*) became increasingly characteristic, within a range of 30 to 80 km.

Meanwhile, around the margins of the Bajío and in Hidalgo, the rock-walled sheepwalks or *cañadas* not only continued to be used, but even expanded, as the interdigitation of livestock and agriculture became tighter, with sheep kept in mountain pastures during the winter, wheat growing season, then descending into the interstitial land among standing crops of corn, barley, and vetch during the summer (Butzer, 1989b).

The wars of independence (1810-21), marked by long bouts of guerrilla conflict, widespread banditry, and almost uncontrolled military requisitioning, threw the livestock economy into disarray and completely disrupted the Mexican *mesta*. With the return of peace, the herds were sadly depleted, start-up capital was lacking, and the uncompetitive regional wool centers succumbed to foreign, factory-made textiles, as trade barriers were removed. In Nuevo León, the number of sheep and goats decreased from 1 115 000 in 1810, to 661 000 in 1832, and 403 000 in 1850, while the proportions of sheep and goats were reversed. Thereafter large estates in northern Mexico favored sheep, while the rural population stocked goats for subsistence purposes. Only in New Mexico and Arizona, where Indian blanket weaving had become a lasting tradition, did the sheep population continue to increase steadily, until the end of the century (Denevan, 1967).

With Mexican independence, two centers of cattle-raising emerged north of the present border, in California and Texas. These were to play a major role in the settlement of the western United States. Alta California had 92 000 cattle in 1803, that expanded to 425 000 head by 1834. American occupation in 1846, followed by the gold-mining boom, created an immense demand for beef, with a corresponding expansion of the herds. It was from this Hispanic center of cattle-raising that cattle ranching in the American Far West -- counting almost 10 million head in 1880 -- was derived, particularly the secondary concentration in the Columbia Basin (Jordan, 1992).

In Texas, there were over 100 000 cattle during the late 1820s. Further cattle were then introduced to the eastern parts, from source areas in Florida and the Carolinas (Jordan, 1981; Jackson, 1986). In 1860, these herds had expanded to 3.5 million head, increasing to 4.5 million by the end of the Civil War (1865). Such phenomenal numbers of cattle, exceeding any previous counts in all of Mexico, only awaited market opportunities.

In 1867, cattlemen from Texas decided to drive a huge herd of open-range cattle some 700 km north, to the advancing railroad in Kansas. This major event opened the Abilene Trail, that created the phenomenal era of the Cattle Empire on the Great Plains (Bowden, 1980). The great spring trek to Kansas peaked with 700 000 animals in 1871, as the railroad network carried livestock to the burgeoning meat markets of Chicago and the East Coast. By then, a spectacular form of cattle transhumance began to span the whole of the Great Plains, from Texas to Montana, with the animals driven over 1500 km northwards in the spring and back again in the autumn, before the first snows. Cattle competed for the natural habitat of the buffalo. In 1884, a million head were driven north by 4000 *vaqueros* with 30 000 horses, marking the climax of the greatest transhumance system ever known.

But the days of the Cattle Empire were brief. Prices dropped as rail transshipment became efficient. Private ownership by homesteaders and small-hold ranchers began to close off the open range with barbed wire fences. Sheep vied increasingly for rangeland, and Wyoming in 1880 had 450 000 sheep in competition with 521 000 cattle, with the sheep spoiling pastures for cattle because of their habit of close grazing. Then, summer droughts and early blizzards hit the cattle transhumants hard during the decade after 1882. Finally, it was recognized, in 1886, that cattle could indeed be pastured on the northern Great Plains during the winter because the warm chinook winds, a foehn effect downwind of the Rocky Mountains, periodically melted off the snow. In a scant 20 years, this monumental cattle transhumance strategy, based on Texas, had become obsolete.[3]

By then, the American West was well on its way towards a more diversified economic development. Cowboys were rapidly displaced by farmers, miners, and small-town merchants, who looked eastward, to an increasingly standardized America, that stood under the sign of its new industries. The anachronistic pastoral economy lived on only in film and fiction. But, modelled so closely on the Spanish *mesta*, it represented the final act in the great drama of Hispanic livestock raising, an abrupt and stunning conclusion worthy of a play by Lope de Vega.

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3. Surprisingly enough it remains impossible to establish whether or not nineteenth century Anglo-American land use -- let alone a more specific question such as stockraising prior to the introduction of barbed-wire fencing -- led to local or general environmental deterioration in the Great Plains or West. Quaternary geologists and paleoecologists have not yet turned their attention to such fine-grained and applied problems, but equally important is the potential of using documentary evidence, which ranges from vegetation described in land deeds to early photography. Interesting is that Denevan (1967) found no correlation between nineteenth century Hispanic livestock numbers in New Mexico and the onset of gullying.

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CHAPTER 8

LAND-USE SUCCESSION IN THE GULF LOWLANDS OF MEXICO

Alfred H. Siemens

There were sizeable communities at many places along the Gulf Coast of Mexico at the time of contact. Drastic depopulation followed, as is well known, and repopulation was slow. Some distant areas, as in southern Veracruz and southwestern Campeche, cleared for use previous to the Columbian encounter, were not only reforested but were not used again until the second half of the twentieth century. Such vegetational or land-cover change is an important concomitant of occupance and reoccupance, but the evidence from the Gulf Coast accords only partially with what might have been expected. The land-use change that followed contact, on the other hand, was more direct and lasting. The significance of both land-cover and land-use change may be clarified by taking a long view of the lowlands, that is by tracing the evidence for what seems to have been a quite intensive agriculture in the Classic Period (ending about A.D. 800) and through to the ranching and agriculture of the present.

Several emphases will become apparent. The first is chronological and is laid on the time just after contact, when the die was cast. The second is regional; central Veracruz will come up repeatedly. It offers numerous points of departure and happens to be where much of the research basic to this argument was carried out. Links will be made repeatedly to other regions in the Gulf Lowlands. Thirdly, particular note will be taken of succession within areas subject to inundation. In various ways, at various times, this has been prime land. For observations on changes in land use and vegetation changes to get beyond generalities there must be a recognition of at least the principal physiographic variations within the lowlands, moving from the sea inland: beach ridges and dunes;

floodplains with levees, wetlands underlain by recent deposits; and hill lands underlain by older, eroded and dissected sedimentary formations. All this is interrupted by the volcanic hill and mountain massif in the Tuxtla region. The picture is complicated further by climatic variations: an increase of precipitation from the coast southward toward the mountains, and semiarid enclaves in rain shadow areas, particularly in central Veracruz.

An instructive superimposition may be noted in the wetlands of central Veracruz, just behind the dunes northwest of the port (Figures 1, 2, and 3). Fence lines and differences in grazing practices give these lowest of the lowlands an expansive geometry. A closer patchwork of cropping surrounds them on neighboring levee slopes and low hills. Within many pastures one can easily recognize the rectilinear patterning that signals the remains of prehispanic wetland agriculture. This superimposition, which the author has found not only in central Veracruz but also in many of the riverine lowlands of northern Veracruz and in the basin of the Candelaria River in Campeche, indicates two rather different responses to a particular set of natural environmental conditions, responses that nevertheless inform each other. The objective of this paper will be to outline what intervened and to suggest an interpretation.

A Lowland Basin About 500 A.D.

The stratigraphic profile of a test pit dug into one of the prehispanic planting platforms in a wetland in the San Juan Basin northwest of the city of Veracruz allows us to bring into position some key evidences (Figure 4; Siemens *et al.*, 1988). The anthropogenic stratum that pertains to the surficial patterning occurs around a meter below the surface. Plant microfossils show the presence of maize and associated ceramics allow the postulation of a Classic period date, somewhere around 500 A.D. We may deduce an agricultural incursion, but it is quite likely to have been cursory at first and then intensified by canalization and platform buildup, which left the pattern. The silty matrix of the evidence for agriculture indicates continued seasonal flooding even after canalization a kind of yearly fallow. And the sedimentation obviously continues long after the traces of agriculture fade out.

Settlement of corresponding chronology may be found on "islands" within the wetlands and on the surrounding hill land. Stone lines, the boundaries of what were apparently agricultural fields of a similar chronology, have been found in many locations on the sloping hill land toward the west (Siemens,1989: 195-208; Sluyter and Siemens, 1992). An integrated production system may be postulated for this landscape that includes the dry season agriculture in the wetlands, wet season cultivation on

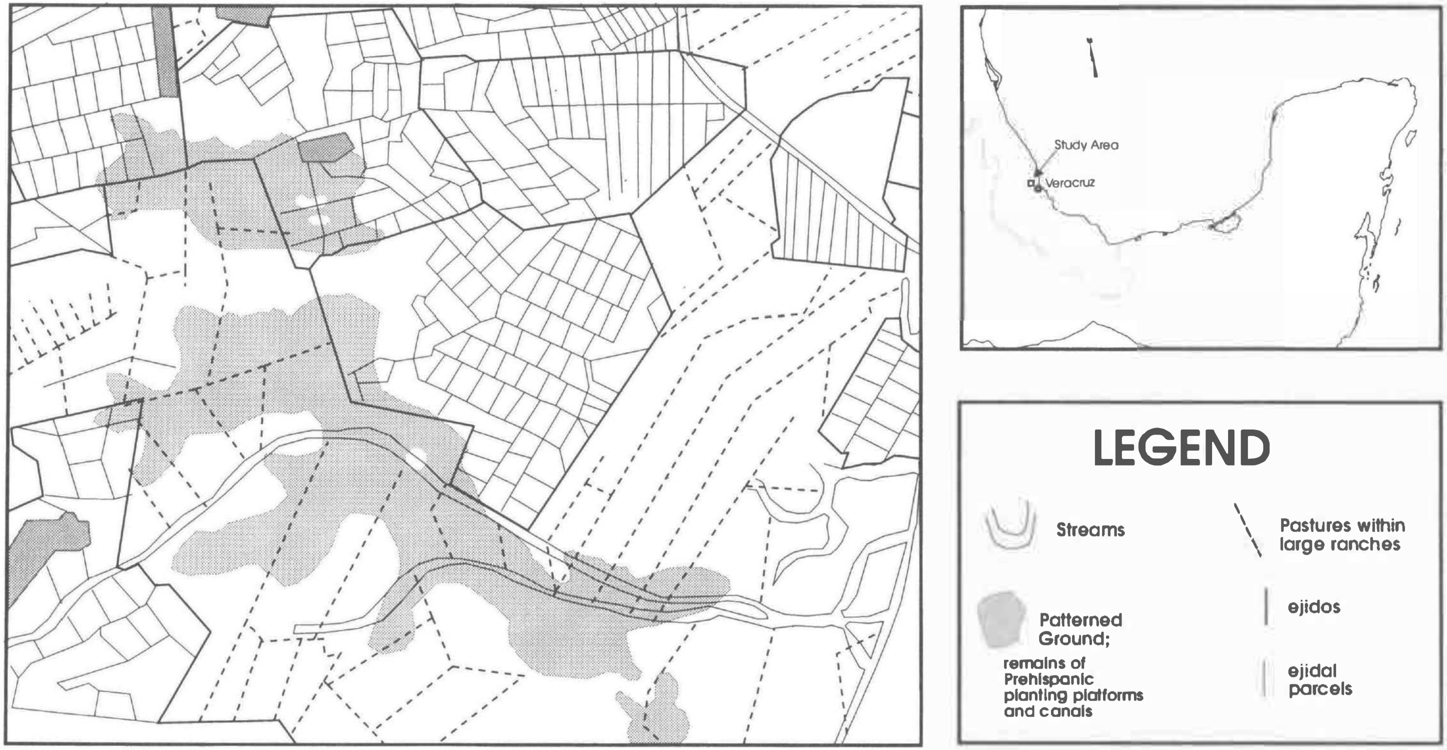

Figure 1. Superimposition of contemporary and prehispanic land use in the San Juan/La Antigua River basin, central Veracruz.

Figure 2. An oblique air photograph of a portion of the San Juan/La Antigua River basin, with patterning in wetlands - the remains of prehispanic agricultural platforms and canals - and the geometry of modern ranching superimposed.

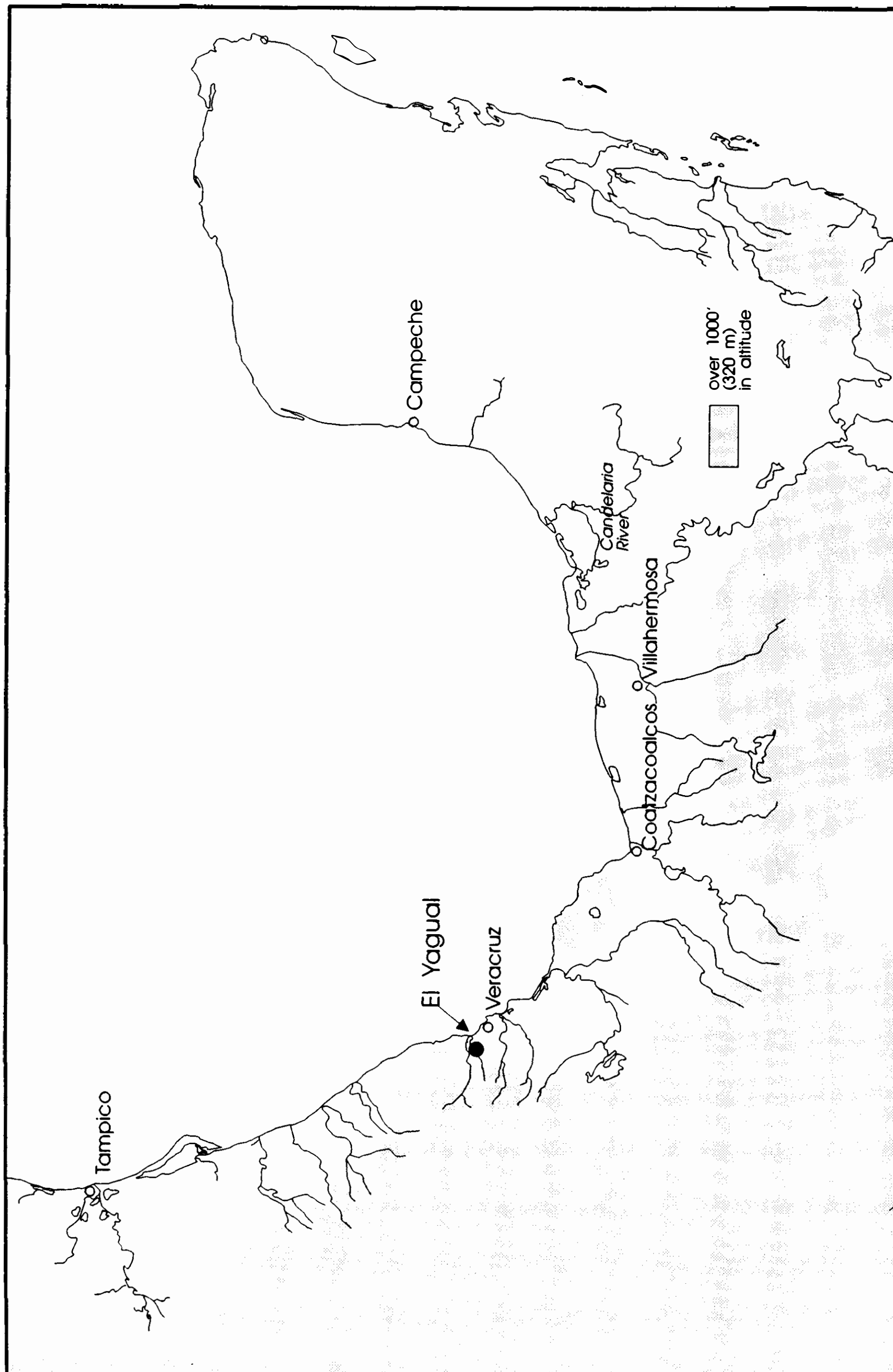

Figure 3. The Gulf Lowlands of Mexico, including the location of the excavation represented in Figure 4, a site called "El Yagual".

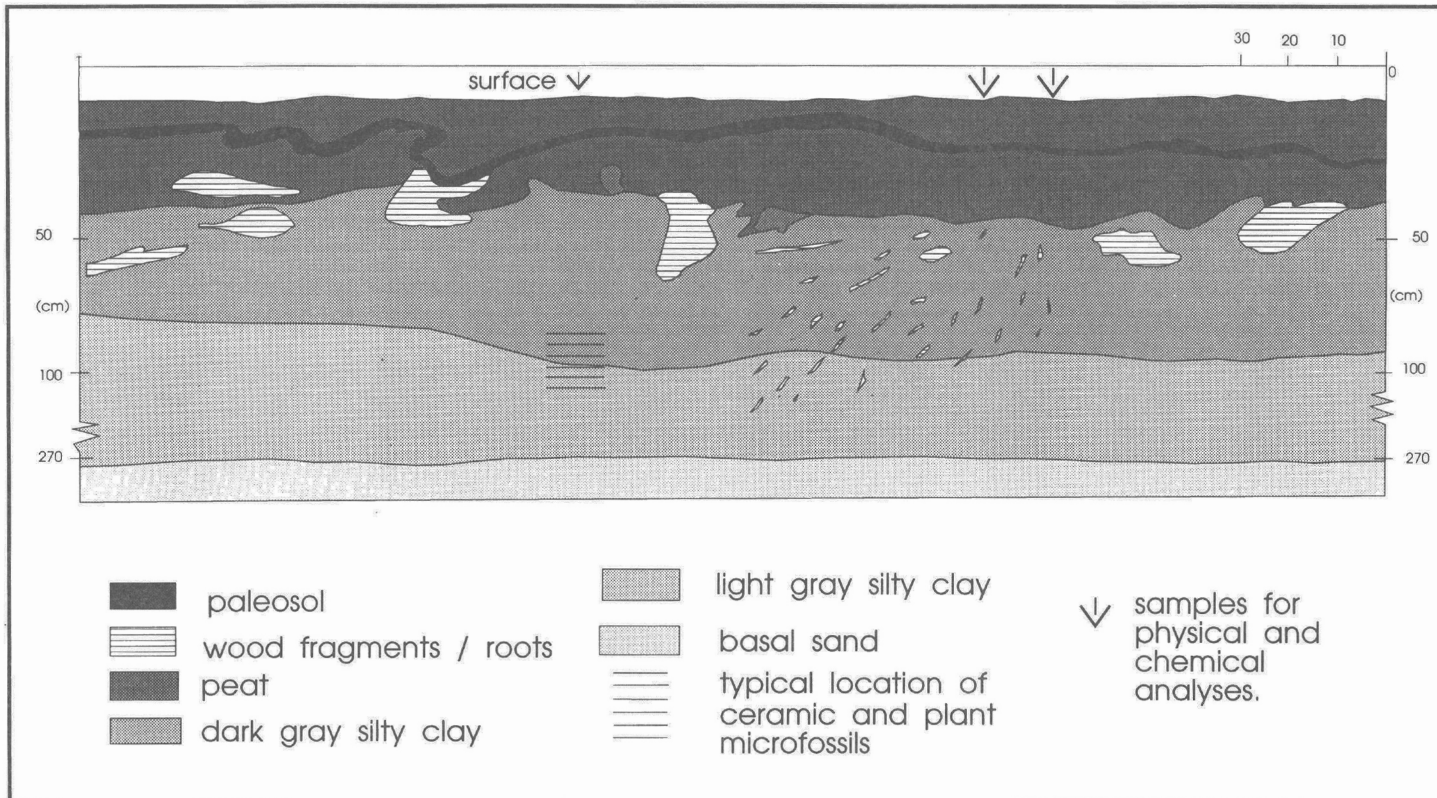

Figure 4. Profile of a test excavation of a prehispanic platform at El Yagual in the state of Veracruz (see Figure 3), Mexico, June, 1983.

neighboring hill land, the tending of kitchen gardens, plus fishing, hunting and gathering, all of which easily evokes arcadian imagery, which should be regarded with care. With this, of course, one must envisage extensive clearing in both the forests on the hill land (*selva baja caducifolia*) and on the margins of the wetlands (*selva alta* or *selva mediana perennifolia*) -- taking the relevant vegetational designations from Gómez-Pompa (1977).

Patterning identified in northern Veracruzan riverine wetlands awaits closer investigation. Various major projects have been focused on this phenomenon in the Maya lowlands to the east. The findings have been quite elaborate, but it may suffice here to indicate that a roughly similar system and chronology have been postulated for various locations there (e.g. Turner, forthcoming).

An Hiatus ?

It is apparent that intensive use of patterned wetlands lapsed in central Veracuz long before the encounter. In the stratigraphy exposed during our test excavations evidence regarding the nature and chronology of wetland agriculture fades quickly upward from the horizon we have associated with the surficial patterning (Figures 2 and 4). Dark silty clay continues grading into peat interspersed with roots and other forest debris. No further ceramics nor microfossils of cultigens were found (Siemens *et al.*, 1988). After the abandonment of the wetlands yearly floods came and went, as before; the filling in of the wetland continued, but tree growth and hydrophytes closed in as well. The wetlands of the San Juan Basin seem thus to have been alienated from whatever settlement and agriculture persisted on the surrounding hill land.

There is also palynological evidence from Lake Catemaco, southeast of Veracruz, which seems generally relevant and corroborative (Byrne and Horn, 1989). Forest clearance is apparent for the Formative Period (well before the time of Christ) and again in the Classic. Then there is an abrupt decline in agricultural indicators in the Late Classic.[1] This indicates an hiatus of well over 500 and perhaps as many as 1000 years.

In other wetlands of the lowlands where patterning is extensive, a similar chronology

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1. It should be noted that the phases of the cultural chronology of the Veracruzan lowlands are still not very clear and that the Post Classic Period, in particular, is not well understood.

seems to pertain and perhaps a similar alienation may be postulated. However, there is other evidence to the contrary and there are other interpretations. This is an aspect of the continuing investigation of the ancient lowland agricultural systems that most needs systematic testing in various locations. A great deal hinges on a clarification of settlement and livelihood in the Postclassic. It is clear that there were sizeable populations in the lowlands generally at the time of contact, as will be developed, but how they were sustained in any given area is not so clear. A variety of linked activities in neighboring microenvironments, without agricultural "intensification", could quite well have been sufficient. The forest debris and the buried soil up near the top of the profile in the San Juan Basin, together with related evidence, indicate clearing and an integration of these wetlands into at least rudimentary ranching early in the Colonial Period. Some wetlands in the lowlands remained alienated, probed only by hunters and fishermen, or perhaps by logwood cutters as in Campeche, until the second half of the twentieth century.

The Encounter

For those working on the ancient use of these environments it has repeatedly been important to search the documentation of the encounter and the work of the early Spanish chroniclers of New Spain in order to probe the hiatus, or as some would have it, the "protohistoric" period (Adams, 1977: 258) as well as to consider the impact of the encounter itself. There is an impressive array of scholarship, but one repeatedly comes up against some limits.

Bernal Díaz del Castillo's (1963) account of the Spanish landings remains absorbing reading. The old soldier, who began his account when he was over 70, felt he needed to set the record straight, and he did indeed become the prime source on the conquest of New Spain.

There is a good deal in his accounts about the coast, the currents, weather conditions, anchorages, the sandy shoreline, the insects, and the scarcity of food. The Spaniards appreciated very much what was brought as gifts and for barter from nearby settlements. On their first foray toward Cempoala, they were impressed by the greenery that surrounded it (Díaz del Castillo, 1963:107). López de Gómara was even more enthusiastic: within the town itself it was " all gardens and greenery and well-watered orchards" (López de Gómara, 1964: 70). It was no wonder that the Spaniards were impressed by greenery after their landing on the dreary coast behind the protected anchorage that would eventually become the harbor of present Veracruz. They came just before Easter, at the height of the dry season, when the vegetation on dunes and hill land is grey and dormant.

There is very little more. Even after the Spaniards had chosen the site of the present La Antigua as the place to build Veracruz, there is nothing explicit regarding fixed dunes nor about the basin that began just on the other side of the river, which was rich in prehispanic remains to be found many years later. The Cortés party did see deer on meadows west of what is now La Antigua (Díaz del Castillo, 1963: 106). These could have been wet or dry savannas, but more likely the latter, on the eastward extremities of the hill land underlain by Tertiary sediments.

The greenery and the provisions brought to the beach do give an early impression of productivity in lowland central Veracruz. Other parts of the lowlands were invested with a similar vague aura of fruitfulness during the early decades of the sixteenth century. While the precise wording of the accounts cannot be pursued very far because the observers were applying medieval categories and were preoccupied, the various indications together nonetheless put all the lowlands in a favorable light.

A review of the early characterization of the rest of the Gulf Coast arc can begin with Acalán, the Maya province at the western base of the Yucatán Peninsula. It was more or less coterminous with the basin of the Candelaria River above its rapids, which were barriers to raiding from the coast (Figure 3). Acalán was made up of some 75 communities and a sizeable capital, Izamkanac. Cortés came by it on his remarkable overland journey to Honduras in 1524-25. The visit and the place emerge from a suite of documents found and analyzed by Scholes and Roys (1968). The result is a rather good portrait of a place, just before most of its people were swept away. It is effective, unselfconscious geography from an historian and a linguist.

Two hundred and thirty soldiers, 93 horsemen and 3000 unwilling Mexican participants under the command of native chieftains, including Cuauhtemoc, made their way across the grain of the lowlands, slogging through wetlands and building many bridges. This journey leaves one astonished; it seems as wrongheaded as it was heroic. What a costly and inappropriate way to move through such terrain! By the time the company approached Acalán they were desperate for food, and they found it, in abundance. Subsequent tribute lists indicate something of the variety of what will have become available: honey, hens, beans, maize, squash seeds, chile and calabashes (Scholes and Roys, 1968: 396). Cortés and his companions were to extol the wealth and the resources of Acalán, but they did not find gold, which is not surprising since the streams of the province emerge from karstic terrain.

Nothing is said about the system by means of which the abundance was produced;

there is certainly no mention of anything like the platforms and canals for which we would eventually find the visual evidence at various places in the Candelaria River basin in 1968 (Siemens and Puleston, 1972). However, this is hardly remarkable; in the account of their arrival in Tenochtítlan there is a good deal about their enchantment over gardens, canals and canoes, but not an explicit word there either about the method of cultivation, even though they were in the midst of *chinampas* in full production (Díaz del Castillo, 1963: 214, 231).

One date has been obtained from a test excavation in a platform along the Candelaria River; it is only a straw in the wind, but it does allow the possibility of a chronology accordant with the Classic dates obtained for the system elsewhere in the lowlands (Siemens and Puleston, 1972; Turner, forthcoming). It is quite possibly that the wetland fields had long been abandoned by the time of contact.

There were various sorts of canals on the Candelaria floodplain, however, a point that has been difficult to establish in the literature. A network of trans-floodplain canal lines is superimposed in places on the closely meshed canals that define the planting platforms. The former seem to postdate the latter and can be integrated into parts of the settlement pattern that prevailed at contact. The trans-floodplain lines point to an agricultural logic that excluded the wetlands. The people apparently needed to get across the wetlands to agricultural land on *tierra firma*, where, presumably, they practiced shifting cultivation.

Moving westward, one comes to the lowlands of Tabasco, occupied by the Chontal Maya. Cortés noted that there were many farms around the lower Grijalva. "The land is very fertile and abounds in maize, fruit and fish and other things which they eat" (Cortés, 1972: 23). The conditions at contact, and a great deal more, are outlined very well in a comprehensive and often incisive regional geographical study by West, Psuty and Thom (1969: 89-103).

They review early postcontact Spanish accounts, which portray the Chontalpa as quite densely populated, well connected eastward and westward by overland and coastal trading routes, and as agriculturally very productive. Maize and a range of other food crops are noted, grown presumably by means of slash and burn cultivation, as well as an export crop-cacao. Moreover:

> "A common ecological pattern underlay the subsistence base of practically all the Tabasco lowlands: fertile soils of the stream levees, abundant and varied aquatic life in the rivers and adjacent marshes and lakes, and plentiful game within the savanna grasslands and acahual (abandoned slash-burn fields) nearby." (West, Psuty and Thom, 1969: 101)

This may be taken as a good hypothetical, microenvironmentally articulated summary of subsistence in the lowlands generally. In fact, the complex, seasonally varied, patchwork of mid-twentieth century lowland Tabasco, before it was affected by the exploitation of petroleum and modernization, is a good approximation of what would have been seen in the floodplains of the lowland rivers at contact.

The Tabascan lowlands have been searched for the remains of intensive wetland agriculture, but the characteristic patterning has not been found in any substantial complexes. There are, however, indications that something like a raised-field system may have been encountered by the Spanish conquerors at several places in the basin of the Usumacinta River (Pohl, 1985: 36). Limited examples of patterning have been found within the Usumacinta Basin some distance inland, in eastern Chiapas (Siemens and Puleston, 1972).

Information regarding agricultural productivity comes from what had been the Olmec heartland in western Tabasco and southern Veracruz, home of "the first truly complex culture in Mesoamerica" (Henderson, 1979: 89). It pertains to the Preclassic and antedates most of the evidence of wetland agriculture in the Mesoamerican lowlands; indeed, no traces of patterning have been found in the wetlands of the area. By the time of the conquest it was occupied by Nahuatl and Popoluca peoples (West, *et al.* 1969: 99). These lowlands yielded rubber, cotton, cacao, and every sort of food, as well as various articles of luxury. Aztec merchants trade routes passed through the region (Scholes and Warren, 1968: 776).

One of Cortés captains, Diego de Ordaz, was sent from Tenochtitlan, where Cortés was dealing with Montezuma, to the lands around the lower Coatzacoalcos River in order to assert Cortés authority there. He found the mouth navigable; here was a good port, but it was too distant from the capital to be useful. There was good farming and grazing land, however (Díaz del Castillo, 1963: 268)

Just how productive and sustainable these particular lowlands have been for millennia emerges very well from Coe and Diehl's (1980) remarkable book on the people of the lower Coatzacoalcos. They sketch the seasonally integrated agriculture on the various microenvironments of the floodplain, stressing the importance of the cultivation of the seasonally emergent gentle backslopes of the levees - without canalization, which complements cultivation on the hill land of *tierra firma*. This, they believe, plus all the other productive activities carried out in this environment, was more than sufficient to sustain the population numbers that may be deduced for the Olmec period. Such a system was probably what the Spaniards saw in action too. It is sobering to see how this setting has been polluted by the petrochemical industry in our day.

Early Spanish reports on the Papaloapan River basin provide a curious variant. Pedro de Alvarado entered it without the permission of his commander Juan de Grijalva, who is memorialized to this day in the name of the town at its mouth. On this and the subsequent entry during Cortés journey westward along the coast, some of the settlements of the basin were explored and productive agriculture found here as well. López de Gómara (1964: 52) declared rather unhelpfully for us that, "The land it drains is good land; its banks are beautiful." He went on to catalogue an amazing array of fish, birds and land animals, but he also noted the dramatic flooding for which this basin would become notorious. It would be the venue of the first of the great Mexican river development projects of the mid-twentieth century, the prime imperative of which was flood control.

Barbara Stark has looked carefully at the meager evidence on the economy of the Papaloapan Basin at contact and has identified some specialization among the communities in the various physiographic regions and a location of the larger ones between contrasting resource zones (Stark, 1974, 1978). Something like this is plausible for other river basins of the lowlands at the time; it is certainly indicated for the surroundings of the San Juan Basin.

Looking northward from central Veracruz and reviewing early reports on the basins of that part of the coastal plain, yields nothing very useful from the accounts of the conquerors, but does bring us to the impressive work of Isabel Kelly and Angel Palerm (1952), and that of Stresser-Pean (1968), particularly the latter's review of the ancient sources on the Huasteca, as this region has long been known, and most particularly to one statement:

> "The Aztec applied to the Huasteca, as to other warm moist lands of the Gulf of Mexico, the name Tonacatlalpan, 'land of food,' doubtless being of the opinion that these regions were fertile and free from drought. They also thought that the name was justified by the great variety of plants cultivated in the warm parts of the Atlantic slope."
>
> (Stresser-Pean, 1968: 588)

In summary, the lowlands generally and the series of regions discussed, are given an aura of agricultural productivity. The agricultural element seems to have consisted largely of linked cropping in neighboring microenvironments, including the seasonal use of emergent wetland margins. A good deal more direct evidence is obviously needed, but there is the possibility of some operative canals and planting platforms. In some wetlands at least, this system seems to have lapsed and indeed there is an indication that agriculture generally was less extensive in parts of the lowlands than it had been in the Classic Period. Nevertheless, it was obviously still extensive enough generally, and well supplemented by other productive activities, to impress the conquerors.

Colonial Succession

There is an account of how the conquerors were together at their first settlement in central Veracruz, between a bay they were using as a harbor and the town of Quiahuiztlan. They had by this time explored the lowland coast and made a number of incursions; Cortés considered it was time for some formalities:

> "He called them together and spoke to them, saying that God had evidently favored them by guiding and bringing them safely to such a good and rich land (as it truly seemed to be, to judge by what they had seen in the short time since their arrival), abundant in provisions and filled with people, who were better dressed, more civilized, reasonable and intelligent, with better houses and farms, than all the others thus far seen or discovered in the Indies; that it was likely there was much more to it than they had seen; that for that reason they should thank God and make a settlement there, and penetrate the country and enjoy the grace and favor that Our Lord had shown them... So saying, Cortes took possession of the country".
>
> (López de Gómara, 1964: 65-66)

The effects, of course, were devastating. They have been described in many ways, but come down to a few essentials. Between 1520 and 1570, over 90% of the population of the lowlands died. From regional estimates presented by Gerhard (1972), West *et al.* (1969), and Scholes and Roys (1968) -all explicitly conservative regarding precontact population numbers- one can assemble a map of this depopulation (Figure 5).

The massive literature reviewed in these and other sources indicates various causes. In some areas the lowland population was reduced by slaving and warfare, as in the Pánuco region. In other areas there were particularly severe abuses by *encomenderos* and disruption of trade, as in Acalán. Cattle menaced Indian agriculture and may have been a factor in depopulation within the Chontalpa (West *et al.*, 1969:118). The primary factor

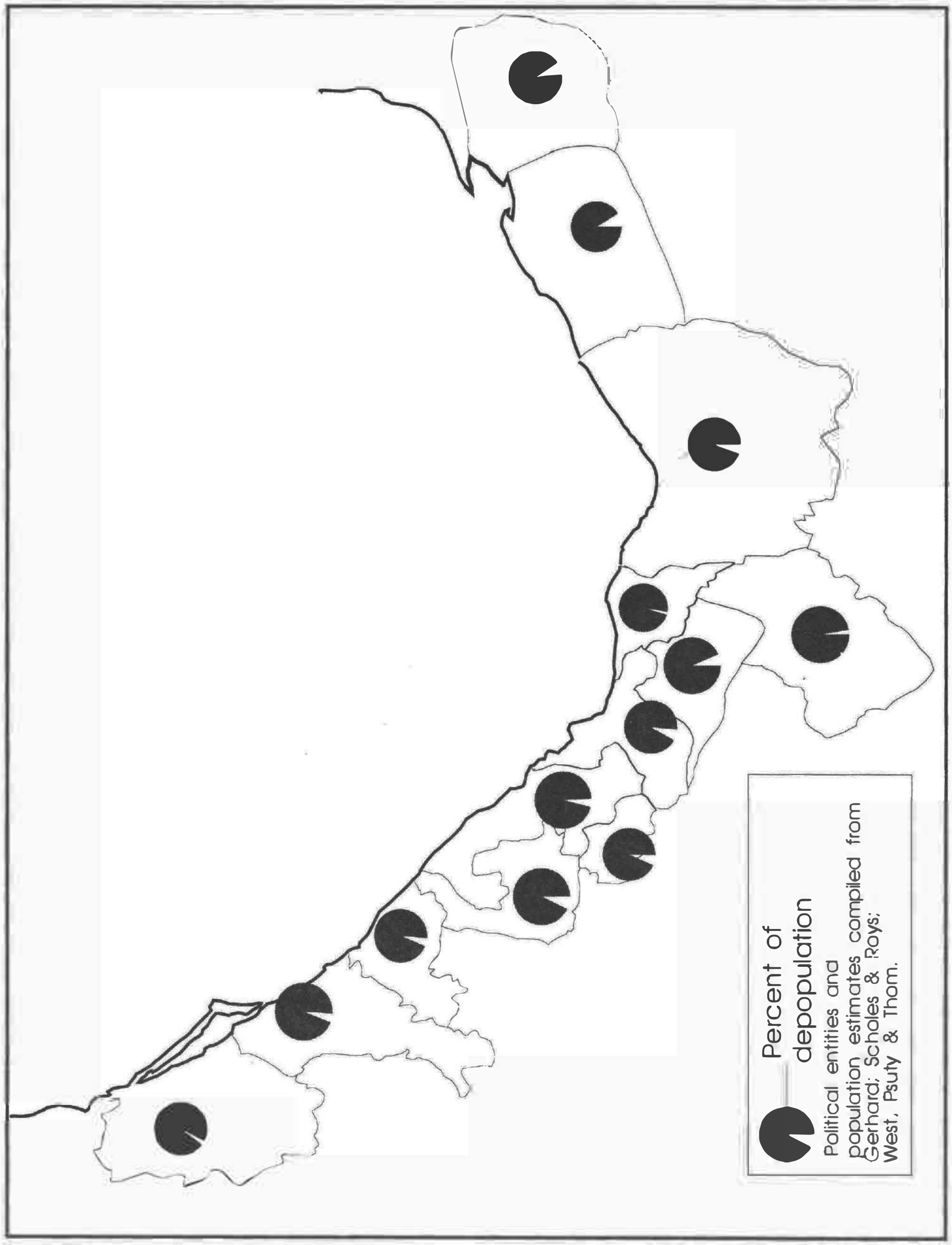

Figure 5. Depopulation in the Gulf Lowlands of Mexico, 1520-1570. Mean percentage of depopulation: 91%.

throughout the lowlands, however, was decimation by disease. González Jácome (1988: 4-23) has traced the specific diseases that were involved and reviewed the grim dimensions of this whole demographic catastrophe.

The areas that were found to be well populated and productive at contact can logically be thought of as having been deforested, or "open" (Parsons, 1989: 316), but only in the way that a tropical terrain largely subject to shifting cultivation with some sort of fallow can be considered open. Woody growth in one stage or another of regeneration is always in sight. Hill land, the fixed dunes, and wetland margins too, must have had the moth-eaten look that tropical lowland used in this way has now. How these deduced conditions and the deduced changes can eventually be reconciled with microfossil evidence, such as that being generated for the surroundings of Lake Catemaco, and whatever may yet emerge from similar investigations elsewhere in the lowlands, remains to be seen.

It is fairly clear that substantial and, indeed, rapid reforestation followed depopulation in the lowlands and elsewhere on the mainland, as on the Caribbean islands (Parsons, 1989: 316-317). This too must not be overgeneralized, however. The survivors were not able to maintain cultivation on even the best lands: the levee tops and other alluvium or colluvium just above seasonal flooding. The margins of the seasonally flooded wetlands, land from which one can get an additional crop if one needs it and is so inclined, were certainly left, if indeed they were still in use at all. The newly abandoned land was overtaken soon by woody growth. On hill land and on the dunes *acahual* from previous cultivation was freed to mature back into a low scrubby tropical forest that loses a good deal of its foliage in the dry season. Kitchen gardens were quickly overgrown. The wetlands proper, patterned with the remains of ancient cultivation, were probably already covered by forest and hydrophytes for centuries.

The forest in these areas subject to inundation must not be thought of as *selva alta* entirely, but rather a mixed and discontinuous combination of brush, stands of palms, and high tropical forest proper. And there probably were areas of open grassland, edaphically controlled or anthropogenically enlarged, within the wetlands as well. All this abandoned land, on hill land and wetlands, was left free, as is often said, for the entry and spread of cattle.

Something of the nature of early colonial ranching in central Veracruz emerges from the 1571 Hernández "Declaración sobre Veracruz" (Paso y Troncoso, 1947), the 1580 Patiño Relación Geográfica (Pasquel, 1958), which was actually compiled by a "médico", Lic. Alonso Hernández Diosdado and hence, conceivably, of particular value, as well as the analysis of *mercedes* related to this region by Butzer and Butzer (this volume). This may be expanded to encompass northern Veracruz with the help of Doolittle (1987) and projected eastward into the Chontalpa (Tabasco) on the basis of the materials presented by West *et al.* (1969).

Most sources refer in one way or another to the meager scattering of Amerindians and the great numbers of cattle. The latter is particularly well put by the Lic. Hernández Diosdado in 1580:

> "Se sigue ser esta comarca de la Vera Cruz tan fertil y abundante de pastos, que en poco más de siete leguas á la redonda se apacientan de ordinario más ciento y cincuenta mil cabezas de ganado mayor, entre vacas y yeguas, sin la innumerable cantidad de ganado menor que baja cada año á invernar á esta comarca, de las provincieas de Tascala y Cholula y otros partes, siendo esta tierra en este particular la Extremadura de estos reinos".
>
> (Pasquel, 1958:187-88)

Before the end of the sixteenth century cattle ranching was widespread in the lowlands. It had become important in Tabasco (West *et al*., 1969:118-119). By 1620 there seem to have been 176 000 head of cattle in the Panuco region (Doolittle, 1987: 4-5). The Butzers (this volume) estimate of 400 000 cattle in the Gulf Lowlands early in the seventeenth century is quite plausible .

The cattle did well in the multistoried vegetation of many species grown up over abandoned gardens and fields and were able to graze, as well, on native grasses in the savannas, on hill land, adjacent to the actual low lands of the river floodplains. They were periodically cleared of woody growth and renewed by fire. There was grazing in places on the fixed dunes; cattle could browse in the scrub forest found among the dunes, on hill land toward the west or south, and in the many canyons that cut the sloping hill land. There were the lower stories of the gallery forests. And, the animals could graze and browse in the wetlands, a very important resource for tame and wild cattle in the lowlands around the Panuco, in Tabasco, and certainly also in Central Veracruz.

Large fragments of wood and a buried soil above them in our excavation in central Veracruz (Figure 4) indicate clearing, presumably in aid of ranching, within lands subject to inundation. One may postulate it for many other similar locations. A striking confirmation of clearing and frequent subsequent burning of dried grasses may be seen in the rather imposing stands of pyrophytic palms that often occur on land subject to inundation within the pastures of large properties, over the top of the patterns left by ancient agriculture. They seem mainly indicative of historical perturbation. Lic. Hernández observes, however, that there was already a great abundance of palms in 1580 (Pasquel, 1958:196); they thus seem to have prehispanic significance as well. *Palmares* are often referred to as indicative of sustained human intervention (e.g. Rzedowski, 1978), but apparently have not yet been very well studied in that regard.

There are numerous "islands" within the wetlands, almost invariably with remains of prehispanic settlement. They present a refuge in times of flooding and were used for corrals and the shelters of *vaqueros* in colonial times, as they still are at the present.

One may envisage for the early colonial period a spontaneous or vaguely managed seasonal movement between adjacent microenvironments, a limited kind of transhumance. The cattle went on their own or were driven on to hill land during the time of the rains and into the wetlands or on to exposed margins of lakes when water levels subsided and the surrounding vegetation lapsed into dormancy. The cattle thus came to reenact the rhythm that formerly governed the lives of the precontact agriculturalists.

In addition, there was full-scale transhumance of *ganado menor* from the Mesa Central into savannas on the sloping hill land of central Veracruz (Butzer and Butzer, Figure 1, this volume; Paso y Troncoso, 1947: 199-200). Many upper surfaces of this terrain are webbed with the remains of an agricultural field system not too different from *metepantlis* or semiterraces on gently sloping terrain (Siemens, 1989: 195-208; West, 1970, 364-68). Proximate and presumably related settlement remains indicate mostly Classic occupance, but the land use could be later too. Colonial grazing over these remains raises various further issues regarding central Veracruzan land-use succession, which we cannot deal with here.

Then there were the *cimmarones*. Feral cattle in large numbers have often been mentioned in discussions of the colonial period in the lowlands (e.g. Parsons, 1989: 316-17). The Hernández Declaración, in its own curious style, sketches a scene in central Veracruz:

> "Ganados de aca: son bacas muchas y muchas cimarronas y muchos toros y muy brabos; de la carne de los toros bravos y de xaretaderas no se aprovecha por caer lejos".
>
> (Paso y Troncoso, 1947:199)

Dampier (1906:157-60, 179) reports from the area immediately to the south of the

Laguna de Terminos in the seventeenth century that large herds of feral cattle grazed swampy terrain, also called savanna, and that they were being hunted for hides and tallow.

The repertoire of skills, artifacts, and terminology of livestock production that was introduced from Spain cannot be reviewed here, but indications are that early ranching in the lowlands was fairly rough and ready. Differences between the tame, the half wild, and the wild were not always very clear. Cattle were not so much herded as hunted: brought down with a *desjarretadera*, a curved knife on the end of a long pole that served to cut the tendon of a hind leg (Dary, 1981: 18-19). The animal was stripped of what could be carried away and the carcass left to rot. When fresh meat was needed in one of the coastal settlements the animals were driven in, perhaps with the help of a few tamed beasts among the wild, and then slaughtered on the outskirts.

The numbers of the livestock that astounded observers, their rapid reproduction, the ferocity of the bulls, and the need to hunt itself, may be seen as largely a function of ferality. Evidently, when cattle escape dependence their size may increase by natural selection, reverting to predomestication characteristics (Clutton-Brock, 1981:21-22). One might add that unrestricted feeding, particularly with a free movement between microenvironments, would enhance vitality.

There will have been parasites and predators, of course; a tropical lowland environment is anything but benign for cattle. These problems, however, would have afflicted the tame as well as the wild, and quite possibly the first more than the second. Also, both Patiño's Relación and the Hernández Declaración explicitly downplay the seriousness of predators in lowland central Veracruz (Pasquel, 1958: 199; Paso y Troncoso, 1947:198). *Cimarrones* could do quite well and seem not to have been regarded as a plague so much as a valued resource.

Several areas in the lowlands have been identified as hearths of colonial ranching: central Veracruz, Almería, in the surroundings of the lower Nautla River, and the environs of the Panuco River (Doolittle, 1987). Ranching also extended eastward in the lowlands. It is noted near the mouth of the Papaloapan River (Chevalier,1970: 30) and much further eastward, at least as far as the lands south of the Laguna de Terminos (West *et al.*, 1969:118-19).

Commercial cropping was also going on in various parts of the lowlands. Cacao had been important in Tabasco before contact; it remained so after, but eventually the groves had to be moved southward into the mountains because of pirate raids along the lower river courses. By the end of the colonial period, production had dropped because of the competition in Central and South America (West *et al.*, 1969:116-17). In the seventeenth and eighteenth century, the English took a good deal of dyewood out of the depressions bordering floodplains around the Laguna de Terminos (West *et al.*, 1969:120-21) a colorful chapter in the history of the lowlands!

Sugar was produced on the famous large plantation in the Marquesado del Valle in the Tuxtla highlands (Chevalier, 1970:145). It was apparent also northwest of Veracruz, on higher alluvium, just above the lands subject to normal seasonal inundation, around and over ancient settlement sites, and along the Paso de Ovejas and the La Antigua and the Actopan Rivers. It seems to have been produced, as well, on such colluvium at the base of neighboring hill land as could be provided with irrigation water. The pre- and postcontact land use of central Veracruz continues to be investigated, but it is apparent that such a concentration of commercial agriculture is apparent elsewhere in the Gulf Lowlands and that land subject to inundation is prime land for ranching generally as well.

Trade continued along trails through the lowlands and up into the highlands. The goods were carried mostly by human carriers and mule trains. Carting was possible, with some difficulty, along the main roads into the interior from Veracruz (Pasquel, 1958:188; Rees, 1976: 18-21). On the eve of independence this had become easier along the newly surfaced road into the interior via Jalapa.

In addition to these commercial activities one can postulate subsistence agriculture in and around the remaining settlements, gradually spreading again as the population recovered. This included shifting cultivation, of course, as well as seasonally orchestrated cropping on floodplains, particularly in the Chontalpa, and kitchen gardens everywhere. Hunting, gathering and fishing complemented all of this.

Humboldt, passing through the lowlands early in the nineteenth century, recognized luxuriance in the natural environment and great potential for production in the land, once the hill land was taken properly in hand, once the wetlands were drained. He indicted the lowlanders, who had succumbed to what he saw as the blandishments of this luxuriant environment; they had not been able to make proper use of the resources (Siemens, 1990a: 205).

Humboldt also articulated the dangers of the lowlands; he struggled with the horrible puzzle of yellow fever. It had long been known, and after Humboldt's observations it became common knowledge that these coasts were unhealthy; one needed to move through them cautiously and expeditiously. Few travellers moved along the lowlands, across the grain of its rivers, during the Colonial Period. There is an instructive exception, the good bishop of Tlaxcala, Fray Alonso de la Moto y Escobar, who travelled along the lowlands in the early seventeenth century, concerned for his parishes, suffering awfully from the mosquitos, but noting also a good deal of what he saw (González Jácome, 1987). The lowlands were very difficult to colonize and to garrison. New Spain was fortunate, in a manner of speaking, to have a natural defense of its heartland -the inhospitable tropical lowlands- for it had only minimal defenses of other kinds.

Nineteenth Century Observations

With independence, Mexico was fully open to foreign observers. Most of them passed through the lowlands along the main road into the interior, from the port of Veracruz up to Mexico City via Jalapa. Their commentary provides us with a further reading of land use and vegetational cover, among many other things. As in the case of the sixteenth century Spanish visitors, the accounts often say more about the observers than the observed.

Most of them carried Humboldt in their baggage, so to speak. They looked to confirm the luxuriance of the natural environment and the inadequacy of the lowlanders, or the Mexicans in general, for that matter, and of course they were not disappointed. They were seeing the heritage of the Spanish colonial period, and they were bound to shake their heads over it. They were not at all impressed with the agriculture between the port and the summit of the Sierra Madre Oriental. They saw little evidence of the plow anywhere, and denigrated what they could see of shifting cultivation; the lowlanders obviously had not begun to exploit the potential of their land. And yet the travellers were routinely amazed at the wealth of produce on sale in the markets, a misreading on several counts.

One can deduce from this and a good deal more that although overall Mexican population figures had come back up more or less to precontact levels, the lowlands were still sparsely occupied. Many areas would not be reoccupied until well into the twentieth century, as along the Candelaria River, the once quite closely occupied ancient province of Acalán.

There is fairly good information in this commentary on ranching in the lowlands, especially in the absorbing book that Carl Sartorius (1961) wrote at mid-century after having lived near Huatusco for many years . Something of the complementary use of neighboring microenvironments is apparent in his account of subsistence agriculture in the lowlands. He has a good deal to say on ranching in the lowlands; cattle were driven or moved spontaneously up and downslope.

Sugar was still being produced as well as some cacao and coffee in their respective niches. These were turbulent, disorganized times. Lamentations by Mexican observers indicate very difficult living conditions in rural areas, with little commercial production (e.g. Iglesias, 1831/1966). The lowlands were a kind of archipelago, a disarticulated countryside, with little translowland trade and many small production regions forced to market within limited areas.

The lowlands were still regarded as unhealthy; foreign visitors stood a considerable chance of contracting yellow fever and dying of it, particularly if they travelled in the lowlands during the rainy season and had not been immunized to it with a mild case when they were children. This scourge, as well as malaria would not be lessened until the vectors could be eradicated in the twentieth century. Among the resident population, gastrointestinal diseases were the dominant killers. The minority with means moved seasonally to Jalapa, above the altitudinal limits of the vectors: according to most of the accounts an altogether paradisiacal place. The foreign traders living and working in the lowlands were seen by the transient observers as the sallow and debauched victims of their environment.

There are only a few indications of what vegetation cover was like in the lowlands in the nineteenth century and those come, again, mostly from central Veracruz. Dry savannas were extensive on the hill land, probably a good deal more extensive than they had been at contact. The lower reaches of the major floodplains had regained much of their precontact population and will have looked more or less as they did then. Between them were vast forested areas, thinly populated. Along the Veracruz-Jalapa road the wetlands were perceived as mostly forested. One has the impression that one is seeing the landscape just before the onset of late nineteenth and early twentieth century inmigration, settlement and clearing for agriculture as well as expanded ranching.

Lowland Land Use in the Latter Half of the Twentieth Century

When this investigator's field observations in the lowlands of southern Veracruz began in the 1960s, Mexico's "March to the Sea" was well underway. One could distinguish older core areas, now quite densely occupied once again, with subsistence agriculture on small *ejidal* and private holdings, commercial agriculture of various sorts (e.g. sugar, pineapple, sesame seed) on holdings large and small, and ranches, growing in number, extent, and sophistication.

Around the cores was what seemed then a convoluted frontier, where the forest was being cleared and new communities and scattered new individual holdings were being established. Gaunt reminders of what had been high forest punctuated many horizons. On the newly cleared land, very often, a brief period of maize cultivation was followed by the planting of one or another of the African grasses that had been introduced in the late nineteenth or early twentieth centuries (Parsons, 1989: 297-311). A further expansion of ranching was the objective. Mexico needed meat, as government officials said.

It was an important part of the education of a graduate student to find that much of the best land in the lowlands was in large holdings, which had somehow been exempted from agrarian reform, and that the agrarian code's "*pequeñas propiedades*", meant to be the general designation for private holdings in the postrevolutionary countryside, was in fact a euphemism for something more like "*propiedades grandes*." Invasions of such properties by the landless were frequent, and shootouts were not uncommon. But southern Veracruz was "developing" rapidly, as were other areas in the lowlands.

Throughout the lowlands, projects were underway, largely to achieve expansion and improvements in commercial production. They included a colonization project in the basin of the Candelaria River, unoccupied for centuries except by transient woodcutters and chicle-tappers (Siemens, 1966). The forest that had overgrown ancient Acalán was machine-cleared over vast areas in short order. The Chontalpa was under a massive redevelopment scheme that proposed to drain huge areas and rationalize holdings for commercial production. There were many others. In a few decades the lowlands were littered with ailing or failed projects and *proyectismo* had become a word for a disease.

Parallel to all of this, traditional agriculture was being studied in several of the major lowland floodplains by Coe and Diehl, as well as by West and his associates, and others, notably Gliessmann and his colleagues, at an agricultural college in Tabasco. In Veracruz, a long-term watch was mounted over the agriculture of the community of El Palmar, northwest of the town of Cardel, where hill land and wetland were still being cultivated in seasonal rotation (Siemens, 1990b).

As these and many other rediscoveries of old systems were underway, the systems themselves became less and less relevant to larger trends within the lowlands toward commercial agriculture, which was in turn, enduring ups and downs contingent on international economic conditions. Subsistence agriculture became largely untenable; much of the land on which it was carried out, including many *ejidal* parcels, was put under commercial production contracts, notably in the ambits of the sugarmills. Many small holdings were simply left unused, others were integrated into symbiotic ranching arrangements with large landholders (Del Angel Pérez, 1991).

The wetlands, the best lands for dry season food production, a critical element in subsistence agriculture from ancient times to the present, have long been out of bounds for any such activity. This brings the discussion back to the image with which this essay began (Figure 1). This land is now generally cleared and encompassed within cattle ranches one of the most striking aspects of the long process of succession in lowlands.

A Concluding Comment

The appropriation of land for ranching subject to inundation can be seen as having been detrimental in the long run to the agricultural economic development of the lowlands, particularly the intraregional production of the subsistence requirements of the many marginalized lowlanders. Our observations at El Palmar and elsewhere indicate that where small-scale agriculturalists have access to wetland margins, they do often make advantageous use of it, general economic conditions permitting, even when wetland agriculture is not among their traditions.

Meanwhile, nutritional standards and living conditions generally remain as precarious as they have ever been among a considerable proportion of the rural population. Many agriculturalists now seek employment in industry, inside or outside of the lowlands.

The analysis of David Barkin, a highly regarded economist working in Mexico, has become quite compelling in any consideration of these most recent phases in the land-use succession within the lowlands, and indeed the country as a whole. He proposes a resurgence of small-scale food production; in his mind it presents the most viable basis for the resuscitation of the Mexican economy. This encourages those who have dared to think that traditional systems might provide modern answers. Barkin (1991: 24, 62) has little doubt that the modernization of agriculture by means of advances in technology and the application of the theory of comparative advantage -with the parallel massive development of ranching in the lowlands- have done very little to resolve the problem of rural development or eliminate hunger. Something like the ancient intensive use of wetlands might now be very useful.

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CHAPTER 9

HUMAN-INDUCED LANDSCAPE CHANGES IN AMAZONIA AND IMPLICATIONS FOR DEVELOPMENT

Nigel J.H. Smith

One of the most persistent myths about Amazonia is that it has long been a wilderness, virtually untouched by humans until relatively recently. Amazonian forests are often portrayed as sparsely settled or essentially empty until modern times (Dickinson, 1987; Salati, 1987). The idea that the vast Amazon lowlands have been bypassed by human civilization and have lingered as a cultural backwater has pervaded thinking about the region and has undoubtedly played a part in shaping attitudes towards development. In the early 1970s, for example, the Brazilian agency for colonization and agrarian reform talked about the "demographic void" in Amazonia in its publications dealing with ambitious settlement schemes for the region (INCRA, 1973). The perception of Amazonia as raw, untamed nature awaiting modern development with few precedents has led to some inappropriate policy decisions.

Debates about human carrying capacity in Amazonia and the notion that the forests and waters of Amazonia have proved inhospitable to civilization have raged for several decades (Beckerman, 1979; Evans, 1964; Gross, 1977; Meggers, 1954, 1971). The upland forests, especially, have been thought to have always been sparsely settled, with environmental constraints imposing a virtual nomadic existence on those aboriginal groups unable to secure land by rivers (Denevan, 1966; Richards, 1977). Swidden agriculture, it has been argued, cannot sustain a complex, stratified society (Harris, 1972). Alleged shortages of protein, diseases, poor soils, and even a torrid climate have been invoked to account for the apparent emptiness of Amazonia and the lack of precontact state societies with monumental architecture on the scale of the Aztecs, Incas, or Mayas.

Such ideas, also widely disseminated in the media and among decision-makers in sociopolitical life, have created the impression that Amazonia is essentially a "clean slate" upon which ambitious, modern development can now enter the stage. While it is true that Amazonia is emerging from a mostly extractive economy to a fully developed region with a wide range of activities in the primary, secondary, and tertiary sectors, a lack of appreciation of natural and cultural resources in the region has led to some unfortunate environmental and social consequences.

Amazonia is understandably becoming more integrated with national economies and international markets, and development initiatives are certainly warranted. But a better understanding of the historical dimensions of resource management in Amazonia could help guide some efforts to develop soil, water, and forest resources.

Amazonia has witnessed a long history of human settlement with varying degrees of intervention in natural ecosystems. Humans have sculptured landscapes to create fields and enrich campsites for millennia. Some of these interactions have been ephemeral, while others have had lasting impact. The Columbian encounter actually brought some respite for the forest and other ecosystems in Amazonia as the indigenous population plummeted after contact. Only recently has the forest once again come under widespread attack, but this latest wave of clearing is taking place on landscapes that have often been through several slash-and-burn cycles in the distant past. A review of human-induced landscape changes in Amazonia could provide some insights into the current debate about deforestation rates, global warming, and sustainable development.

Densities and Impacts of Precontact Populations

Hunters and gatherers probably penetrated the region tens of thousands of years ago. Precisely when people first reached the New World is still disputed, but some place the antiquity of man in the Americas between 40 000 to 60 000 years ago (Horgan, 1992; Marshall, 1990; Morell, 1990). Hunters may have been butchering kills in Orogrande Cave in southern New Mexico at least 30 000 years ago (Appenzeller, 1992). A credible date of 33 000 B.P. has been posited for a campsite at Monte Verde in southern Chile (Dillehay and Collins, 1988). Closer to the Amazon in Piauí, a rock shelter at Pedra Furada contains stone tools in strata dated to 32 000 years B.P., and more recently to 39 200 B.P. (Butzer, 1991; Guidon and Delibrias, 1986).

By at least 9000 years ago to the north, in the middle Orinoco Valley, preceramic stone-tool makers were inhabiting the forest/savanna ecotone (Barse, 1990). But hunters and gatherers have been interacting with Amazonian environments a lot longer than that.

People probably first entered Amazonia during the late Pleistocene, when the region was drier and cooler than present (Colinvaux, 1987; Damuth *et al.*, 1970). Parts of Amazonia currently covered by forest may have been occupied by scrub savanna 20 to 40 thousand years ago. The precise location of these open habitats is unclear, but the ecotone between forest and savanna would have provided a rich resource base for new arrivals.

Hunters and gatherers entered Amazonia (Figure 1) from various directions at different times. Major penetration routes included the Orinoco and Casiquiare Rivers, the relatively open coast of Amapá, and the Andean foothills. People were probably traveling regularly between the Negro and Orinoco Rivers by at least 16 000 years B.P. (Lathrap, 1977). Tongues of savanna or *cerrado* extending into the forest would have afforded especially easy access to the region. Such protrusions of scrub savanna flank the northern and southern edges of Amazonia.

Other penetration routes may have been along rivers. During much of the Pleistocene, rivers in Amazonia were downcutting their profiles since the sea level had dropped 100-150 m (Bigarella, 1965; Bigarella and Andrade, 1965). Rivers without extensive swamps and complex, interconnecting lakes would have been easier to follow than rivers that have filled in much of the scoured former floodplain, such as the Amazon, Juruá, and Purus. Such actively downcutting rivers would have narrower floodplains and still provide important resources for hunters and gatherers, such as shellfish and turtles.

Although population densities of hunters and gatherers was probably low, they nevertheless altered some landscapes. Repeated burning of natural islands of grassland that arose due to edaphic and/or drainage conditions has greatly expanded their area (Figure 2; Aubréville, 1961). A long dry season in some parts of Amazonia has been invoked as a predisposing factor in the formation of savannas in Amazonia (Hills, 1969; Rivière, 1972), but climate alone cannot account for all the patches of scrub-grassland in Amazonia nor their extent.

Hunters and gatherers burned grassland and scrub to flush game and kill small animals, thereby creating more open habitats. Larger game could be ambushed as it fled the approaching fire, while slow-moving tortoises, lizards, and snakes would be overcome by the flames. Frequent torching of the savanna in the dry season would also improve visibility for hunting (K. Redford, pers. comm. 1990). Certain species of game, such as deer, are attracted to the lush growth following burns, thereby improving hunting

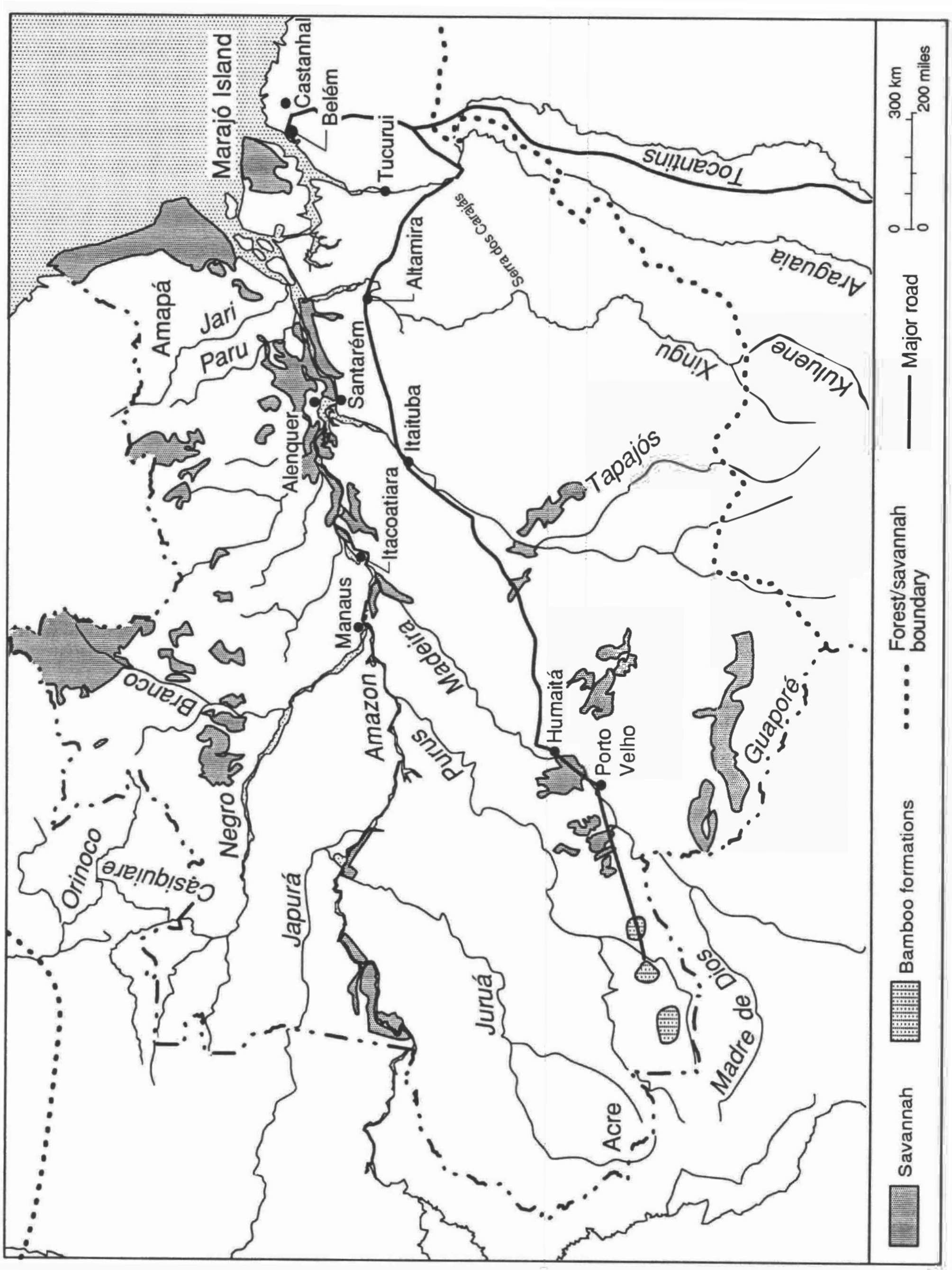

Figure 1. Amazonia

Figure 2. Fire set in cerrado on top of iron-ore capped mesa to improve browse for sheep and goats. Serra dos Carajás, Pará, Brazil, July 1974.

yields.

The practice of burning the savanna for hunting purposes continues among indigenous peoples inhabiting the ecotone between the Amazon forest and savanna. The Xavante torch the savanna and the underbrush of adjacent galeria forest every year on the southern fringe of Amazonia to drive game towards clubs and volleys of arrows (Gross *et al.* 1979; Maybury-Lewis, 1974).

The broad savannas of Roraima and eastern Amapá are derived in part from fires set before farmers began cutting and burning the forest. The extensive, periodically inundated grasslands of the Gran Pajonal in the Peruvian Amazon are probably human-derived (Denevan, 1971; Scott, 1977). Pockets of scrubby savanna in other parts of Amazonia, such as near Humaitá on the left bank of the Madeira River and in Rondônia, may have been expanded by early hunters and gatherers. Dense stands of native bamboo (*Guadua* sp.) in parts of eastern Amazonia and Acre (Figure 3), such as in the Antimari Reserve, may be a result of old slash-and-burn cycles practiced by farmers, or hunters and gatherers operating in semi-open environments that were later invaded by bamboo after repeated burns (Moran, in press).

The creation, or expansion, of savanna landscapes due to burning in ancient times is not unique to Amazonia. Early man in Panama, for example, created open environments as a result of farming and hunting activities that allowed the passage of certain animals, such as deer, rabbits, and gray fox into South America (Bennett, 1968). After massive depopulation of indigenous groups following contact with the Spanish, the Darien gap returned to forest. Little if any of Central America's forests can be considered truly virgin (Cook, 1909,1921).

In addition to setting periodic fires, hunters and gatherers in Amazonia undoubtedly enriched campsites with certain fruit and nut trees. Women, especially, may have selected or favored certain highly productive or tasty fruits for planting around habitation sites. Other fruit or nut trees arose from discarded seed. Cupuaçu (*Theobroma grandiflorum*), for example, is relished for its fine-tasting pulp that surrounds the oblong "beans;" the latter sprout readily when tossed on moist ground. Campsites may have only been occupied at certain times of the year, but planted fruits would provide welcome harvests at the next visit. Although hunters and gatherers probably never achieved high population densities, they nevertheless had a marked impact on Amazonian landscapes.

Landscape changes became even more pronounced when large-scale farming came on the scene. Maize has been cultivated in the Ecuadorian Amazon for at least 6000 years (Bush *et al.*, 1989), and root-crop farming began long before that, particularly with cassava (manioc), sweet potato, and the New World yam. By the time Europeans

Figure 3. Bamboo (*Guadua* sp.) in forest near Rio Branco, Acre, Brazil, 19 November 1991.

arrived, many parts of the Amazon basin were being farmed, and settlement was particularly dense along silt-laden rivers. "White-water" rivers provided fertile alluvial soils for crop production and abundant fish, freshwater mussels and shrimp, turtles (particularly species of *Podocnemis*), manatee (*Trichechus inunguis*), and capybara (*Hydrochoerus hydrochaeris*). Many villages were established along the upland bluff overlooking floodplains so that the inhabitants could take advantage of animal and plant resources from both várzea and upland environments (Hilbert, 1957).

Estimates of human populations in Amazonia around A.D. 1500 range from one to almost seven million, or even higher (Benchimol, 1985; Denevan, 1966, 1970, 1976; Smith, 1980). Three decades ago, such figures would have been considered inflated, but now they are increasingly recognized as plausible. Only recently has the region's population regained levels encountered when the first Europeans arrived.

In 1800, only 90 000 people were recorded in Amazonia, and by 1840 the population was still only 129 000 (Santos, 1980:59). The beginnings of the rubber boom helped swell the regional population to about 330 000 people in 1872, and by 1960, some two and a half million people were living in the Brazilian Amazon (IBGE, 1989). By 1992, approximately 15 million people were residing in the Brazilian Amazon.

Substantial parts of Amazonia must have been cleared at time of contact to support several million people. In 1940, only a fifth of the people in the Brazilian Amazon was urban (Saunders, 1974), but close to half of the people living in Amazonia today inhabit towns and cities. Furthermore, urban dwellers rely heavily on imported food. The population in 1500 was more rural and evenly dispersed, and had to obtain most of its food locally. Only the interior of northwestern Amazonia may have been sparsely settled as a result of the extensive tracts of infertile, sandy soils.

Early European explorers and missionaries in Amazonia remained close to rivers, so we have few accounts of population densities in the interfluvial forests at time of contact. Nevertheless, anomalous groupings of certain plant species coupled with archaeological evidence point to much denser populations in many parts of interior Amazonia than has hitherto been suspected. Pioneer highways and accompanying settlement have exposed numerous black earth sites with pottery on a wide variety of soil types (Figure 4), suggesting that sizeable and sedentary populations once occupied "pristine" upland forests (Eden *et al.* 1984; Smith, 1980).

Earth removal in various parts of the Amazon Basin also attest to human alterations of the landscape in remote times. Trenches some 13 km from the Kuluene River in the Upper Xingu are one indication of dense aboriginal populations in parts of Amazonia's upland forests in the past. At one site in the Kuluene forest, the trenches are up to three

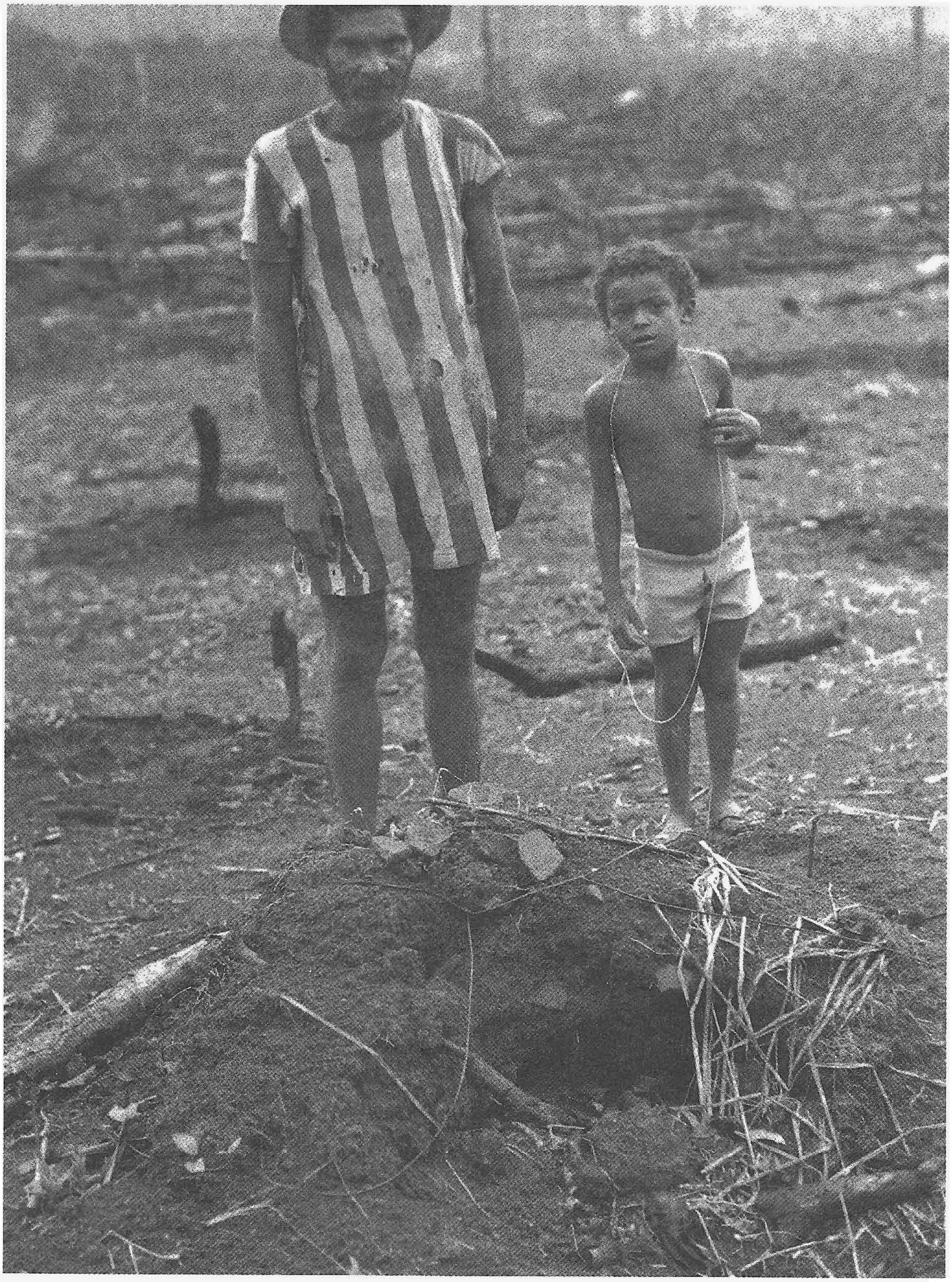

Figure 4. Transamazon settlers with potsherds unearthed in a field cleared on a yellow oxisol, km 19 Altamira-Marabá, Pará, Brazil, December 1978.

meters deep and encompass a potsherd-rich village site of some 110 ha (Dole, 1961). Such a large village must have housed several thousand inhabitants. More trenches, also presumably dug for defensive purposes, have been found in other parts of the Kuluene drainage and in the Guaporé basin. Depressions, measuring some 400-500 m long and 200 m wide on the plateau south of Santarém may have been excavated to retain water for the dry months (Gourou, 1949). If aboriginal groups diked the floodplains of rivers and prepared planting platforms, the restless nature of most rivers would have erased such efforts.

The Amazon floodplain has long been recognized as a propitious environment for the development of advanced cultural groups. A surprising recent find, however, is the antiquity of ceramic-makers along the banks of the resource-rich river. Pottery samples from Taperinha, on the middle Amazon floodplain near Santarém, have been dated from 7110 to 8025 years B.P. (Roosevelt *et al.* 1991). Significantly, Taperinha pottery is indigenous, and not derived from Andean or Mesoamerican cultures.

Other archaeological evidence is accumulating to suggest a prolonged interaction between people and their environment in Amazonia. Charcoal has been located at various depths in widely scattered sites in the heterogeneous region. Charcoal layers in soils of the upper Rio Negro have been dated at 6000 B.P., and some ceramic shards mixed with anthrosols are approximately 3750 years old (Saldarriaga and West, 1986; Sanford *et al.*, 1985; Sponsel, 1986). Charcoal obtained from a shellmound along the Bragantina coast east of Belém is some 5000 years old (Simões, 1981). Most of these charcoal deposits are from cooking fires or slash-and-burn farming, since natural fires are extremely rare in the Amazon rainforest. Sombroek (1966:187) attributes charcoal found at 1.5 m depth on the plateau south of Santarém to indigenous activities. Charcoal has also been found in soil profiles at Km 70 and Km 100 of the Altamira-Itaituba stretch of the Transamazon.[1]

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1. In Gleba 24, lot 20 at km 70 of the Altamira-Itaiba stretch of the Transamazon, charcoal was found at 15 cm depth in a black anthrosol (*terra preta do índio*) containing potsherds. The black earth extended to 35 cm depth and covered one hectare. In Gleba 31, lot 23 of the south *travessão* of the Transamazon Highway at km 100 of the Altamira-Itaituba stretch, charcoal was found at 1.26 m depth when a colonist dug a well.

Reconfiguring the Landscape with Economic Plants

Various cultural forests have been identified in the region, evidence of widespread interactions with the forest and intimate knowledge of its resources (Balée, 1989a; Balée and Campbell, 1990). Liana forests (*mata de cipó*), for example, are a late successional stage or a disclimax, resulting from repeated slash-and-burn farming cycles (Sombroek, 1966). Mata de cipó is particularly evident on well-drained sites in the Tocantins and Xingu River basins (Figure 5).

Indigenous groups have enriched the forest surrounding camps and along trails with various useful plants, particularly fruit and nut trees, since the Paleolithic (Table 1). Along the forest/savanna ecotone in southern Amazonia, the Kayapó have created forest islands in grassland that contain plants with myriad uses, from medicine to food (Posey, 1983). A similar pattern of "relict plants" resulting from past human activities has prevailed in other tropical regions, such as around ancient Maya sites in the Yucatán (Gómez-Pompa, 1985, 1987; Gómez-Pompa *et al.*, 1987; Harris, 1978; Turner and Miksicek, 1984).

Some game species, such as brocket deer (*Mazama americana*), paca (*Agouti paca*), and agouti (*Dasyprocta* spp.) would be attracted to sites enriched with fruit and nut trees. In this manner, early inhabitants in Amazonia increased gathering and hunting yields.

Brazil nut (*Bertholletia excelsa*) trees are widely distributed in Amazonia, but form notable concentrations in the middle Tocantins Valley, in parts of the Jari watershed, around Alenquer, eastern Acre and the contiguous area of Madre de Dios in Peru. Brazil nut trees are sparse or absent from much of north-central and northwestern Amazonia.

Many Brazil nut groves may have been planted in remote times. A striking example is the dense grove of ancient Brazil nut trees on the upland bluff four kilometers west of Itacoatiara, Amazonas. For 220 km along the highway from Manaus to Itacoatiara, Brazil nut trees are extremely rare until one approaches the environs of Itacoatiara, the site of dense aboriginal settlements in the past.

Concentrations of economic plants in various Amazonian environments suggest a long history of forest manipulation by indigenous people, perhaps extending back tens of thousands of years. Useful palms often associated with archaeological sites in Amazonia include tucumã (*Astrocaryum vulgare*), caiaué (*Elaeis oleifera*), mucajá (*Acrocomia eriocantha*), inajá (*Maximiliana maripa*; Figure 6), and babaçu (*Orbignya phalerata*); the latter often forms dense stands in eastern Amazonia (Balée, 1988, 1989b).

In eastern Amazonia, tucumã palm is sometimes used to make twine. In Altamira in

Figure 5. Liana forest (mata de cipó), Serra dos Carajás, Pará, Brazil, 2 February 1990.

Table 1. Some fruit trees planted or arising spontaneously from discarded seed around habitation sites in Amazonia.

Common Name	Scientific Name	Habitat
Bacaba palm	*Oenocarpus distichus*	Upland forest
	O. bacaba	Upland forest
Tucumã palm	*Astrocaryum aculeatum*	Upland forest
Caiaué palm	*Elaeis oleifera*	Floodplain forest
Mucajá palm	*Acrocomia eriocantha*	Upland forest/open areas
Inajá palm	*Maximiliana maripa*	Upland forest
Uricuri palm	*Scheelea* sp.	Upland forest
Yellow mombim	*Spondias mombim*	Floodplain and upland forest
Abiu	*Pouteria caimito*	Upland forest
Frutão	*Pouteria pariry*	Upland forest
Cacauí	*Theobroma speciosum*	Upland forest
Cacao	*Theobroma cacao*	Floodplain and upland forest
Cupuaçu	*Theobroma grandiflorum*	Upland forest
Marimari	*Cassia leiandra*	Floodplain forest
Ingá	*Inga* spp.	Upland forest
Piquiá	*Caryocar villosum*	Upland forest
Uxi	*Endopleura uchi*	Upland forest
Mangaba	*Hancornia speciosa*	Open areas

1991, I purchased a sturdy hammock of tucumã fiber fashioned by the Parakanã Indians. The Carajá, a related group, also make hammocks with tucumã fiber (W. Balée, pers. comm., 1991). In parts of central and western Amazonia, a related palm, tucumã (*Astrocaryum aculeatum*), provides an oily, yellow flesh much appreciated by locals (Figure 7). Concentrations of this spiny palm are especially evident in the environs of Manaus, and likely result from enrichment in early times. Babaçu densities often increase spontaneously after burns, whereas the other palms may have been planted, or sprung from discarded seeds around campsites and villages. Babaçu has also been planted, such as near Tucumã in the middle Xingu (A. Anderson, pers. comm., 1990).

Caiaué, introduced to Amazonia long ago from Central America, is a good indicator

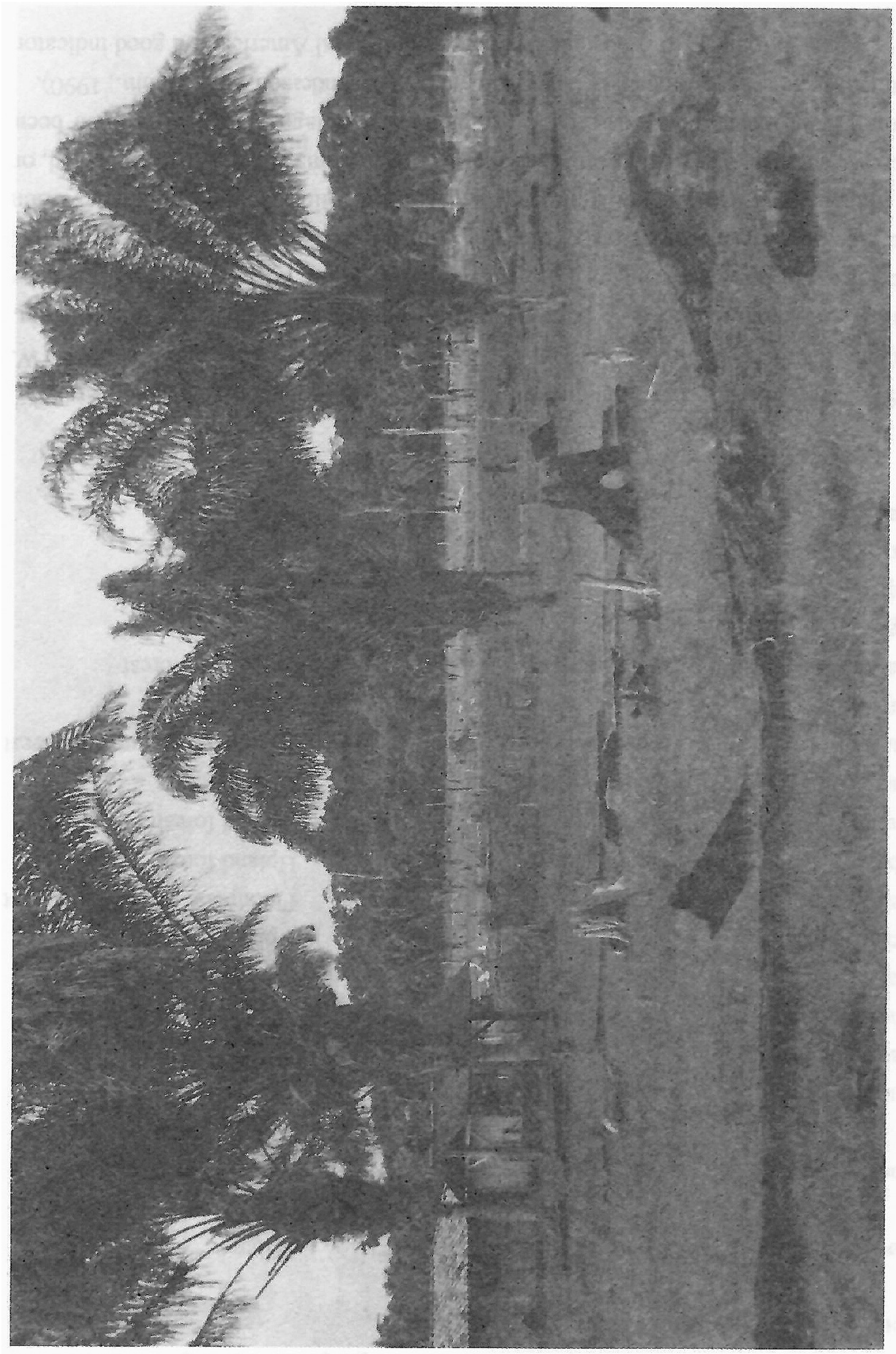

Figure 6. A concentration of inajá palms (*Maximiliana maripa*) which were spared when the forest was cleared for crops and then pasture, PA 150, near Mojú, Pará, Brazil, 2 April 1991.

species for black earth and potsherds along river banks, such as the Urubu in Amazonas. The Mundurukú claim that their ancestors planted patches of mucajá palm in savanna along the Upper Tapajós (Frikel, 1978). In eastern Acre, dense stands of uricuri (*Scheelea* cf. *martiana*) may be attributed to indigenous plantings (Figure 8). As in the past, fruits of uricuri are gathered, the tough outer skin is peeled off with teeth or a knife, and the yellow, oily flesh is relished. Uricuri are spared when clearing the forest for fields, and the large, arching fronds serve for thatch.

Both floodplain and upland forests have been artificially enriched with fruit trees. People gather the long, slender pods of marimari (*Cassia leiandra*, Figure 7) along the Amazon floodplain in the region of Manaus and Itacoatiara during high water. The white pulp surrounding the seeds is relished, and in some cases, the seeds are saved for planting (Cavalcante, 1988:164). Various species of another arboreal legume, *Inga*, have been planted or have germinated from discarded seed in upland forests (Balée and Moore, 1991).

Yellow mombim (*Spondias mombim*, syn. *S. lutea*) has long been planted in floodplain and upland forests. The Tiriyó of the Upper Paru de Oeste near Suriname harvest fruits from groves of yellow mombim that they recognize were planted long ago and are reproducing spontaneously (Frikel, 1978). In March and April, fishermen harvest fruits of yellow mombim, known locally as cajá or taperebá, from disturbed sites along the Amazon, near Itacoatiara, and the Altamira area of the Xingu. The succulent, tart fruits are eaten raw, mashed into water to make a refreshing drink, and are stirred into ice cream. In season, yellow mombim sells briskly in urban markets, and ice cream manufacturers store frozen pulp for year-round use.

Another tree equally at home on the higher parts of the floodplain and in terra firme forest is cacao (*Theobroma cacao*). Shade-tolerant cacao is sometimes found in high densities on anthrosols in western Amazonia (Allen and Lass, 1983). Cacao was first used as a snack by indigenous groups who appreciated the refreshing pulp surrounding the seeds; the fruits evolved for dispersal by primates. Some indigenous peoples undoubtedly enriched their village and campsites with the understorey tree (Smith *et al.* 1992).

Along the Manaus-Itacoatiara highway which slices through 230 km of upland forest and several archaeological sites on white sand campinas, unusual concentrations of bacaba palm (*Oenocarpus bacaba*) occur, often associated with tucumã palm. The purple, plum-sized fruits of bacaba palm make a smooth and satisfying drink, while the golf ball-sized fruits of tucumã are rich in vitamin A.

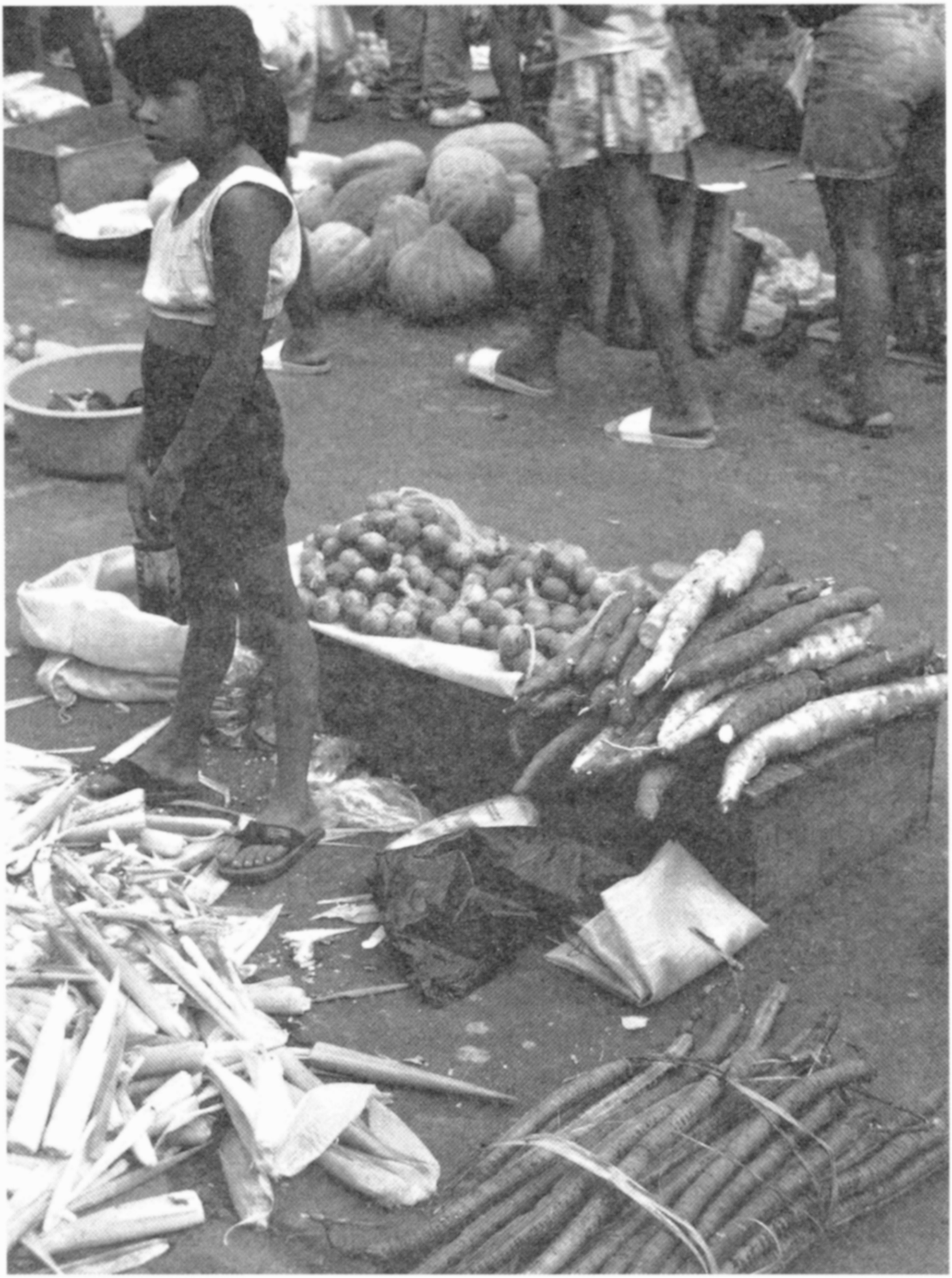

Figure 7. Tucumã palm (*Astrocaryum aculeatum*) fruits in plastic mesh sacks behind girl and bundles of marimari (*Cassia leiandra*) fruits in right foreground, street market in Itacoatiara, Amazonas, Brazil, 13 April 1991.

Figure 8. A dense stand of uricuri palms (*Scheelea* cf. *martiana*) spared when the forest was cleared, km 100 BR 364 Rio Branco-Porto Velho, Acre, Brazil, 17 November 1991.

Indigenous groups have planted dense concentrations of piquiá (*Caryocar villosum*), a giant forest tree that produces tennis ball-sized oily fruits and valuable timber, in parts of the forest stretching from the Upper Xingu east to Maranhão (Frikel, 1978). Other fruit trees planted in Amazonia in ancient times include mangaba (*Hancornia speciosa*) in open sites, and various species of *Pouteria*, such as abiu (*Pouteria caimito*) and frutão (*P. pariry*). Uxi (*Endopleura uchi*), a forest giant that supplies oily, green fruits much procured during the rainy season, has been sporadically planted in gardens and around campsites in the distant past, such as near Castanhal in Pará. Cultural forests are thus often mistaken for "natural" forests in Amazonia, and much of the "pristine forest" in Amazonia may have been managed swidden fallow at time of contact (Denevan and Padoch, 1987; Sternberg, 1986).

The Forest Returns

After contact, the indigenous population declined precipitously (Hemming, 1978, 1987; Ribeiro, 1967). Perhaps 90 % of the Indians perished within the first hundred years of contact, mostly from introduced diseases, such as smallpox, tuberculosis, and influenza. Later, malaria took its toll. Malaria vectors were already present in Amazonia where several species of anopheline mosquitoes reside, but malaria parasites (*Plasmodium falciparum* and *P. vivax*) may have been introduced from Africa when slaves were brought to the New World.

The forest returned in many cases as secondary succession continued to mature forest without interruption. Forest has been slowly closing in on islands of campina in the Manaus region, often former sites of Indian villages. Sandy campinas, resulting from sandbanks from ancient rivers, made excellent village sites while people farmed the surrounding forest on clay-rich oxisols. Although the forest reclaimed areas formerly in fields or agroforestry systems, botanical signatures of long gone cultures remained.

Brazil nut trees can live for centuries. Other anomalous concentrations, such as uricuri palm in eastern Acre, would have maintained themselves from natural regeneration. Other pockets of artificially enriched fruit and nut trees may have been obliterated or at least thinned as seed and leaf predators took advantage of the unnatural concentrations of certain species.

A pattern of waxing and waning of forest cover is not unique to Amazonia. The forests of New England in the United States, for example, are more extensive now than they were during the time of the colonies (Foster, this volume). The oak forests of southern England, severely cut back in Roman times, had largely returned by the time

Henry VIII assumed the throne, only to be felled again for iron smelting, building materials, and agriculture (Perlin, 1989:163, 168, 177, 189). Contraction of forest in Amazonia, however, is likely to lead to higher extinction rates because of the high biodiversity and endemism in tropical rainforests.

During the colonial period, little clearing of the forest took place. The small pockets of Portuguese and Spanish garrisons and missions scattered along the major rivers did not result in much farming activity. Some cacao was planted on the higher parts of the lower Amazon floodplain as well as in the vicinity of Belém; sugarcane was also cultivated to a limited extent around Belém. For the most part, though, traders were mainly interested in valuable hardwoods and spices from the forests.

Range cattle were introduced to the savannas and pockets of cerrado in Amazonia during the eighteenth century. Spanish cattle of the Texan Longhorn type were first brought to the grasslands of Roraima in 1787 (Rivière, 1972:13). The practice of burning the grasslands thus continued, although for different purposes. Torching the *cerrado* kept the forest in check and promoted more nutritious forage grasses and herbs for the hardy criollo cattle. The tempo of burning increased as the cattle population multiplied; within a hundred years of their introduction, some 30 000 cattle roamed Roraima, and their number had grown to approximately 300 000 head by the 1930s (Rivière, 1972:15).

Even the rubber boom of the late 1800s and early part of the twentieth century had little effect on the forest landscape. If anything, it helped promote the return of the forest as indigenous groups were killed or enslaved, particularly in western Amazonia. Spurred by a searing drought in 1877, some 300 000 migrants poured into the Amazon Basin from the Brazilian northeast to try their hand tapping rubber (Benchimol, 1985). But little forest clearing took place because company managers and grubstakers discouraged rubber tappers from growing their own crops. Handsome profits were realized by forcing rubber tappers to pay exorbitant prices for food and other goods in stores operated by the owners of the rubber tree tapping areas (*seringais*). After the collapse of the rubber boom in the early 1920s, Pará and Acre lost inhabitants as many migrants sought a better life elsewhere.

Reclaiming the Wilderness

For most of the five hundred years that have elapsed since Europeans arrived, much of Amazonia's forest has experienced a long respite from significant clearing. Only within the last few decades has another cycle of major landscape changes emerged in response to a suite of development initiatives. The assumption of power in Brazil by a military government in 1964 installed a fresh vision of Amazonia as a manifest destiny to be occupied and tamed for the benefit of all Brazil. Some neighboring countries, particularly Peru, followed suit with plans to colonize and settle portions of their Amazonian territories, in part because of national security concerns. The Acre lesson has not been lost on Brazil's neighbors. The Brazilian state of Acre was acquired from Bolivia when Brazilian rubber tappers penetrated the region and effectively occupied it. With Brazil putting a stamp of sovereignty on its vast northern territory, neighbors would be wise to do likewise.

Fiscal incentives and bold settlement schemes set the stage for profound landscape changes starting in the late 1960s. Cattle raising, planned colonization along pioneer highways, hydroelectric dams, and large-scale mining operations have started to change the face of Amazonia. In spite of popular belief that the Amazon forest is being totally destroyed, the scale of the region and the concentrated nature of many of the development thrusts have prevented any major ecological catastrophe thus far.

Traditionally, most of the cattle in Amazonia have been raised in "natural" grasslands, such as occur in Roraima and Marajó, and along floodplains of white-water rivers. In floodplain areas, small, upland pastures were created to stock cattle during high water. In some cases, cattle were kept on the floodplain on tethered rafts during the annual flood. With the advent of fiscal incentives, cattle raising shifted to upland forest.

Forest clearing for cattle ranches led to the destruction of at least 11 million hectares of rainforest from the mid-1960s to mid-1980s. Companies could invest up to half of their taxes in government-approved development projects in the North; many of these ranches were installed for land speculation purposes (Hecht and Cockburn, 1989). Concerns that the "grass rush" and colonization would trigger the formation of deserts (Goodland and Irwin, 1975; Paula, 1972) have not been realized, however. About half of the pastures formed in upland forest are degraded by overgrazing and/or weed invasion. Some of them are being recuperated, whereas others are being allowed to revert to forest.

Most of the ranches cleared with fiscal incentives were set up in Pará and northern Mato Grosso. Many ranchers own tracts of several hundred thousand hectares, and vast openings have been created in the forest. Unlike the pattern in pre-contact times when forest clearings were numerous but small, some artificial pastures extend uninterrupted for tens of thousands of hectares. Such large cleared areas are more likely to cause extinction of highly restricted species and will prolong the recovery of the landscape for future uses, including forest rehabilitation.

The push to open national integration highways (PIN--Programa Nacional de Integração) highways in 1970 opened up more areas of forest to small, medium, and large-scale farmers and ranchers (Fearnside, 1986; Moran, 1981; Schmink and Wood, 1984; Smith, 1982). Although this new, planned grid of highways, with the Transamazon serving as the backbone, triggered much concern about massive forest destruction and severe ecological repercussions, the overall impact of pioneer highways has not been as severe as feared. In parts of Rondônia and eastern Pará, however, new highways and associated feeder roads have triggered rampant deforestation.

The PIN highway scheme has had limited overall impact on the environment because some of the planned highways have not been built, such as the northern perimeter highway, and because the Transamazon does not link settlers to major markets. The increased price of oil, particularly in 1973 and 1978, coupled with chronic recession during much of the 1980s and early 1990s, has dampened economic activities and forced the government to scale back some of its ambitious road development plans.

In Rondônia and the Altamira and Marabá areas of the Transamazon, significant settlement and associated clearing has penetrated as much as twenty to thirty kilometers on either side of main pioneer roads, but elsewhere the PIN highways remain but a hairline fracture across a sea of forest. A trend towards use of second growth, or improving existing pastures, rather than clearing mature forest appears to be strengthening. Second growth communities are often closer to roads and are old enough to generate sufficient ash for fertilizing crops.

Furthermore, many farmers are learning that it makes ecological and economic sense to plant a mix of perennial crops on their land (Figure 9). Even recent colonists often learn quickly that agroforestry systems protect the soil, conserve moisture, reduce pest and disease pressure, and provide a variety of products for the home and market. Farmers in many parts of Amazonia are experimenting with a wide variety of perennial and annual crop mixes in response to local ecological conditions and market opportunities.

Hydroelectric dams received a major push in the 1970s, partly in response to the rising costs of petroleum for diesel-powered electrical plants and a desire to develop relatively inexpensive electricity to smelt bauxite. Large reservoirs have now formed along some rivers, such as the Tocantins and Uatumã. Upland lakes are a novel feature of Amazonian landscapes; floodplain lakes are mostly confined to white-water rivers, are generally small, and fluctuate greatly in response to flood cycles.

The largest reservoirs, created by the closing of the Tucurui dam on the Tocantins

Figure 9. A field recently planted with peach palm (*Bactris gasipaes*), cupuaçu (*Theobroma grandiflorum*) and banana; Brazil nut trees (*Bertholletia excelsa*) in background have been spared. Nova Califómia, km 155 BR 364 Rio Branco-Porto Velho, Acre, Brazil, 17 November 1991.

and the Balbina dam on the Uatumã, have each flooded some 2000 km^2 of forest (Figure 10). Dam construction has focused on clear or black-water rivers, where premature siltation problems are expected to be minimal. Less than 5000 km^2 of forest have been flooded by hydroelectric dams in Amazonia, a relatively small area considering that the Brazilian Amazon occupies 3.8 million km^2. For the moment, the push to develop the hydroelectric dams in Amazonia has abated, mainly because the international donor community is concerned about ecological and social impacts, particularly on tribal communities and fish resources. When the price of petroleum resumes its upward spiral, the pressure to build more dams will mount.

Landscape impacts from mining occur on two levels: on the site or sites where minerals are extracted, and in association with development and settlement. Overall, vegetation changes as a result of mining itself are minimal. Development activities generated by mining have the greatest potential for drastically reducing forest cover.

To date, the mining operation with the greatest potential for radical landscape changes is in the greater Carajás area. In the case of the iron ore concession at Carajás, the mining operation itself is well run with careful pollution control procedures. The 411 000 ha concession, run by Companhia Vale do Rio Doce (CVRD), has one of the best protected sections of forest in southeastern Pará.

Plans to operate pig-iron smelters along the 980 kilometer railway linking Carajás to a deep-water port in Maranhão, on the other hand, could lead to the annual destruction of 1500 km^2 of forest (Anderson, 1990). This rate of forest destruction in a relatively small area would be unprecedented, and could result in serious losses of soil and plant resources, as well as adverse impacts on communities that depend on the forest. How many of the pig-iron smelters will eventually be built is unclear at this point. Under current economic conditions, fuelwood plantations for charcoal production are not viable.

The manganese mine at Serra do Navio and associated hills is winding down after several decades of environmentally benign operation. Settlement along the railroad from the Amazon River to Serra do Navio has not provoked massive deforestation, and many perennial cropping systems are now in place, including oil palm. At the Trombetas bauxite mine, Mineração do Norte carefully stockpiles the overburden of topsoil, and after the bauxite has been removed, re-covers the area with topsoil and seedlings of native trees.

Even with satellite data, controversy still rages about deforestation rates and the amount of area currently cleared in Amazonia. In part, the picture is confused because of the inability of remote sensing techniques to differentiate between advanced second

Figure 10. Tucurui reservoir with several dead Brazil nut trees (*Bertholletia excelsa*), Eletronorte Base 4, Pará, Brazil, August 1988.

growth and forest. Assumptions on deforested areas also hinge on whether one considers all forest removal as permanent. Estimates of the cleared area in Amazonia are in the 8-12 % range. Overall, then, much of Amazonia remains in forest, particularly in Amazonas State in Brazil. A consensus has emerged that deforestation rates have slowed.

In spite of the development push that began in the 1960s, it seems unlikely that the area cleared today is any larger than it was in 1500. Certainly, the pattern of clearings and localized ecological impacts are different since the Columbian encounter, but the area of forest is probably greater now than when the Europeans arrived.

The dynamics of landscape change since the late paleolithic have profound implications for the debates about climate change and sustainable development. No evidence has emerged that current deforestation in Amazonia is altering rainfall regimes or contributing significantly to the buildup of greenhouse gases in the atmosphere (Smith *et al.* 1991). Aborigines appear to have installed a number of cultural mechanisms to check overexploitation of valuable animals and plants, but some inadvertent extinctions of flora and fauna surely occurred during extensive farming activities in the past. The "extinction spasm" now underway in the humid tropics may not be the first such ecological bottleneck for rainforests of the New World.

Another important implication of high population densities in the past is that Amazonia clearly has potential for sustainable development. Given the perishability of many plant parts in the humid tropics, it will be difficult to reconstruct ancient cropping patterns. But the more that we can decipher about how Indians managed their agroecosystems in the past, as well as understand how the remaining indigenous groups exploit the forest and cultivate plants, the greater the chances for success in the future.

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CHAPTER 10

LAND-USE HISTORY AND FOUR HUNDRED YEARS OF VEGETATION CHANGE IN NEW ENGLAND

David Foster

"The upland climax vegetation of New England? Trees, of course."

H. M. Raup

Introduction

Forests in New England are extraordinarily resilient. Despite centuries of cutting, burning, grazing, deforestation and recent pollution, trees repeatedly return to dominate most upland sites unless substantial energy is expended to exclude them (Raup, 1979; Smith, 1979; Russell, 1980). The agriculturally motivated deforestation and reforestation of New England over the past 250 years comprises a series of ecologically significant landscape transformations that presage the widespread destruction of forested ecosystems in many developing regions of the world today. And yet, despite the return of forest cover to an extent that may rival that of the presettlement landscape, there are many questions concerning the long-term impacts of land-use history on the structure, composition and spatial patterning of modern forests. Equally important are persistent legacies in biotic and functional characteristics of forest ecosystems that have developed as a consequence of human activity and historical changes in forest vegetation.

The New England landscape provides an opportunity to examine the long-lasting impact of extensive land use on forest ecosystems. Lessons learned from such an analysis may be applied towards understanding other parts of the world where forest cover has been substantially altered or removed and eventually recovered. In broad areas of Fennoscandia, eastern North America, and Central America the current cover of forest vegetation effectively obscures the evidence of the landscape transformations that have occurred as a result of intensive agricultural activity. In even larger portions of the developing world deforestation and forest ecosystem modification are presently occurring at a prolific rate. Thus, a major objective of this review of changes in the New England landscape is to provide information relevant to a general understanding of human impacts on forested regions.

A final objective is to focus in more closely on the social causes of the changes that have occurred in New England forests. Information on the economic, technological, and historical factors underlying human activity provides a context for understanding the changing pressures on forests in this region. Ultimately, it is hoped that a broader understanding of the dynamic changes in the landscape will provide a strong basis for guiding decisions on future research, conservation priorities and management activities of this forested area.

In reviewing the natural forest dynamics, human history and landscape transformation of New England this paper focuses on the states of Connecticut, Rhode Island, Massachusetts, Vermont and New Hampshire as they share many similarities in physical features, biological characteristics and human history. It excludes much of Maine, which differs greatly in terms of forest conditions and land-use activity. Most of the discussion deals with the upland heart of the region where most of the forested area occurs. However, the coastal and riverine lowlands were important regions of commercial enterprise and population density; activities in the lowland centers were inextricably interwoven with the transformations in the upland landscape (Cronon, 1991). These connections are commented on in this paper where relevant.

Following a brief review of regional characteristics, insights from paleoecological studies are utilized to highlight the dynamic nature of the precolonial vegetation in response to natural environmental change and disturbance. A detailed review of the history of colonial settlement and development of the New England landscape is then presented to provide the social context for understanding the resulting vegetational changes. Finally, the vegetational, faunal and ecosystem consequences of this human land use are outlined. This background is used to discuss potential future changes and areas for further study.

Regional Characteristics of the New England Landscape

Physical and biological features

The New England states, excluding Maine, form a roughly rectangular area 250 by 450 km in size that extends north and east from the Atlantic Ocean. Physiographically the region consists of seven broad areas, the coastal lowlands, inland uplands, the Connecticut River valley, the Champlain valley and the White Mountains, Green Mountains, and Taconic Mountains (Figure 1). These regions differ in bedrock geology, as well as general elevation and relief; however, with major exceptions in the Connecticut River valley and Taconic range the geological substrate is comprised of acidic, relatively nutrient-poor material. The entire region was glaciated until approximately 10-13 thousand years ago. Variation in the depth and texture of surficial materials is the result of local glacial geomorphology. In general the soils are shallow and bedrock is extensively exposed.

Substantial variability in regional climate results from elevational and coastal-inland gradients. Average annual rainfall exceeds 1000 mm and is evenly distributed through the year. Summer temperatures average 22°C (July) whereas winter averages drop to -4°C (January) in inland locations. Regional differences in growing season length exceed three weeks between southern coastal and northern locations. Within the region the broad valley of the Connecticut River provides a distinct environment due to its low elevation and the predominance of broad, level areas of glacial lake sediment, sandy deltaic material and floodplain deposits.

The regional vegetation changes latitudinally with local variation due to elevation in the Connecticut Valley and northern mountains (Figure 2). Northern hardwoods-conifer forest covers much of Vermont and New Hampshire, extending southward along the White and Green Mountains into northern Massachusetts. Important hardwood species in this forest include sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*), yellow birch (*Betula alleghaniensis*), paper birch (*Betula papyrifera*) and red maple (*Acer rubrum*). Among the conifers, red spruce (*Picea rubens*) and balsam fir (*Abies balsamea*) are common in the north, whereas hemlock (*Tsuga canadensis*) and white pine (*Pinus strobus*) increase to the south. Southern New England forests (Central Hardwoods) include more oak (*Quercus alba, Q. velutina, Q. rubra*), gray birch (*Betula populifolia*) and hickory (*Carya ovata, C. cordiformis*) along with red maple and

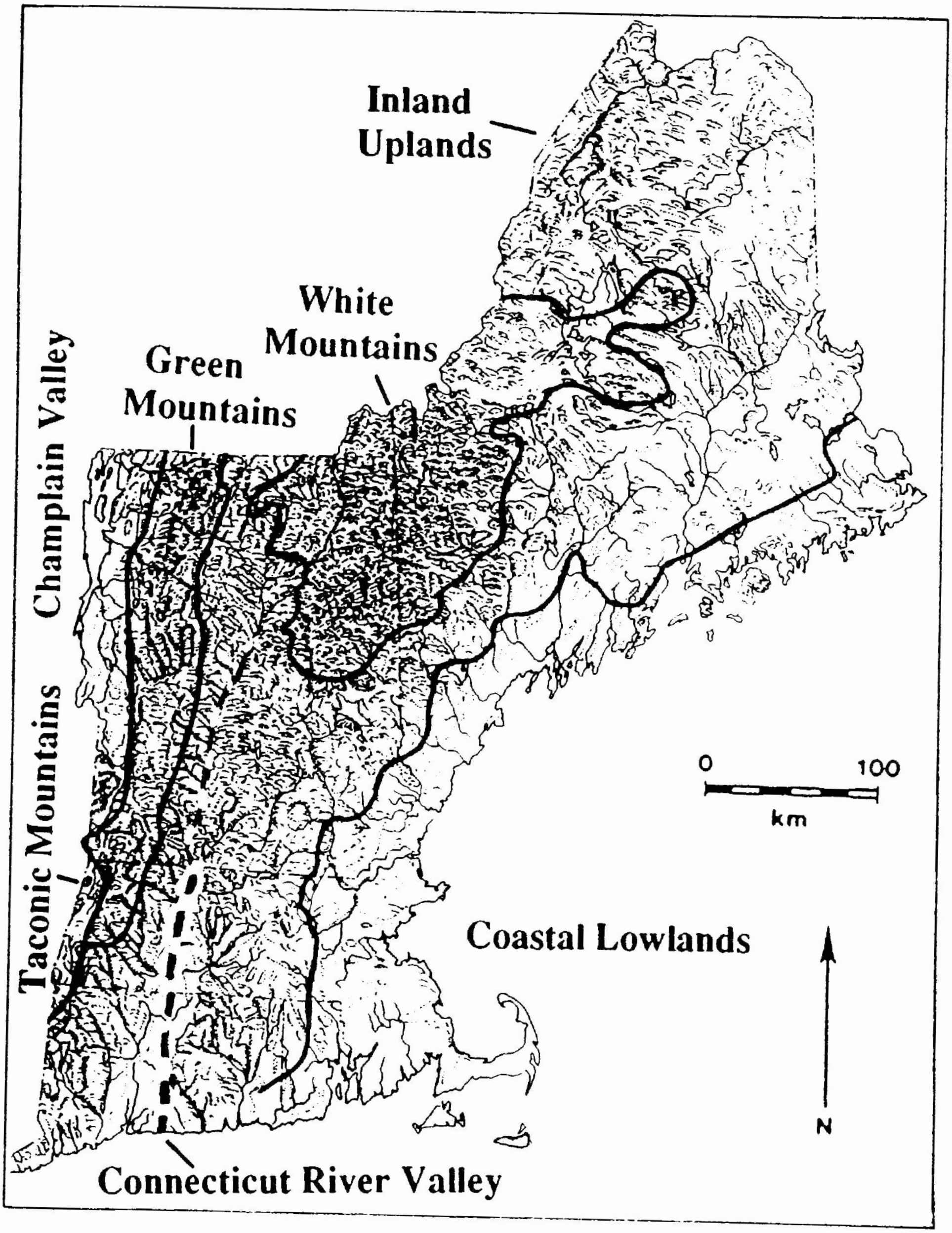


Figure 1. Relief map of New England depicting the major physiographic regions. Modified from Wright (1933) and Jorgensen (1977).

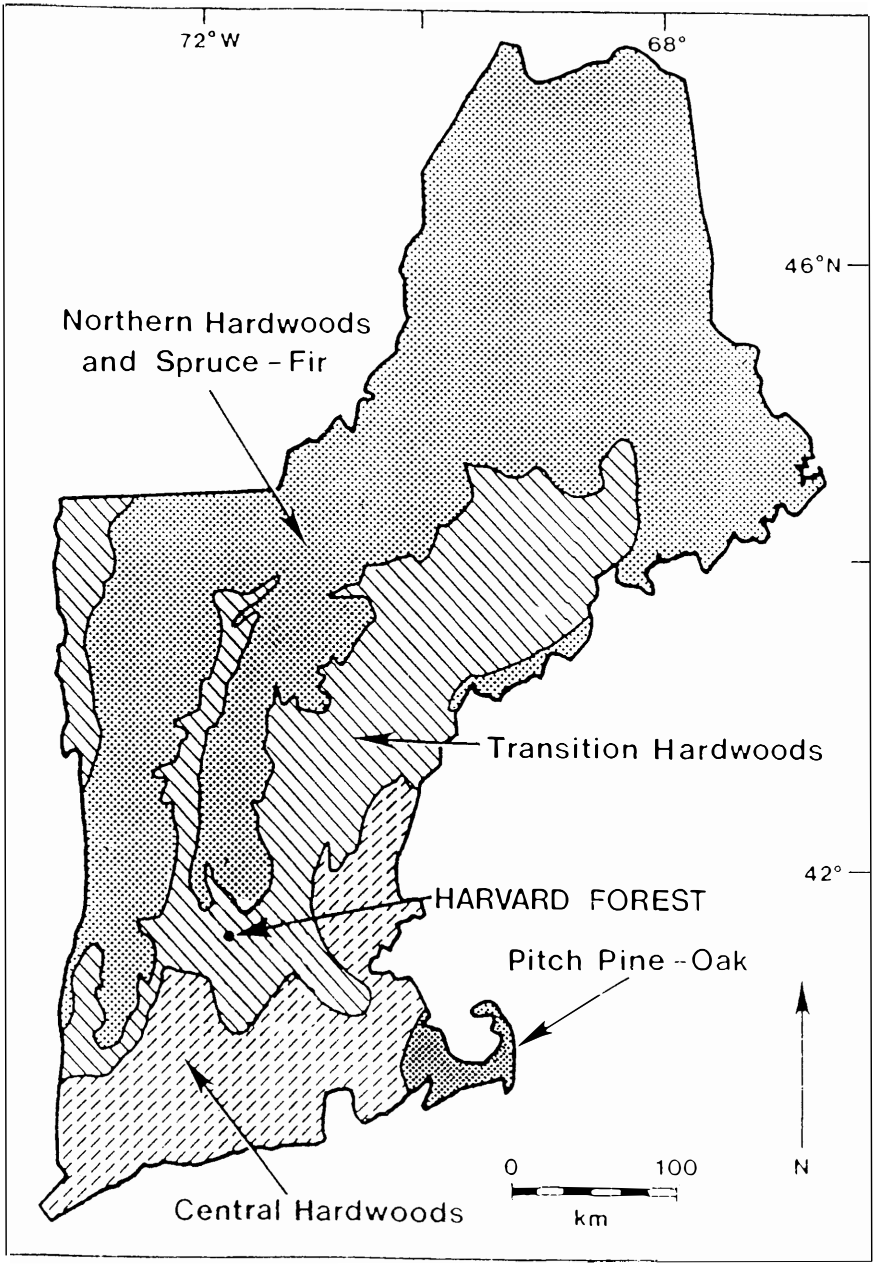


Figure 2. The major forest vegetation zones in New England. The Transition Hardwood forest extends far north along the low Connecticut Valley and in southern Maine. Northern Hardwood forest extends southward along the White and Green Mountains into northern Massachusetts. Glacial sandy deposits forming the area of Cape Cod support a xeric forest of pitch pine and scrub oak species. Modified from Westveld (1956).

community occurs across central Massachusetts, up the Connecticut River valley and through eastern New Hampshire. A distinctive vegetation of pitch pine (*Pinus rigida*) and oak (*Quercus ilicifolia, Q. stellata*) species occurs on sandy soils across Cape Cod and inland on outwash deposits.

Dynamics of the precolonial landscape

Any serious attempt to evaluate the role of European settlers in transforming the landscape of North America must establish the range of environmental conditions and dynamics of the vegetation during "presettlement times," when aboriginal peoples and natural processes shaped the landscape. Although the earliest historical accounts contain some insight on this period, they provide only a snapshot view that may be biased by the background or motivations of the recorder (Russell, 1980; Cronon, 1983; Crosby, 1986). In contrast, paleoecological studies provide a lengthy temporal perspective for evaluating vegetation and environmental conditions in a consistent manner from prehistorical through modern times. Specific topics addressed by the paleoecological record that pertain to the understanding of the impact of European settlement on the region include: the rate of presettlement ecosystem change, the role of non-climatic factors (e.g. natural and aboriginal disturbance processes) in altering terrestrial and aquatic environments, and the evolutionary context for the organization of plant and animal communities.

The paleoecological record from New England supports the viewpoint of environment and vegetation as dynamic on geological and ecological time scales (Watts, 1973; Davis, 1986; Hunter *et al.*, 1988; Huntley and Webb, 1989). Major environmental factors including climate have changed continuously in the recent past, though at variable rates. Coupled with natural disturbance processes, this dynamic environment has generated shifts in the overall ranges of many plants and animals and changes in the composition and structure of forest communities. These observations support the notion of plant and animal communities as aggregations of individualistic species responding to unique combinations of climatic, edaphic, biotic and historical factors (Fisher, 1933; Wright, 1977).

In New England vegetation and environment have varied continuously in time and space since the last glacial period (Figure 3). Following great changes in precipitation, temperature, and wind conditions in the millenia after deglaciation, temperate climatic conditions broadly similar to the present were established between 8-10 thousand years before present (B.P.). Thus the major modern forest zonations (e.g. conifer forest at

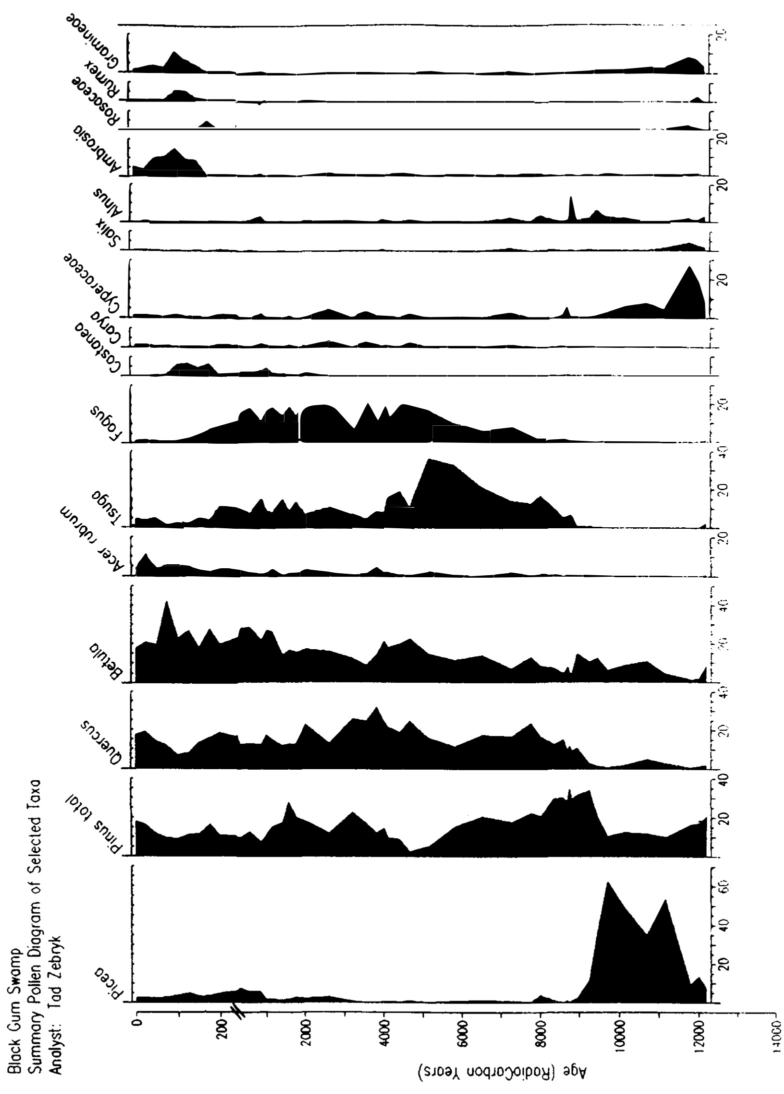


Figure 3. Pollen diagram from the Black Gum Swamp at the Harvard Forest in central Massachusetts depicting the major vegetational changes in the vegetation over the past 12 000 years. Tundra communities were replaced by boreal forest dominated by spruce until approximately 9200 years B.P. when pine and other tree species became important. Changes in relative abundance of species resulted from climate change, species migrations, disease (*Tsuga*) and fire until 250-300 years BP when European settlement resulted in major deforestation and the increase in agricultural weeds, herbs and successional species. Note vertical scale change at 250 years B.P. Modified from Foster and Zebryk (1993).

high elevations and latitude, mixed forest in central New England, and oak hardwood forest in southern New England) have been in place for approximately 8000 years. Since that time, however, climate has fluctuated through a series of long- and short-term trends. From 8000-5000 BP warmer conditions resulted in expanded northern ranges(e.g. white pine across Ontario; Björck, 1985) and increased elevational range of some temperate species (e.g. hemlock and white pine in the White Mountains), and decrease in abundance of boreal species (e.g. spruce; Davis, 1985). Climatic conditions during this 3000-year period include decreasing precipitation and an increase in the mean annual temperature of approximately 2°C, but with warmer summers and cooler winters than today (Davis, 1986). During this warmer, drier period many of our common tree species (*Acer rubrum, Tsuga canadensis, Fagus, Carya* spp.) migrated into southern or central New England, and a number of sites experienced higher fire frequency (Davis, 1985; Patterson and Backman, 1988).

Progressive cooling of the climate over the last 4000 years has been detected throughout the northeastern United States (Davis, 1958, 1985; Gajewski, 1987, 1988; Webb, 1988) with the most significant vegetational changes occurring in the last 2000 years (R. B. Davis *et al.*, 1975). A reduction in the elevational and latitudinal range of many taxa was accompanied by regional increases in spruce 2000 to 1000 years ago (*Picea mariana* and *P. rubens*; Gaudreau and Webb, 1985; Gajewski, 1987; Foster and Zebryk, 1993), and a broad decline in the abundance of hemlock and beech at many sites within the past 400-1000 years (Figure 3; R. B. Davis *et al*,. 1975; Backman, 1984; Bennett, 1985; Gaudreau and Webb, 1985, Whitehead and Jackson, 1990; Foster and Zebryk, 1993). One important though somewhat enigmatic change during the past 3000 years is the migration of chestnut through southern New England to its present range limit in southern Vermont and New Hampshire (Paillet, 1982; Russell, 1983; Bennett, 1988b).

Natural disturbance processes

Throughout the presettlement period disturbance processes including fire, wind, and pathogens have altered the vegetation but with variable frequency and intensity across New England. Collectively these disturbance processes exerted a profound impact on the local distribution of species, the landscape mosaic of vegetation and the regional characteristics of forests (Fisher, 1933; Cline and Spurr, 1942).

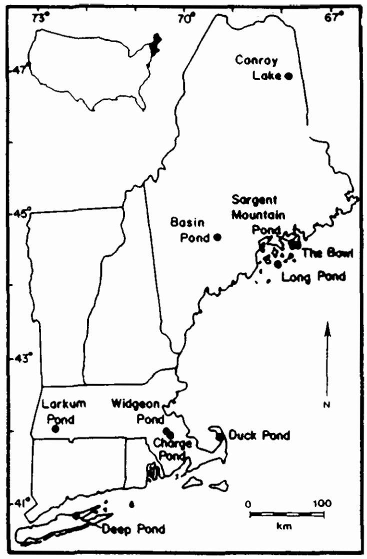
Fire

Fire was the most prevalent disturbance process, with its importance controlled geographically by climatic conditions, fuel abundance, and ignition potential (lightning and aboriginal populations). Analysis of the charcoal and pollen content of lake sediments suggests that the frequency and overall importance of fire in New England decreased inland and northward from coastal areas (Figure 4; Patterson and Sassaman, 1988; Patterson and Backman, 1988). In the sandy and dry environment of Cape Cod, the coastal islands and southeastern Massachusetts, fires were frequent and maintained an open oak and pine forest (Backman, 1984; Winkler, 1985; Dunwiddie, 1989). Lower fire frequencies are recorded in coastal Maine (Backman, 1984), southern Connecticut, and east-central Massachusetts (Davis, 1969; Winkler, 1985) and evidence of fire is nearly absent from the northern hardwood forest in western Massachusetts (Backman, 1984) and the White Mountains (Davis, 1985). A recent study in central Massachusetts, albeit from a low-lying and moist site that should be relatively protected from burning, documents fires approximately every 1000 years (Foster and Zebryk, 1993). Thus a general trend of decreasing fire is apparent along climatic gradients (dry and warm to moist and cool) and vegetational gradients (oak and pitch pine to central hardwoods to northern hardwoods and spruce-fir). However, a comprehensive evaluation of the ecological role of fire in New England is currently precluded by the very low density of sites. For example, there is no basis for examining trends related to higher Indian populations in coastal areas, the major river valleys, or the Champlain Basin in Vermont. Nor is it possible to evaluate local differences in fire regime as controlled by physiography, vegetation pattern, and soil.

Fire undoubtedly exerted an impact on the vegetation at many scales. Regionally, frequent fires in southern coastal areas would favor a greater proportion of fire-adapted sprouting species, including oaks, hickory, birch, chestnut and pitch pine. Indeed palynological and historical evidence indicates a decrease in many of these species with fire control (Whitney and Davis, 1986; Abrams, 1992). Locally, the distribution of individual species may have been determined by their susceptibility to fire. Studies have suggested that hemlock, a highly fire-sensitive species, may have been restricted to mesic, protected sites across southern New England due to frequent surface fires (Bromley, 1935; Cline and Spurr, 1942; Niering and Goodwin, 1974; Davis, 1981a).

Impacts of Indian Land Use

Archaeological evidence indicates a regional gradient of Indian population density and impacts paralleling that of fire frequency: decreasing from coastal and southern



Pond/Lake	Location	Charcoal: Pollen Ratio Average Precolonial	Average Postcolonial	Ratio Post: Pre
Larkum	Massachusetts (central-inland)	27.5	190.5	6.9
Basin[1]	Maine (north-inland)	80.9	385.5	4.8
Conroy[1]	Maine (north-inland)	38.7	291.1	7.5
The Bowl	Maine (north-central)	123.4	390.9	3.2
Sargent Mountain	Maine (north-central)	131.3	161.2	1.2
Long	Maine (north-coastal)	151.9	320.9	2.1
Deep	New York (south-coastal)	650.1	1040.2	1.6
Duck[2]	Massachusetts (central-coastal)	250.7	160.7	0.6
Charge	Massachusetts (central-coastal)	713.9	2895.0	4.1
Widgeon	Massachusetts (central-coastal)	580.7	968.2	1.7

[1] Data from Winkler (1982) as modified from Swain (1981).
[2] Values are approximately 50% low due to problems differentiating small particles from pyrite.

Figure 4. Location and average charcoal abundance of sedimentary fire-history studies in the northeastern United States. There is a general trend of increasing precolonial charcoal abundance from inland and northern sites to coastal and southern sites. Most sites exhibit an increase in charcoal abundance following European settlement. Modified from Patterson and Backman (1988) and Patterson and Sassaman (1988).

regions to the north and from major river basins into highland areas (Figure 5). Along the latitudinal gradient there is a shift from a partial reliance on agriculture to primarily hunting and gathering (Patterson and Sassaman, 1988). The hilly and mountainous regions of interior Vermont and New Hampshire were probably subjected to the least impact by Indian land use.

Agriculture came very late to the eastern woodland Indians and may have involved short fallow or semipermanent cultivation that generated a mosaic pattern of fields, abandoned garden and village sites, and intact forest (Doolittle, 1992). Although early historical accounts abound with descriptions of local forest clearance around Indian villages, there is little evidence that aboriginal activity exerted an impact on the broad-scale pattern of vegetation as would have occurred for example through extensive slash-and-burn agriculture (Burden *et al.*, 1986a/b; McAndrews, 1988; Patterson and Sassaman, 1988). To date there is no conclusive paleoecological record of Indian modification of the New England forest landscape. Even in coastal regions where Indian population densities were presumably highest there is a general absence of the pollen of cultivated plants or fluctuations in weedy and early successional species that would suggest extensive forest clearance and farming (Winkler, 1985; Dunwiddie, 1989).

Wind Damage and Pathogens

Wind damage and pathogens are natural disturbance processes of regional importance in the precolonial landscape. Soil evidence of the uprooting of forest trees extends back nearly 1000 years and documents the ubiquity of wind damage in northeastern forests (Fisher, 1933; Stephens, 1955; Lyford and MacClean, 1966). The relative importance of different types of wind damage apparently varies across New England, with downbursts and northwesterly storms more important in northern New England and tropical storms increasing to the south (Hosier, 1969; Bormann and Likens, 1979; Foster, 1988 a/b). Historical analysis indicates that hurricanes may occur with a frequency of one major storm every 50-100 years and a decreasing gradient of importance across New England from southeast to northwest (Figure 6; Foster and Boose, 1992; Boose *et al.*, 1993). General considerations of the meteorological characteristics of tropical storms suggest that catastrophic storms may be restricted to pathways similar to the hurricanes in 1815 and 1938, which would constrain the strongest winds to those coming from the south and east and going in a northern direction (Foster and Boose, 1992). Thus, there may exist some predictability in landscape-level exposure to tropical winds, with level, south- and east-facing slopes being most exposed and steep northwesterly slopes protected (Boose *et al.*, 1993). The absence of specific stratigraphic markers associated with wind

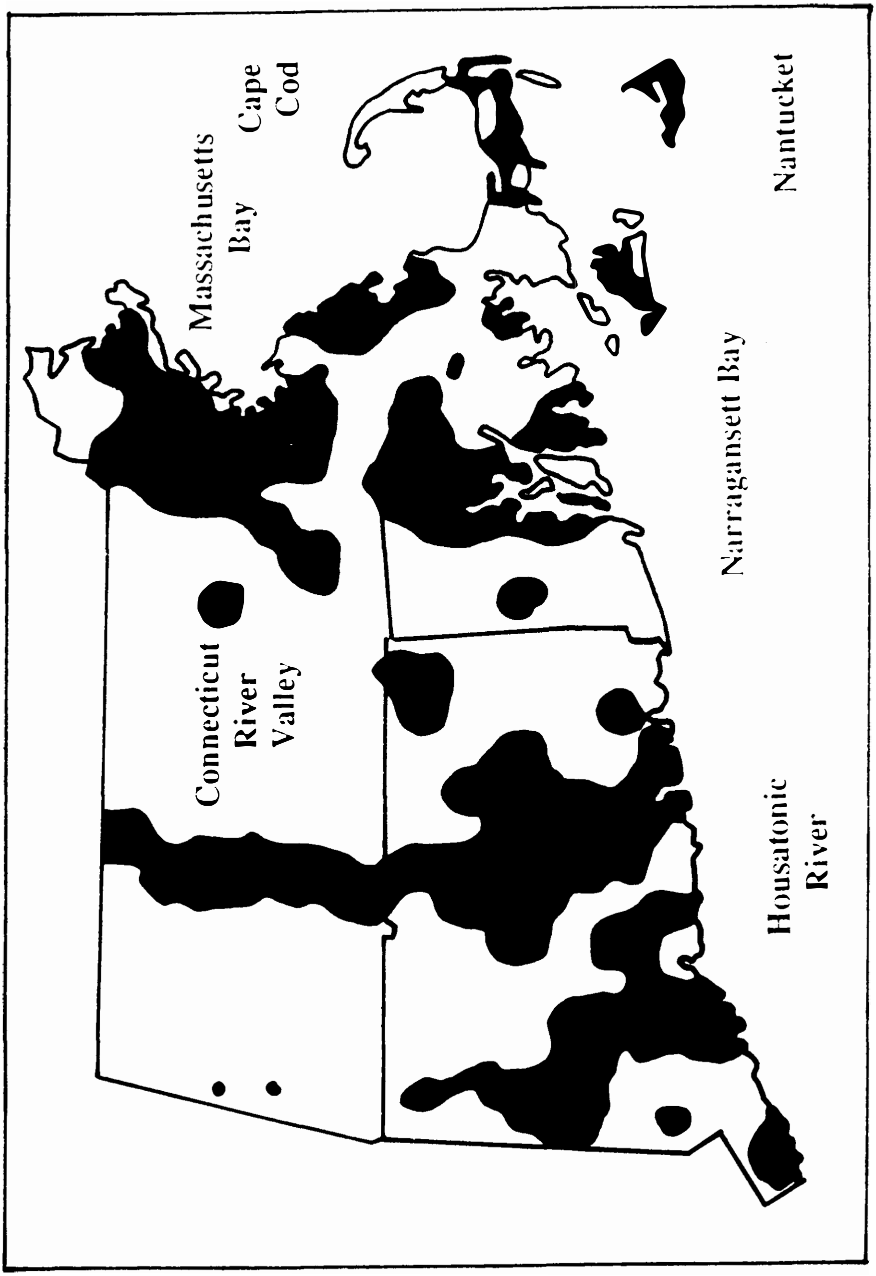


Figure 5. Areas of concentrated aboriginal populations in southern New England during the Late Woodland period (A.D. 1000 - A.D. 1600) preceding European settlement. Populations were concentrated along major river valleys, the coast and the larger islands of Nantucket and Martha´s Vineyard and were low across broad upland areas. Modified from Patterson and Sassaman (1988).

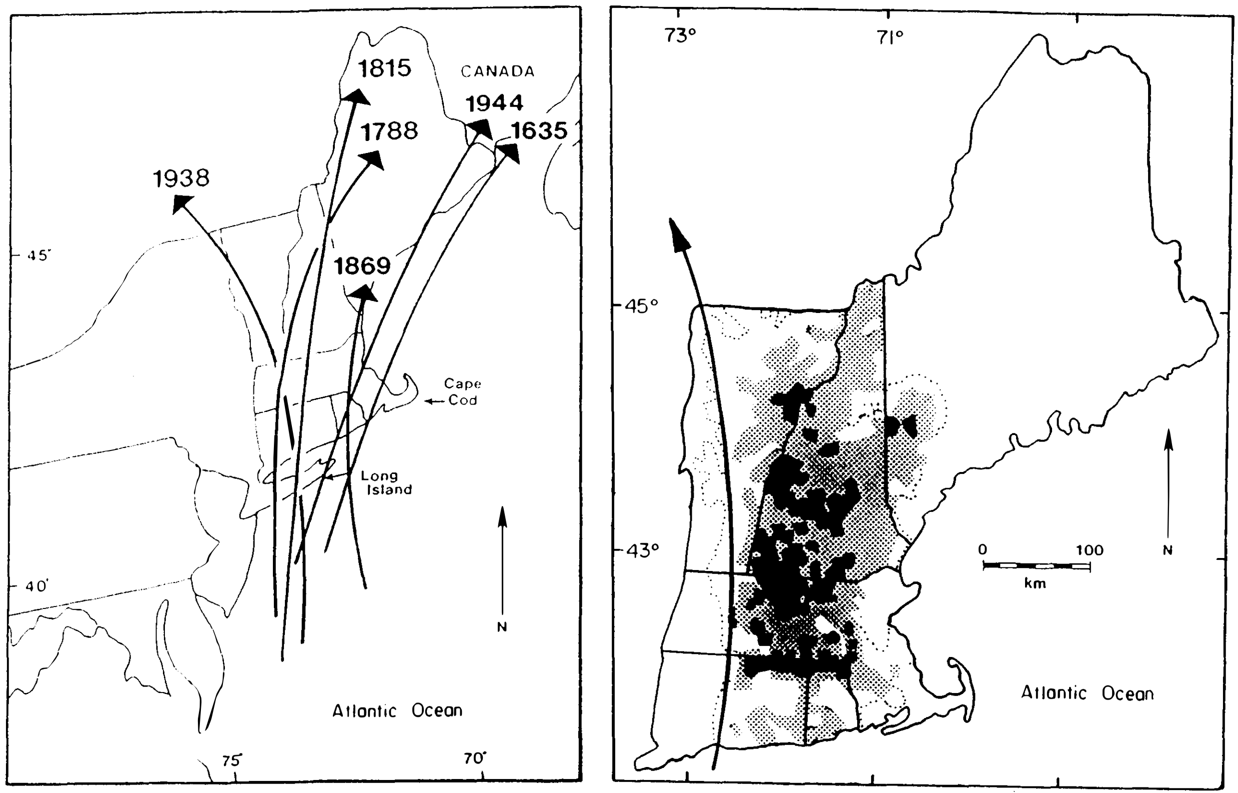


Figure 6. Paths of the major hurricanes that have impacted New England from 1600 to present (a) and the damage inflicted on forests in the region by the 1938 hurricane (b). Damage is indicated in four categories: black -extreme; stippled -moderate; white within enclosed line - slight. Approximately 3 billion board feet of timber were windthrown by the storm, more than 600 lives were lost and damage costs exceeded $100 million. Modified from Smith (1946) and Foster (1988b).

damage will make it difficult to verify these broad conclusions over presettlement times using paleoecological techniques (Foster and Zebryk, 1993).

For pathogens there is but a single putative presettlement event, but it was of broad-scale and long-lasting importance. Starting approximately 4800 BP there occurred a major and apparently synchronous decline of eastern hemlock across its range (see Figure 3; Davis, 1981a; Webb 1988). The rapidity of the decline, its similarity to the impact of the chestnut blight, and its apparent independence from climate change or decline in other species, lead Davis (1981; Allison *et al*,. 1986) to identify it as the result of a pathogen. One possible candidate is an insect like the eastern hemlock looper, which is currently decimating kilometer-wide areas of hemlock across central Massachusetts.

Hemlock persisted during this period in low population levels throughout its range (Davis, 1981b; Allison *et al.*, 1986; Foster and Zebryk, 1993) and recovered to approximately its former abundance in 1000-1500 years, evidently through the evolution of resistance to the pathogen. A number of important observations concerning forest response to pathogens can be drawn from this event: (1) the reorganization of communities after this event differed regionally, and took 400-500 years; (2) hemlock eventually recovered to its original abundance in some locations but in general was reduced somewhat due to the importance of new species that had immmigrated during the interim, or to slight changes in environmental conditions; and (3) significant ecosystem-level changes occurred at many sites, in terms of altered soil characteristics and chemistry, changes in stream water and aquatic processes, and varied forest structure (Whitehead, 1979; Davis, 1985; Ford, 1990; Whitehead and Jackson, 1990).

Insights from the Precolonial Landscape for Understanding Modern Ecosystems

Major lessons from paleoecological studies that pertain to the understanding of the environmental setting encountered by European colonists and their impact upon these ecosystems are manifold: (1) both the environment and the biotic communities arrayed across the New England landscape have a dynamic presettlement history (Fisher, 1933); on an ecological time-scale forest communities never reached a long-term equilibrium; (2) once perturbed by natural disturbance or climate change vegetational adjustment is long-lasting, e.g. on the order of 400-500 years (Foster and Zebryk, 1993); (3) most of the human and natural disturbance processes in pre-colonial times were infrequent and distributed in a geographically uneven pattern controlled by climate, physiography and possibly the distribution of aboriginal populations; and (4) the forest communities encountered upon European settlement had been established for only approximately 2-3 thousand years and were comprised of species that evolved under rather dynamic edaphic and environmental conditions (Spear, 1989; Whitehead and Jackson, 1990).

European Settlement and Expansion in New England

From well-established coastal settlements, European colonists expanded northward and inland through New England at an uneven pace (Figure 7; Monroe *et al.*, 1980; Donahue, 1983). Due to the absolute reliance of early settlers on agriculture, topography exerted a strong influence on migration and settlement patterns. Initial expansion in Connecticut occurred along Long Island Sound (Atlantic Ocean), and northward along the river valleys of the Thames, Connecticut and Housatonic. This was followed much later by gradual dispersion into the northwestern and northeastern highlands. After the end of Queen Anne's War (1713) settlement progressed west and northward across Massachusetts and in 1725 the General Court of Massachusetts commenced using land grants to pay debts, especially for military service (Clark, 1983); the highlands of Massachusetts were allocated in this manner by 1760 and settlers from southern New England began moving into central and northern Vermont by way of the Champlain and Connecticut River valleys. The more rugged and remote areas of the northeastern highlands and Green Mountains were not settled until the 1820s.

Agricultural Development of Upland New England

In the approximately two to three centuries that have elapsed since European settlement, the interior and non-urban regions (primarily upland, hill country) of New England underwent a series of dramatic changes in population density and distribution, social organization and economic base that have exerted long-lasting impacts on the natural environment. Although time-transgressive across the region, often occurring earlier in the south and near the coast, many of these changes were part of regional and generalizable transformations (Figures 8 and 9; Cronon, 1983). Some of the changes occurred rapidly and were true revolutions, in terms of their alteration of lifestyles and their ecological consequences (Merchant, 1989).

Most towns were carved *de novo* from Indian lands with an initial objective of establishing adequate numbers of settlers and agricultural areas for self-sufficiency. In the seventeenth century, towns were initially based on the European model of a centralized and common field system (Donahue, 1983; Garrison, 1985). However, this

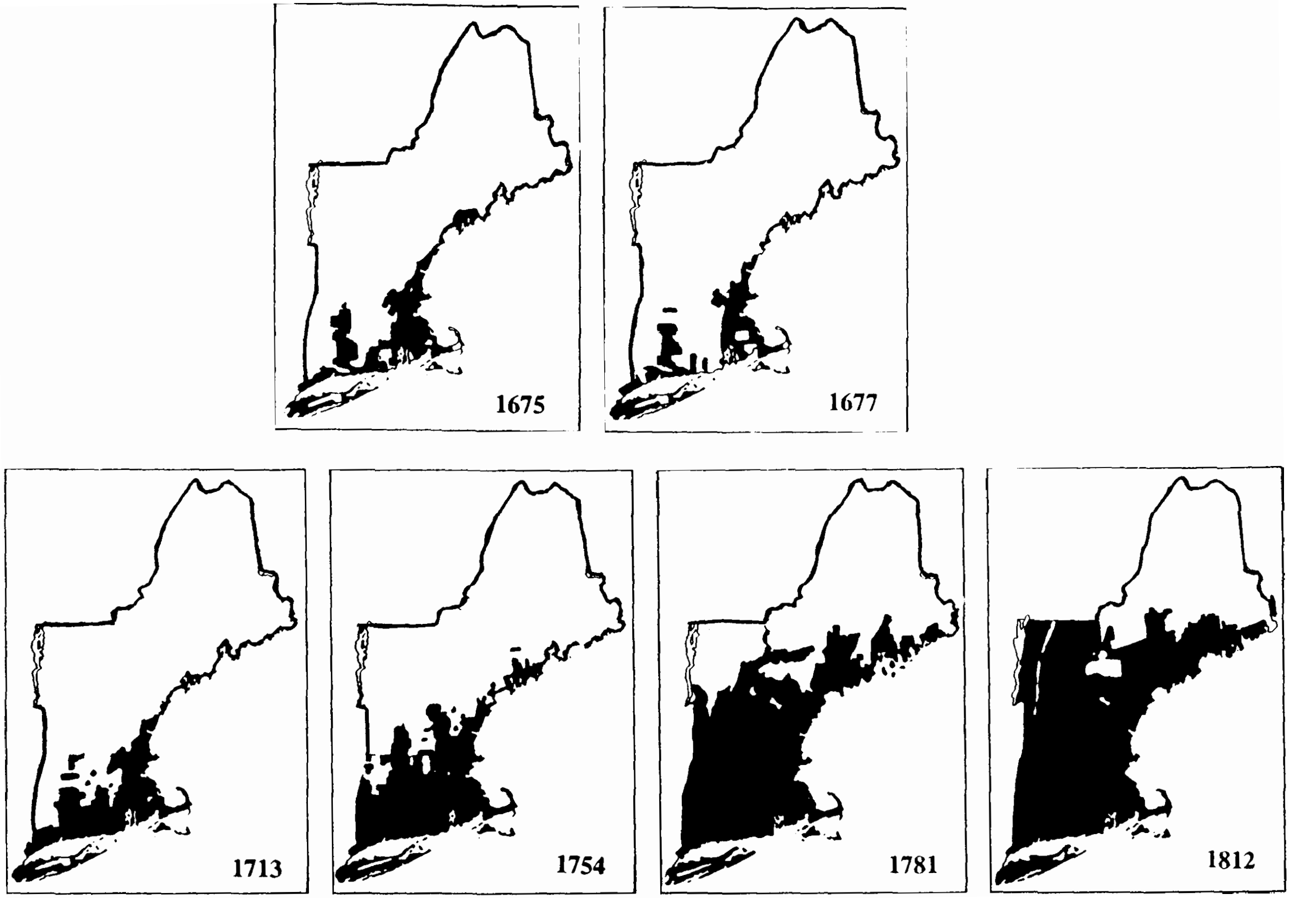


Figure 7. Expansion of the New England frontier from the late 17th century to 1812. Note the initial concentration along the coast and Connecticut River valley during the period of the Indian wars in the 1670s, followed by rapid expansion. From Robinson (1988).

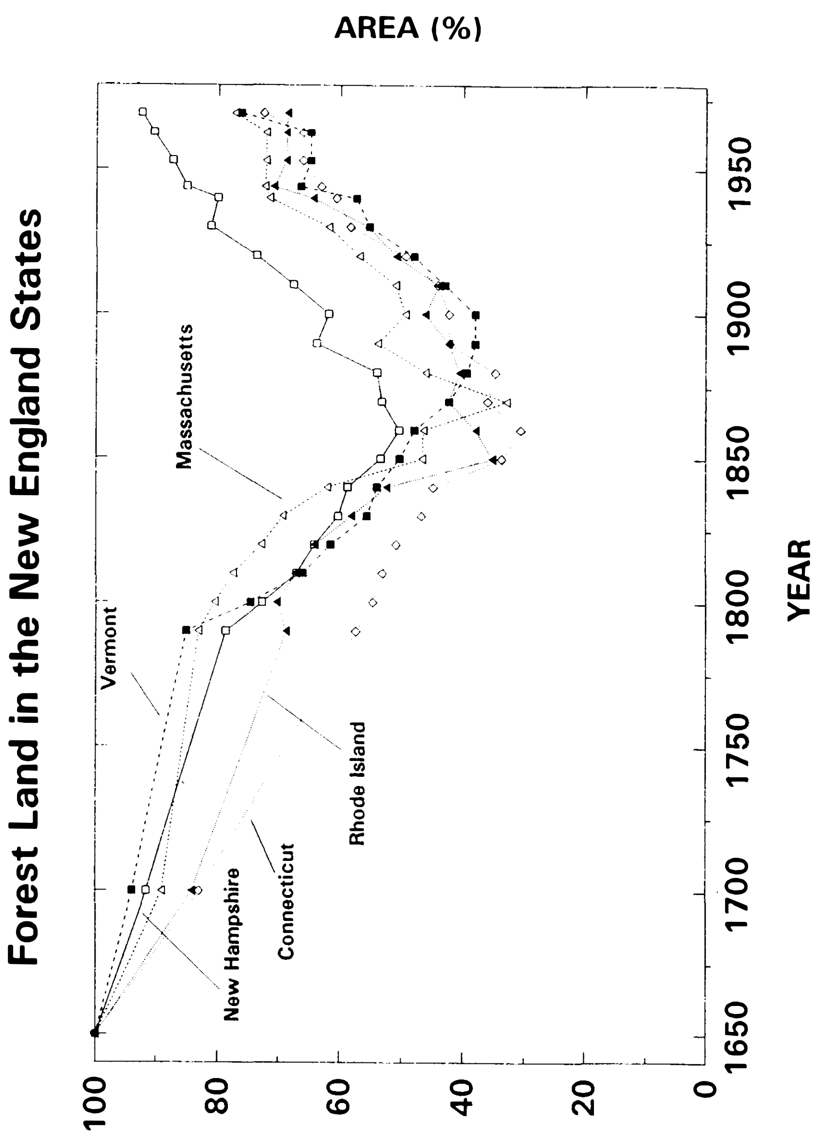


Figure 8. Historical changes in the extent of forest cover in the New England states, excluding Maine. Despite environmental, geological, biotic and social variation across the region, the timing and extent of deforestation and reforestation are remarkably similar. Data were compiled by E. M. Gould, Jr. from the U.S. Census, Baldwin (1942) and unpublished sources.

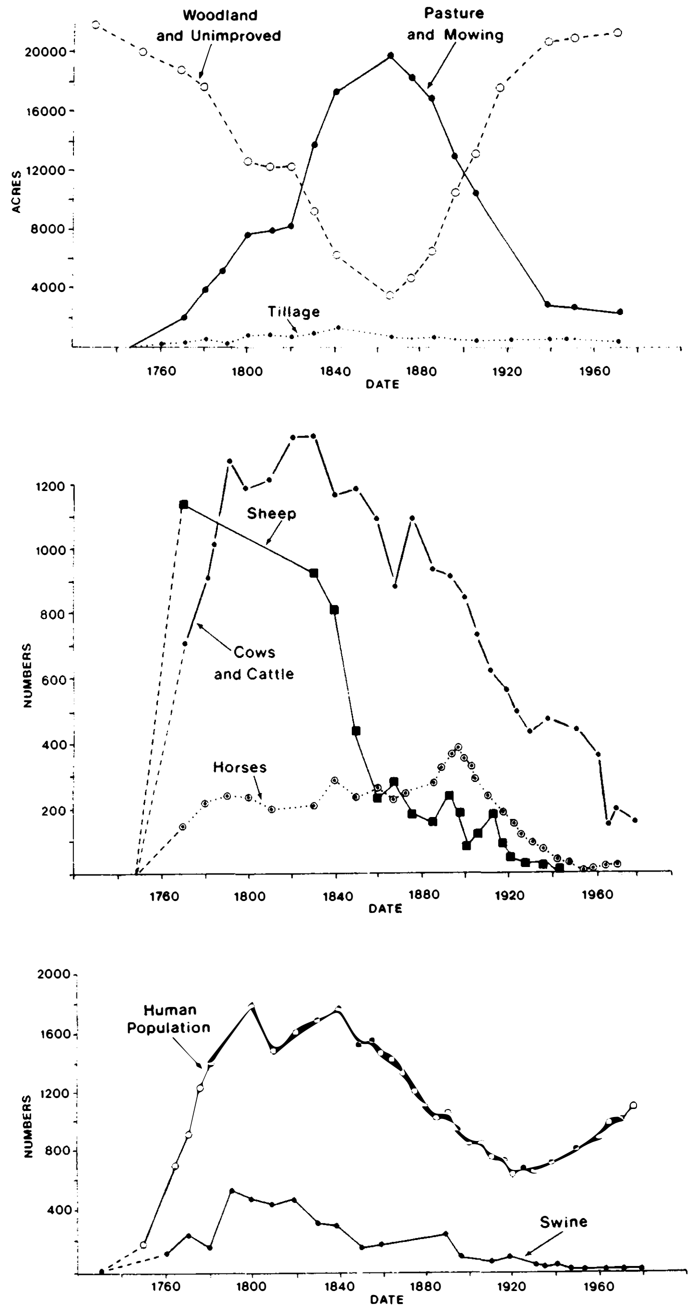


Figure 9. Historical changes in land-use, domestic and human population for the town of Petersham in central Massachusetts. Data are from Petersham tax records and the U.S. Census.

organizational pattern was abandoned in the early eighteenth century in favor of a uniquely New England model of dispersed settlement and individual ownership of private land. Towns (the entire area of a township) were approximately 6 x 6 miles, which represented a practical size in an era of foot transportation, such that all inhabitants were easily within one hour of the village center, the meetinghouse, and church (Gould, 1978). With the General Court providing land, the first years in a town's history were usually marked by land speculation and trading, with few of the original proprietors actually settling on their land (Willson, 1855; Gates, 1978).

In the hilly uplands, hilltops were often selected for the village center and initial clearing as they supported the best agricultural soils characterized by good drainage and relatively few stones (Botts, 1934; Bogart, 1948; Black and Wescott, 1959). In contrast, settlers in broad valley areas took advantage of the level and easily tilled plains for much of their agricultural activity. Land was cleared through girdling and cutting of trees, followed by the burning of slash and wood and the planting of successive grain crops and then corn (Preston, 1822). Land use was determined by a careful reading of the land based on topography, moisture and forest vegetation and frequently assisted by extensive trial and error (Belknap, 1792). In highland areas of New England, individuals were documented as initially clearing 0.5-2.0 ha of forest per year for agriculture (Raup and Carlson, 1941; Bogart, 1948).

Through much of the eighteenth century dispersed, low-intensity agriculture and home- and village-based artisanship were the dominant employment, family occupation and economic base of rural New England (Gates, 1978; Garrison, 1985). Populations were dispersed and low (e.g. 20-35 per km^2). Farmers developed their holdings of 10-40 ha into a mixture of woodland (10-25%), woodland-pasture (10-25%), open pasture (50%) and a limited extent of arable land (< 10%) for grain and diverse crops (Figure 9; Garrison, 1987; Raup and Carlson, 1941). Few individuals maintained the livestock, land base or equipment necessary for all of their own needs; however, in the aggregate and through cooperation and exchange, townships were largely self-sufficient (Pruitt, 1981). All towns supported diverse artisans, shops, mills (for grain, wood and linen) and tanneries (Pewson, 1895). Roadnets were developed primarily for internal circulation and provided relatively poor access to distant markets (Raup and Carlson, 1941). Despite these drawbacks, the amount of trade and travel noted in farm journals of the day was remarkable (Stabler, 1986). Beef (self-transportable; Gates, 1978) and potash provided the major exports from hill towns (Bogart, 1948; Multhauf, 1981), timber was a more important commodity along watercourses, and diverse agricultural products originated from the large river valleys (Gates, 1978; Rothenberg, 1981; Garrison, 1985). Regional markets included Boston, New York, Montreal, Hartford and Providence and international trade was substantial (Pabst, 1941; Pruitt, 1981; Baker and Patterson, 1986).

Commercial Farming and Industrialization

From the late 1700s through the mid-to-late 1800s the economy, social organization and landscape of New England underwent a complete transformation (Pabst, 1941; Merchant, 1989; Baker and Izard, 1987). This period embraced a shift from home production and local consumption to a market farm economy leading to commercial and intensive agriculture (Bidwell, 1916; Bogart, 1948; Kimenker, 1983; Garrison, 1985). During this period an extensive transportation infrastructure developed through road construction and improvement and the building of canals and railroads (Rothenberg, 1981). New village centers were established and urban areas were developed based on water power and industrial activity. In response to the availability of new markets for agricultural goods, New England farmers responded with increased production. This was accomplished through accelerated clearing of forest land, including marginal sites, and through land improvement by drainage (Torbert, 1935; Barraclough, 1940).

Beef and wool production remained preeminent until canal and rail connections with the west and the relaxation of wool tariffs in the 1830s-1840s reduced profit margins on these commodities (Pabst, 1941). Farming was a productive enterprise for full-time employment or in combination with small-scale production of manufactured goods. Most farm families (e.g. > 50% in central Massachusetts; Raup and Carlson, 1941; Gould, 1950) also engaged in home production of shoes, hats, or clothes and many farmers derived additional income running tanneries, sawmills or gristmills (Mann, 1889; Baker and Patterson, 1986). Local industry thrived. For example, in the mid-1840s Petersham, Massachusetts, a town of approximately 1800 individuals, supported two wheelwrights, a button factory, four shoemakers, a laddershop, carriageshop, two stores, ten sawmills, two gristmills, three tanneries, six blacksmiths, a cidermill and a cooper: a diversity of enterprise matched throughout the region (Brown, 1895; Fiske, 1979). This was a period of maximum agricultural activity, population density, and commerce in the hill towns (Willson, 1855; Raup and Carlson, 1941), as well as the beginning of industrial concentration. Many towns literally moved downhill, either relocating their village center along river banks or establishing separate village sites in order to utilize water power (Botts, 1934; Torbert, 1935; Gould, 1950; Robinson, 1988). The factories, which started small and employed local residents and new immigrants, progressively grew to become a major source of northern textiles and wooden products (Botts, 1934; Meeks, 1986).

The 1830s and 1840s oversaw a revolution in transportation as railroads and canals provided regional and interregional movement for people and goods. It has been estimated that prior to 1820 the cost of shipment for one ton of material 20 miles by road in New England was equivalent to the fare for movement of the same material from Boston to London (Pred, 1966). Efforts to provide inexpensive railroad connections began in Massachusetts in 1835 with the construction of the Boston-Worcester Railroad and the subsequent Boston-Albany line across the Berkshire Mountains into New York State. At the end of the 1830s the United States railroad system consisted of a mere 2800 miles of disjointed line; by 1860 it comprised a well-articulated network of 30 600 miles (Pred, 1966). Canals linked the midwest through Lake Erie (1824), Lake Champlain to the Hudson River (1822), Providence, Rhode Island to Worcester, Massachusetts (1828), and provided flat boat access up the Connecticut River to central Vermont (Meeks, 1986). The mania for canal construction prompted efforts to connect regions across extreme obstacles; for example serious but never realized plans were laid to connect the Connecticut and Champlain Lowlands via the 800 m divide across the Green Mountains in Vermont. When successful, such projects provided access to new markets and encouraged the exponential growth of the valley towns that they reached; however, reverse flow of new products and alternative sources of goods from distant areas provided competition for New England farmers. Through the period 1850-70, much of New England was eventually integrated into the national economy and distribution network (Meeks, 1986; Merchant, 1989).

Agricultural Decline and Specialization

Transportation, technological improvements and social changes tied to the Industial Revolution produced major transformations in agricultural and industrial areas of New England (Black and Wescott, 1959). The availability of inexpensive western grain (e.g. corn imported from the midwest in 1840 cost $.10 per bushel in Peacham, Vermont, versus an estimated cost of $.75 for local grown; Bogart, 1948), beef, and other agricultural goods resulted in a decline in diversified farming and specialization on bulky or perishable crops including dairy products, fruit, vegetables, poultry, hay and firewood for the growing urban markets (Chase, 1890; Currier, 1891; Davis, 1933; Donahue, 1984; Baker and Izard, 1987). Crop specialization was determined by distance and transportation to markets: urban towns and their adjacent areas concentrated on cordwood, market crops and milk, more distant towns shipped butter, cheese and hay (Pabst, 1941; Baker and Patterson, 1986).

Growing industrial activity in valley towns and large mill towns (e.g. Worcester and Lowell, Massachusetts, the Naugatuck Valley, Connecticut and Providence, Rhode Island), coupled with a good distribution system eliminated much of the need for local production and artisanship. The result was the closure of many village shops and small factories and a decline in the home-production system, beginning as early as 1850 in central Massachusetts and 1870 in northern Vermont (Raup and Carlson, 1941; Bogart, 1948; Thorbahn and Mrozowski, 1979). A major demographic shift began as especially the young left farm villages for the cities and the midwestern states (Pabst, 1941; Gates, 1978; Barron 1984). In Vermont, between 1840 and 1900, 42% of the towns experienced greater than a 25% decline in population (Robinson, 1988). In this period 40% of the natives emigrated from the state and the urban population increased over 80% (Barron, 1984). Throughout New England this period of agricultural and industrial specialization was accompanied by a concentration of population, energy, and human activity (Figure 10). Paralleling the demographic shift, there occurred widespread abandonment of farmland; between 1850 and 1900 approximately nine million acres of new forest established naturally on former farmland in New England (Barraclough and Gould, 1955). In Vermont, New Hampshire and Maine two million acres of cleared land were reforested from 1880-1900 and more than 11 000 farms were abandoned (Robinson, 1988).

There were many causes for the decline in rural agriculture, small industry and population; however, changes in the fertility of the land was not prominent among them (Black and Wescott, 1959; Raup, 1966; but see Donahue, 1983). New England farms were productive, farmers were prosperous (Raup and Carlson, 1941), and even at the peak of agricultural abandonment the productivity of New England farmland compared favorably with other parts of the country (U. S. Census, 1880; Bell, 1989). In fact, there is evidence that the quality of tilled land improved through the eighteenth and nineteenth centuries in hill towns (Jones, 1991).

There were disadvantages to New England land; for example, the soil is stony and small field sizes were not conducive to the scaled-up agricultural practices accompanying increased mechanization. However, the major factors operating in the agricultural decline appear to have been largely external to the land. These primarily social factors included a growing attraction to the life, jobs and financial benefits of cities and industrial activity, a declining interest in agricultural lifestyle, a decrease in economic opportunities in small

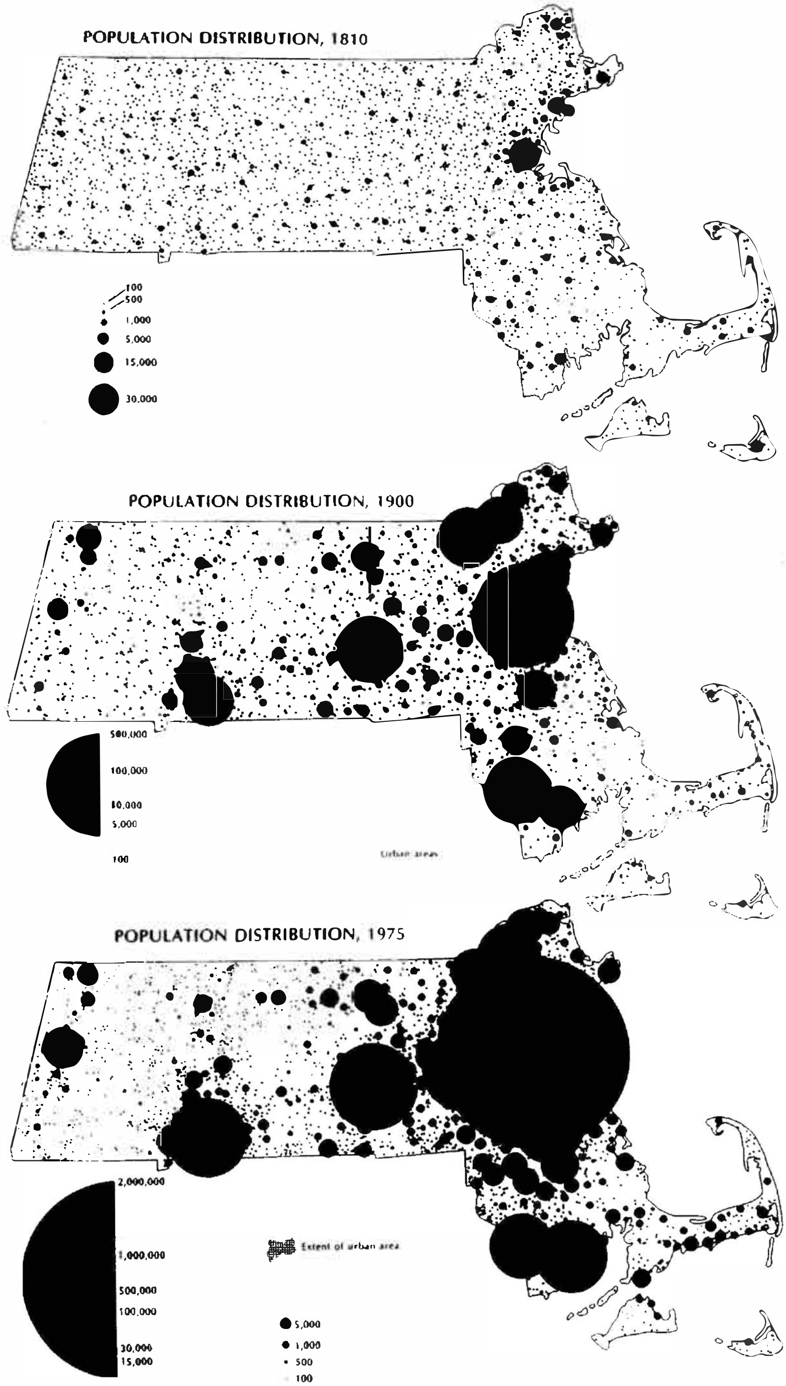


Figure 10. Historical changes in population distribution in Massachusetts. In the agricultural period (1810) density was low (412 000 inhabitans) and remarkably evenly distributed (79% in rural areas), with the exception of Boston, Salem and a few other coastal communities. With industrialization into the 20th century there has occurred a tremendous increase and concentration of population into urban and suburban centers. In 1975, 85% of the population of 5.8 million individuals were located in urban areas. Many of the rural communities have actually undergone a great decline in population during the past 100 years. Data from the U.S. Census with maps modified from Wilkie and Tager (1991).

towns, and the opening of new lands in the midwest and far west (Gould, 1978; Garrison, 1985). The young left the farms but many of the prosperous farm families also relocated (Mann, 1889; Barron, 1984).

Rural Transformations During the Last Century

As the populations of rural towns declined there was a parallel reduction in the local tax base (Willson, 1855; Gates, 1978). Land could be purchased at auctions or bank sales on speculation, for consolidation into adjoining farms, and for second homes by urban dwellers (Brown, 1895; Gates, 1978). Attempts were made to revitalize the towns through agricultural societies, the promotion of tourism (Robinson, 1988) and local efforts like the establishment of Old Home Days seeking to draw former residents and departed children back to their native towns. However, many hill towns were gradually reduced to a residual group of permanent residents and an expanded seasonal population (Black and Brinser, 1952). Miles of stone walls, old cellar holes and abandoned roads in a forested landscape testified to the old agrarian past. This decline contrasted markedly with the phenomenal growth of nearby mill towns.

The newly formed forests gave rise to new activity based on a wide variety of forest products, including timber, furniture and especially shipping containers. Fields seeded into white pine, which provided excellent material for boxes, crates and barrels. The old road system provided access for logging operations throughout the backwoods, the advent of the portable sawmill enabled work on remote forest stands and the rural landscape provided an underemployed population for woods work (Gould, 1978). The result was an unprecedented level of cutting activity; by the peak in 1909-1910, approximately 2.5 billion board feet of timber were being cut annually (Figure 11; Hawes, 1953). The timber boom generated increased land trading and speculation (Gates, 1978; Behre, 1932), but also resulted in the cutting of the last virgin stands in southern New England and the production of a largely even-aged forest of low quality. As the better forests were all cut, and alternate forms of packaging were developed, the intensity of cutting decreased.

Since World War II the urbanization of New England has continued (Meeks 1986). Villages and towns within an hour of expanding urban and industrial areas have been strongly affected by suburbanization. Small towns elsewhere have been influenced by the secondary house market and a rising interest in country living (Fiske, 1979). Tremendous expansion of the interstate highway system has greatly reduced travel time throughout the region and furthered the influence of suburbs on the rural landscape.

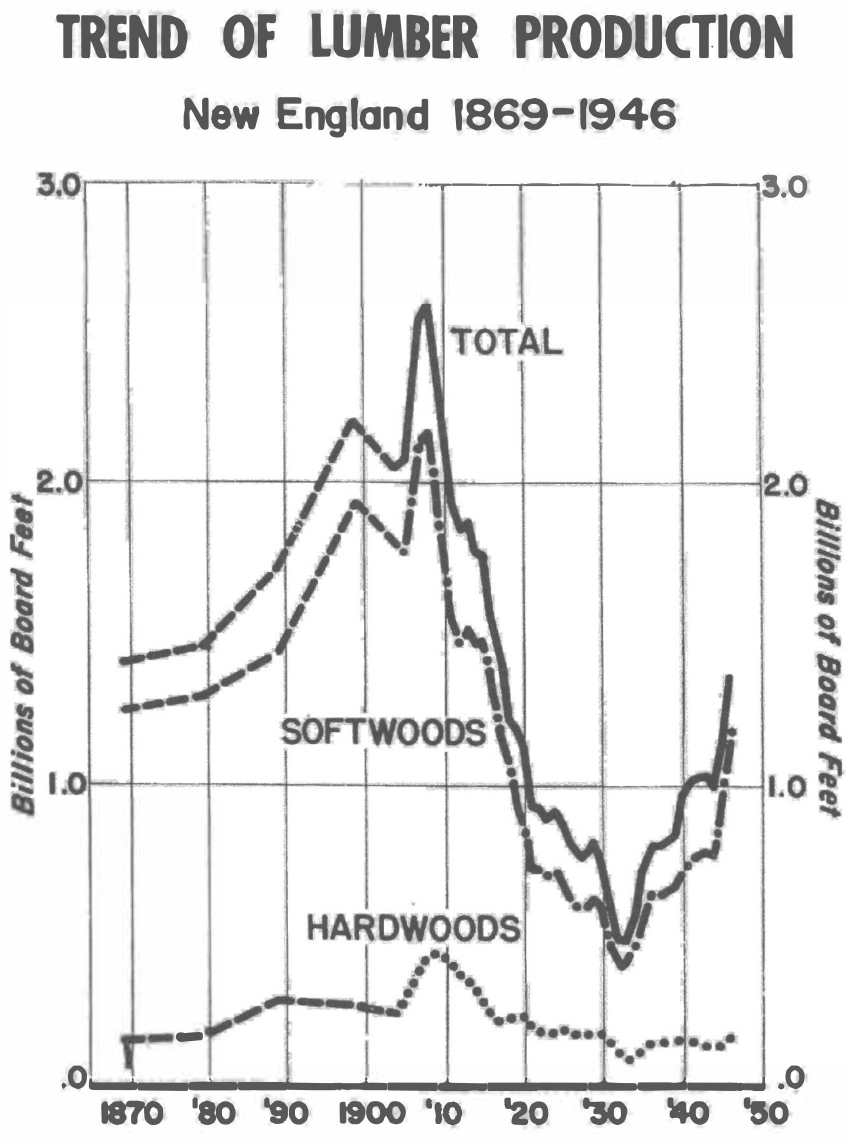


Figure 11. Changes in lumber production in New England through the period of farm abandonment and industrialization. The increase in softwood harvesting during the late 19th and early 20th centuries included substantial quantities of white pine growing on abandoned farm fields. Data from Baldwin (1949).

Many of the mill and valley towns and even leading cities of the industrial revolution have been drastically changed by international competition and resulting high levels of unemployment. The forest landscape, however, continues to receive less intensive use. The scattered farming that does occur is largely monoculture (e.g. dairy cows), limited in geographical scope, and yet generally more productive than ever (Rozman and Sherburne, 1959). Concentration on the best lands, high quality imported feed, and better breeding have resulted in decreased numbers of farms, farmland and even cows with little reduction in production (Meeks, 1986). Although the modern demand for lumber is the greatest in history, production is near the lowest in the past century (Dunwoody, 1974). Meanwhile, New England's wood products are being provided substantially from outside sources while the local timber base continues to increase (Gould, 1966).

Forest and Ecosystem Response to Land-use History

An assessment of historical changes in the forest conditions of New England faces numerous challenges: (1) the precolonial ecosystems were dynamic and thus there are no baseline or pristine conditions with which to compare; it is a continual problem to separate out effects of human activity from those of natural disturbance, climate change, and forest growth (Spurr, 1950; Raup, 1979; Hunter *et al.*, 1988; Sprugel, 1991); (2) no good examples of unaltered forests exist for comparison due to the long and pervasive impact of altered disturbance regimes, introduced pathogens, modified animal populations, and changed atmospheric conditions; and (3) there is an absence of consistent historical documentation.

Nevertheless, it is clear that European settlers introduced novel disturbances of a magnitude, frequency and intensity unlike processes operating in the presettlement landscape. Thus it is valuable to evaluate the available evidence concerning the role and nature of changes in forest communities over the past 200-300 years and to compare them to evidence from the time of settlement or the paleoecological literature.

Changing extent of forest land

Considerable regional variation exists in the timing and extent of changes in the forest area across New England. For example, large portions of the Connecticut River Valley were settled and cleared by the late seventeenth century and remain open today whereas the adjoining uplands, settled later, have gone through a complete cycle of deforestation and reforestation (Garrison, 1987). In contrast, suburban areas around Boston, Providence and Hartford are undergoing a secondary deforestation and fragmentation as second-growth forests are being cleared for housing developments and commercial activity (MacConnell, 1975).

Despite this variability the regional pattern of deforestation and reforestation is remarkably consistent (Figure 8). With the exception of Maine, where large northern tracts have never been cleared, each of the New England states shows a major decrease in forest area through the late 1700s, a peak of open, agricultural land from 1830-1890 when only 20-40% of the uplands remained forested, and rapid reforestation through the late nineteenth and early twentieth centuries. The northern states (Vermont and New Hampshire) lag somewhat behind those to the south in terms of the timing of these trends. At present, the New England states range from 65-85% forested. Within this regional setting the upland hill towns, like Petersham, Massachusetts, present an extreme. Settled late relatively to much of eastern Massachusetts, Petersham was cleared rapidly for agriculture (Figure 9). The maximum extent of cleared land (approximately 85%) greatly exceeded that of the state on the whole and the process of reforestation on abandoned land proceeded much more rapdily. Today Petersham is 95% forested, compared to the state average of 70%.

Changes in the pattern of forest land

Very little is known about the detailed pattern of deforestation and reforestation within any region of New England and thus we have a very incomplete understanding of what the landscape distribution of forests was at different periods of time. Historical information and a consideration of agricultural activity indicates that local clearing occurred outward from established homesteads and roads towards the back of individual properties (Averill *et al.*, 1923; Foster, 1992). In many hill towns this would have resulted in the initial opening of land along major hill tops and ridges and progressive clearing of forest into valleys, rocky slopes and more inaccessible locations (Bogart, 1948).

At the height of agriculture the forest remnants comprised a highly fragmented system of discontinuous woodlands (Figures 12 and 13; Hawes, 1933). Historical studies suggest that most farmers maintained small woodlots as a source of fuelwood, poles and small materials, often on rocky or wet sites (Averill *et al.*, 1923; Cline *et al.*, 1938). Larger forest areas were scattered throughout the countryside on relatively remote locations or on shallow and poorly drained soils (Fisher, 1921). Preliminary analysis from central Massachusetts indicates that the major factor associated with the distribution of these larger wooded areas was accessibility: there is a positive relationship between forest area and distance from roads, houses and village center (Foster 1992).

Slightly more information is available concerning the process of reforestation, due to the existence of maps from the 1830s, late 1800s and twentieth century (Figure 14). Reforestation appears to be essentially a reversal of the suggested pattern of deforestation, driven by the progressive abandonment of agriculturally marginal and remote sites. The result is the continual expansion and eventual coalescence of individual wooded areas and the gradual shrinkage and subsequent fragmentation of the remaining open areas (Fisher, 1921; Spurr, 1956; Foster, 1992). In the modern upland landscape of New England non-forested sites are primarily town or urban centers, residential areas and agricultural fields (MacConnell, 1975). The latter are restricted to the better agricultural soils, either in broad valleys or at the crest of major ridges (Black and Westcott, 1959).

Structural changes in the forests

Paleoecological records indicate that the last 300 years have witnessed the greatest and most rapid change in upland vegetation since deglaciation 14 000 years ago (Figure 3; Jacobson and Grimm, 1986; Jacobson *et al.*, 1987; Foster and Zebryk, 1993). The major cause of this change, an acceleration in the rate and intensity of disturbance, has generated a striking structural pattern in forest communities. On a stand basis the modern forests are largely even-aged, comprised of trees that initiated through sprouting, seedling establishment or release after an intensive, large-scale disturbance such as logging, fire or field abandonment (Frothingham, 1912; Winer, 1955; Smith, 1979). These human activities have also imposed an oftentimes abrupt patterning of communities in the landscape in terms of age, height and composition (Figure 14d; McKinnon *et al.*, 1935; MacConnell, 1975). Across subtle environmental gradients contrasting land-use histories on adjacent parcels have resulted in sharp changes determined by arbitrary political boundaries, ownership boundaries, or management decisions (Barraclough, 1940). The result is a patchy mosaic of forest and non-forest communities.

The forest mosaic in the modern landscape of New England is determined by a number of human and natural factors: clear-cutting for fuelwood and timber products, especially through the 1930s, fires, particularly until the early 1900s, grazing field abandonment, and the impact of the 1938 hurricane and associated salvage cutting (Merrill and Hawley, 1924; Baldwin, 1949; Winer, 1955; Brown, 1960). Based on

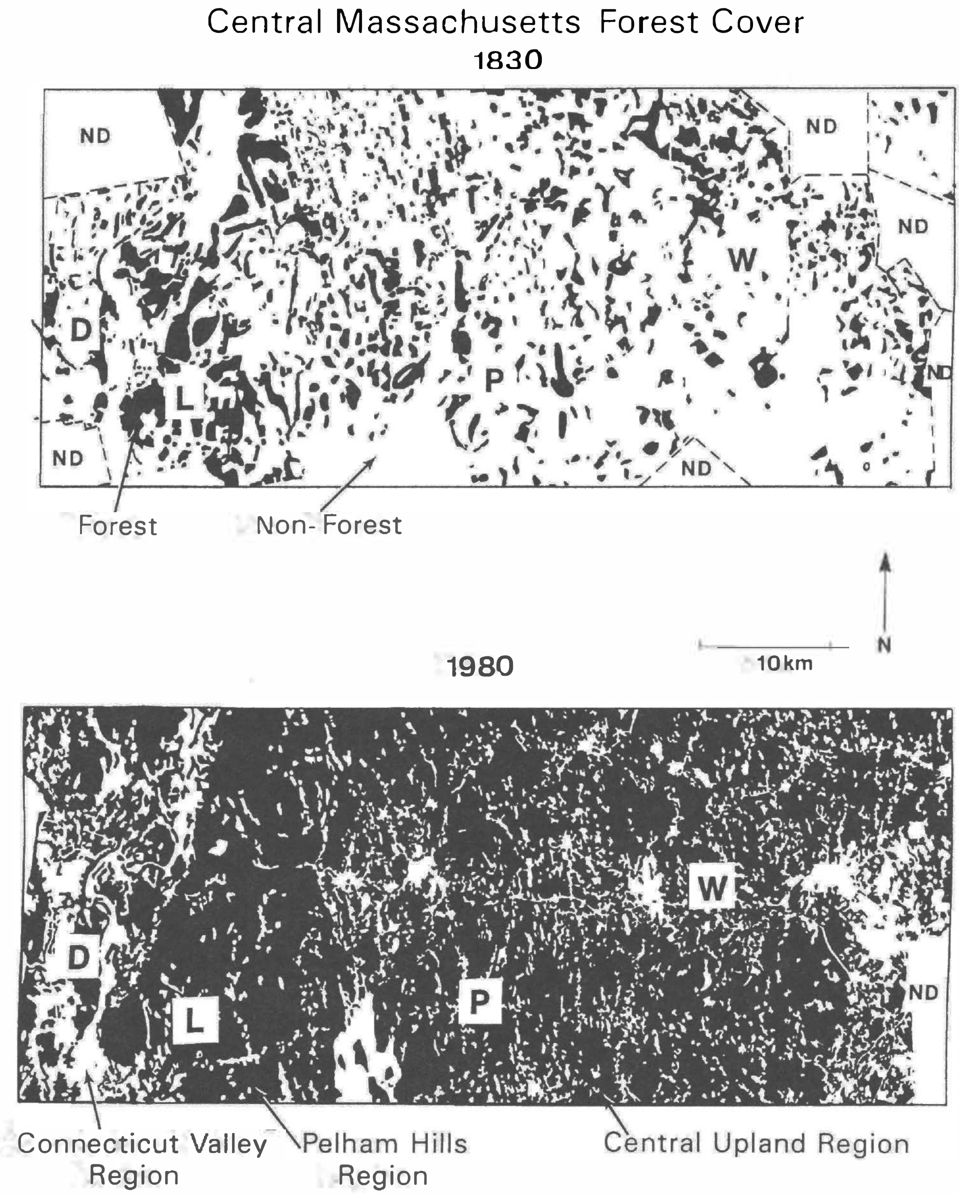
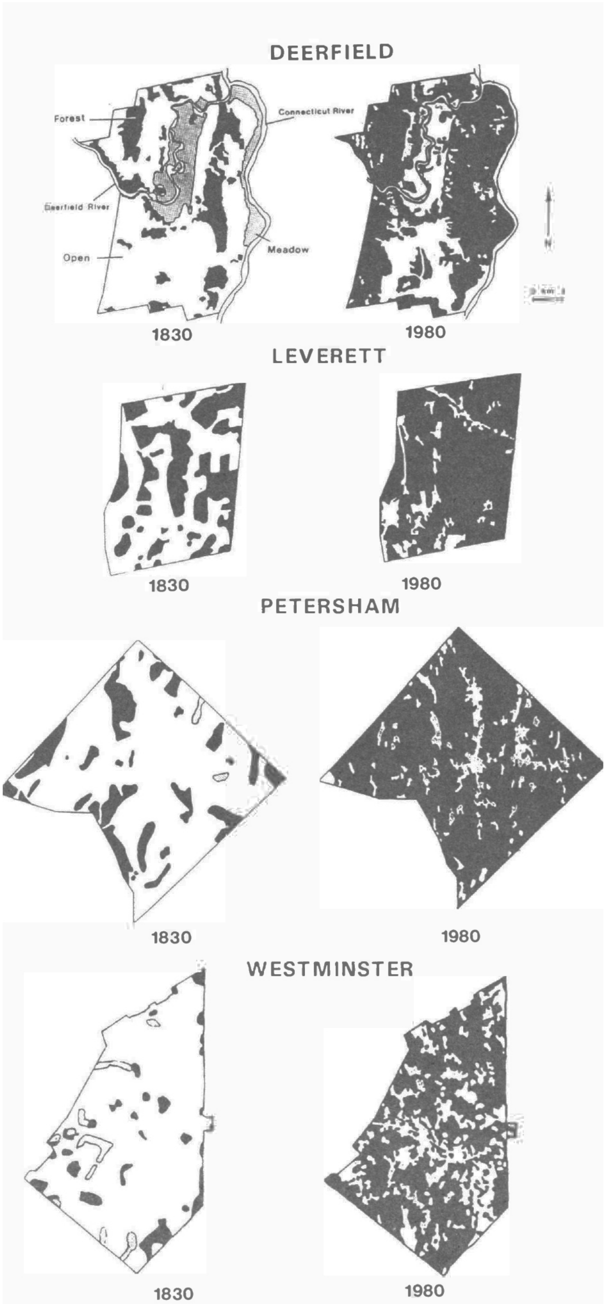


Figure 12. Forest cover (black) for north-central Massachusetts in 1830 at the approximate peak of agricultural clearance, and in 1980. Major physiographic regions include the Connecticut Valley, the rough Pelham Hills, and the undulating Central Upland regions. Four townships are indicated: D - Deerfield in the Connecticut Valley Lowland, L - Leverett in the Pelham Hills; P - Petersham in the rural Upland, and W - Westminster in the more urbanized Upland. ND indicates no data.



Deerfield in the CT Valley Lowland was cleared early and extensively, with agricultural fields on level glacial sediments, broad meadows utilized for hay, and forest restricted to N-S bedrock ridges. Productive agriculture continues today on the valley bottom.

Leverett, in the Pelham Hills, was least extensively cleared due to steep, rough terrain and was abandoned from agriculture in the early 1800's. Extensive forests have been the basis for a thriving and diverse wood industry through the late 19th and 20th C.

Petersham occupies a rural location in the Central Uplands area on rolling terrain. It was extensively deforested for agriculture, with small woodlands restricted to steep, inaccessible slopes and wetlands. Abandonment of farms was rapid in the mid- to late 1800's and reforestation has occurred on all except the best soils, situated on crests of N-S hills.

Westminster is located in the Central Uplands adjacent to the urban communities of Fitchburg, Leominister and Gardner. Extensively deforested for agriculture it has served as an important source of fuel wood, dairy products and market crops for the surrounding population to the present. As a consequence it is less forested than Petersham and is characterized by young coppice forests.

Figure 13. Maps of four townships characteristic of different physiographic regions in central Massachusetts depicting distinctive amounts and patterns of forest, open land and meadow in 1830 and 1980. See Figure 12 for the location of the townships.

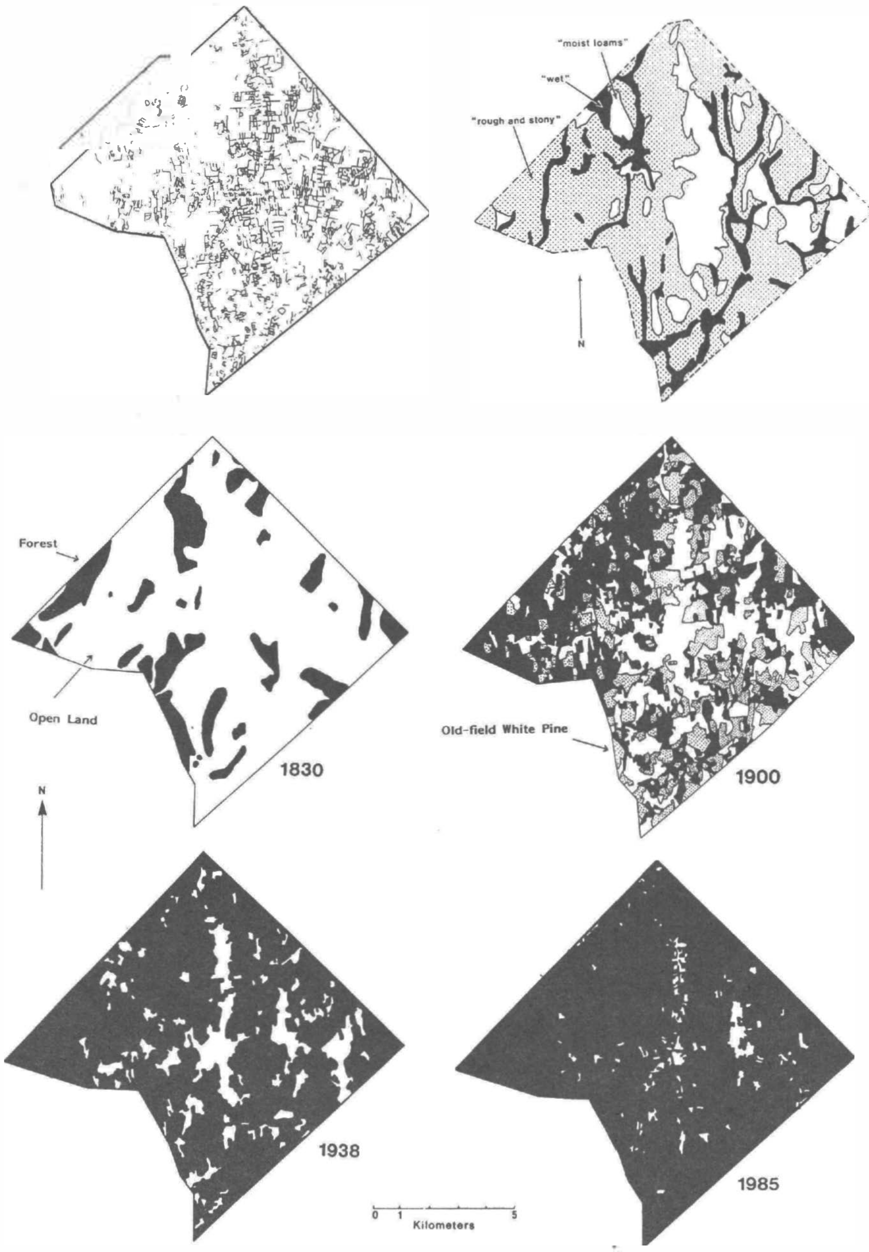


Figure 14. The town of Petersham, Massachusetts depicting (a) the distribution of stone walls, (b) broad soil characteristics and (c-f) the pattern of reforestation from the approximate height of agricultural activity in 1830 to the modern period. In the map of 1900 stippled areas depict areas of old field white pine established on fields abandoned in the previous 30 years.

historical characteristics there are two major classes of forest land in New England: (1) primary forests on sites that have never been cleared, and (2) secondary forests on former agricultural land that has reverted back to woodland (Cline and Lockard, 1925; Stephens and Waggoner, 1980; see Peterken, 1977). Both forest types generally have been clearcut often followed by fire, so that cutting history is a major determinant of modern structure.

Across New England, fuelwood cutting was the major use of wood products into the 1880's (Frothingham, 1912; Reynolds and Pierson, 1942), so much so that the potential for depleting supplies for home, railroad and industrial use was a major concern in the middle part of the nineteenth century (Emerson, 1846; Cook, 1961). Many woodlots were cut on a 20-40 year rotation in order to provide domestic heating and industrial sources of charcoal and chemicals (Cook, 1961). As much as three-quarters of the fuelwood cut in the early 1800s went to domestic needs, as the average farm could consume more than 20 cords per year (Reynolds and Pierson, 1942). In particular regions, such as the Naugatuck Valley and adjoining uplands in northwestern Connecticut, hundreds to thousands of hectares were clearcut annually to fuel the brass, lime and iron industries (Frothingham, 1912; Winer, 1955). Elsewhere, growing town centers and cities provided a constant demand on the surrounding countryside (Cline *et al.*, 1938). After the 1830s the railroad industry required extensive material for ties and fuel; in Massachusetts alone more than 54 000 cords of wood were used as fuel on 560 miles of railroad during the period 1844-45 (Cook, 1961).

With the development of efficient stoves, access to coal supplies, and concentration on logging of old-field white pine in the late 1800s and early 1900s, timber and related forest products finally surpassed heating as the major use of wood. The development of the portable sawmill enabled logging to proceed in even the most remote stands (Smith, 1970). The resulting cutting through the 1920s reached essentially all old-growth timber and most second growth stands of merchantable age (Nichols, 1913). Cutting peaked in most New England states between 1905 and 1910 (Kneeland, 1918), with approximately 2.5 billion board feet of pine cut annually, in contrast to the 1870s when the annual cut was less than one million board feet (Barraclough, 1940). Then, in 1938 the hurricane destroyed forests across a 100-mile path from southern Connecticut into central Vermont, prompting an unequaled salvage operation in which more than 3.5 billion board feet of timber were harvested and stored in ponds and lakes to deter decay until the logs could be milled (NETSA, 1943).

Throughout the settlement period and with increasing logging activity, fire became an important cause of stand regeneration and landscape patchiness (Graves and Fisher, 1903; Patterson and Backman, 1988; Fahey and Reiners, 1981). Fire was used extensively following logging to reduce residual slash; frequently these fires as well as those set by railroads escaped into surrounding areas. By the early 1900s fire was seen as one of the major deterents to forest improvements and extensive efforts were made to evaluate its extent and effect and to limit its occurrence (Hawes, 1923; Gould, 1942; Merrill, 1974).

As early as 1840 warnings were being sounded concerning forest destruction and the poor quality of New England's woods (Emerson, 1846). By the early 1900s this message had become a common theme (Massachusetts State Foresters' Office, 1906). It was recognized that current tax laws, the absence of forest management, and the onslaught of fire, clear-cutting, grazing and disease had led to a condition of young, even-aged stands dominated by inferior hardwood species (Cline *et al.*, 1938). The legacy of the period from 1880-1920, the so-called "Period of Forest Devastation" (Hawes, 1923), is the even-aged patchwork of stands in the modern landscape (Fisher, 1921).

The even-aged and mosaic quality of the forests pertains as well to New England's public lands in State and National forests. These forests comprise the bulk of the preserved land in the region and are often erroneously conceived by the public to represent examples of natural and undisturbed ecosystems. To the contrary, the majority of public forest land was purchased at extremely low prices due to the young and poor quality of its timber and its low suitability for immediate productive use (Gould, 1986a). For example, in the White Mountain National Forest (WMNF), the largest continuous forest preserve in New England, over 70% of the area was cut-over (often clear-cut) or burned between 1870 and 1930 (Gould 1986b). In 1936 it was estimated that few forests in the WMNF exceeded 40 years of age; the average was less than 20 years. Haul roads totalling more than 4000 km and over 100 km of railroad track provided access throughout the area. Today more than 17 000 ha of this forest has been designated as Wilderness despite the omnipresent evidence of roads and railroad track and an average stand age less than 80 years old. To the west in Vermont, a similar story holds; the largest state-owned forest preserve (Groton State Forest) was established on land extensively clear-cut and then burned by fires at the turn of the century.

Changes in species composition

Recognition of the physical structuring of forests in the New England landscape does not address the question of whether human activity has altered substantially the composition of forest communities and the relative abundance of species in this region. The answer appears to depend on the scale of analysis (Siccama, 1971; Foster, 1992). Studies based on early forest descriptions, land surveys, and pollen records suggest that on a regional basis the broad distribution of species and forest types has altered little across New England (Raup, 1957). In central Massachusetts, for example, an analysis of vegetation descriptions on a township basis reveals an elevational and latitudinal zonation of central hardwoods, transition hardwood and northern hardwood forest that broadly parallels the modern map (Westveld, 1956; Foster, 1992).

On a stand and landscape scale, however, studies of old-growth forest, fine-scale pollen analysis, and forest reconstruction indicate that considerable change has occurred in the relative abundance and distribution of species and in the relative importance of particular forest types (Figure 15; Winer, 1955; Siccama, 1971; Whitney and Davis, 1986; Glitzenstein *et al.*, 1990; Foster and Zebryk, 1993). In fact, the inability of many early studies to explain forest composition on the basis of site properties alone has led to a widespread conclusion that land-use history closely regulates local vegetation type (Merrill and Hawley, 1924; Stout, 1952; Goodlett, 1960).

An increase in pioneer or early forest species has been widely cited as the major cumulative impact of historical land-use activity (Lutz, 1928; Spurr and Cline, 1942; Smith, 1979). Including such trees as gray birch, aspen, pin cherry, black cherry and red cedar, these pioneers increased as a result of the widespread disturbance and the early successional habitats created by cutting, clearing, and burning. Repeated cutting, grazing and fire also selected for hardwood species that sprouted prolifically, including chestnut, oak, red maple, birch and hickory (Graves and Fisher, 1903; Frothingham, 1912; Fisher, 1931). Consequently, sprouters increased, especially in forests utilized for fuelwood and charcoal around cities and in mining areas (Winer, 1955; Whitney, 1993).

Chestnut is the preeminent example of a sprout-hardwood species that benefitted greatly from repeated human disturbance to forests (Paillet, 1982; Russell, 1987). Producing extensive basal dormant buds and capable of phenomenal rates of height extension and diameter increment when reproducing vegetatively (Zon, 1904; Paillet and Rutter, 1989), chestnut responded to cutting or fire by massive proliferation and rapid stand dominance (Murdoch, 1912; Foster *et al.*, 1992). Paleoecological studies indicate that the abundance of chestnut increased substantially from presettlement time through the early twentieth century when the chestnut blight was introduced on trees imported from Asia. By the turn of the twentieth century chestnut accounted for approximately 50% of the standing timber in Connecticut (Frothingham, 1912).

White pine is another species that has undergone major changes in abundance and

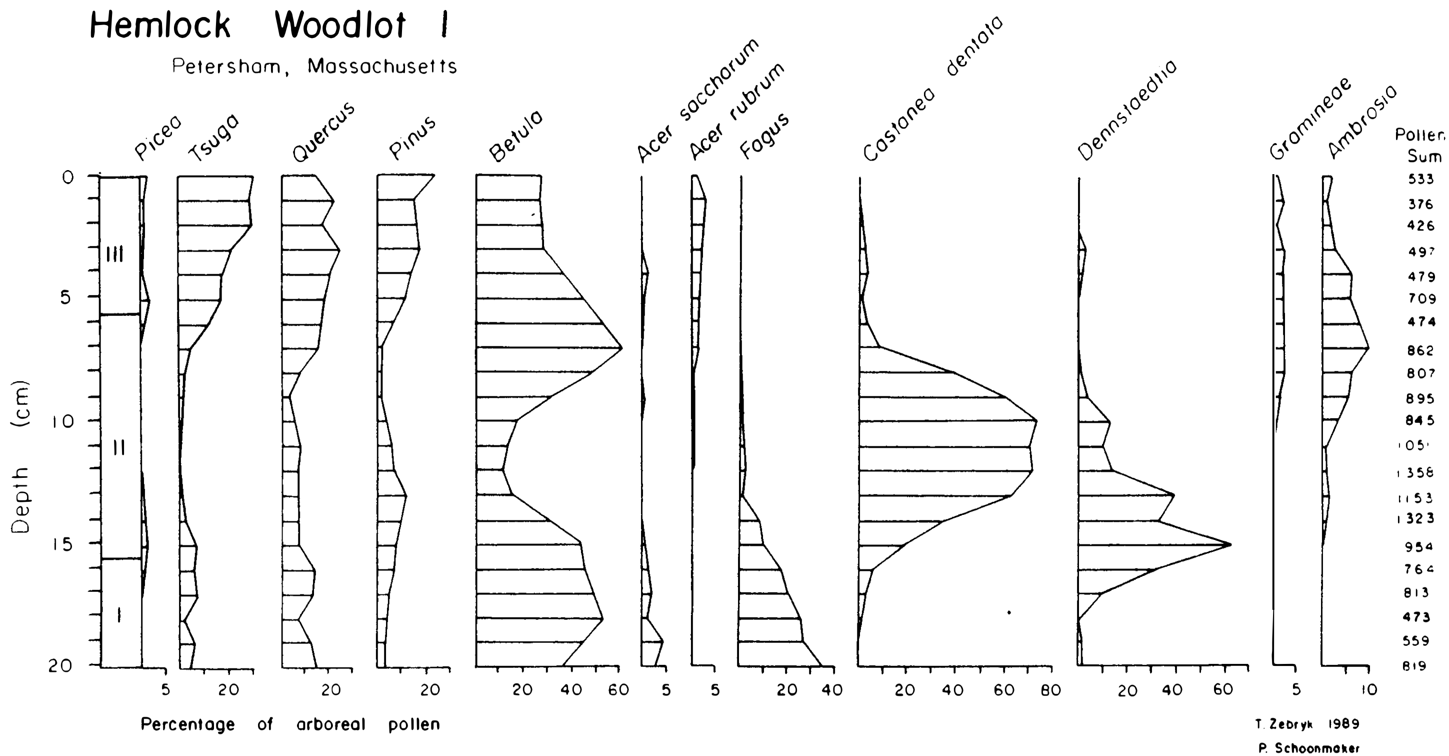


Figure 15. Pollen diagram from the humus soil in a hemlock forest at the Harvard Forest, Petersham, Massachusetts. The site is a primary forest that was never cleared for agriculture but was clear-cut early in the settlement period (at about 18 cm depth) and then cut repeatedly for fire wood. Tree species respond quite individualistically to the series of human impacts. Chestnut (*Castanea*) benefitted greatly from the cutting activity until it was decimated by blight in 1913. Beech (*Fagus*) and sugar maple (*Acer saccharum*) nevr recovered to presettlement levels of abundance whereas hemlock (*Tsuga*), pine (*Pinus*) and red maple (*Acer rubrum*) have gradually increased to the present. From Foster *et al.* (1992).

distribution through the historical period. In the pre-settlement landscape white pine presumably had a patchy distribution, scattered throughout old-growth stands and dominant only on dry, sandy soils and on fire-prone sites. However, the circumstances associated with farm abandonment provided a unique opportunity for the widespread establishment of white pine (Spring, 1905; Egler, 1940). Fence-row trees and scattered pines in woodlots represented an abundant seed source in the agricultural landscape. Grass, thin sod, and litter provide an excellent seed bed for white pine, which was able to thrive in the absence of competition on neglected pastures, particularly if grazing reduced competition with the hardwood species. The gradual abandonment of pastures and fields in the mid- to late 1800s provided ideal conditions for the development of massive pine stands (Figure 14). By the turn of the century the volume of white pine timber exceeded 7 billion board feet and led to the designation of the northeast as the white pine region (Nichols, 1913). Subsequently, intensive cutting and selective removal of pine by the 1938 hurricane greatly reduced this abundance (Foster, 1988b; Gould, 1966). The pine forests provided an excellent site for hardwood (red oak, red maple, white ash, birch) establishment (Cline and Lockard, 1925) and thus a gradual succession has occurred through time.

Many studies have shown that conditions prevailing at the time of field abandonment, especially seed bed, seed source and the extent of grazing, strongly determine the composition of the initial pioneers and of the subsequent vegetation. Thus, red cedar in the south, white pine in the central region and red spruce to the north are favored by grazing and a pasture seed bed, whereas gray birch, red maple, aspen and paper birch became established more readily in the absence of grazing and on mineral soil in former tilled fields (Lutz, 1928; Raup, 1937; Spurr, 1956).

Concomitant with the increase in pioneer and sprouting species through the early 1900s there occurred a decline in some tolerant, mature forest species, notably hemlock, beech and red spruce, but also including sugar maple and yellow birch in some areas (Chittenden, 1905; Egler, 1940; Winer, 1955; Spurr, 1956; Siccama, 1971; Hamburg and Cogbill, 1988). For beech and hemlock this reduction involved a great acceleration of a decline beginning before settlement (Brugam, 1978a/b; Gajewski *et al.*, 1987; Foster and Zebryk, 1993). Hemlock in particular, is highly susceptible to fire and largely has been eliminated from upland areas that have burned in the past two hundred years (Winer, 1955). Hemlock is seldom eliminated by cutting alone, due to the abundance of advanced regeneration (Lutz, 1928; Merrill and Hawley, 1924); however, once it is removed from an area by fire or land conversion for agriculture, hemlock is very slow to reinvade (Kelty, 1984). Thus, the presence of older hemlock trees in the landscape has been interpreted as an indication of primary forest conditions (i.e. never cleared; see Figure 15) and a long-term absence of fire (Marshall, 1927; Winer, 1955; Smith 1950; Kelty, 1984).

With the decrease in fire and the elimination of chestnut by blight the major trend in forest composition throughout New England during the twentieth century has been a steady increase in long-lived shade tolerant trees especially hemlock and sugar maple (Spurr, 1956) but also including beech and red spruce in some areas (Egler, 1940). Effective fire control has enabled the widespread establishment of these species as an understory component in many stands dominated by less tolerant sprouting species such as oaks, birch, chestnut (Graves and Fisher, 1903; Smith, 1950; Abrams, 1992). Sugar maple and hemlock are capable of persisting as advanced regeneration that ascends into the canopy through openings caused by mortality or larger disturbance (McIntosh, 1972). Thus processes such as the demise of the overstory chestnut, the 1938 hurricane, and logging activity serve to release these shade-tolerant species and effectively accelerate a successional process possibly towards a more self-reproducing canopy (Spurr, 1950; Kelty, 1984; Paillet, 1982; Abrams and Nowacki, 1992).

Grazing, by cattle, horses, sheep and pigs is a final critical, though elusive, factor shaping forest composition. During the height of agriculture in the mid-nineteenth century most extant forest areas and woodlots were probably grazed (Graves and Fisher, 1903). As late as the 1930s, Guise (1939) estimated that 48% of New England woodland was currently pastured, with grazing often accompanied by light burning to increase the cover of grass. Grazing maintains an open understory, tends to cause a retention of weedy species and decreases the component of hardwood species. The prevalence of this practice 50 years ago must be a strong determinant of the existing composition of our forests.

Despite intense modern interest in forest fragmentation and species diversity, essentially no quantitative information is available concerning the loss of species other than game birds and mammals resulting from the massive destruction of forest habitat in the northeastern United States over the past 300 years (Figure 16; Bickford and Dyman, 1990). Few studies have critically addressed the changes in floristic composition or have successfully examined the relative contributions of land use versus environmental factors in controlling this composition (Whitney and Davis, 1986; Marks and Smith, 1989; Foster, 1992). In fact, most efforts to examine impacts of modern fragmentation fail to even mention the severe deforestation of the temperate forest region that occurred a century and a half ago (see DeGraaf and Healy, 1990). Thus, there has been little serious attempt in this effort to learn from history.

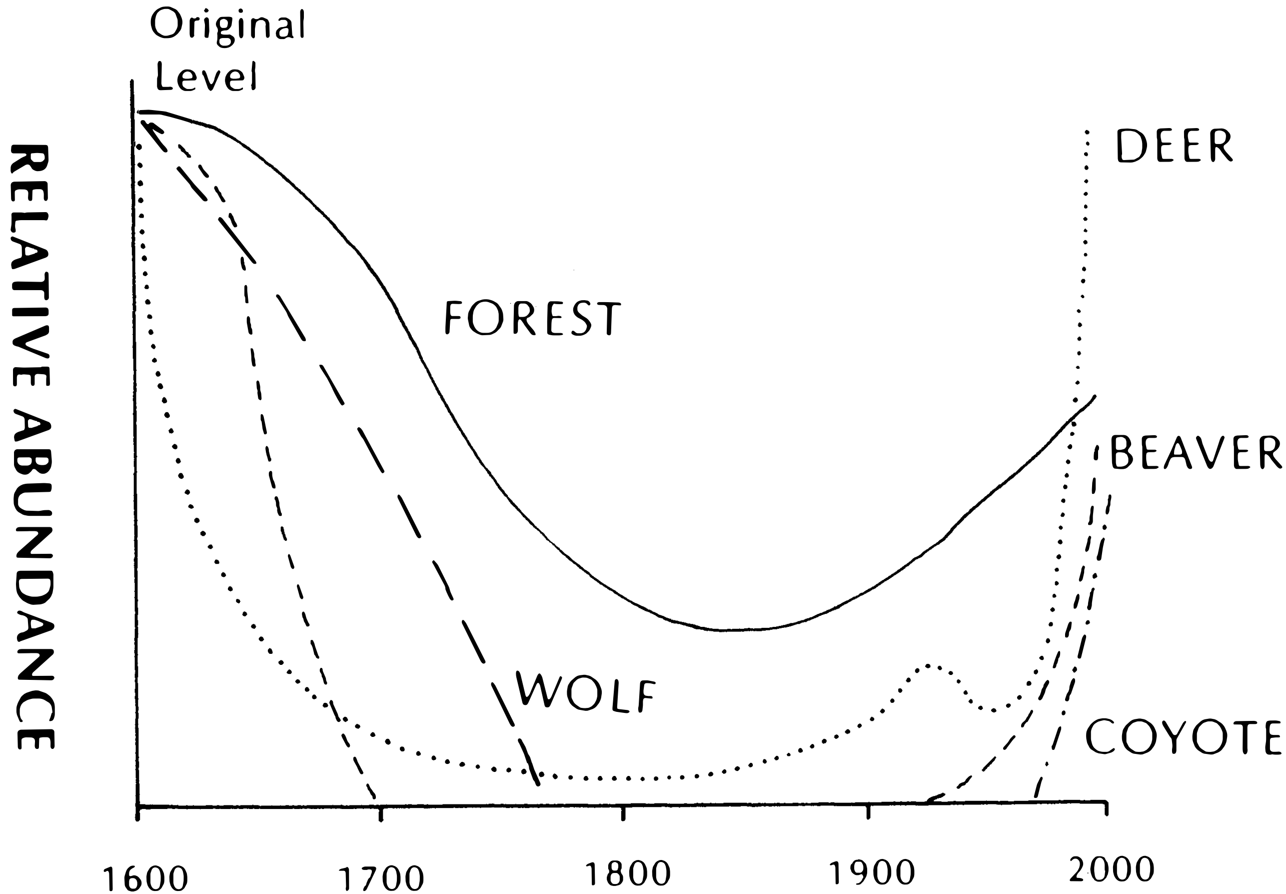


Figure 16. Changes in the relative abundance of selected mammal species in Massachusetts over the past 400 years. Whereas the wolf has been eliminated, beaver have been reintroduced and the coyote represents a new species in the landscape. From Bickford and Dyman (1990).

Occasional studies have identified species thought to be restricted to or more abundant in primary woods (e.g. Niering and Egler, 1966). In Connecticut, Nichols (1913) suggested that *Hamamelis virginiana, Kalmia latifolia, Cornus alternifolia, Acer pennsylvanica, Viburnum alnifolium* and *Taxus canadensis* occur predominantly in forest areas never cleared. This list was largely corroborated by Whitney and Foster (1988) in a study focussed on northern Massachusetts and southern New Hampshire. Following on more extensive research in Great Britain (see Peterken, 1977; Peterken and Game, 1981, 1984) it has been argued that the major factors restricting colonization of this group of species into secondary forest included (1) low seed production and dispersal, (2) possible changes in soils through agricultural use, and (3) competition by established plants (Whitney and Foster, 1988; Gerhardt, 1993). Peterken's studies in England indicate that as much as one-third of the flora has not effectively colonized secondary forests from primary forest refuges (Peterken and Game, 1984). However, this work also suggests that survival for plant species in the primary forests is largely unaffected by forest area or degree of isolation (Peterken and Game, 1981). Rather, the major loss in species diversity has come about because the remaining primary forests cover only a subset of the original forest sites and woodland species.

One study that has attempted to examine floristic relationships with historical and environmental factors was reported by Foster (1992) from central Massachusetts. Using Canonical Correspondence Analysis it was shown that a combination of edaphic factors (soil moisture and slope position) and land-use history (primary/secondary woodland, cutting history, abandonment date and the distinction between pasture and cultivated lands) provided a significant and informative model of stand and species variation. In this study of the Harvard Forest, primary forests were concentrated on intermediate to poorly drained sites and were characterized by many of the species listed by Nichols (1913) and Whitney and Foster (1988).

Altered seed pools are one critical legacy of land-use activity that will continue to influence the future dynamics of the vegetation. The extreme longevity of seeds of the weedy species that are characteristic of old field and early successional habitats results in a long-term imprint of past vegetation. The seed pools in second-growth forests are often compositionally distinct from the existing vegetation and are dominated by field and shrubland taxa, such as Gramineae, Polygonaceae, *Comptonia*, etc. (Livingston and Allessio, 1968; del Tredici, 1977; Ellison, 1992) that were growing on the site 50-100 years earlier. When such second-growth forest extensively disturbed, the resulting vegetation response is often unexpectedly dominated by agricultural weeds, rather than forest species. For example when the more than 200-year-old Cathedral Pines forest, a stand of old growth white pine and hemlock was uprooted by tornado in 1989, one of the most abundant species on the disturbed soil was pokeweed (*Phytolacca americana*), a weedy plant characteristic of abandoned areas and road sides. Whether the seeds were carried in from surrounding agricultural areas by birds or represent long-term storage from an extremely ancient field, this weedy species came to dominate in a forest protected for its national natural significance (Patterson and Foster, 1990).

Even on primary forest sites that appear to provide analogues for the original natural vegetation due to the dominance of shade-tolerant species and old canopy trees, the composition has changed markedly through the settlement period. In two separate stands on the Harvard Forest dominated by mature hemlock (exceeding 100 years in age), a history of cutting, windstorm damage and chestnut blight have triggered major structural and compositional changes (Figure 15; Oliver and Stephens, 1977; Foster *et al.*, 1992). In both cases clear-cutting of hemlock, pine and hardwoods in the 1700s resulted in a dominance of chestnut, birch, oak and other sprout hardwoods. Repeated cutting altered the relative abundance of these species somewhat; however, the major change occurred through the demise of chestnut and cessation of cutting that allowed hemlock to become gradually dominant (see Merrill and Hawley, 1924; Winer, 1955).

The review of available studies provides ample evidence of major transformations in the composition of individual stands and extent of individual species. Postsettlement land use has involved new landscape processes that have driven these changes, including: altered natural disturbance regimes and novel disturbance processes; introduction of exotic species including pathogens; modified roles of grazers, dispersers and pollinators; and long-term changes in soils and their seed pool constituents. The vegetation at any point in time or space is a result of underlying environmental conditions and the selective action of these various processes interacting with the available flora. Across the landscape this intersection of historical and environmental factors creates a highly complex mosaic (Smith, 1979). The intensity and frequency of disturbance during the modern period has resulted in a mosaic that changes more dynamically than that of the pre-colonial landscape.

Ecosystem Impacts of Land Use and Forest Change

The structural and especially the compositional changes of forest communities resulting from past land use represent long-lasting impacts. Equally important are the less obvious modifications of terrestrial and aquatic ecosystem processes. These would include changes in soil conditions, alterations in hydrology, and modifications of animal populations. All of these factors have important direct effects on forest conditions and many may continue to affect the productivity of terrestrial ecosystems and feedbacks between the biosphere and atmopshere.

There is long-standing debate concerning the impact of land use on soil properties and subsequent feedback with regard to modern forest conditions. Much of this discussion has been shaped by the strongly held belief that agricultural abandonment in nineteenth century New England was propelled in large part by the exhaustion of the nutrient capital of the land through destructive farming practices (Donahue, 1983). Decreased nutrient availability is thought to affect the modern vegetation through reduced productivity, slower rates of succession and altered competitive interactions among species of contrasting nutrient demand. However, with the recognition of the many social factors driving the changes in agricultural practices in the nineteenth and twentieth centuries, much of this reasoning has been called into question (Raup, 1966; Bell, 1989).

Direct impacts of modern forest harvesting, land clearance and agriculture have been used to infer past effects. Forest clearance initiates a series of microclimatic effects that alter the radiation and moisture balance of forested areas and influence soil properties. Reduced transpiration increases soil moisture, which combined with increased temperatures, generally leads to accelerated soil biological activity, a reduction in soil organic matter, and a release of nutrients. Increased mobilization of nutrients can lead to loss through leaching and subsurface runoff. Direct modification of the upper soil layers through plowing or heavy trampling by grazing animals may leave long-lasting physical changes in terms of soil homogenization and a decrease in microtopography. In addition, the reduction in ground cover and disturbance of the soil surface may lead to accelerated erosion. Evidence of increased inorganic inputs and nutrients to aquatic systems and the deposition of fine soil material in depressions and at slope bottoms indicate that erosion and the transport of nutrients from the uplands has occurred extensively (Brugam, 1978a/b).

Removal of the forest canopy alters wind movement, increasing the velocity across open areas. One consequence is decreased snow depth, a factor that strongly regulates soil temperatures and frost depth through insulation. Whereas many northern forests experience essentially no soil frost due to the depth of snow and organic matter, adjoining cleared areas may freeze to a depth exceeding one meter (Bormann and Likens, 1979). Enhanced frost action disturbs the soil surface, moves stones towards the surface and reduces soil biological activity by both large and microscopic organisms.

The long-lasting impacts of these soil changes would be expected to be distributed differentially across the landscape due to the selective nature of human activities on different sites and soils, the differential susceptibility of different physiographic units and soils to these effects, and the subsequent history of vegetation on the various sites.

In addition to direct effects on soils there is the potential for indirect removal of nutrients from sites through the harvesting of timber and agricultural products. For example, the extensive production of potash from New England clearly represented a literal export of nutrient capital from the uplands. Some authors have argued that many of these nutrients were extensively redistributed across the landscape. For example, nutrients from pastures may have been removed as forage by grazing animals and added to tilled fields in the form of manure supplements (Jones, 1991). On a broader scale hay produced on the uplands of Massachusetts in the summer was consumed by cattle in the Connecticut River lowland in the winter and then added to lowland fields as fertilizer (Garrison, 1987). The resulting movement of nutrients may have accentuated differences in fertility that already occurred naturally in the landscape.

Attempts to address these nutrient movement questions using historical sources provide equivocal results. A study by Jones (1991) of agriculture in Deerfield and Petersham, Massachusetts, indicated that crop yields on tilled fields increased continually in both towns from 1780 to 1850. Although it was argued that the source of the apparent nutrient inputs (i.e. manure) to the crop fields came at the expense of inputs to hay fields, hay production held fairly constant through the same period. Recent studies by J. Aber and J. Melillo at the Harvard Forest provide indirect evidence for nutrient re-allocations within the colonial landscape (Aber *et al*., 1991). In experiments designed to test the response of forest communities to nitrogen inputs these researchers discovered that, contrary to their expectations, conifer stands were more nutrient-rich than nearby hardwood stands. This finding runs counter to the general observation that conifer species dominate on less fertile and more acidic sites but can be explained on the basis of land-use history. In central New England many old-field white pine and conifer plantations occur on the most recently abandoned sites such as former tilled fields, whereas many hardwood forests are second-growth stands on old pastures. The tilled sites, probably initially more fertile, received manure supplements for years. Thus, the soil characteristics of the conifer stands reflect history rather than an equilibrium setting.

Terrestrial and aquatic linkages

Lake sediments provide a continuous record not only of the changes that occur in the terrestrial vegetation but also dynamics of the lake system itself. Because the nature of the recording medium does not change through time lake sediments provide a consistent record of changes in water quality, organic and inorganic inputs, biota and productivity.

Most lake ecosystems in the northeastern United States exhibit profound changes during the historical period despite a lengthy Holocene record of relatively little change. Sedimentation rates increase, often markedly, and the inorganic fraction of the sediment increases, reflecting soil instability and erosion across the watershed. Associated with mineral inputs is generally an increase in nutrient loading, which often triggers increased primary productivity (Brugam, 1978a). In severe cases, the enhanced productivity can lead to increased decomposition in the lake water, which can consume available oxygen resulting in anoxic conditions and fish mortality.

Detailed studies of these changes indicate that lake and upland ecosystems are tightly coupled and that lakes respond rapidly to alterations in land use. As lake sediments integrate the activity in the larger watershed the history of changes may be complex. Two studies that show the detail of these changes and their linkage to land-use activities include research by Brugam (1978a/b) in Connecticut and Engstrom *et al.* (1985) in Vermont (Figure 17). Brugam's study of Linsley Pond in southern Connecticut illustrates a sequence of progressively more intensive changes in the upland ecosystem. Following deforestation a subtle increase in primary production accompanies changes in pollen frequencies. Farming in the watershed in the early 1800s led to increased organic erosion, input of nutrients from manure and household refuse and a noticeable change in the algal composition. A fundamental alteration of organic and inorganic matter fluxes to the lake and enhanced nutrient inputs parallel expansion of dairy farming in the watershed in the early 1900s. Suburban development in the 1960s resulted in hypereutrophic conditions.

Engstrom's study on Harvey's Lake, Vermont evaluated the feasibility of restoration efforts of the eutrophic lake based on the extent to which modern conditions might reflect a departure from the presettlement situation (Figure 17). Examining the inorganic geochemistry, pigments and diatoms as well as pollen, the researchers showed two major increases in primary productivity (1780 and 1945) associated with extensive logging activity and a major increase in the input of dairy wastes into the lake. Construction of a sawmill on the primary inlet in 1820 coincided with the onset of anoxia and the incorporation of woodchips into the sediments. Anoxic conditions, presumably resulting from the decomposition of sawmill debris, lasted until 1920 when the mill was closed. Dairy waste enrichment of the inflowing stream, accompanied by an expansion of summer homes, produced a dramatic shift in the algal populations to blue-green algae and a new development of anoxic conditions. Thus, modern limnological conditions are markedly different from those that prevailed for over a thousand years before settlement

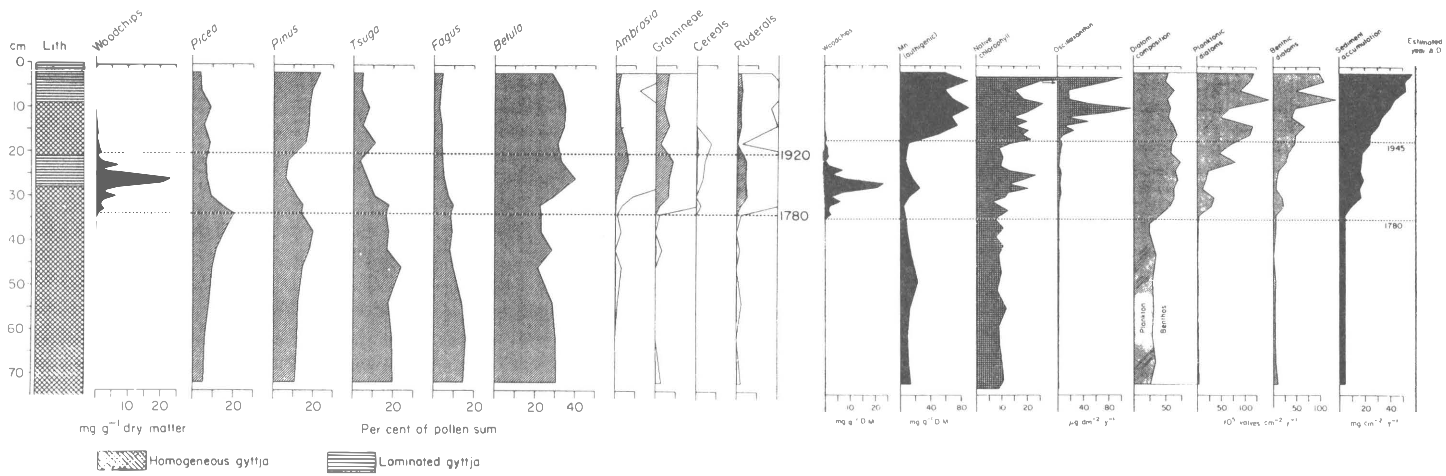


Figure 17. Pollen and sediment stratigraphy from Harvey's Lake, northeastern Vermont, depicting major changes in the regional vegetation, lake chemistry and aquatic biology occurring after colonial settlement in the area (about 1780 A.D.). Forest cutting, land clearance and agricultural activity are indicated by the general decline in all tree species except birch, and increase in herbs and weed species, whereas the concentration of woodchips are derived from a period of lumbermill operation near the mouth of an inflowing stream. Increased nutrient inputs in the period 1780 to 1945 from erosion and agricultural activity resulted in increased sediment accumulation and algal production (see chlorophyll and diatoms stratigraphies). Following extensive construction of summer homes in the 1940s and substantial nutrient additions from sewage run-off, those trends were enhanced, blue-green algae became important (indicated by oscillaxanthin) and the bottom waters became oxygen-depleted (indicated by the dramatic increase in manganese). Adapted from Engstrom *et al.* (1985).

and represent the cumulative impact of changes in the watershed during the intervening period.

Animals and pathogens

Humans and their impact on the landscape have been tied to major changes in the abundance and distribution of animal species and major plant pathogens (Figure 16, Table 1). These, in turn, have affected the forest landscape in innumerable ways. Information is primarily available for major game animals and economically important plant pests, although even here much of the data is anecdotal or from indirect sources (Bickford and Dymon, 1990).

Evidence suggests that most of the large, broad ranging species were largely eliminated from New England or the northeastern United States during the first episode of forest clearance. This group would include elk, caribou, wolf, mountain lion, lynx, wolverine and marten. From Massachusetts these species plus moose and Indiana bat have been extirpated to the present and an additional 75 animal species are listed as endangered or threatened. A number of species have been introduced or have extended their range northward, especially after 1900. These include coyote, possum, turkey, vulture, cardinal, mocking bird and the rainbow and brook trout. The vast majority of species, however, have undergone major changes in abundance even to the extent of being locally eliminated and subsequently reestablished. The recent expansion of turkey across New England and the southward spread of moose are major examples. The early species to increase include many edge species such as deer, which was nearly eliminated in the mid-1800s and has reached densities detrimental to the vegetation in many areas today. Many of the species increasing today, such as moose and turkey are forest species that benefit from the great expansion of woodland.

Future Changes in New England's Forests

The major lesson derived from the retrospective view of the forests of New England is that they are dynamic on geological and historical time scales. Thus, with certainty we can face the future and expect additional change. Ironically, in an age of global concern with deforestation and forest fragmentation, one of the major trends observed in the recent past and anticipated in the near future for New England is a continual aging and growth of the forests and a net increase in the carbon that they store (Figure 18, Table 2). With active harvesting proceeding much more slowly than growth there will be continued

Table 1. Current status and tally of wildlife and plant species in Massachusetts showing native, introduced extinct and extirpated species listed in the state since 1620. Adapted from Bickford and Dymon (1990).

		Native						Rare			%	
	Total	Inland	Marine or Coastal	Introduced by man	Natural Range Expansion	Extinct	Extirpated	End *	Th *	SC *	Rare	Federally Listed End & Threat *
Mammals	94	58	28	8	2 coyote opossum	2 eastern elk sea mink	8	7		5	14	7 6whales 1 bat
Birds	434	188 nest annually 40 year round 93 predictable migrants 19 nest irregularly 129 vagrants		5 pigeon starling ring-necked pheasant house sparrow mute swan	25+ turkey vulture mocking-bird cardinal	4 heath hen great auk passenger pigeon Labrador duck	1 gray cheek thrush	9	7	15	14	5 bald eagle peregrine falcon Eskimo curlew roseate tern piping plover
Reptiles	30	24 14 snakes 9 turtles 1 lizard	6 turtles				1 five-lined skink	7	4	3	48	6 5 sea turtles 1 Plymouth redbelly
Amphib-ians	23	22 7 frogs 3 toads 12 sala-mander		1 mudpuppy salamander					2	6	36	
Fish	78	30	21	27	1		1	3	3	3	20.5	1 shortnose sturgeon
Total	659	618		41	28+	6	11				18	19
Plants	2,700			950			50	106	80	50	14	2

* End.- Endangered, Th.- Threatened, SC - Special Concern

increase in mature forests and corresponding species of plants and animals (Dickson and McAfee, 1988). While the forests mature they will be affected by many new processes. Ownership patterns have changed rapidly during the second half of the twentieth century as more urban dwellers have "bought a piece of the woods," leading to a highly fragmented pattern of relatively small individual parcels (Figure 19). Consequently, in the suburban backyard as well as the north woods there is an increasing challenge to manage, regulate and even understand large forest areas as the property maps become more heterogenous and as conflicting viewpoints proliferate (Harper *et al.*, 1992). Equally invisible as the property boundaries are the novel stresses being imposed on our forest ecosystems. Across New England atmospheric inputs of nitrogen (NO_x) form a gradient increasing to the north and west and with elevation (McNulty *et al.,* 1990). Nitrogen, the major limiting nutrient for plant growth in New England forests, acts initially as a fertilizer, quite probably enhancing productivity and altering the competitive balance among species. At higher concentrations it may actually saturate the soils and lead to negative consequences including nutrient loss through leaching (Aber *et al.*, 1989). Increasing levels of CO_2 (Figure 20), which are implicated in future global warming, are also exerting a subtle and largely undetected impact on forest communities. Plant growth, predator relations, competitive interactions and organic matter quality are all modified by CO_2 concentrations, leading to altered community interactions and ecosystem function (Bazzaz and Fajer, 1992). Finally, our forests face the continued impact of introduced and native pathogens as predator relations and abundances change. As I write this epilogue the old-growth hemlock forest located a mile from my Harvard Forest office and from which we have learned so much concerning long-term forest dynamics is being threatened by native insect populations (eastern hemlock looper) and an introduced species (wooly adelgid). As they have through their long past, our woods are poised to be tested for resilience, and are certain to change.

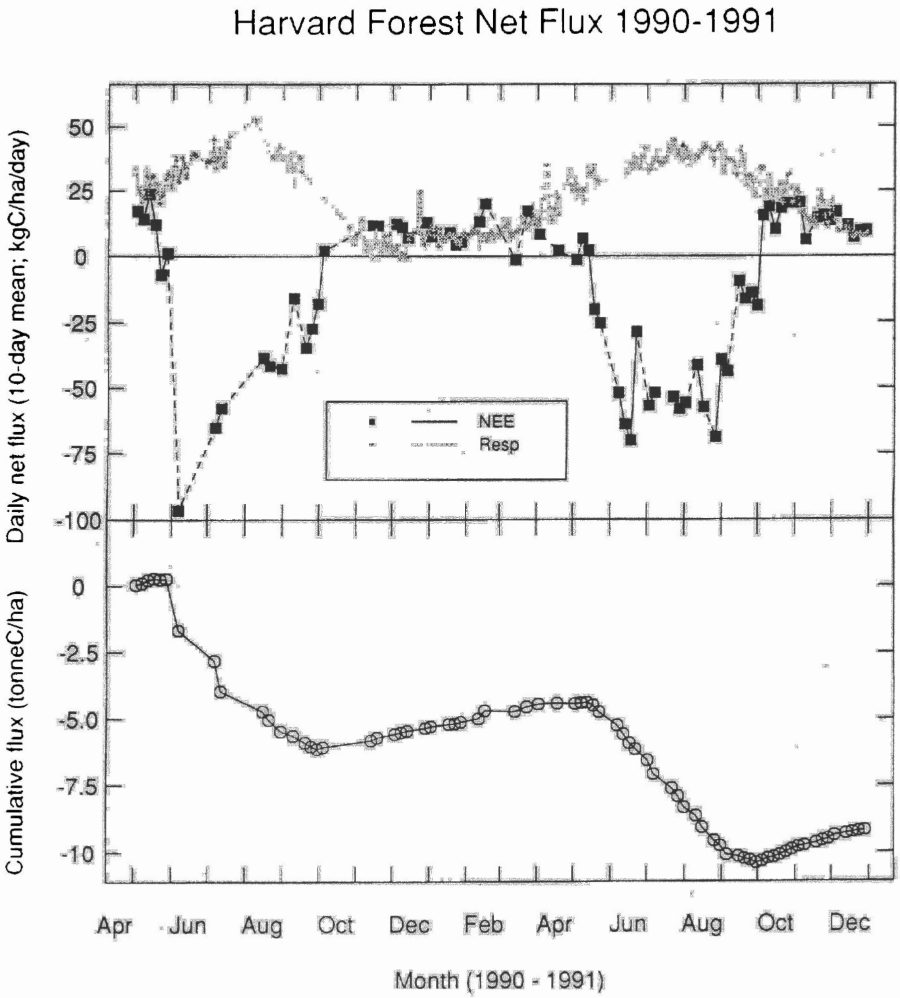


Figure 18. Exchange of CO_2 from mixed hardwood-conifer stands at the Harvard Forest, Petersham, Massachusetts. The upper panel depicts the mean net ecosystem exchange (NEE) and respiration (Resp) averaged over 10-day periods, in KgC/ha/day, plotted against day of the year. Lower panel depicts cumulative net CO_2 exchange (tonneC/ha) for April 1990 - December 1991. As is typical for most of New England this relatively young forest (55 years old) is accumulating considerable quantities of carbon. As a consequence temperate forests may be a major sink for carbon on a global basis. From Wofsy *et al.* (1993).

Table 2. Timber growth versus removal in the New England states from 1935 to 1985. Growth exceeded removal in all but the earliest period as indicated by the percent (G:R) increase. Data were obtained from Baldwin (1942, 1949), Irland (1982) and USDA (1990). Values given in millions of cubic feet of wood.

	1935			1944			1952		
	Growth	Removat	G:R	Growth	Removat	G:R	Growth	Removat	G:R
Softwood	193	244	79%	419	375	112%	491	339	145%
Hardwood	315	327	96%	478	386	124%	302	149	203%
Total	508	571	89%	897	761	118%	793	488	163%

	1976			1985		
	Growth	Removat	G:R	Growth	Removat	G:R
Softwood	838	395	212%	440	356	124%
Hardwood	506	243	208%	478	386	124%
Total	1304	638	211%	1057	565	187%

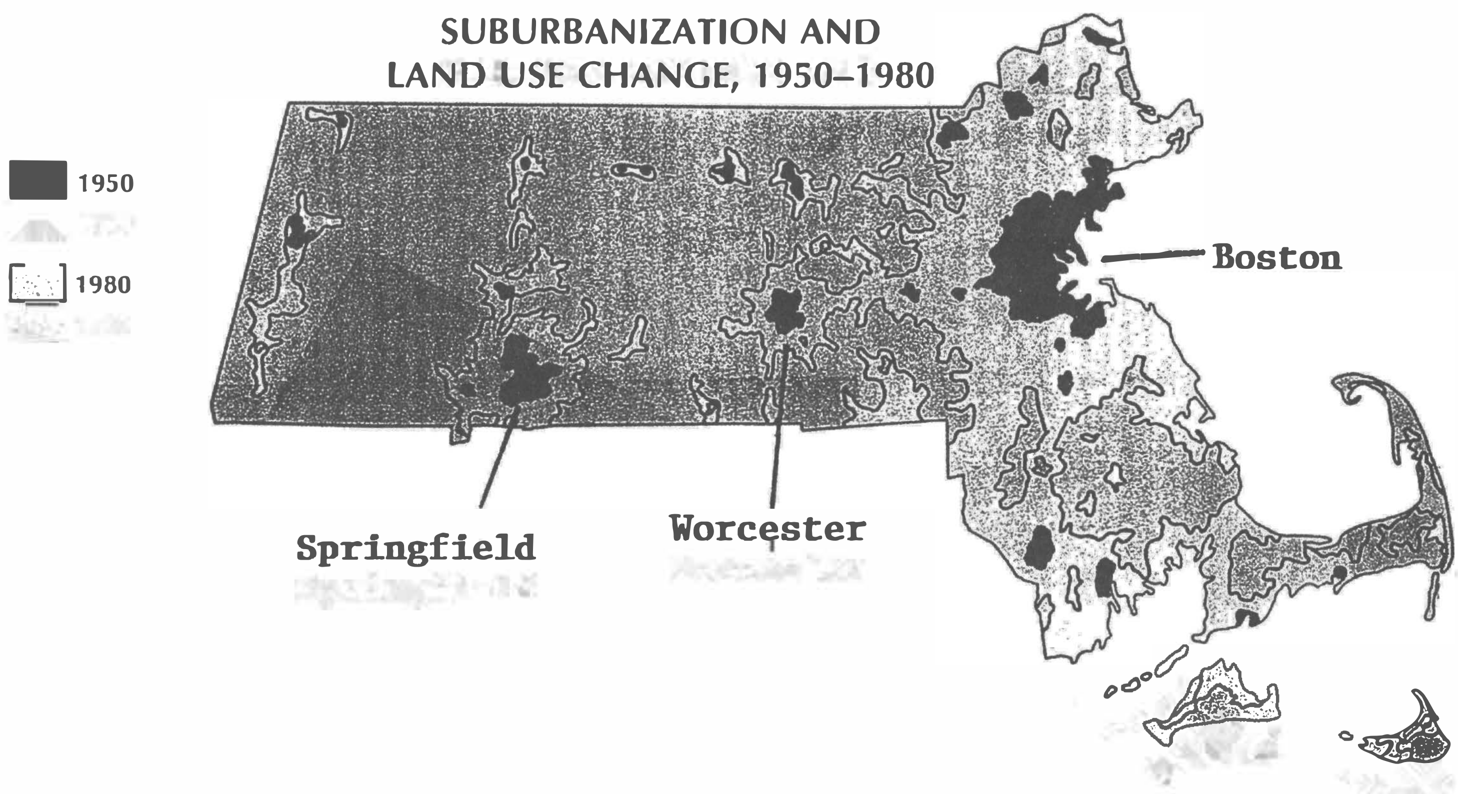


Figure 19. The progression of suburbanization in the state of Massachusetts during the last half of the 20th century. A growing population and improved road transportation system have resulted in a conversion of former agricultural and industrial towns to residential communities around the major cities of Boston, Worcester and Springfield. Modified from Wilkie and Tager (1991).

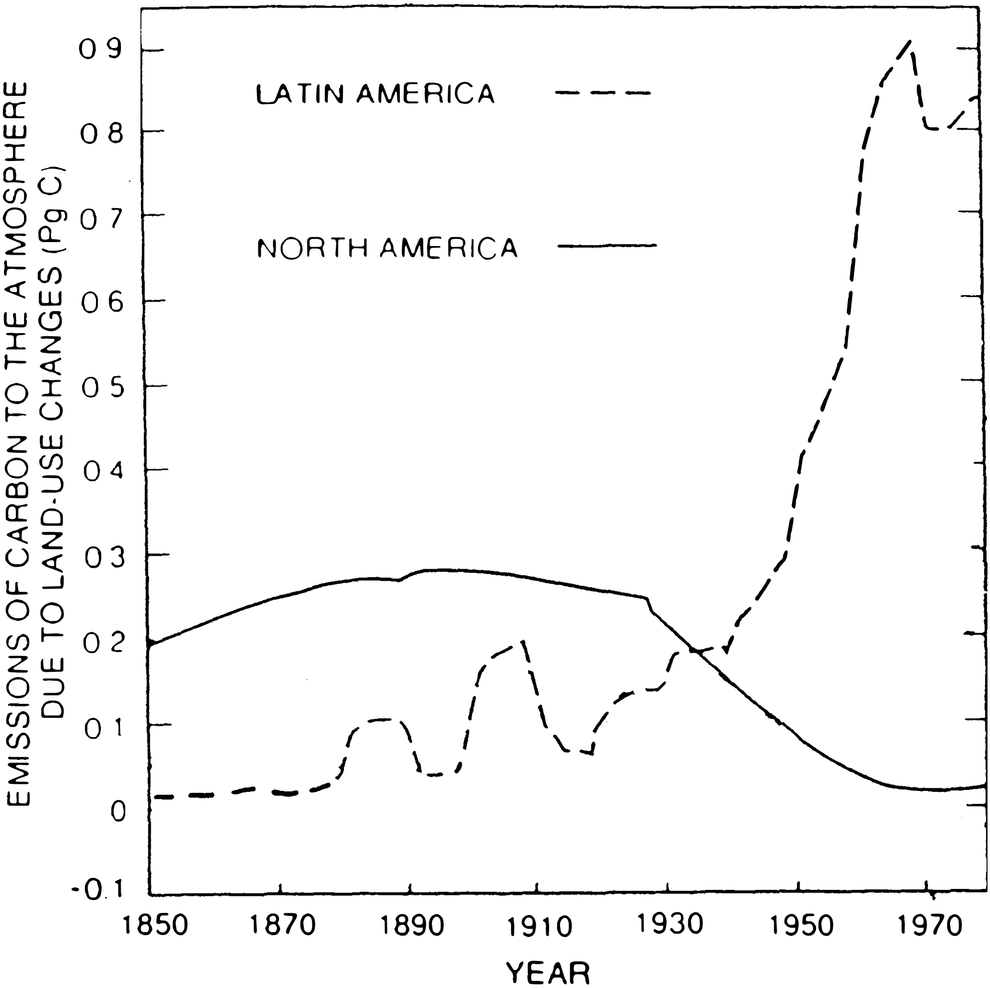


Figure 20. The annual net flux of carbon to the atmosphere (PgC = 10^{15} grams) from North America and Latin America resulting from human land-use. The graphs illustrate that whereas deforestation and increased agricultural activity across Central and South America have led to accelerated release of CO_2 during the last 50 years, the same period has witnessed decreased emissions in North America. A major contributor to this continent-wide decline is the conversion of former agricultural land back to forest and consequent storage of carbon in forest ecosystems. From Dale *et al.* (1991).

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CHAPTER 11

EXCHANGES OF WEEDS BETWEEN THE AMERICAS AND MEDITERRANEAN EUROPE

R. H. Groves

"Wherever man travelled, he carried with him both useful and useless plants centuries before we have any historical records of his travels".

(Ridley, 1930: 634)

Plant propagules have moved around the world naturally ever since plants evolved. Amongst crop species, for instance, the coconut (*Cocos nucifera*) moved both naturally by sea and was moved by non-Europeans from South America to Asia long before Europeans knew of the existence of the American continent (Ridley, 1930). A species of wild cotton (*Gossypium herbaceum*) is presumed by Purseglove (1968) to have reached South America from Africa/Asia prior to 1492, although this claim is still questionable, even using current methods for analysis of DNA composition (Wendel, 1989). For non-crop species, however, more examples could be cited of natural movements of propagules without necessarily invoking human means; for example, the movement of seeds by birds from one land mass to another or the movement by flotation of fruits of strand plants such as several *Cakile* species. *Lantana camara* is now a widely distributed and invasive plant of South American origin that has been moved around the world by humans for horticultural reasons. But locally and regionally, *Lantana* fruits may be effectively dispersed by birds; it was one of the first species of woody plant to appear on Krakatoa after that Indonesian island erupted in 1883 (Ridley, 1930).

This chapter discusses the evidence for an increased rate of movement of some plant propagules between Mediterranean Europe and the Americas over the last 500 years since

Columbus crossed the Atlantic Ocean to and from the West Indies. Over this historical period, most movements of crop plants have been greatly advantageous to human well-being. Other biotic exchanges, however, have been deleterious, such as those of the invasive terrestrial plants called "weeds." I shall assess some of the evidence for plant invasions in the early period following the Columbian encounter (1492-1606), but because this evidence is poorly documented, I shall perforce also use some better documented case histories of more recent invasions from which to formulate a number of general conclusions. The role of climate and its influence on initial invasive success will be highlighted, especially in relation to weed invasion of the two areas of Mediterranean climate in the Americas: Chile and California. The role of weeds as they may affect change in land cover and climate, either regionally or globally, will be touched on, although the absence of quantitative information may preclude the formulation of any but the most general assessment.

The Early Columbian Encounter Period (1492-1606)

"...the most important changes brought on by the Columbian voyages were biological in nature".

(Crosby, 1972: xiv)

Columbus sailed from the shores of a Mediterranean Europe that was already ecologically disturbed by agriculture and forestry. By the end of the fifteenth century few natural ecosystems remained. For instance, deforestation was such that Spain was an importer of wood from northern Europe by A.D. 1500 (Sale, 1991). The general absence of an ecological sensitivity, it has been argued by some, was a widespread attitude brought to the settlement of lands by Europeans; it was an unacknowledged component of the overall mind-set that Crosby (1986) termed "ecological imperialism." One concomitant feature of this general European attitude was that many of the plants that inevitably occurred as contaminants of the crop plants Columbus took with him were already adapted to disturbed land -- a theme I shall return to subsequently.

Documentation of initial impressions of the natural history of the West Indies is extremely sparse. There was no naturalist on board any of the three ships when Columbus sailed from Spain. Columbus' own logbook (Cohen, 1969) contains many references to the visual impression the "new" vegetation, animals, and humans made on him. For instance, in the logbook for the first voyage of 1492-93, Columbus writes :

"the trees are of many kinds, each with its own fruit, and all have a marvellous scent. It grieves me extremely that I cannot identify them, for I am quite certain that they are all valuable and I am bringing samples of them and of the plants also". (Cohen, 1969: 70)

Columbus' acknowledgement of his deficiency in natural history is repeated subsequently and often but, nevertheless, none of the following three voyages included a natural historian to make good this acknowledged deficiency.

The accounts of the subsequent voyages are similarly lacking in biological details, though some crop plants are identified, such as "a grain like panic-grass that the Indians call maize", cotton, tobacco and others (Cohen, 1969: 79). On returning to the West Indian island of Isabela during the second voyage, Columbus told his son that "a farmer gathered ears from wheat which had only been sown" two months previously. "They also gathered chick-peas bigger than the stock from which they were grown. The seeds of all the plants they sowed came up in three days and on the twenty-fifth day were ready to eat." Whilst Columbus recognized the short-term agricultural potential of the land he arrived at and introduced to it some European crop plants (Hendry, 1934), there is little evidence of his concern for those other plants that inevitably were present as contaminants in his supplies of crop seed. Columbus' only reference to a terrestrial weed is in his log for November 6, 1492 when he mentions a plant species he rated as of no marketable value: "weeds in their hands to drink in the fragrant smoke" (Sale, 1991: 103). So much for Columbus' predictions; the species happened to be tobacco! Subsequent naturalists did better but were still blinkered by their own European ecological heritage and by their economic preoccupations with crop plants and their agronomy.

An early and more authoritative record of the incidence of non-cultivated plants is that of Fernandez de Oviedo (Stoudemire, 1959) who, in 1526, published an account of the natural history of the West Indies in which he noted the great abundance of citrus on Hispañiola (now Haiti and Dominican Republic). Of the group of plants called citrus, Fernandez de Oviedo refers to "sweet orange and bitter orange trees, and very beautiful lemon and citron trees, and these fruits are to be found in abundance" (Stoudemire, 1959: 10). Presumably these species are respectively, *Citrus sinensis*, *C. aurantium*, *C. limon* and *C. medica* (Purseglove, 1968). The first three species probably originated in tropical, subtropical, and dry monsoonal regions of Southeast Asia and were brought to Europe between the eleventh and thirteenth centuries. *Citrus medica* is, however, of southwest Asian origin and is considered to have been brought to Europe about 300 B.C. (Purseglove, 1968). Columbus took at least some of the above species with him on his second voyage in 1493; they became naturalized soon after. Whilst the climates of Mediterranean Spain and the tropical West Indies differ markedly (Figure 1), it was the subtropical and tropical origins of most species of the genus *Citrus* that was one major factor in their initial spread away from cultivated areas on Hispañiola. Another factor in their success is that seeds of these *Citrus* species are still spread naturally in the West Indies, both by water (de Acosta, as cited by Crosby, 1972: 66) and by birds that feed on the fruits (Morris, 1886).

Fernandez de Oviedo remarked on the necessity to keep weeds and grass out of the maize fields until the crop is high and "stands far above the grass and weeds" (Stoudemire, 1959: 14). But just what those weeds and grasses were in Hispañiola maize crops in 1526 we can only surmise.

Columbus third voyage brought him into contact for the first time with the American mainland along the coast of Venezuela. This was an event that opened the way to a wide range of different environments to which plants brought from Europe could be taken. When Cortés arrived in Mexico in 1519, he encountered a climate fairly similar to that of the Caribbean islands. When Pizarro reached the coastal valleys of Peru in 1531, and subsequently those of Chile, he encountered an environment climatically very different from those of the West Indies and coastal Mexico but similar to that of Spain. For the first time crop plants indigenous to the Mediterranean Basin could flourish in the wet, cool winters and dry, hot summers of Peru and Chile. Wheat, grapes and olives could be grown and harvested to produce the bread, wine and olive oil that are still the staple items of Mediterranean culture. Inevitably, annual grasses and other herbaceous plants of Mediterranean origin were introduced as weeds of crops at these new locations. So too began the creation of cropping and grazing systems similar to those that had evolved in Spain (González Bernáldez, this volume); these enabled invasive plants to find a familiar niche in wheat crops, vineyards, olive groves, and grazed grasslands.

The seemingly inexorable increase in the number of naturalized plants that characterizes the contemporary flora of nearly all regions thus began. The deliberate spread of crop plants was rapid (Purseglove, 1968). An indication that non-crop plants also spread early (and were noticed!) is provided by Crosby (1991). European clover (*Trifolium repens*?) was so common around Mexico City by 1592 that the Aztecs gave it the common name of ocoxochitl after a low-growing indigenous plant that also prefers shade and moisture (Crosby, 1991: 74). In the absence of quantitative data for specific regions of Central or South America, the current rate of increase in the number of naturalized plant species may now be assumed to be fairly constant at about four to six

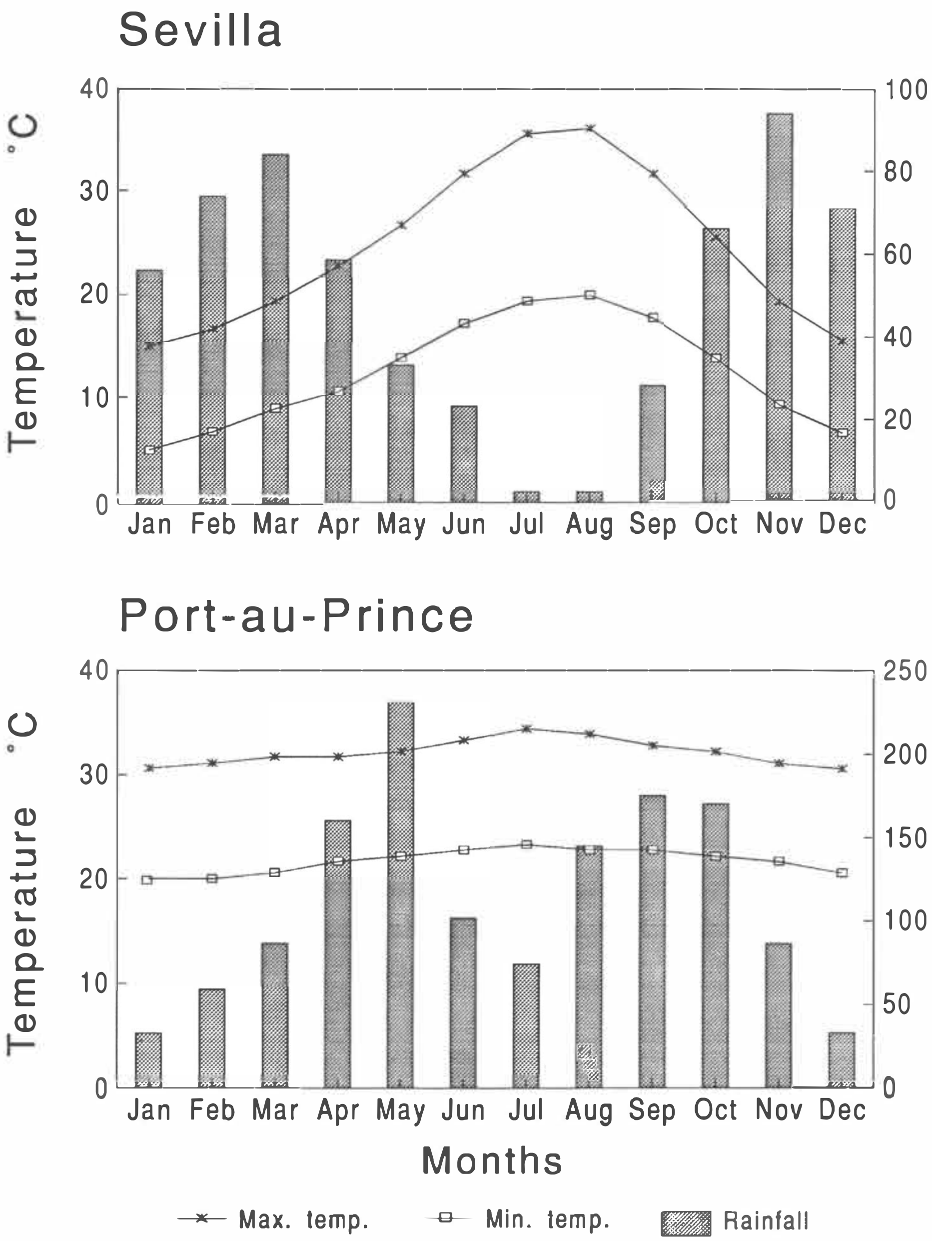

Figure 1. Mean monthly rainfall (mm) and maximum and minimum monthly temperatures (°C) for Sevilla (Spain) and Port-au-Prince (West Indies) showing the marked dissimilarity in climate between the regions that Columbus left from and arrived at in 1492. Source: Meteorological Office, 1958. (data from Anonymous, 1961).

per year, a rate that applies to climatic regions as different from the Mediterranean-climate areas of California and South Australia as subtropical Queensland and the region of Auckland, New Zealand (Groves, 1991). Records for this postulated early increase in numbers of naturalized plant species covering the Columbian period are, however, non-existent.

Subsequent Periods (1607-1992)

"There was no such thing as a typical European colony...: each inevitably expressed the styles and strategies of the country (and the regions) whose peoples set it up, each adapted according to the conditions of its environment".

(Sale, 1991: 268)

Histories of Spread of Some Plant Species

The seventeenth century was marked initially by permanent settlement of the east coasts of North and South America by English, French, and Dutch groups. Direct movement of plant species between temperate northern Europe and northeastern North America (cf. Spain and the Mediterranean Basin) thus became possible. For instance, in 1672, Josselyn (as cited by Ridley, 1930: 638) listed among his "New England Rarities" species such as *Agropyron repens*, *Capsella bursa-pastoris*, *Taraxacum officinale sens. lat.*, *Senecio vulgaris*, *Chenopodium album*, *Anthemis cotula,* and *Arctium lappa* -- all typical northern European components of temperate pastures. Such species were better adapted to temperate North America than were most of the plants from Mediterranean Spain when they arrived in the climatically dissimilar West Indies. Whilst northeastern America was being colonized by northern Europeans and their crop plants and associated weeds, Mediterranean plants were continuing to accompany Spanish immigrants to Peru and Chile. The plants were also carried by Spanish missionaries to northwestern Mexico and into (Alta) California.

With the increasing slave traffic from West Africa across the Atlantic, another route for biological exchange opened up in the sixteenth and seventeenth centuries. At about the same time, plants were being moved in ever-increasing numbers west to east and then redistributed, often deliberately, to other regions. Some of the first sites for such redistribution were the Jesuit mission settlements in Asia, whose establishment had been made possible by the Portuguese discovery of a route to the East Indies. The Jesuits deliberately introduced crop plants indigenous to the Americas, such as papaya and pineapple, to Asia, and these were undoubtedly accompanied by weedy species. In this context, *Mimosa pudica* (a sensitive plant) seems to have been taken to Asia as a curiosity (Ridley, 1930).

In general, plant movements followed trade routes across the Atlantic and then beyond. But from 1565 another important trade route operated across the Pacific, between Acapulco and the Philippines, by way of Guam (Purseglove, 1968). Just as some American crop plants reached Asia via the Atlantic and Indian Oceans, others were carried across the Pacific on Spanish galleons. To repeat a recurring theme of this chapter, so too were unwanted plants disseminated accidentally, some of which subsequently were to become weeds.

In the West Indies changes were also occurring in the flora. Many of these arose because of altered land use, especially cattle grazing and subsequently sugarcane cropping, that enabled plants introduced earlier to spread. New species continued to be introduced. An early French introduction to the outer Leeward Islands, for instance, was purslane (*Portulaca oleracea*), the cultivated succulent herb of European origin. This herb escaped rapidly from cultivation to become an especially troublesome weed on St. Kitts, where it is still noxious (Harris, 1965).

As new settlements were established in South America by the Spanish and Portuguese, new opportunities for introductions of undesirable plants were created. Sometimes it was the deleterious effects of early grazing regimes on grassland areas that created the conditions for subsequent spread of weeds. Nowhere is this better recorded than for the pampas of Argentina and Uruguay, a landscape that had been drastically changed by the 1830s when Charles Darwin visited the region. This was only about 75 years after cattle grazing had begun (Mack, 1989), but after a somewhat longer period of horse grazing. Darwin commented at length on this plant invasion "on so grand a scale" (Darwin, 1839: 138). Cardoon (*Cynara cardunculus*) and giant thistle (*Silybum marianum*), both of Mediterranean origin, formed impenetrable thickets over the formerly grassy plains. These infestations severely limited further cattle grazing, increased fuel production, limited travel by horse (Darwin's mode of travel) to old cattle tracks, and even created dense cover for robbers (Mack, 1989). Rarely has a plant invasion been so drastic and obvious in its ecological effects.

Apart from discovery of 'The Great South Land', the world by this time was beginning to become one planet biogeographically. The result of different waves of settlers from different cultures in Europe and elsewhere was a mixture of plant species in the Americas that originated in cool temperate Europe, in Mediterranean Europe, and in subtropical regions of Asia and Africa. The potential for a cosmopolitan flora was greatly increased by about 1700 and had become a reality for the Americas by the end of the gold rushes in western America about 150 years later. As well, some American plants were beginning to spread and interfere with human activities in Europe, Asia, and Africa. Whilst in Europe some American crop plants had considerable effect, that of the weeds introduced to Europe from the Americas was more delayed.

The Spread of Avena Species

Despite the absence of any documentation, it is almost certain that the first propagules of weedy plants of Mediterranean European origin entered the Americas as contaminants of the cereal seed deliberately imported from Spain, beginning with Columbus' second voyage. Among the group of grass species occurring in the western Mediterranean (Jackson, 1985), seeds of wild oats were more likely to be present as contaminants than most other species; they are similar in size to cereal grains and are difficult to distinguish from cereal oats (*Avena byzantina*, syn. *A. sativa*). The common name "wild oats" refers to several *Avena* species: the common wild oat *A. fatua* and the bearded oat *A. barbata*, as well as to several other *Avena* species. All species are annuals. The weedy species differ from cereal oats by having hairs on the lemma and an awn that is not straight.

On first introduction to the West Indies it is unlikely that wild oats persisted in the tropical conditions of that region. Wild oats are still not recorded, for instance, among the introduced flora of the Outer Leeward Islands after centuries of opportunity (Harris, 1965). Other subsequent introductions may also have failed, until the settlement of Peru and Chile enabled the wild oat plants to encounter a Mediterranean climate to which they were already well adapted (Figure 2). Whilst the history of introduction of wild oats to South America is unknown, its subsequent introduction to California from northwestern Mexico is less obscure. Initially, in the late eighteenth century, grain production in coastal California was localized to the mission stations. The grain provided flour for subsistence and hay for horses. *Avena fatua* is one of the 16 species known to have established during the Spanish colonization of California (1769-1824); plant parts of it were positively identified by Hendry (1931) in adobe bricks of known age. It is highly likely that the closely related congener *A. barbata* was also established in the same period "but remained uncollected because of its similarity to *A. fatua*" (Frenkel, 1970: 145). Both species are now widespread throughout many environments in California.

One factor in the ecological success of *A. fatua* and *A. barbata* in California (and by

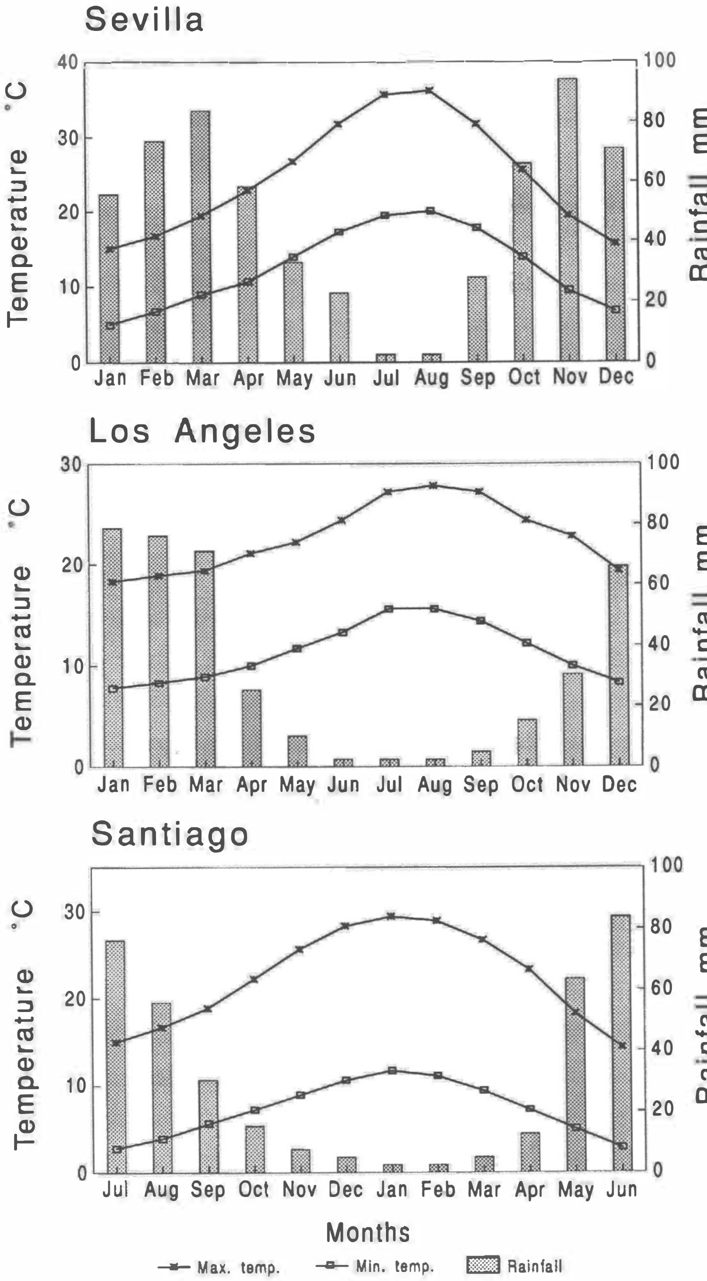

Figure 2. Mean monthly rainfall (mm) and maximum and minimum monthly temperatures (°C) for Sevilla (Spain), Los Angeles (California), and Santiago (Chile) showing the similarity in Mediterranean-type climate between all three regions. Source: Meteorological Office, 1958 (data from Anonymous, 1961).

inference, Chile and Peru) is the apparent change in genetic structure of the species since their introduction. For *A. barbata* these changes have been characterized in considerable detail, initially by isoenzyme techniques and, more recently, using ribosomal DNA polymorphism (Rejmanek *et al.*, 1991). Results using these techniques in a comparison of 541 Eurasian and 97 Californian populations showed that no alleles unique to California were present. Californian populations differed from Eurasian samples more than any two Eurasian regions differed among themselves (see Figure 8.3 in Rejmanek *et al.*, 1991). There is now fairly conclusive genetic evidence for a Spanish origin for at least some of the contemporary Californian populations of *A. barbata* and for increasing adaptation among these populations to a range of Californian habitats having different moisture and temperature regimes (Perez de la Vega *et al.*, 1991). The latter authors suggested that the Spanish rainfall-temperature combinations are more complex than those of California and that allelic associations that predominate in California are present at only a few sites in Spain (Perez de la Vega *et al.*, 1991).

This example of a pair of closely-related species shows the important role of climate in invasive success initially and a continuing role for genetic change in maintaining such success in an evolutionary sense. In addition, European settlement has provided extensive areas of the agronomic conditions to which these grasses had adapted over several millennia in the Mediterranean Basin.

The Spread of Solanum elaeagnifolium

Solanum elaeagnifolium (Silverleaf nightshade or White horsenettle) is an erect perennial species of the widespread genus that contains many invasive species as well as the potato (*S. tuberosum*). *S. elaeagnifolium* is native to central North America from Arizona to Missouri in the United States and to northeastern Mexico. The species has spread to many other regions, including the Mediterranean Basin (Guillerm *et al.*, 1990). It can be a weed of crops such as cotton, maize, potatoes, sorghum, and lucerne (alfalfa); it is also a crop weed in parts of North and South America outside its native range and even in its native area, such as Texas. Whilst it has probably been spread widely as seeds contained in a globular berry, within a local region the species increases in density also by cutting of the extensive root system with each cultivation and subsequent regeneration from root and rhizome segments (Parsons, 1973; Guillerm *et al.*, 1990). Different modes of reproduction are followed depending on the type and timing of cultivation (Guillerm, 1991).

In the western Mediterranean Basin, the first record of this American introduction is from Montpellier Botanic Garden in 1855 (Guillerm *et al.*, 1990). The climate of southwestern France is different from that of the southern United States and northern Mexico, especially in the different amounts of rainfall in summer (Figure 3), which is the season when *S. elaeagnifolium* mainly flowers and begins fruiting. Nevertheless, the distribution of *S. elaeagnifolium* has extended from Montpellier (Figure 4), and the weed is now widespread throughout the eastern and western Mediterranean. It is becoming a major weed in Morocco, to which it was introduced accidentally in 1950 (Tanji *et al.*, 1985). *S. elaeagnifolium* occurs there as a weed of irrigated crops, such as cotton, maize, and sesame (Tanji *et al.*, 1985), a situation where the soil moisture and temperature regimes are similar to those in the southern United States. The species may still have considerable potential for further spread in the Mediterranean Basin and almost certainly will increase in significance as a weed of irrigated cropping lands in the region.

This example shows that climatic dissimilarities between the regions of origin and introduction may be compensated for by agricultural factors, such as supplementary irrigation. There has probably been more than one introduction of *S. elaeagnifolium* to Europe, however, as is undoubtedly the case with the earlier movement of wild oats in the reverse direction. This example also shows the role that botanic gardens may play as foci for spread of invasive plants. Many plants other than *S. elaeagnifolium* have spread in this way.

The Introduced Floras of Several American Regions

One could continue to quote anecdotal accounts of the history of plant invasions over a wide range of environments. Having chosen two contrasting species and discussed them in some detail, I wish now to jump to the present and briefly look at the origins of the introduced floras of several regions of the Americas and assess the net effect of 500 years of human contact with Europe.

Some information on the origins of the naturalized floras is available. Incomplete though some of these data are, they show that the main source of plants introduced and naturalized to the Americas is Europe, including Eurasia (Table 1); at least two thirds of the naturalized floras of seven different American regions have been introduced from Europe or Eurasia. Movements between different regions of the Americas, whilst still significant, are of much lesser magnitude. The weeds came initially from the same provenance as the settlers and after 500 years they continue to dominate the introduced flora of most American regions. In other words, results of recent analyses

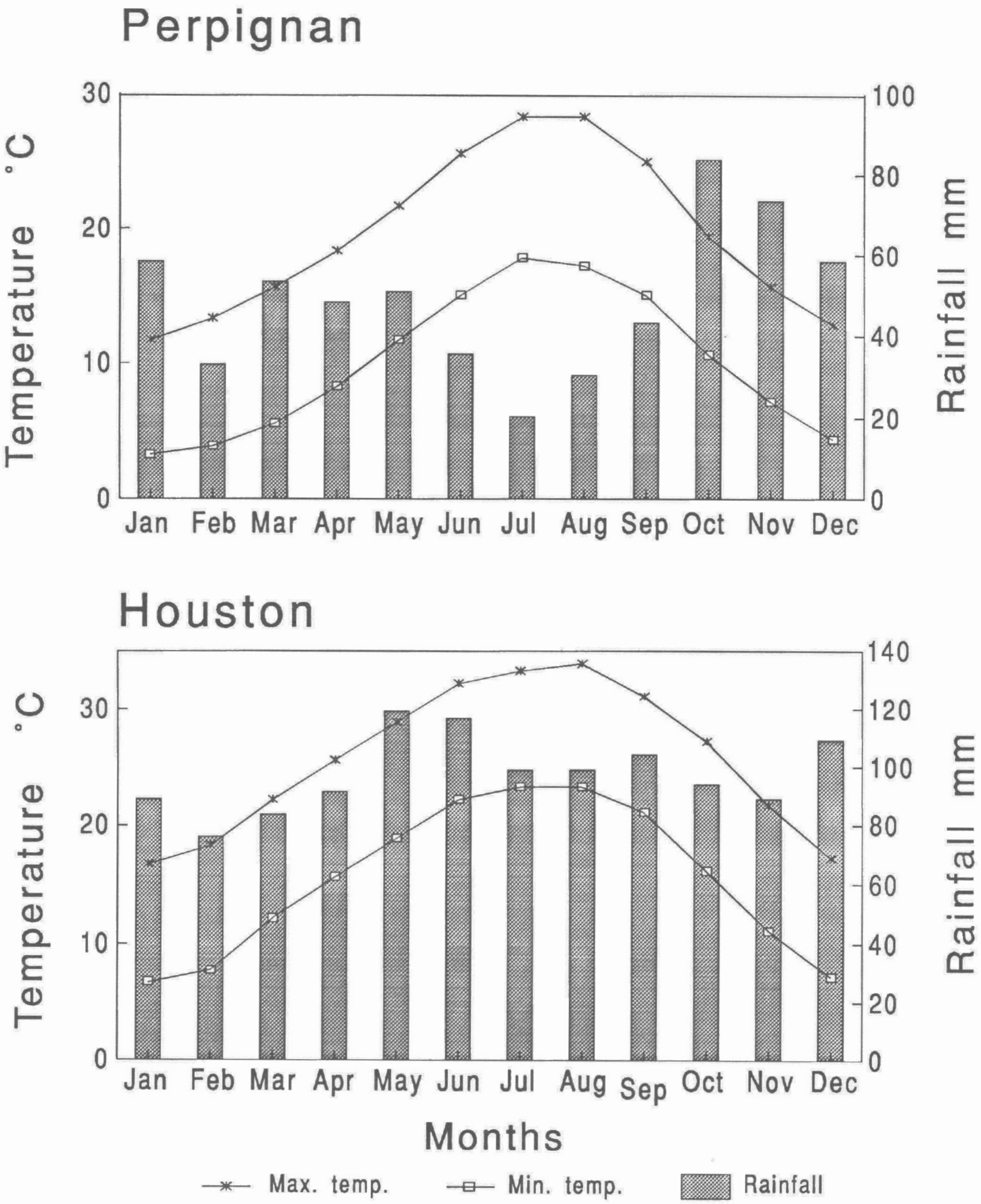

Figure 3. Mean monthly rainfall (mm) and maximum and minimum monthly temperatures (°C) for Perpignan (France), and Houston (Texas) showing dissimilarities in both rainfall amount and temperature regimes between the two regions. Source: Meteorological Office, 1958 (data from Anonymous, 1961).

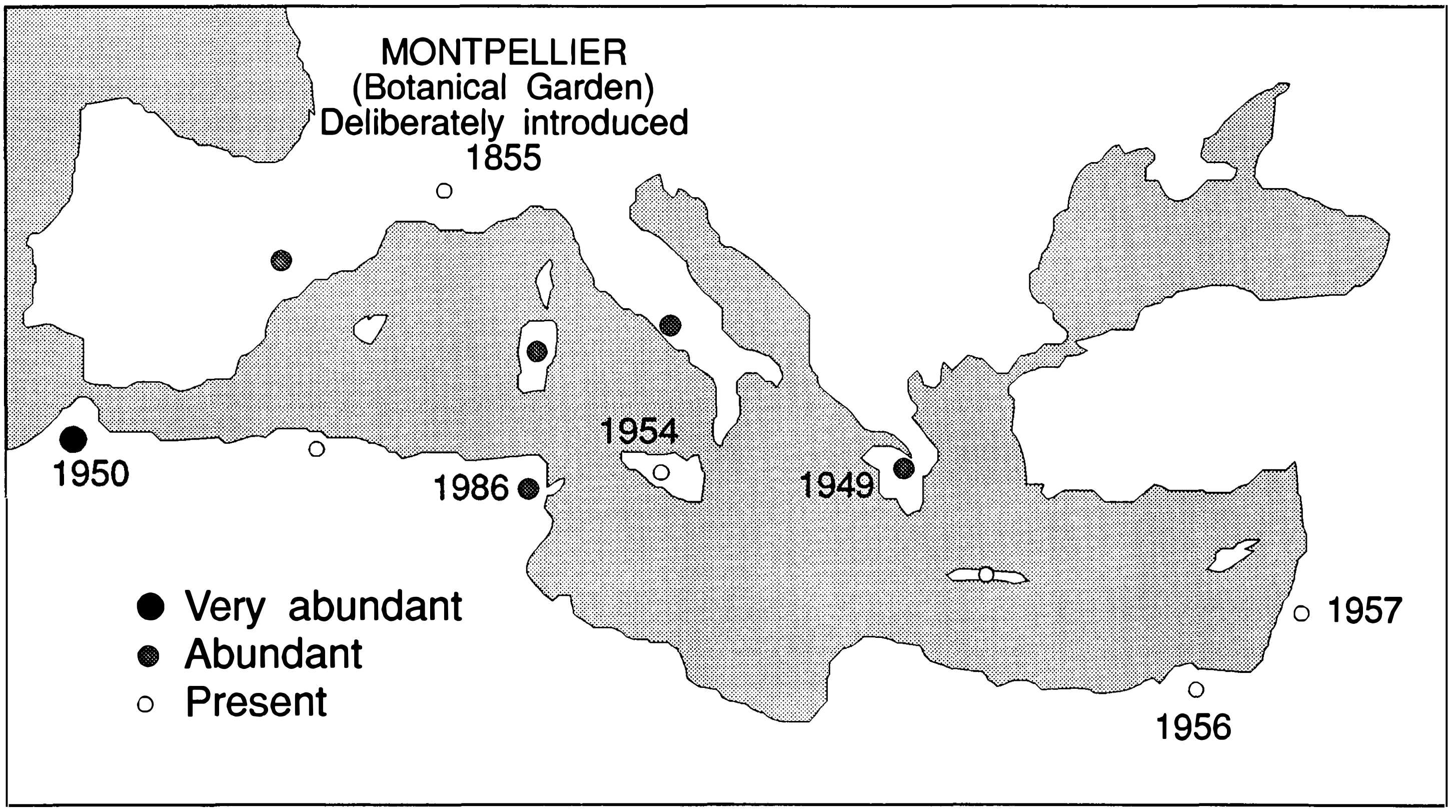

Figure 4. Recorded spread of *Solanum elaeagnifolium* in the Mediterranean Basin; its first known introduction was to Montpellier (France) in 1855 (redrawn from Figure 8 in Guillerm *et al.*, 1990).

(Groves, 1991; Rapoport, 1991) bear out Crosby's (1986) description of ecological imperialism -the biological expansion of Europe- over the five centuries since Columbus left the southern coast of Spain to cross the Atlantic.

Table 1. Composition of the naturalized flora of several American regions

Region	Origin of naturalized flora (%)					Reference
	Eur	Amer	Afr	Aust	Others	
California	70	17	5	5	3	Groves(1991)
Chile	82	11	-	2	5	Groves(1991)
Mexico City	78	9	8	-	5	Rapoport(1991)
Bariloche	85	13	2	-	0	Rapoport(1991)
Argentina	*c.* 75	?	?	?	?	Marzocca *et al.* (1976)
eastern America	*c.* 86	?	?	?	?	Fogg(1945)*
USA	*c.* 66	?	?	?	?	Jacques(1959)*

* as cited by Rapoport (1991), no reference given

Discussion and Conclusions

"We are seeing, because of changes in our global environment, that the ideas that accompanied Columbus now require revision if nature is to have a future."

(King and Dudley, 1991: 250)

The chances for movement of plant propagules around the world have greatly increased since Columbus opened a new trade route from Mediterranean Europe to the Americas. There is no evidence yet for a slowing in the number of naturalized species present in any one region (e.g. Frenkel, 1970, for California). Rapoport (1991) has predicted an increase in the number of plant species interchanged between tropical countries, such as central America and Africa. Perhaps this will be the next big change in the total American flora, unless quarantine services in most countries can be made much more effective. As agriculture diversifies in the Mediterranean, as for instance in the growing of irrigated rice in the Camargue of southern France, so will the number of different sites available for introduced plants increase. Many of these introductions will come from the Americas. The two-way movement of plants across the Atlantic will continue, albeit perhaps at a reduced rate in the future.

This review has looked at some of the evidence for the exchanges in undesirable plants between Europe and the Americas. One recurring theme has been that evidence is mainly circumstantial, usually retrospective and grossly inadequate. This situation arises partly from an attitude to natural history held by late fifteenth century Europeans that is very different from present attitudes. Columbus' knowledge (and that of the early conquerors) of natural history did not match his navigational skills. Consequently, early records of plant invasions rarely if ever exist. The situation has not improved greatly over 500 years, except in a few cases such as that presented for *Solanum elaeagnifolium* in Figure 4.

Whether weed invasions of the type described in this chapter have effected change in land cover or climate, either regionally or globally, is not known but is also a moot point. In some regions, such as the Mediterranean-climate areas of Chile and California, there has been a shift in grass cover from native perennials to introduced annuals (Jackson, 1985) and more bare ground in summer as a consequence. Cover values may have changed seasonally in regions such as the Central Valley of California, at least prior to intensive cropping of this region. Invasions of a number of African grasses to Central and South America (Parsons, 1972) may not have led to changes in land cover values as such, although they have been associated with changes from either forest or shrubland to grassland over extensive areas of the American tropics. If the question is difficult to answer regionally, global considerations are even harder, despite the widespread invasions of weedy plants to Africa, Asia, and Australasia not discussed in this chapter.

Weed invasion is only one biotic process indicative of environmental change. Despite the apparent paucity of evidence for most weeds, what can be concluded from this brief review? Six conclusions are evident that may contribute to the formulation of some wider-ranging principles concerning environmental change.

(1) The climate of origin of a plant species will be a major determinant of success of its establishment and initial spread in the region of introduction. Mediterranean European plants only became naturalized when they encountered Mediterranean-type climates in Chile and California.

(2) Many Mediterranean European plants were preadapted to disturbed agricultural land. Whilst climatic similarities may have influenced establishment success the plants

usually spread in response to land disturbance. They flourished when similar ecological conditions were created in the Americas.

(3) The main agents of dispersal were humans, who initially inadvertently introduced weeds as contaminants of crop seed, but who subsequently continued and still continue deliberately to introduce plant propagules for horticultural, pastoral, culinary, or medicinal purposes. In this regard, it appears that botanic gardens may have played a significant role as centers for organized redistribution of plant materials and cultural techniques.

(4) Once introduced, many plants spread naturally, were spread by the animals that the settlers also introduced, or else were spread by indigenous animals, especially birds.

(5) Some Mediterranean European plants have changed genetically since their introduction to take advantage of the wider range of different environments available in the Americas either locally or regionally: a period of selection of 500 years or less.

(6) More European plants have invaded the Americas and did so more quickly than vice versa. This difference may have arisen because of the greater diversity of environments available in the Americas than in Europe. The reverse flow of American plant species to Europe, although slower initially, may increase in the future, especially as the agricultural pattern in Europe diversifies. There has been a much longer period of selection for the ruderal habit in European species.

The floras of different regions of the world are neither yet identical nor composed only of a few major weeds. That prospect is becoming more real, however, especially in agricultural regions of Mediterranean-type climate. Increased research attention to the study of past and present biological exchanges may help to avert the dismal prospect of such uniformity for the next quincentenary.

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CHAPTER 12

LAND-USE CHANGE IN THE SEMIARID AND ARID TROPICS OF AFRICA

Christian Pieri

Introduction

The high hopes raised by the green revolution and technology transfer in the early 1960s now seem unfounded. Agricultural production has stagnated -even fallen- in several less developed countries, mainly in the arid zones with unpredictable rainfall. The agricultural crisis in sub-Saharan Africa is a case in point (World Bank, 1989). The increasing imbalance in the resource base threatens to jeopardize the heritage of future generations. The population growth (+3%) is outstripping availability of arable land where soil degradation is already an acute problem (ISRIC-UNEP, 1990). The production increases urgently needed to meet the food requirements of this rapidly growing population can only be achieved through crop intensification and new methods of soil management (Mellor *et al.*, 1987). But any new measures in this direction should be accompanied by a careful assessment of its environmental impact. This evaluation should be based on a historical analysis of the consequences of the changes in the region and their effect on renewable resources (Simmons, 1987).

The Columbian encounter was associated with serious political and economic upheavals in Africa (Braudel, 1949). The most noticeable and immediate of these phenomena was the slave trade. Whether this turmoil really led to modifications in land use that left a permanent mark on the agroecosystems and land cover has yet to be determined. For instance, was slaving responsible for reducing labor sufficiently to lead to a disintensification of farming and afforestation in some locales? The answer to these questions and the analysis on which it would be based would lead to an understanding of how rural environments continue to function and of the technical and cultural relationship between these populations and their environment. These complex relations determine the organization of the agrarian landscape today and the rules by which rural populations operate. Such an analysis would indicate the conditions that must be respected in sub-Saharan Africa for disseminating improved and sustainable management methods in the arid and semiarid tropics. This knowledge is indispensable for mobilizing farmer participation in agricultural development. The importance of farmer participation in attaining the objective of sustainable agricultural development is strongly stressed by the organizations that strive to overcome the African crisis (Groupe de Travail Coopération Française, 1989; World Bank, 1989; FAO *et al.*, 1991) and specialists (Parikh, 1991).

This article briefly analyzes the main factors of change after A.D. 1500 of the semiarid, Sudano-Sahel region of Africa, between the Saharan Desert and the wet tropics. It attempts to explain how, despite the despicable triangular slave trade flow among Africa, Latin America and Europe, and the colonization of Africa in the nineteenth century, rural Africa has been characterized by stability and isolation (Gourou, 1991). The Columbian encounter apparently had minimal impact on land use and land cover in this region of the world. Major changes in use and cover have been a very recent phenomena.

Stability and isolation were dictated by the need for security to survive in environments that may be perceived as precarious for cultivation. Direct attempts to change agriculture during the colonial period had little effect on the deep-rooted and tightly woven system that had evolved in close harmony with the environment. Real change in land-use systems came about only after the exponential population growth in the 1970s.

Changes in Land Use

Sources of Information

African history is still an inadequately explored area. Current knowledge of the history of the rural population is even more limited. The years closest to the colonial period are the least known, and this is not the only paradox of African history (Coquery, 1965). The Arabian geographers Al-Bakrî (11th century), Ibn Battûta and Ibn Khaldûn (14th century), and Leo the African (16th century) have left behind their accounts of sub-Saharan agriculture. Then followed three and a half centuries of "sleep" (de Vaulx, 1960) without any authoritative written accounts; they correspond to what historians call the "dark ages" of an isolated Africa (Cornevin and Cornevin, 1964). The reports were resumed with the creation of the African Association in London in 1788. Other sources of information are the narratives of the bold explorers like Mungo Park who reached the Niger River in 1795; Denham, Clapperton, and Ouduey who visited Chad in 1823; René Caillé who reached Tomboutou in 1828; and Barth who visited Aïr in 1851.

The lack of detailed literature makes it difficult to accurately analyze the historical, social, technical, and economic changes at issue here. Recent work by eminent geographers, such as P. Gourou (1982, 1991), and others is contributing to fill this gap.

Factors of Change before Modern Times

The date 1492 symbolizes the significant difference between Europe and Africa at the end of the Middle Ages. Cornevin and Cornevin (1964) even go to the extent of stating that while the great discoveries brought the Renaissance to Europe, they signaled the closing and decline of Africa.

Slave trade and population density

The large-scale slave trade organized by the major European powers from the sixteenth century onwards drained Africa of its human resources. More than 10 million people -probably even 25 million- were taken away, as judged by the number of Africans sold abroad; if losses "during transit" are included, however,the total could well have reached 50 million people. These figures should be compared with the total population to understand the magnitude of this depletion. Ki Zerbo and Braudel (1978) set this total figure between 25 and 50 million for the period around 1650, which is much lower than earlier estimates of 100 million.

It must not be forgotten that slave trade, like the gold trade, was practiced as early as the eighth century, long before its climax in the sixteenth century. Black Africans who had settled in northern Senegal and western Mali supplied the Islamic states of northern Africa with slaves. Between the eighth and thirteenth centuries, three million slaves were hauled away from their land (Daget, 1990). In the thirteenth century, the kingdoms of Bornou and Kanem (modern Chad) conducted intensive trade with the Ottomans who had just conquered the eastern Mediterranean region. The slave route from Chad to Tripoli is stamped in the collective memory of the Africans. Gourou (1982) reports that a convoy of slaves was seen as recently as 1905 in Oubangui (modern Central African Republic).

The first direct consequence of slave trade was that population growth stagnated, even if the ravage was mitigated by the practice of polygamy and the fact that this trade affected mainly the male population. This "human mining" was not the only reason responsible for low population density in the African semiarid tropics (Gourou, 1991). An indirect but significant consequence was that it encouraged tribal warfare, disintegration of the states, and human migration. As a result social organization and land management practices were molded to enable the people to confront permanent insecurity.

In addition, African land use had to confront exceptionally difficult "natural enemies." The continent has the highest human mortality rate on the planet owing, in part, to widespread endemics, such as yellow fever, and human and animal trypanosome diseases, which do not occur in other regions of the tropics. Some of these diseases have been brought under control recently, but others still remain a serious threat and new ones have developed (AIDS).

The impacts of these conditions in sub-Saharan Africa are important by way of comparison with similar environments elsewhere. The eastern Deccan Plateau in India, for example, has similar soil (sandy soils from ancient crystalline shield) and climate (drought) conditions to the semiarid portions of western Africa. The Deccan Plateau, however, has a population density of 385 inhabitants/km^2 (in the Tamil areas), almost 25 times that of the current density of 15 inhabitants/km^2 in the Sahel (World Bank, 1989). Both areas have known human migration and disease epidemics, although these have been less in India, but the human impacts seem to have been greater in Africa.

New Crops and Their Impact

The biotic exchanges following the Columbian encounter did not escape impacts on sub-Saharan Africa, which had long exchanged species with other regions of the tropical Old World, such as *sativa* rice, banana, and sugarcane from Asia . Exchanges from the Americas were somewhat delayed temporally, but subsequently have become quite important, including maize, pineapple, groundnut, various cucurbits, and several fruit trees.

Cassava (manioc), from South America, spread widely to become a staple throughout tropical Africa, supplying 40% of the calories in the current African diet. Cassava is less labor-intensive than the native yam which needs the preparation of large mounds to yield well [1]; it can also resist soil and rainfall constraints better than most competing crops. Moreover, cassáva does not need storage as it can be left in the soil. Leaf and tuber yields are high and it enjoys wide consumer acceptance (Terry ***et al.***, 1987). The success of this crop is linked to its easy integration into traditional cropping systems without the need for innovations. Its spread across tropical Africa has probably not had any major and direct land-use and -cover consequences.

Unlike cassava, crops such as irrigated rice, sugarcane, fruit trees, or pineapple need high investments in land improvement (e.g. terracing, irrigation) and reconstitution of soil fertility. Such investments are contrary to some traditional strategies and, for this reason they have not been as successful as cassava in traditional agricultural systems.

Trade Flows

The early trade flows between the Old and New Worlds did not pass through Africa (Figure 1)[2]. The sea voyages stopped at the Gulf of Guinea, where the Europeans had established several forts or small garrisons as the center for the slave trade. The forts controlled only a small coastal strip; continental Africa remained sovereign, a land where few foreigners dared to venture. The Congo River, for instance, was only discovered by Europeans in 1877 almost three centuries after the discovery of the Amazon River by Orellana in 1542. Until the end of the nineteenth century, Africa was jealously guarded by the African kingdoms and slave traders.

Impact of Colonization

Although Africa had been exploited through the centuries, the core remained relatively untouched, unlike the modifications that took place in Europe, Latin America, and Asia. Colonization is a recent phenomenon in sub-Saharan Africa in relation to its millennial past. Foreign armies met with the fierce resistance from the native people and could only penetrate the interior gradually.

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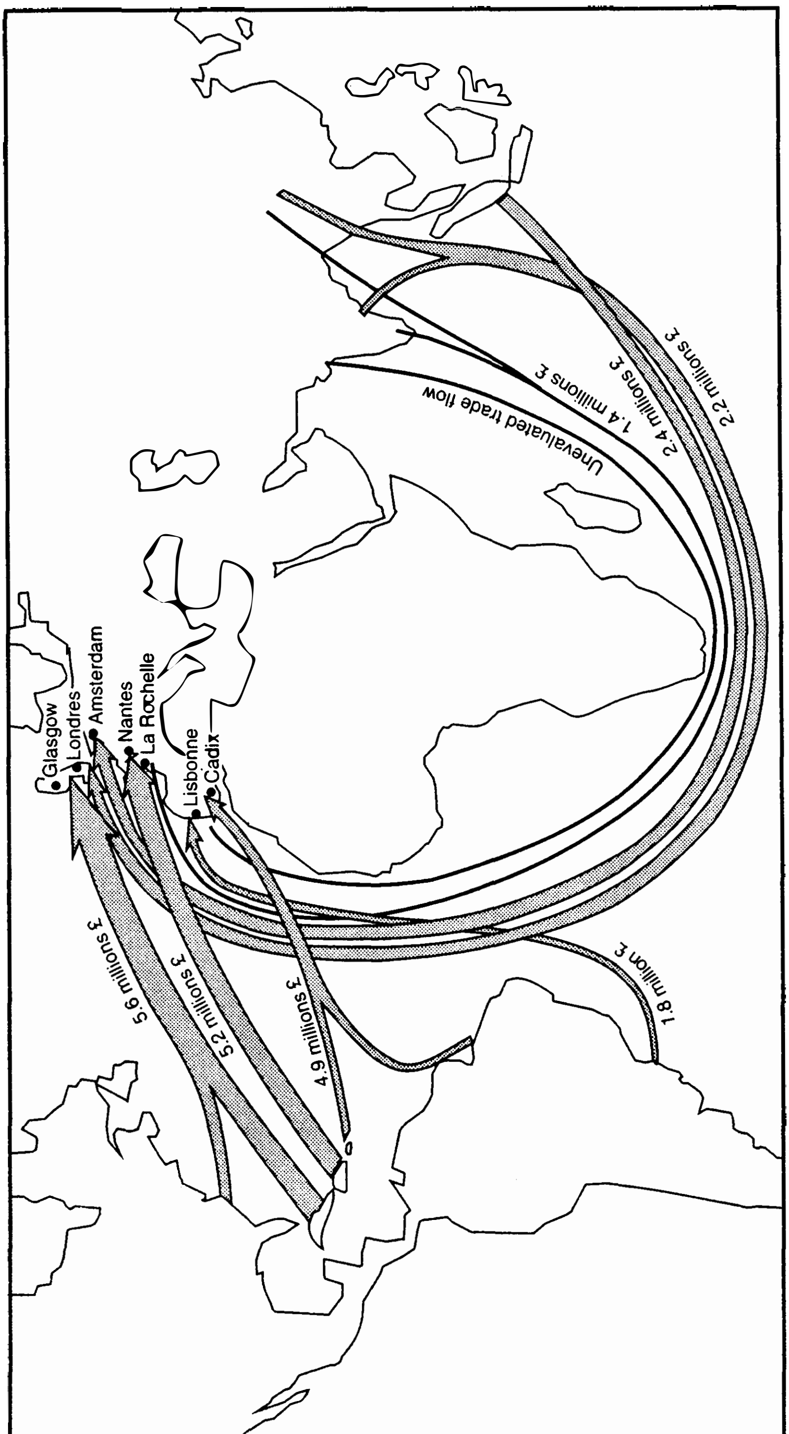
1. Cassava and mounding went hand-in-hand among Amerindian cultivators. The species generally produces better in such conditions, but it can prosper without mounding and can typically yield better than other root crops without mounding (Terry, Akoroda, and Arene, 1987).

2. Likewise, European sea routes and trade flows to the Orient bypassed Africa because its resources were thought to be limited compared to the enormous -and accessible- wealth of India and Indonesia.



Source: Encyclopedia Universalis, 1981.

Figure 1. Major world trade flows (1770).

Change came to Africa only in the second half of the nineteenth century. The improvement in health conditions and transport facilities for the movement of people and goods started transforming the lives of people. Urbanization gained momentum. Insecurity and isolation that had cut off Africa from the world were diminished. But these changes did not have an immediate impact on land use. While plantations (oil palm, cocoa, coffee) were established in the tropical forest zone, subsistence farming continued in the semiarid tropics until the spread of cotton cultivation during the past two decades.

The first large-scale agricultural projects after World War II, which aimed above all to meet the needs of the colonizers, were completely incompatible with the Africa experience and situation and, therefore, unsuccessful. Temperate-zone technology was not appropriate for much of the region, leading to serious consequences, and the subsequent failure of these projects was certainly not an incentive to the African farmer to change systems of cultivation.

The creation in Mali of the large irrigation system of the Office du Niger, and the establishment of 10 000 ha of mechanized groundnut crops in Casamance, Senegal (mainly by the Compagnie Générale des Oléagineux Tropicaux) did not prompt a large response from the local farmers. The systems encountered difficulties from the invasion of the rice fields by rhizomatous rice and weeds and spread of the bilharzia vector, and severe erosion in the groundnut-growing area because of plowing methods used in temperate systems. These problems only served to show farmers the sound basis of their traditional systems (Boussard, 1990).

Some small-scale projects have been successful (e.g. vegetable production, orchards around the cities). As long as the Sudano-Sahelian zone was thinly populated and land was abundant, however, African farmers preserved their traditional practices as they saw no urgent need to change. Jacques Giri, a specialist on the region, wrote in 1983: "Some people claim that it [colonization] had killed the traditional society. I was struck instead by the vigor of this society ... by its unchanged system of farming land ... by the deep-rooted traditions in the villages and nomadic tribes."

Tradition and Recent Changes

What are the main characteristics of this agricultural civilization that has endured for more than ten centuries in the semiarid zones of sub-Saharan Africa? Although African communities are historically and culturally heterogeneous, they all belong to what Giri (1983) calls a *civilisation de l'espace*. The main values of this civilization were linked to the quality of life of each individual, a harmonious relationship with the natural environment, solidarity within the entire group, respect for ancestors, and an oral tradition in which unanimity is reached through consensus. While it is difficult, however, to demonstrate that different professed views of nature lead to different environmental outcomes, once standardized for land pressures, length of occupance, and technological capacity (Kates, Turner and Clark, 1990), the relatively low land pressure historically in the semiarid zones and the apparent slow changes in them until this century, facilitated the use of environmentally benign systems of cultivation based on community management of the rural landscape and shifting cultivation practices. To a large extent this traditional form of land-use management explains the relationship that farmers maintain today with the natural resources they exploit (e.g. Scott, 1984).

Traditional Organization of Land Use

Traditional African societies are basically organized on lineages. A founding lineage, or segments of a lineage, occupy and develop an agricultural area that, over time, is organized into villages. Communal control over farm lands governs the activities of the village on the basis of seniority (power of the elders), solidarity, and consensus. In this way the organization ensures security, cohesion, durability (reproduction) of the lineage (Benoit-Cattin and Faye, 1982). The social rules for managing natural resources are supported by complex and restrictive family ties and links between different age groups.

This organization of farm lands by different, autonomous lineages linked through a network of several hundreds of villages enabled the African savanna peoples to survive environmental vagaries and external aggressions. The lineage/village-based organization also institutionalized certain modes of behavior that have variously been characterized as "backward" and reluctant to change, leading to a large literature speculating and theorizing as to the reality of this reluctance and why it exists[3].

The integration of the individual in the "lineage-village complex" was almost perfect. Even the destitute found a place in this society. But because land belonged to the lineage or village and its future was ensured through a respect of customs, any technical or social (e.g. cooperatives) innovations were primarily suspect. Communal control of the use of natural resources deterred offenders. These measures still exist today. In Casamance (Senegal), cattle are still let loose in fields that are cropped without the approval of

3. For reviews of these themes or specific themes see: Pingali, Binswanger, and Pigot 1987; Turner and Brush 1987; Richards 1985).

the assembly of the heads of families. Such reprisals often thwart the recommendations of extension services which seek to maintain a system of continuous farming and to improve productivity.

In other cases, traditional practices such as the priority given to food crops over cash crops were justified by religious or mystic reasons. Although such reasons were often incompatible with recommendations by the extension services, they were rarely transgressed (and are not even today). In practice, an individual is rarely allowed to be different, and accumulation of personal wealth is contrary to the tenets of this society. For example, a farmer cannot become a trader in his own village. Craftsmen belong to a certain caste and trade, and pedalling is reserved to certain tribes such as the Dioulas and Sarakholés in Mali,Senegal and Guinea. Although villages engaged in some form of sale or barter of cattle, local trade at the start of the century was mainly conducted by non-Africans.

The organization of rural areas into lineage-village complexes strengthened the development of a large number of dialects (an important factor for isolation) and the separation of crop and animal production. Extension services are therefore faced with resistance to their attempts to promote mixed farming.

Throughout the semiarid zone, fields are arranged in concentric circles round the villages; lands beyond the fields are rarely cultivated. Concentration of fields around a village nucleus was a defensive response to tribal warfare. These conflicts also explain why certain tribes have settled in remote, less agriculturally prime areas, having abandoned lands of high agricultural potential. For example, the Dogon of Mali and the Gourma of Cameroon sought refuge in steep rocky hills, and the Diolas of Senegal in the mangroves of Casamance.

Traditional Soil Management

Slash-and-burn cultivation is the main form of soil preparation. The implements are very simple; only the hoe and machete are used. The plow and other draft implements have been developed only recently. The seed is sown after lightly hoeing the surface. Seedbed preparation (ridging) is often required, however, because the topsoil is made up of fine sand and silt and is prone to soil sealing. Water accumulates on the surface and impedes seedling emergence, causing runoff and erosion.

After some years the soil structure disintegrates, and the topsoil is capped owing to a flattening of the ridges under the impact of rain and accumulation of alternate layers of clay and silt in the furrows. This is why African farmers prefer to clear forests (leaving the large trees) where the soil has a better structure, is more permeable, and does not need ridging. Soil chemistry also changes with cultivation (exhaustion of organic and mineral nutrients). These factors, combined with the uncontrollable accumulation of weeds, force farmers to move to another area (Pieri, 1992).

This type of extensive management is the result of an "anti-investment" attitude linked to land availability and the absence of private land ownership, and does not hold for areas of high land pressure (e.g. Turner *et al.*, 1992). The economic logic underlying this system is that known as "consumption production" which aims to reduce risk and yield higher returns to labor compared with more intensive agriculture (Lele, 1989).

Over centuries African farmers in semiarid zones have preferred shifting cultivation and nomadic agriculture except in times of tribal conflict. Some tribes who were driven to marginal lands developed sophisticated systems of land management with high labor input for terracing, water storage, and organic matter recycling (e.g. Turner *et al.*, 1992); they also devised strategies to protect their groups against invaders. Although there was no surplus (save "normal" surplus: that obtained beyond needs owing to good harvests), production was adequate to meet the needs of a varied population living in diverse physical environments.

The changing socioeconomic and demographic conditions in Africa over the last few decades call for new production and management techniques. But the close interdependence between land-use management and the social structure makes promotion of any new technology difficult because it implies alteration of deep-rooted customs.

Factors of Change in the 1970s

The 1970s marked a turning point in Africa. The change was sudden and in all domains: population growth, development policies, urbanization, means of communication and information. The environment was subjected to severe pressure, which was aggravated by the serious droughts in the early 1970s. The continent, and particularly its semiarid zones, plunged into a crisis which had never occurred before in its long history (Watts, 1989).

The population of the seven Sudano-Sahelian countries appears to have stagnated over the centuries, with 9 million people reported in 1900. Then it surged to 30 million in 1980 and will probably reach 50 million in the early part of the twentyfirst century (Figure 2). Rapid urbanization is a striking phenomenon of this population growth. Around 1920 only one percent of the population lived in cities, today more than one-third of the inhabitants lives in the cities. In the southern portions of the Sudano-Sahel, the

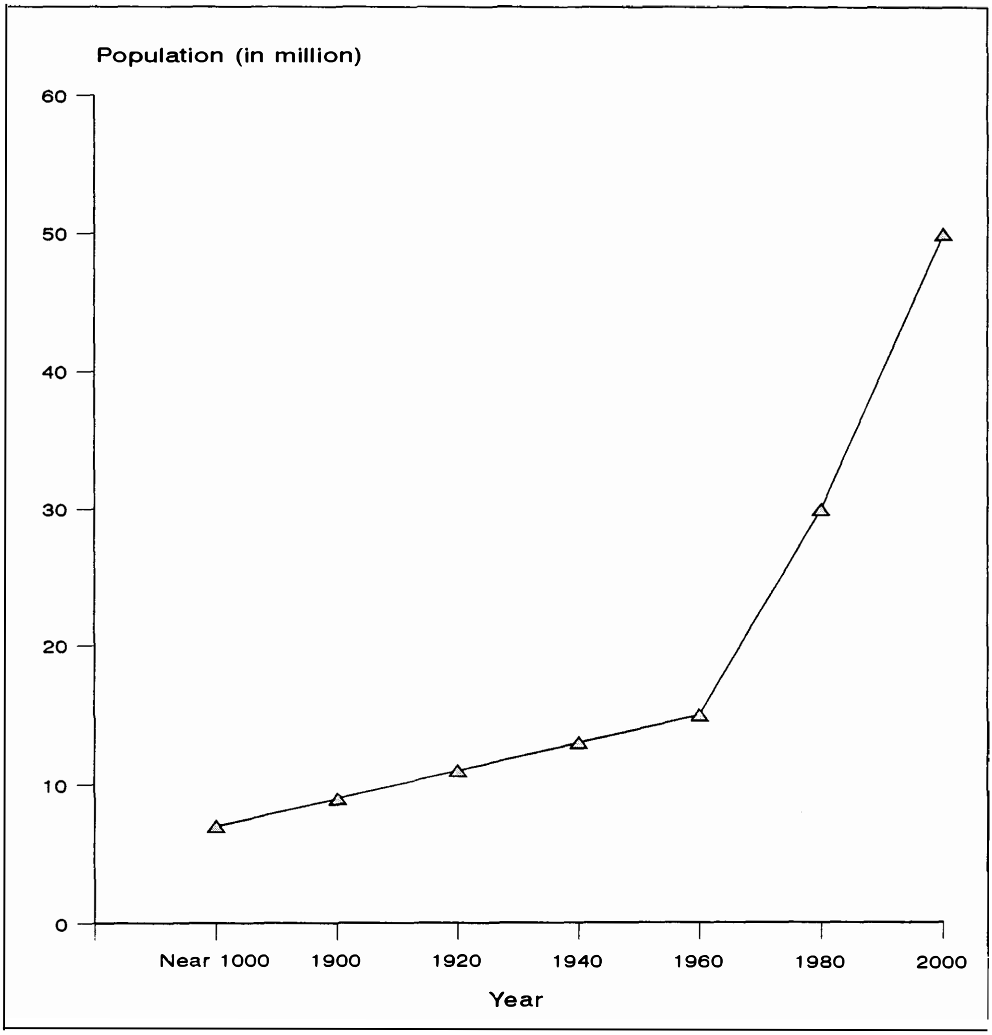


Figure 2. Increase in population in seven Sub-Saharan Countries: Burkina Faso, Gambia, Niger, Mali, Mauritania, Senegal, Chad.
(Source: Estimates for year A.D. 1000 From Braudel (1949), and for 2000 from World Bank (1989).

concentration in urban centers is even higher: 44% in Côte d'Ivoire and 46% in Cameroon (World Bank, 1989). Despite urban growth and rural migration, rural population density is increasing steadily because of high population growth. As population grows, more land is cleared and the cropped area encroaches onto forests and rangeland. The fallows are shortened and sometimes disappear completely. Fallowing in the traditional system allowed gradual regeneration of soil fertility. Land degradation has set in because of water erosion and leaching of organic and mineral reserves. This in turn causes physical (structure, porosity) and biological (micro-, meso-, and macrofauna activity) degradation which is even more detrimental. In the sub-Saharan savanna, the transformation from shifting to continuous cultivation without suitable modification of land management practices, has halved their productivity within 30 years (Pieri, 1992).

The repercussions on deforestation and the exhaustion of firewood are clearly seen from the changes in the Côte d'Ivoire forests (Figure 3). In 80 years the forest cover was reduced to one-third its original area. Deforestation has been more intense in the past 20 years and corresponds to the abrupt change in the 1970s. In the Sudano-Sahelian countries, wood is the major source of energy. Annual average per capita consumption in Burkina Faso is 20 kg oil equivalent compared with 8230 kg oil equivalent in the United States (Giri, 1983). This may be comparatively very low, but it still exceeds the regeneration capacity of the savanna woodlands that are being destroyed by overexploitation (0.5-1.0 m^3/ha/yr) (Clément, 1982).

Although there has been little change in land management at village level, the cultural techniques have been being gradually modified. Draft cultivation was introduced in Mali (former Sudan) in 1929; fertilizers were first used on groundnut in 1949 in Senegal; selected seeds were distributed for the first time in 1945. These changes were mainly prompted by the development of cash crops, starting with groundnut. It was followed by cotton whose area in West Africa has increased eightfold from 100 000 ha in 1955 to 800 000 ha in 1980. Input consumption for cotton followed the same curve. The impact of the development of cash crops was noticeable at several levels. It accelerated the saturation of arable lands. Contrary to conventional belief, these crops did not replace food crops but were added to the existing food crop systems (Pieri, 1992).

The extension of cropped area, monetarization of agriculture, integration -although limited- of cattle for draft power, have completely transformed the relationship between farmers and their physical and social environment. Villages are broken up into hamlets and sometimes into farms. Concurrently, the extended family is divided into mononuclear families. Community tasks are now ensured by temporary paid laborers.

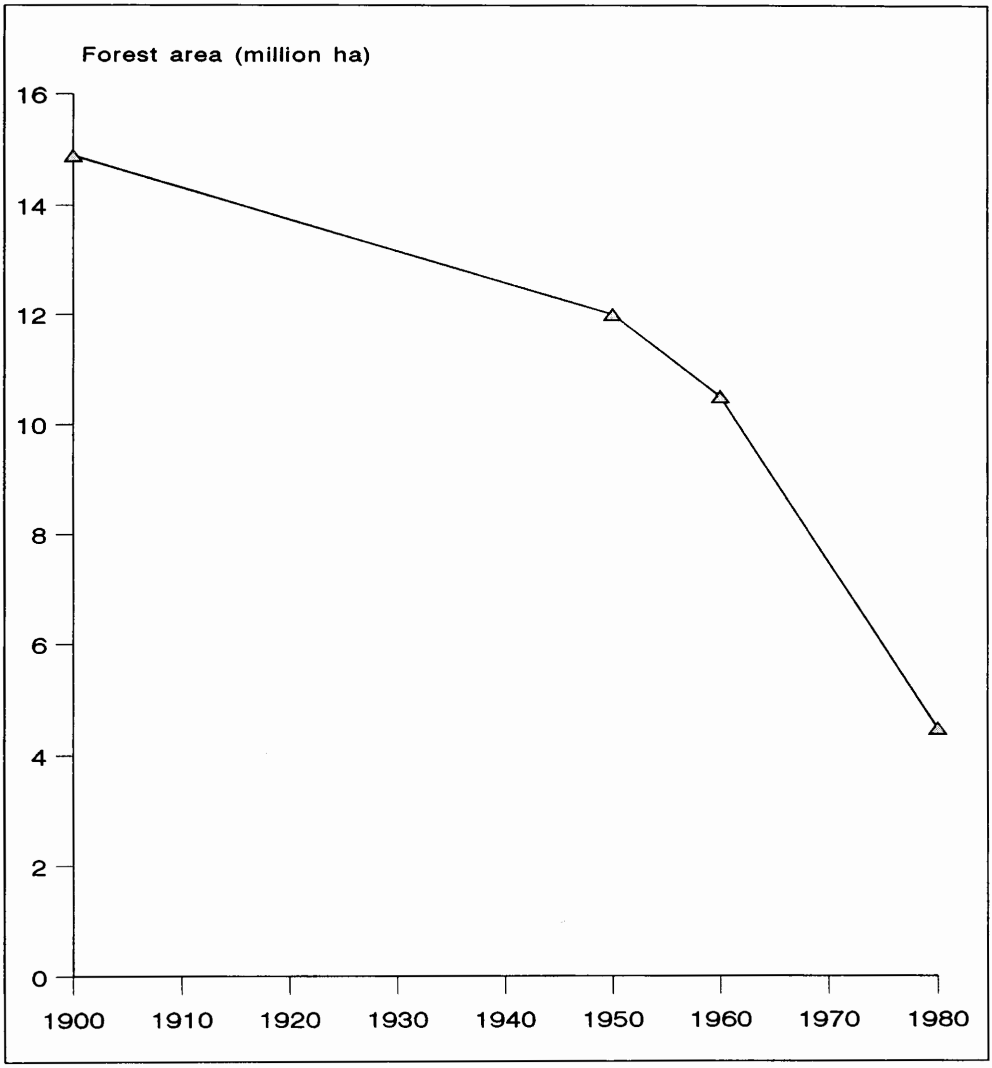


Figure 3. Deforestation rate in Côte d'Ivoire (1900-1980)
(Source: Blanc-Pamard 1987).

The traditional rules of communal control over natural resources are weakening. Crop and livestock production are combined on certain farms as the ancestral contracts that governed interaction between farmers and transhumant herders are no longer valid. New commercial and credit systems are established.

Thus for the past two decades the entire system of production and social governance has been changing. To some, these changes are drawing sub-Saharan Africa towards the same type of disaster that occurred in Europe during the Dark Ages after the fourteenth and fifteenth centuries. Others interpret the change as a challenging opportunity for improving land-use and production systems. Despite these conflicting views, all agree that there is an urgent need to promote new and more productive land-use management methods that are compatible with the physical and social environment. The new systems should be developed from the lessons drawn form the past.

The Future Learns from the Past

Everyone, from government authorities to village assemblies, is aware that the highly integrated land-use systems inherited form the past are now obsolete. They offer a better option, however, than the absence of any control, as evidenced by the disastrous effects of the extractive and degrading practices of shifting cultivation techniques without proper fallowing. The recent "years of development" have proved that attempts to redress the situation through an exclusively technological or economic approach is not likely to set sub-Saharan agriculture on the path toward sustainable growth.

One of the artisans of the "green revolution" stressed that planned targets can only be attained through the simultaneous development of technology, services, and an agricultural policy that complement and strengthen each other (Swaminathan, 1986). And yet it took India a long time to arrive at a satisfactory synthesis of the three components. Similarly, Africa with its diversity and variability cannot ignore this integrated approach.

Such an approach would also help to overcome conflicting situations. Food shortages are usually more critical in urban centers than in villages. To overcome this deficit, farmers need to increase food crop production beyond subsistence needs through improved land management. For this they need incentives (fair prices, better storage, handling and credit facilities, and equitable land tenure systems) although they may not necessarily be acceptable to urban populations. But a sound, far-sighted policy would seek to reconcile the conflicting interests of urban and rural populations. Recent research by the World Bank on land tenure in Africa indicates that a strengthening of traditional customary rights rather than land titling as recommended in Asia would ensure secure tenure in Africa (Garbus *et al.*, 1991), although comparative studies do not necessarily demonstrate a correlation between tenure systems and the intensification of agriculture in Africa (Turner *et al.*, 1992).

Current debate tends to correlate population density with environment degradation (Boserup, 1990). The critical density threshold estimated for the African savanna is 50-100 inhabitants/km^2. However, "population can also be the resource that creatively finds solutions to problems including the environmental one" (Parikh, 1991: 6). Policies should be rational and adjusted to the basic social organization in rural areas.

This grassroots approach becomes more relevant with the current trend of state disengagement in agricultural activities. Responsibility would thus be transferred from the state to these organizations (subsidiarity principle). International and national organizations should be committed to the creation and strengthening of such organizations to promote a modern, market-oriented approach. The subsidiarity principle would lead to a national policy for local development (Mercoiret, 1992). Accordingly, village communities would be given more responsibility in land tenure planning, land development, transport network, and market establishment. This will ensure farmer participation in a sustainable development of farm lands.

It is clear that the traditional social structure and decision-making process are key factors to be considered while developing technology for sustainable increase in land productivity (Mortimore, 1989). In the African semiarid tropics, the success of an improved land-use system depends heavily on restoration of the physical, biological, and chemical properties of degraded soils. The cost of such investments may be high but it is well below that in irrigated systems. The restoration phase should be carefully planned step by step bearing in mind the aspirations and requirements of the community. Valuable experience and knowledge on soil and crop management, including agroforestry and soil erosion (Lal, 1987; Pieri, 1992; Young, 1989) are already available to make incremental improvements in soil productivity feasible.

The resource base restoration stage should be followed by the sustainable development stage. Conservation tillage systems are the mainstay of the approach (Lal, 1989). They are based on an understanding of the factors and processes that ensure sustainability in native ecosystems. These systems are targeted to make the best use of the biotic soil potential demonstrated by the soil microorganisms and the meso- and macrofauna activities (Swift, 1985). Manipulation of the biological soil processes, particularly those concerned with organic decomposition and nutrient mineralization, is achieved by means of plant cover, crop rotation, input regulation and minimum or no tillage. In higher rainfall areas, conservation tillage systems combine no-tillage and direct planting on permanent live or dead mulch (Séguy *et al.*, 1992). Conservation tillage systems maintain high productivity despite lower commercial input use. They reduce pollution and erosion through protection of the topsoil and the use of deep-rooted plants for better absorption of nutrients; they also prevent runoff and nutrient leaching.

Conclusion

Semiarid sub-Saharan Africa is the forgotten region of the world. It has traversed the millennia by adapting its production and social organization to a difficult environment for cultivation. Its primary concern has been survival in the face of insecurity. Slavery and tribal war have added to the burden of farmers confronted with an unpredictable climate and fragile, although abundant, lands.

Rural Africa in this Sudano-Sahel is changing, and these changes have mainly come about during the past two decades. The immediate driving forces are population growth, reduction in land availability, and depletion of firewood resources, although these are connected to large political economic changes threading from the region to the national and international level (Watts, 1983). The immediate problems to be redressed are of very recent origin, although the underlying forces leading to them built through time as the structure of African society has been increasingly disrupted at least since colonial times. The Columbian encounter, therefore, apparently did not lead to major land-use and land-cover changes in the semiarid zones of Africa, pending more complete information on the impacts of slaving. Land-use changes of major consequence are much more recent, twentieth century, phenomena in which Amerindian cultigens have played a role.

Traditional land management by the village communities and lineages forms a coherent whole that covers both agricultural and socioeconomic aspects. Any adaptation or modification must necessarily be considered in a historical, sociological, institutional, and political perspective. A recent World Bank study also highlighted the psychological motives of economic decisions in Africa. In this study, Mamadou Dia (1991: 83), compared the vitality of the "informal" sector with the modernized/westernized sector: "The success of most of the microenterprises is best explained by their ability to reconcile African social and cultural values and traditions with the need for economic efficiency." Farmers prefer to invest in more profitable activities than agriculture and restoration of the resource base. But an agriculture that offers higher income and social status would incite farmers toward a "heritagization" of the resource base.

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CHAPTER 13

LANDSCAPE CHANGES IN THE LAST 500 YEARS IN THE GUADALQUIVIR RIVER VALLEY, SPAIN, WITH SPECIAL REFERENCE TO DOÑANA NATIONAL PARK

R. Fernández Alés, A. Martín, and J. Merino

Introduction

The Columbian encounter triggered deep changes in land uses both in the Americas and in Europe. Many of these changes were responses to transatlantic trade and the rise of industrial-capitalist agriculture that was supported, in part, by the wealth drawn to Europe from the Americas (Turner, this volume). The synergism between the encounter and the emergent economy and technologies of Europe are typically associated with land-use and land-cover impacts on the Americas. These impacts were significant in Europe as well through the direct impacts of Amerindian plant domesticates, but perhaps more importantly through indirect impacts such as changes in population and local economies. The land-cover consequences for Europe have been profound, and understanding them in terms of local ecologies provides significant clues about contemporary global change.

Here we examine some of these land-cover changes as they affected the Guadalquivir River valley and its major production zones, including Seville, as well as its more sparsely utilized reaches, such as the Doñana area along the Atlantic coast. We shall see that the indirect impacts of the Columbian encounter held significant land-cover and vegetational consequences even for the marginally used zones, consequences which may very well be irreparable ecologically.

Background

Seville, located in the Guadalquivir River valley, was the central harbor for the early transatlantic exchanges with the Americas, from 1492 to the end of the seventeenth century, when the monopoly of the Spanish-American trade passed to Cádiz, a neighbour city. During this two hundred year period, agricultural goods from the Seville region were exported to the Americas in great quantities (García Baquero, 1972). Even after Spain lost its American colonies, the region maintained its role as an important commercial center of agricultural products (oil) with exportation to other parts of the country and to Europe (Bernal and García Baquero, 1976). The region remains today as pivotal to agricultural production in Spain, devoting most of its products to industry (e.g. oil, cotton, tobacco, sugar beet) and exportation (e.g. olives, wine, oil, oranges, and early season vegetables) (De Terán and Solé Sabarís, 1978).

Seville's position in the Guadalquivir River valley of southwestern Spain is close to the Atlantic Ocean (Figure 1). The climate is mediterranean however, with relatively high mean annual rainfall of 500-1000 mm and a virtually rain-free period from mid-May to mid-September.

Patterns of land use at regional scale are associated with patterns in soil fertility. The northern and southern mountain ranges of the Sierra Morena and Sierra Sur, with low altitudes of 300-1200 m, have steep relief and poor soils. Forests, shrublands, and grasslands are the dominant vegetation types. The area is used for extensive livestock raising (sheep, cattle, pigs) with stocking rates of less than one sheep equivalent per hectare. Both mountain ranges are rich in wildlife and are also used for hunting.

The valley bottom (0-300 m) contains fine sediments and shows a smoothly undulating relief with very fertile soils. Most of the area is under cultivation (olive trees, cereals, and sunflowers). The river floodplain is irrigated, and is cultivated with oranges, peaches, cotton, among others. The northern part of the river marshes have been put under cultivation with rice in the last 40 years. The southern part of the marshes, which are too saline for crops, and the infertile sandy sediments of the ancient dunes are the only lands not used for agriculture. They are covered with forests, grasslands, and shrublands, and used for cattle raising and conservation. Both salt marshes and sand dunes comprise the Doñana National Park, an important area for waterfowl and one of the last refuges for endangered species as the Mediterranean lynx (*Lynx pardina*) and the imperial eagle (*Aquila heliaca*).

Settlement is markedly nucleated, wit the vast majority of the population living in large villages and towns. Population density is low in the unfertile areas, such as the

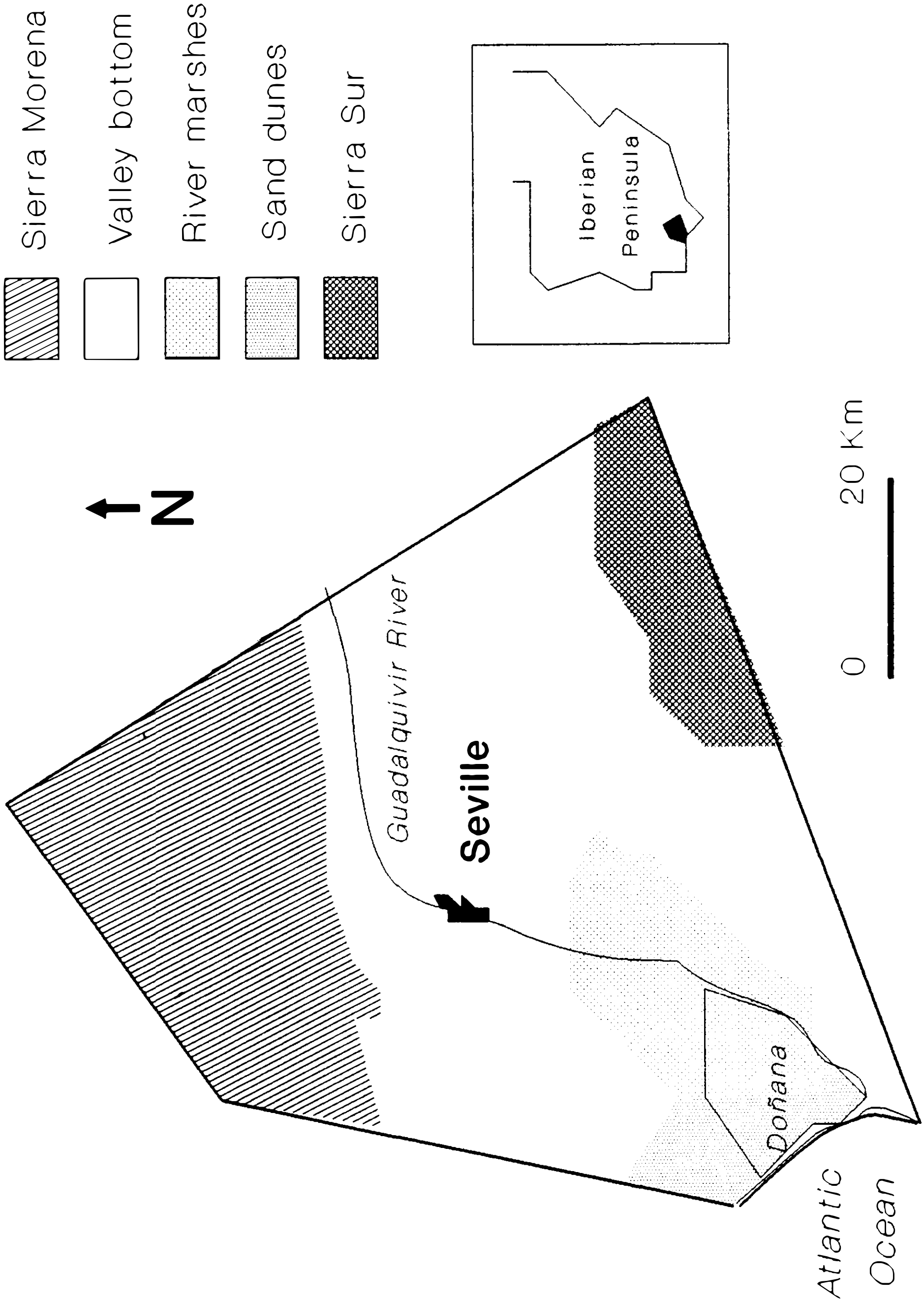


Figure 1. The Guadalquivir Valley Region.

northern mountain ranges (10.8 persons/km^2) and the marshes and sandy sediments of the valley bottom (15 persons/km^2). It is high in the most fertile area of the valley bottom with 83.2 persons/km^2. Half of the population of the region lives in the city of Seville (700 000 inhabitants, 4600 persons/km^2), an important commercial center since Roman times.

Changes in Landscape Structure in the Last 500 Years

In 1750 -the first date for which quantitative information on land uses in the area are available- a significant amount of land was under cultivation, especially in the valley bottom (Table 1). This was the result of the expansion of agriculture in the area from the sixteenth through seventeenth centuries (Bernal, 1981).

As in other Old World countries, capitalist modes of agricultural production spread in the seventeenth century, emphasizing trade in oil and wool. Also an important amount of all agricultural production was exported. During this time, many forests and grasslands used communally passed to private hands.

During most part of the 1700s, the cultivated area changed very little (Bernal, 1981). From the end of this century onwards, changes followed a monotonic tendency towards a progressive specialization of agricultural production within the region, as reflected by an extension and intensification of cultivated areas on the most fertile soils and the abandonment of the least fertile ones (Table 1). The speed of the process is related with economic and social changes.

These changes were particularly important at the beginning of the industrial revolution (1750-1853), when the middle classes bought almost all the available land that had previously been communal property (Bernal and Drain, 1975). The cultivated area increased in the valley bottom, and grasslands, shrublands and forests were converted into olive groves. In contrast, the cultivated area decreased in the northern mountain ranges, as shifting cultivation diminished, increasing the abandoned areas (shrublands).

During the next 100 years (1853-1956), uncultivated land remained as before, and changes occurred only in the cultivated area, where irrigated land and olive groves increased at the expense of non-irrigated herbaceous crops (Table 1). Important changes awaited economic development following the Second World War (1956-1980), when traditional methods of agriculture were replaced by modern technology (Fernández Alés *et al.*, 1992). Cropland increased in the valley bottom up to 95% of its total area, of which more than 15% were irrigated at the end of the period. Currently, oil production still remains very important, but olives have been replaced by the more productive sunflowers.These changes contrast with the "extensification" of land use in the northern ranges; if anything, shifting cultivation has almost disappeared there.

All the changes in land use described above have had a strong effect on landscape structure. As irrigated and non-irrigated herbaceous crops have become dominant in the valley bottom (Table 1), other land use units (olive groves, non-cultivated land) have become fragmented in many small patches. Thus, in 1956, 75% of the area occupied by olive groves and 40% of non-cultivated land appeared in eight patches of more than 1000 ha (Figure 2), while in 1977 these large patches had almost disappeared and the area occupied by small patches (under 100 ha) had become dominant. The total number of

Table 1. Land uses (%) at different dates in two contrasting and representative areas of the Guadalquivir Valley: The valley bottom comprises 150000 ha, and the Sierra Morena 140000 ha (see Figure 1).

	Date			
	1750	1853	1956	1980
VALLEY BOTTOM				
Cultivated land	75.4	82.7	83.9	94.1
Irrigated	0.3	0.3	6.6	16.3
Herbaceous crops	61.8	53.3	43.3	67.1
Olive trees	13.3	29.0	34.0	10.7
Non-cultivated land (forests, grasslands, shrublands)	24.6	17.3	16.1	5.9
Total	100	100	100	100
SIERRA MORENA				
Cultivated land	42.0	31.0	--	19.2
Continuous	1.0	1.5	1.0	1.8
Shifting	35.0	25.0	--	5.0
Olive trees	6.0	4.5	4.7	4.9
Pine and Eucalyptus	2.0	1.0	1.0	7.5
Non-cultivated land	58.0	69.0	--	80.8
Total	100	100		100

patches of non-cultivated land even diminished between these dates (Figure 2). As a consequence, the connections between the more conserved areas that surround the valley bottom (northern, southern and coastal ranges) across the non-cultivated land have diminished.

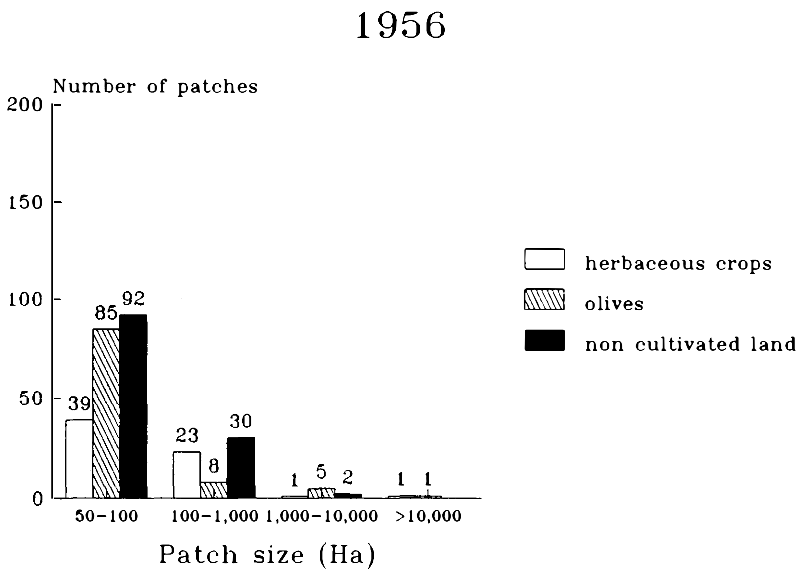
Changes in land uses have not only changed landscape structure; they have also changed the natural elements of vegetation. The trend of change is well documented for the area of Doñana National Park, near the mouth of the Guadalquivir (Figure 1), which has undergone the same trends in land use that have the rest of the rangelands of the region (Merino *et al.*, 1990).

Before the seventeenth century, use of the Doñana area for domesticates was virtually non-existent. Hunting was prevalent, as were fishing in the lagoons, gathering eggs and leeches, cork and tannin extraction from the oak, and small-scale charcoal production. By 1628, however, livestock replaced these activities. Cows, sheep, goats and pigs were introduced in large numbers. Controlled fires were used to improve the productivity and palatability of the vegetation for livestock. Settlements for shepherds appeared, with the inevitable increase in roads and wood gathering for cooking and building. The historical records also show that charcoal burning increased considerably, and there was also distillation of essential oils from *Juniperus oxicedrus*. These activities waned in the later 1700s, and the area was progressively abandoned. The numbers of livestock were reduced, some grasslands and croplands were maintained to breed game animals, and some areas were devoted to timber production (*Pinus pinea*). In 1969, Doñana was declared a National Park, and human intervention was prohibited throughout the area.

Vegetation Changes in the Doñana Area

The area includes a large coastal sand plain, where two main units can be distinguished: mobile dunes and stable sands (Allier *et al.*, 1974). The topography consists of ridges separated by depressions. Because of the existence of a shallow water table and high substratum permeability, the tops of the ridges are arid, while the depressions are mesic. Vegetation on the mobile dunes is extremely scarce, with *Ammophila arenaria* (marram grass) as the dominant species.

On the stabilized dunes, shrubs are the predominant vegetation type. Species composition appears to be controlled by topography through the depth of the water table, changing from an open semidesert shrubland on the ridges, with mainly *Cistaceae* and *Labietae* as dominants, and some scattered individuals of *Juniperus oophora* trees, to



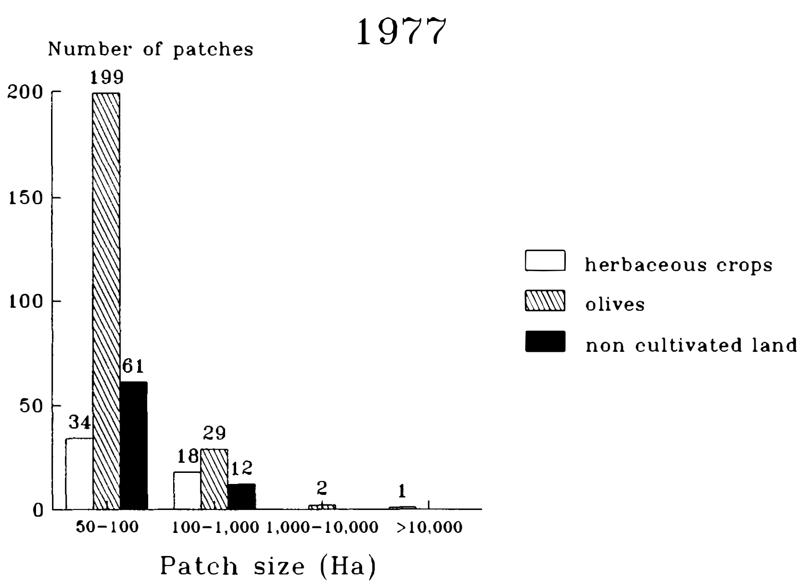


Figure 2. Number and size of patches of herbaceous crops, olive groves, and non cultivated land in 1956 and 1977 in a representative area of the valley bottom (from Fernández Alés et al., 1991).

more mesic shrubs in the depressions dominated by *Erica scoparia* and scattered individuals of *Quercus suber* (cork oak). The more mesic shrubs are scarcely represented while the open semidesert shrubland covers the main part of the area (Merino *et al.*, 1990).

Characteristics of the Species

Species distribution along the depth gradient of the water table is related to the physiological characteristics of the species, which strongly differ between the open and the mesic plant communities. Thus, *Cistus libanotis* (a shrub) and *Juniperus oophora* (a tree), both typical species of the dry habitats, undergo high water stress during the summer, since they experience plasmolysis throughout the whole day during that time of the year (Figure 3). This means that they are not able to extract any water from the soil during the summer months. In contrast, *Erica scoparia* (a shrub) and *Quercus suber* (a tree), both typical species of the mesic habitat, are turgent throughout the year (the plasmolysis lines never cross the water potential curves), so they never undergo any significant water stress, even during the summer. These results suggest that the species of the open communities appear to be designed to withstand strong water stress, and are quite insensitive to changes in water availability. The species from more mesic habitats, however, appear to be designed to keep an adequate water status by keeping their capacity of water extraction throughout the year, but low water accessibility probably overwhelms this control capacity (Merino *et al.*, 1993).

The sensitivity of typical species from dry and mesic habitats to unusually strong changes in soil water accessibility is in accordance with those physiological characteristics. Thus, annual litter production (an indicator of the species production) of the typical species from dry habitats is not very sensitive to strong decreases in water accessibility. On the contrary, during a particularly dry year, the litter production of *Erica scoparia*, the most representative species of the mesic habitats, decreased by 50% . The results of some experiments show that under controlled growth conditions (pots) mortality is much higher in species from mesic habitats with the lack of watering during relativelyshort periods. Field observations also show that under natural conditions, the mortality in *Erica ciliaris* (a typical species of mesic habitats) after a period of intense drought was quite high, while no appreciable variations in species mortality were detected in the species of dry habitats (Merino and Merino, 1988).

In summary, these results suggest that the decrease in water accessibility does affect the species typical for mesic habitats very strongly, while those from more arid ones are

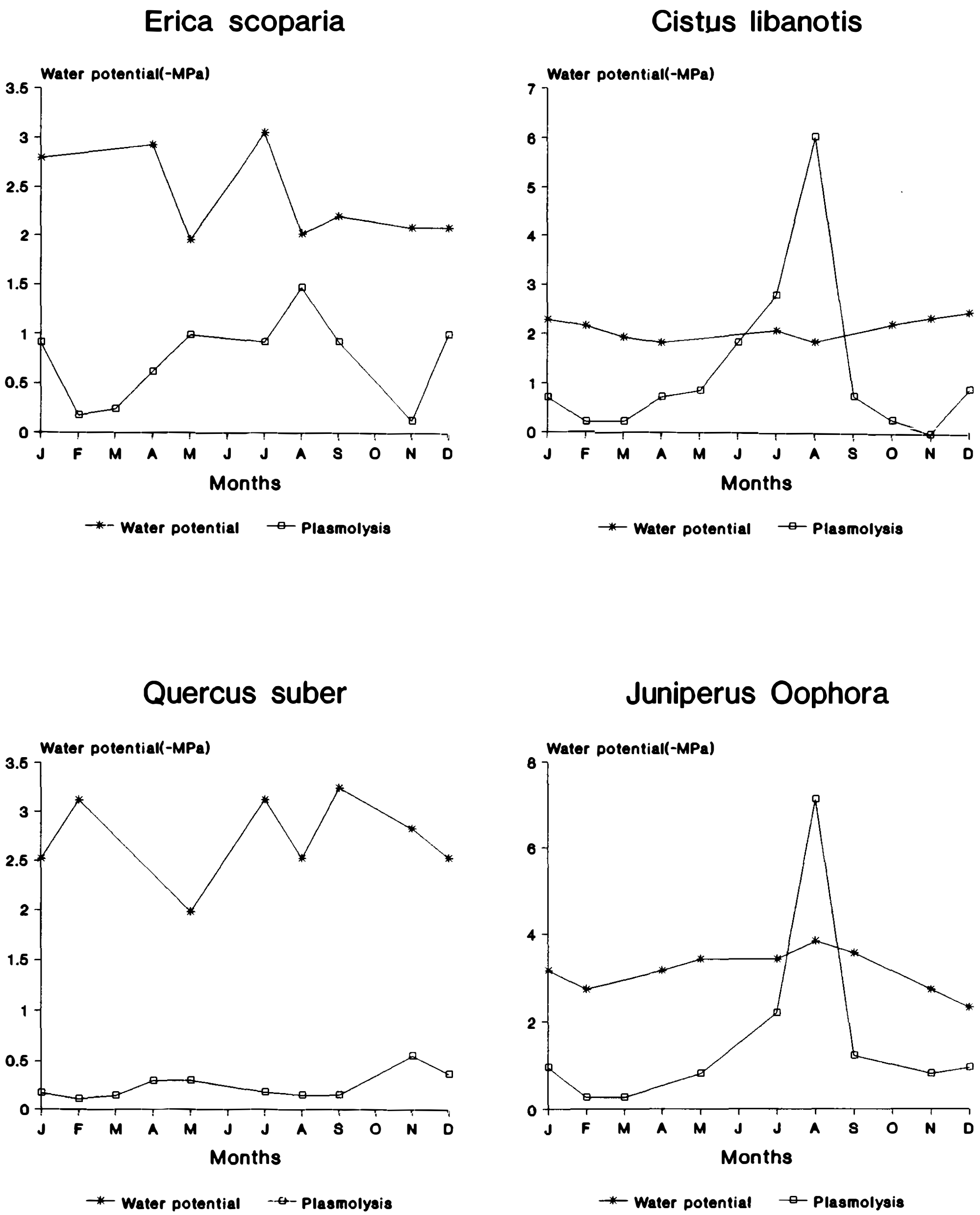


Figure 3. Annual evolution of midday plant water potential at dawn and turgor loss point (in Mega Pascals) in two typical species of xeric (dry) habitats (*C. libanotis and J. oophora*), and two typical species of mesic (moderately moist) habitats (*E. scoparia and Q. suber*) (from Merino *et al.*, 1993).

quite insensitive to them.

Vegetation Changes

The changes in land uses described above have had very important effects on the local ecosystems. Fifty years after the start of intensive exploitation of the area, remarkable changes took place. From 1700 onwards, most of the lagoons of the region disappeared, along with the major part of the riparian forest (poplars, willows, tamarix). Some conspicuous animal species became extinct (e.g. the swan), and some plant species underwent a strong decrease in numbers (e.g. cork oak). In addition, all the attempts of reforestation with previously common species of economic interest (e.g. olive trees, cork oaks) failed. At the time, this failure was attributed to changes in the structure of the soil, which had become unstable and dry, unable to provide the trees with the substratum for root development and plant growth (Granados *et al.*, 1987).

The exploration of the historical records also shows that from 1636 to 1859 the open semidesert community increased in extent, while the area of the more mesic one underwent a significant decrease (Figure 4). Species number also decreased, particularly those that could be typified as "K" strategist (Granados *et al.*, 1988).

In recent times, Gavala (1952) has pointed out a process of secondary dune formation in the region, and the associated spread of a sand layer far away from the dune system by the dominant winds. Granados and colleagues (1988) have dated the beginning of these processes to around the beginning of the eighteenth century. This geomorphological change could be a consequence of the change in land use; grazing, charcoal burning, and cropping destroyed the vegetation cover, suppressing its protective action on the soil and starting the "dunification" process. The development and advancement of the sand dunes and the spreading of a sand layer far away from the dune system, could satisfactorily explain both the disappearance of the small lagoons and the lowering of the water table (and, as a consequence, the decrease in water availability), the difficulties of reinstallation of some species, and the decrease in both the extent of the mesic communities and their species diversity, particularly of those species less resistant to water stress (Merino *et al.*,1990).

Surprisingly, although human pressure on the Doñana area decreased from the 1800s onwards, the ecosystem has not returned to its original state. The landscape is dominated by the open and more arid community, and the more K strategist species of mesic communities remain scarce (Alés, 1987). The apparently irreversible character of this landscape change is due to the permanence of the sprayed sand layer (which is now

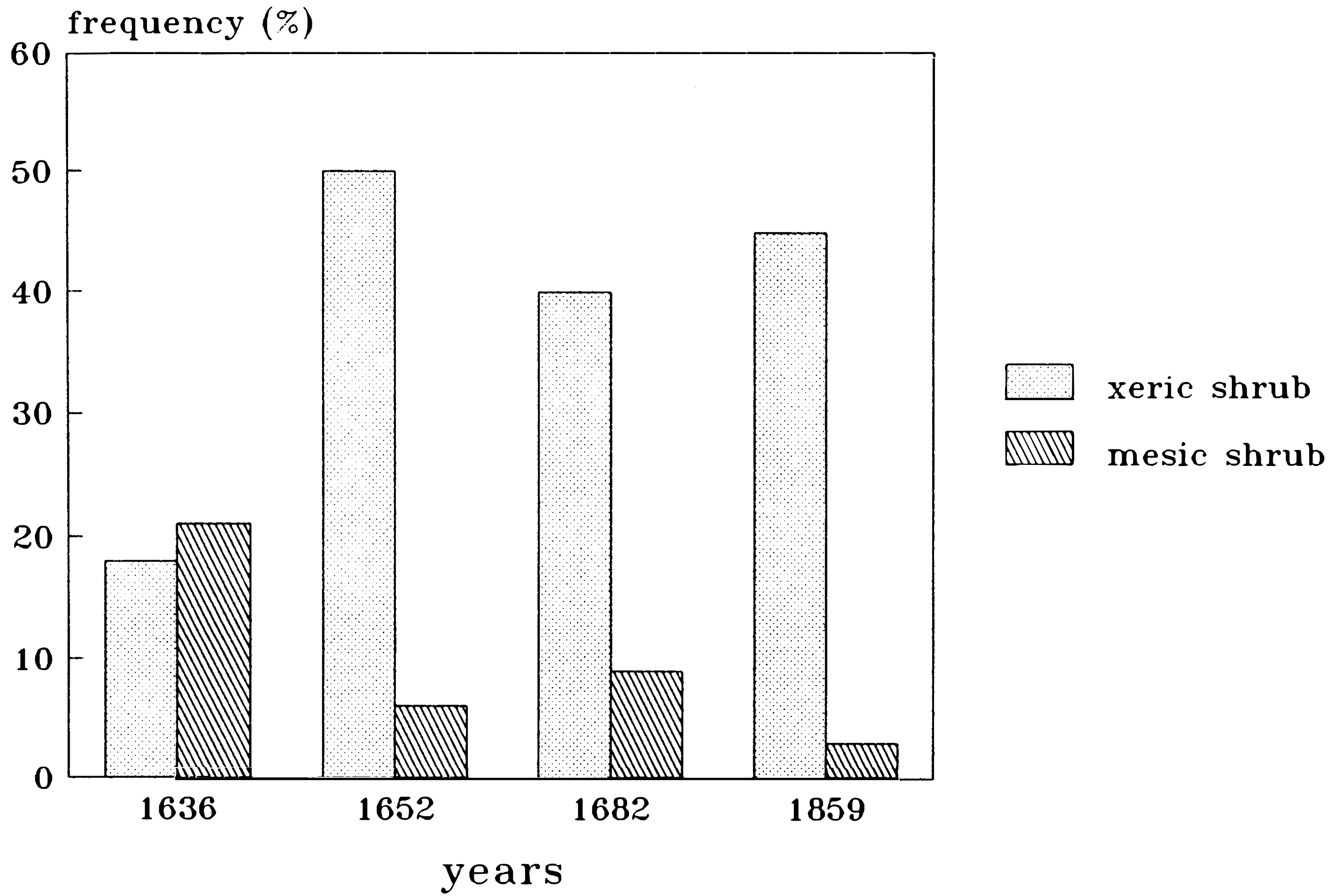


Figure 4. Changes in the relative abundance of xeric (dry) and mesic (moderately moist) communities through the last four centuries (from Granados et al., 1988, modifed).

very stable) and to the lower water availability.

It should be noted, however, that the disappearance of many small ponds from 1956 to 1984 (Fernández Alés *et al.*, 1992), generated new mesic areas, and that these new mesic areas have not been colonized by species that were formerly abundant there (e.g. *Quercus suber*). This lack of ability to colonize new habitats can be related to the dispersion efficiency of the species.

Herrera (1984) classified the Mediterranean woody species into two main groups according to their intrinsic dispersal capacity. The first group (Type I or "r" type plants) mainly comprises common species of the first states of the succession (typically from the *Cistaceae* and *Labietae* families). They produce very small seeds, which are not easily blown by the wind or transported by efficient dispersion vectors. Because of this, they have a low intrinsic capacity for migrating and colonizing new areas. The second dispersion group (Type II or "K" type plants) comprises species producing berry-type or similar fruits, which have a rather high reward for the dispersers (e.g. olive and pistachio trees), and, therefore, they have an high intrinsic capacity for colonizing new areas.

There is some evidence, that in the Doñana area the real dispersion capacity of the species is very low. *Juniperus oophora* (a Type II species), the only tree-like species growing in the dry habitats of the stabilized sand dunes of the Doñana area, produces berry-like fruits which are basically dispersed by foxes (*Vulpes vulpes*) and a bird (*Sturnus unicolor*). Until 40 years ago, this tree was harvested for building and fencing, so that today, mature forests can be found forming only in very localized patches. The young (shrub-like individuals) populations of *J. oophora* are found only on the border of the mature patches, showing that the dispersion of this species has been quite efficient there during recent years. They are absent, however, in areas identical to those under actual colonization but 3 or 4 km distant from the forest patches, even 100 years after the last harvest.

This poor capacity of *Juniperus oophora* to colonize distant areas seems to be due to the fact that during the ripening of its fruit (summer-autumn), the activity of foxes is strongly associated with the forest patches of that species (Rau Acuña, 1989). A similar effect seems to take place with *Sturnus unicolor*, which uses the individuals of *J. oophora* as a perch, as well as a food source. The activities of these two animal species remain restricted to the actual patches of *J. oophora* trees. As a result, the dispersion ability of this species is practically nil beyond the immediate area around the patches, and the forest regeneration of *J. oophora* is very slow, as it only takes place in the limits of its patches (Merino *et al.*, 1993).

These observations are appropriate for other species (see for example Ezcurra *et al.*,

1991) and ecosystems (Hall *et al.*,1991), and suggest that the real dispersion capacity of Type I species, but particularly those of Type II, may be very low and even lower than that normally accepted (Dobson *et al.*, 1989).

In summary, the least exploited areas of the region, such as the Doñana Park, have been deeply altered by human intervention. These changes have been in some cases deep and irreversible, like the spread of a sand layer that modified the water availability and the structure and the diversity of natural vegetation. The return to former states, even where possible, will probably be very slow, due to the low dispersion capacity of species.

Future Changes in the Guadalquivir River Valley

Changes in land use associated with the increase of trade, originally triggered by the Columbian encounter, have altered the landscape structure and function of the Guadalquivir river valley in the past and will probably contribute to its response to new changes in the future.

There are two potential important changes in the near future that could produce further significant changes in the landscape of the region. The first one is related to the agricultural policies of the European Community and GATT (General Agreement on Taxes and Trade), which will lead to the abandonment of agricultural land, not only in the infertile areas, but also in some of the fertile ones at the bottom of the valley. This response will follow from the economic disadvantages of the area with its potential competitors elsewhere since agriculture in the valley at present is highly subsidized. Models considering these changes predict the regeneration of the abandoned areas towards the most mature stages of succession.

The second change is related to the expected potential global climate change, which in Mediterranean areas will probably be associated with both a rapid increase in and a decrease in annual rainfall average temperature of around 1 to 4 °C of around 40 mm for the next hundred years (Schneider, 1989). This means a significant decrease in water availability for the region. In this case, models predict species migrations to new areas having climatic conditions in equilibrium with their physiological characteristics (Birks, 1990).

In any case, the ability of natural ecosystems to compensate for these disturbances will depend on the ability of species to migrate to new habitats. As demonstrated by the strong relationships between *Juniperus oophora* and its dispersion vectors, the dispersal capacity of a particular species, however, depends in many cases upon the degree of integrity of the ecosystem, which appears to be quite diminished. Besides, because of the considerable simplification and fragmentation of the actual landscape, present-day conditions differ greatly from those which probably existed in the first half of the Holocene, when the diversity and continuity of the landscape (habitats and communities) probably allowed the easy migration of species (Birks, 1990).

It follows, therefore, that in abandoned lands, or in large areas that undergo a climate change, local communities will remain with low diversity, since there will not be a substitution of the local (impoverished) communities by others coming from the surroundings. In the case of a global climatic change, the substitution of the local species by others coming from elsewhere will be rather improbable. Global climate change will trigger a complex process which will probably include not only the decrease in mesic habitats, but also the decrease in species diversity, (particularly that of the "K" type species) both in mesic and dry habitats. The kinds of impacts associated with human activity in the region may well be exacerbated by climate change.

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CHAPTER 14

DEMOGRAPHIC AND RESOURCE CHANGES IN THE BASIN OF MEXICO

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Natural Resources, Growth and Collapse of Human Societies

The urban and demographic growth of the Basin of Mexico is one of the main national worries, not only because of the possible consequences of the immense social concentration and the asymmetric relationship it bears with the rest of the nation, but also because of the ominous ecological consequences the clustering of 17 to 19 million people seems to foreshadow. For many, this large human concentration cannot mean but the prelude of a great ecological catastrophe that will lead in the future to the compulsory decentralization of the Basin. For others, the urban connection around Mexico city is the logical result of industrial development and of the technological progress of the twentieth century, and does not represent a problem in itself. According to this second line of thought, technological development will provide the means to defeat the environmental problems posed by the unbridled urban growth.

The purpose of this paper is to examine some of these questions in an historic perspective. To discuss an environmental crisis means to analyze problems of natural resource depletion and natural resource degradation on levels where the well-being and survival of large sectors of the population are at risk. In a modern industrial city, an environmental crisis implies problems in the supply and the quality of resources such as air, water and soil. An ecological crisis in the Basin of Mexico will almost necessarily be generated by the exhaustion of the water supply, the degradation of the air quality to highly unhealthful limits, the silting of the drainage system and the flooding of the city as a result of deforestation, or some other similar problem.

The main thesis of this paper is that natural resource depletion in the Basin of Mexico has been an important problem in the historic past, and has driven the inhabitants to processes of massive emigration and cultural extinction. In arguing in favor of this thesis, I shall define four historic periods in which the inappropriate management of natural resources in the Basin induced the demographic and cultural disintegration of the societies inhabiting the region. In this analysis I shall basically follow the ideas of Whitmore and Turner (1986, also Whitmore *et al.*, 1991) on the occurrence of demographic cycles of population and collapse in the Basin of Mexico, coupled with my own studies on environmental change in the area (Ezcurra, 1990a/b, 1992). I shall discuss in this paper how each one of these cycles occurred in relation to natural resource depletion. Finally, I shall analyze the present situation of the Basin, and its future perspectives.

Extinctions and the Transition to Agriculture

Compared with the long human occupancy of the Old World, man arrived on the American continent in relatively recent times. During the Wisconsin glaciation, towards the end of the Pleistocene period, large masses of ice accumulated in the polar caps and the sea level dropped more than 10 meters. This glacial period started 70 000 BP and ended around 12 000 BP. The drop in sea level allowed human groups to cross the Behring Strait into the New World. The date of the arrival of the first humans on the American continent is still a matter of disagreement (Marcus and Berger, 1984; Martin, 1984; Lorenzo, 1981). From the available information, however, we can certainly deduce that humans arrived in the New World towards the end of the Wisconsin glaciation, after tens of thousands of years of cultural and demographic expansion in the Old World.

The expansion of humans in North and Mesoamerica coincided with the retreat of the Wisconsin glaciers and, at the same time, with the extinction of many species of large mammals such as glyptodonths, antelopes, wild horses, capibaras, deer, various camelids, musk oxen, mastodons, gomphoteres and mammoths (Halffter and Reyes-Castillo, 1975; Martin, 1984). The reasons for these massive extinctions are still controversial (see, for example, Diamond, 1984, and Martin, 1984). A recent theory, known as the "overkill hypothesis", argues that the late Pleistocene extinctions were induced by the arrival of humans, a new predatory species organized in small social groups, culturally evolved, capable of using tools and weapons, and, above all, possessing a deadly efficiency in its hunting methods. The overkill hypothesis argues that many large herbivores, unaccustomed to this new predator, succumbed easily to its hunting methods and became extinct.

What is in any case clear, is that humans in the New World did not develop the capacity to domesticate animals in the same way as the populations in the Old World had done (the exception to this is, of course, the domestication of llamas by the Quechua people). The hunting pressure on the populations of large herbivores, together with the climatic changes of the end of the Wisconsin period, drove many species to extinction and forced humans in the New World to survive gathering plants and small animals, including insects. It is interesting that this same incapacity to domesticate animals accelerated the domestication of crop plants. In a few thousand years, a relatively short time in prehistoric time scales, the hunters that arrived in the New World had changed to sedentary farmers.

In the Basin of Mexico, in particular, archaeologic excavations have shown that the proportion of bones in food remains decreased constantly with time. It is estimated that meat formed less that 1% of the diet of the inhabitants of the Basin during the Classical Period and later (Sanders, 1976; Sanders *et al.*, 1979). For comparison, it is interesting to note that in the Formative Period (1500-800 B.C.), although most of the large herbivores had already become extinct, meat from white tailed deer *(Odocoileus virginianus)* still formed an important proportion of the diet of residents of the Basin of Mexico (Serra Puche, 1988; Serra Puche and Valadez Azúa, 1989). The transformation of human groups from nomadic hunters to sedentary farmers was not an easy process. The archaeological evidence suggests that this transition was forced by increasing problems with food supply and with the quality of the game protein. Thus, we can visualize the establishment of the first populations in the Mexican highlands as a long cycle of population expansion that became limited and threatened by the availability of game animals. This, in turn, stimulated the rapid development of agriculture and the initiation of a new cycle of expansion under new rules of production and social organization.

Tectonic Vulnerability

Geologically, the Basin of Mexico lies within the Central Volcanic Axis, a formation of the late Tertiary, 20 to 70 km wide, that runs across Mexico from the Pacific to the Atlantic in a West-East direction (Mosser, 1987). By its proximity and its direct connection with the Pacific Trench, and also as a consequence of the numerous faults that exist along the Volcanic Axis itself, volcanic processes and tectonic instability in general have been outstanding elements in the course of the history of the Basin. Earthquakes have been a constant problem in its development and will continue to be so in the future. When agriculture started to develop in the Basin, the human groups in the area became sedentary and organized themselves in small settlements in the lower parts of the valley (Lorenzo, 1981; Niederberger, 1979). These settlements occupied low plains areas with a good productive potential, but were sufficiently high so as to avoid flooding during the rainy season (Niederberger, 1979). Between 1700 and 1100 B.C. the first large settlements started to develop northeast of the Basin. Towards 100 B.C. the population of the Basin was around 15 000. Three large settlements developed during this period: Texcoco, northeast of the lake of Mexico, Teotihuacan to the north, and Cuicuilco to the southwest.

Cuicuilco developed in a moister region, with more rainfall than the semiarid settlements of the north. It also received water from the rivers that descended from the Ajusco range. Thus, towards the beginning of the Christian era, Cuicuilco was a flourishing culture, as important or more so than Teotihuacan. However, the eruption of the Xitle volcano around 100 AD generated an immense flow of lava that completely buried this large urban and ceremonial center. Worse still, the Xitle lava flow buried under its basalt mantle the best agricultural soils of the region, and wiped out the Cuicuilco culture. This catastrophe marked for the first time the physical limits that the volcanic geology of the Mexican highlands can impose on human development. This is the first event which recorded with certainty that urban development in the area can be restricted by the tectonic nature of the region. The Xitle eruption produced a demographic collapse and induced massive immigration towards the north of the Basin. This sole event consolidated the future political preeminence of Teotihuacan.

Temples and Desertification

Towards 100 A.D., Teotihuacan had some 30 000 inhabitants. Five centuries later, in 650 A.D., the population reached 150 000 (Parsons, 1976; Millon, 1970). A century later, the population of Teotihuacan had collapsed to less that 10 000. The cause of this decline is not well known. Some researchers attribute it to the rebellion of subdued groups; others, to the exhaustion of the natural resources exploited by the Teotihuacans. Even if the first hypothesis were true, the ecological significance of war tribute was the importing of natural resources with which the local economy was subsidized. In either of the two hypotheses, therefore, the exhaustion of local resources and the conflicts arising from the appropriation of foreign commodities appear as the driving force of the collapse. According to Sanders (1976; see also Sanders *et al.*, 1979). the overexploitation of the semiarid natural resources that surrounded Teotihuacan, together with the lack of a sufficiently developed technology to exploit the fertile but flood-prone terrains of the Basin lakebeds, were decisive determinants in the sudden collapse of this civilization.

There is good evidence that the Teotihuacan area was strongly disturbed at the time of the decline. Even at present the area is seriously desertified and completely lacks woody vegetation. It is possible to calculate, for example, that the amount of wood needed to calcine the mortar and stucco used in the pyramids was in the order of tens of thousands of tons (Cook, 1947). If the wood necessary to satisfy the domestic needs of 150 000 persons (a conservative estimate is 30 thousand tons per year) is added to this amount, it becomes clear that the development of Teotihuacan brought a large-scale process of deforestation in the north of the Basin, with the erosion and loss of good agricultural soils as consequences (the total amount of wood used by Teotihuacan during its last century implies the cutting of 30 to 60 thousand hectares of forest; Ezcurra, 1992). Everything seems to indicate that resource exhaustion was the main determinant of the decline of Teotihuacan.

The Rise and Fall of Tenochtítlan

Various cultures existed on the lake margins before and during the arrival of the Aztec tribes. The lacustrine system at the bottom of the Basin became surrounded by a cluster of towns, and the development of new agricultural techniques, based on irrigation, canals and flood control systems, allowed a great increase in population densities. Around 1325 A.D., the Aztecs -or *Mexicas*- founded their city, Tenochtitlan, on a low, floodable island which in a few centuries became the capital of the powerful Aztec empire and the political, economic, and religious center of Mesoamerica.

Between 1200 and 1400 A.D. an extraordinary succession of cultural and technological changes occurred in the Basin, both before and after the founding of Tenochtitlan (Calneck, 1972). It is estimated that during the late fifteenth century the population of the Basin reached 1.5 million inhabitants, distributed in more than a hundred towns. At that time the Basin of Mexico was probably the largest and most densely settled urban area in the world. When the Spaniards arrived in 1519, the Basin of Mexico was occupied by a well-developed civilization, founded on the cultivation of the surrounding *chinampa* fields (i.e. raised field plots separated by canals, frequently described as "floating gardens"). Care must be taken, however, not to interpret the success of Tenochtitlan as a result of sustainable use of the Basin's natural resources. Although the Basin was a system of high environmental diversity, its productivity was limited in many aspects. Drought and frost affected a good part of the region. To avoid these risks, the Aztecs fished and hunted in the lake, but these harvesting systems required a much higher effort per unit yield than traditional agriculture. Even *chinampa* agriculture, less vulnerable than dryland farming, represented a large effort in moving soil and mud from ditches into the farming plots (Armillas, 1971). As has already been discussed, the extinction of large herbivores forced the inhabitants of the Basin to fish and eat small animals and insects. It also forced the Aztecs to consume the *chinampa* weeds *(quilitl)* as a source of protein, a practice still common on the Mexican Plateau (Niederberger, 1987; Ortiz de Montellano, 1975).

In spite of these innovations in food supply, population growth forced the Aztecs to wage war on surrounding groups and to force them to pay tributes to Tenochtitlan. Some cruel rituals such as cannibalism have been interpreted as a way of imposing Aztec rule by terrorizing the subdued groups (see Anawalt, 1986; Harner, 1977; Duverger, 1983). Matos Moctezuma (1987) has shown that the two pillars of Aztec power were symbolized in the sanctuary of the Main Temple of Tenochtitlan: Tlaloc, the god of water, rain, and agriculture, and Huitzilopochtli, the goddess of sun, fire and war. Thus, the Aztec empire rested both on *chinampa* agriculture and war tribute. The appropriation of alien products became more and more important as the Aztec ruling system evolved. At the height of the Aztec empire, Tenochtitlan imported around 7000 tons of maize, 5000 tons of beans, 4000 tons of chia, and 4000 tons of amaranth every year (López Rosado, 1988). It also imported large quantities of dry chilies, cacao seeds, dry fish, cotton, henequen fibers, vanilla, honey, pulque, tropical fruits and many other products.

In 1519, after a siege of ninety days, the soldiers of Cortés, backed by a large army of local allies that wanted to get rid of the Aztec dominion, took over Tenochtitlan, and in a very short time dismantled the Aztec social structure. The support that Cortés received from other groups was mostly the result of the hatred against the Aztecs that the war-tribute system had generated. In a way, the lack of self-sufficiency of Tenochtitlan played an important role in its own defeat.

With the Spanish conquest, horses and cattle were introduced to Mexico and both the transportation and the agricultural structure changed accordingly. Many of the Aztec canals were filled, to make roads for horses and carts. Thus, the *chinampas* were displaced away from the center of the city. Cattle, sheep, goats, pigs and chickens provided new sources of protein. The land use and physiognomy of the surrounding mountains started to change, mostly through cattle grazing and timber logging. The Spanish conquest also brought a tremendous population decline in the Basin, mostly through the introduction of new diseases (León-Portilla *et al.*, 1972). A century after the conquest the population of the Basin had fallen below 100 000.

From the Colony to Modern Mexico

The Spaniards, however, were also changed by the indigenous culture, in perhaps a more subtle but equally irreversible manner. The Mexican colony became a synthesis of both Aztec and Spanish tradition. Some persistent cultural differences, however, led to further landscape transformations. From early colonial times, it became clear that the new city plan was not compatible with the lacustrine landscape of the Basin (Sala Catalá, 1986). The filling of the Aztec canals to build elevated roads obstructed the surface drainage of the city and created large surfaces of stagnant water, while the grazing and logging of the slopes surrounding the Basin increased surface runoff and silting during the rainy season. The first severe flood occurred in 1533; new floods recurred in 1580, 1604, 1629 and thereafter in shorter intervals. The low altitude of the northern ranges, and the existence of near-level passes between them, drove the colonial government to plan the drainage of the Basin towards the north, from Lake Zumpango. The first drainage canal, the so-called El Tajo de Nochistongo, was 15 km long and opened the Basin towards the Tula Basin in 1608 (Lara, 1988). The larger works of the Canal de Huehuetoca began in the late sixteenth century and continued until the early twentieth century. At first the canal served only as a spillover system, but with the construction of the auxiliary Canal de Guadalupe in 1796, the lacustrine area in the Basin of Mexico began to shrink rapidly (Trabulse, 1983). In spite of the drainage works, navigation by canal was still very popular towards the end of the colonial period. Boats departed regularly to Xochimilco and Chalco from a pier near the old market of La Merced, east of the central plaza known as El Zocalo (Sierra, 1984). The "Canal de la Viga", among many others, remained active throughout all of the colonial period, and represented an important trading route for all agricultural products between the *chinampas* of Xochimilco and the City.

The Independence

The War of Independence (1810-1821) brought little change to the physiognomy of the city (González Angulo and Terán Trillo, 1976). Drainage works in the Canal de Huehuetoca were greatly extended during the nineteenth century. During the prolonged dictatorship of Porfirio Díaz, in the late nineteenth and early twentieth centuries, the Industrial Revolution was imported to Mexico. Factories and railroads were built, and the city was modernized for the benefit of a small, centralist and powerful bourgeoisie whose aim was to transform the wealthier quarters of Mexico, copying the layout of European cities. The Basin ceased to be regarded as a series of separate towns linked more by commerce than by a central administration and started to be considered as a central unit. The newly laid railroads brought peasants looking for employment in the new industries, and some of the smaller towns near the center of the city, like Tacuba, Tacubaya and Azcapotzalco, were engulfed into the urban perimeter.

The Revolution

Between 1910 and 1920 the Mexican Revolution brought a decade of ruthless confrontation between the old Porfirian bourgeoisie, which defended its privileges, and other social sectors demanding more participation in the distribution of the national wealth. Mexico City had at that time approximately 700 000 inhabitants and, unexpectedly, suffered little damage. The Revolution was mostly a rural movement, and the city became a haven for middle-class provincial families, who flocked into the Basin of Mexico searching for cover under the new bureaucracy and the rising industries.

The Revolution became institutionalized in 1924 and peace returned to Mexico City, which started to grow rapidly. Realizing the environmental importance of the surrounding forests, President Lázaro Cárdenas (1934-1940) created various national parks in the mountains enclosing the Basin. The national parks Desierto de los Leones and Cumbres del Ajusco were created to the west and south as a way of restricting the deforestation of the Basin slopes. Unfortunately, during the presidency of Miguel Alemán (1946-1952) a good part of the Ajusco park was given to a paper mill, which started an ambitious timber-logging program (DDF, 1986). The elimination of the park and the deforestation of neighboring areas opened the way for urban expansion.

Modern Mexico

During the post-revolutionary period, and particularly after World War II, the industrial growth that had been heralded by the Porfirian government became a reality. Mexico became an industrial city, and a massive migration started from the country into the city. In less than eighty years the population of the urban conglomerate jumped from 700 000 to a total of nearly 16 million in 1987. Peripheral cities, like Coyoacán, Tlalpan and Xochimilco, were incorporated into the urban perimeter. A deep drainage system was built to remove the torrential urban runoff from the Basin, and most of the old lakebeds became dry. The drainage of the lakebeds and the water extraction from the underground aquifer depressed the center of the city by approximately 9 m from 1910 to 1987. The extremely low wind speeds in the high-altitude plateau, together with intense industrial activity and the emissions of four million vehicles, have degraded the quality of the atmosphere in the Basin to levels that are dangerous to human health.

The Twentieth Century Megalopolis

From 1950 to 1980, the average annual growth rate of Mexico City was 4.8%. Growth has been higher in industrial areas and proletarian settlements, where annual rates have been as high as 14%. In the rapid expansion of Mexico City, migration from rural areas played the most important role (Unikel, 1974; Stern, 1977; Goldani, 1977; Calderón and Hernández, 1987). The birth rate of the City between 1950 and 1980 was around 1.8%, while migration accounted for the other 3% of the growth rate (Goldani, 1977).

The growth rate of the city in spatial extent during the 1950-1980 period was 5.2%. In 1953 the urban area covered 240 km^2 (8% of the Basin) while by 1980 it had increased to 980 km^2 (33% of the Basin). Modern expansion has not kept the old style of urbanization. The new developments are less planned, and generally include less open spaces. Many developments are now built on hill slopes, generating a considerable amount of soil erosion and a significant increase in flash floods after rainstorms (Galindo and Morales, 1987). In 1950, the urban area included a large proportion of agropastoral fields, together with numerous empty lots, and parks. The relative frequency of these open spaces within the city has decreased considerably with the new industrial style of urbanization. All kinds of open spaces within Mexico City are decreasing, but at different rates. Agropastoral fields, previously very important within the city as dairy farms, and domestic maize fields *(milpas)* have been disappearing at an annual rate of 7.4% and are now practically non-existent within the city. Most of these areas are occupied by industrial buildings and housing developments. Parks, private gardens and public spaces have been somewhat better conserved, disappearing from the city at an average rate of 1.5%. New roads have accounted for most of the loss. Overall, vegetated areas have been decreasing at an annual rate of 3.7% (Ezcurra, 1990b). The total rate of change of open spaces and green areas varies considerably from one sector of the city to another. The east of Mexico City, where the larger proletarian settlements lie, is the area changing most quickly: nearly 6% of its open spaces disappeared annually between 1950-1980. Open spaces are disappearing most slowly in the old center of the city (1.0%). The rate of change within the urbanized areas depends on the social position of their inhabitants and on the time of their establishment. In the poorer and more recently established areas, vacant land is quickly transformed into new houses, leaving less vegetated areas per person. The distribution of green areas, like the distribution of wealth, is very uneven at present and varies considerably from one part of the city to another. Although some quarters have more than 10 m^2 of vegetated land per person, others have much less. Azcapotzalco, an industrial quarter with a population of some 700000, has at present 0.9 m^2 of green areas per inhabitant (Calvillo-Ortega, 1978; Barradas and J-Seres, 1988).

Water Supply

During this century, the Basin has gone from a high level of self-sufficiency in natural resources to a complete dependence on imports from other parts of Mexico. The best soils of the Basin are now occupied by houses, the underground aquifer has gone down more than ten meters in some parts, and much of the water in the Basin is heavily polluted. This is obvious in the satellite town of Xochimilco, south of the city, where *chinampa* agriculture is still carried on, but is quickly disappearing because of the descending water table and the high pollution levels of the canal waters. Thus, most of the food and water consumed within the Basin comes from outside its boundaries. Water is pumped at high expense from the Lerma and Cutzamala Basins, where it is also badly needed. In 1976, the city used 1 293 million m^3 of water at an average rate of 41 m^3/s. Thirty percent of this amount (12 m^3/s) came from the Lerma Basin (DDF, 1977). At present, the city uses 60 m^3/s of water (Enciclopedia de México, 1985), of which 18 m^3/s (about 570 million m^3/year) are pumped from the Lerma and Cutzamala Basins.

The average daily supply of water in Mexico City is around 300 l/person, more than in many European cities. Even so, many parts of the city suffer from chronic water shortages. Industrial use is very inefficient, water recycling uses only 7% of the sewage, and nearly 20% of the water supply is lost through deficient pipe systems. Pipe breakage in the sinking muddy subsoil of the old lake bed also represents a continuous health hazard, as microorganisms from the sewage system can contaminate the fractured pipes. Thus, gastrointestinal diseases are among the most common health problems in the Basin of Mexico and a primary cause of infant mortality.

Air Quality

Perhaps the worst problem associated with the uncontrolled growth of the city is the high level of atmospheric pollution within the Basin (SAHOP, 1978; SMA, 1978a/b). This problem is particularly critical during the cold season (december to February) when the low temperatures stabilize the atmosphere above the Basin and the air pollutants accumulate in the stationary mass of air that covers the city (SEDUE, 1986; Velasco Levy, 1983). Studies of the lead (Pb) and bromine (Br) content in the air particulate pollutants in Mexico City have shown that most of the air pollution originates from automobile exhaust (Barfoot *et al.*, 1984; Sigler Andrade *et al.*, 1982). In some parts of the city, particularly towards the center-east, the concentration of total suspended particles exceeds the Mexican and the international air-quality standards more than 50% of the time (Fuentes Gea and Hernández, 1984). The number of cars in the city is also increasing at a 6% annual rate (there were some two million cars in 1979 and four million in 1992). The deterioration of the air quality in the Basin progresses much more rapidly than the population growth and the urban expansion.

Until 1986, lead was probably the worst pollutant in the atmosphere of the Basin (Salazar *et al.*, 1981). Only leaded gasoline was sold, and the concentration of lead in the air increased steadily with the number of cars, reaching a value of 5 $\mu g/m^3$ in 1968 (Halffter and Ezcurra, 1983) and around 8 $\mu g/m^3$ in 1986 (5 times the Mexican standard of 1.5 $\mu g/m^3$). The problem became so critical that in September, 1986, the national oil company (PEMEX) replaced leaded gasoline with low lead-content fuel in which synthetic oxidizing additives partly replaced the action of leaded compounds. The change produced unexpected side effects. While the atmospheric concentration of lead did indeed fall, ozone concentrations above the city rose quickly as a result of a reaction between ultraviolet solar radiation, atmospheric oxygen, and gasoline residues. The present ozone concentration is on average around 0.15 ppm (300 μg/m^3), ten times the normal atmospheric concentration, more than double the maximum limit in the United States and Japan (Avediz Asnavourian, 1984), and high enough to damage most of the urban vegetation (Skärby and Sellden, 1984). Because of the time lag involved in the ozone formation, the highest ozone levels are registered towards the southwest of the city in the direction of the prevailing winds. During the winter of 1991-92, the ozone levels in this area exceeded the maximum allowable standards (0.11 ppm) almost every day, and generated continuous health complaints from the population. During some days, ozone reached concentrations as high as 0.6 ppm (1200 μg/m^3), a level which is considered highly harmful for humans and plants by all standards.

Atmospheric pollution also has a considerable influence on the quality of rainwater. Páramo *et al.* (1987; see also Bravo, 1987) reported, for the 1983-86 period, a significant decrease in the pH of incoming rainwater in Mexico City due to the increasing concentration of sulphur and nitrogen oxides in the air. In the urban parts of the Basin the average pH of rainwater is around 5.5, and a few rain events have been registered with pH values as low as 3.0. The effects of air pollution are not restricted to the urban areas; they can also have considerable impact on the natural ecosystems surrounding the Basin. Hernández Tejeda *et al.* (1985a; see also Bauer *et al.*, 1985; Hernández Tejeda *et al.*, 1985b; Hernández Tejeda and Bauer, 1986), for example, have found that the ozone produced above the city and carried by the dominant winds to the Sierra del Ajusco, southwest of the Basin, significantly reduces the chlorophyll content and the growth of *Pinus hartwegii*, the dominant pine species in the high mountains (about 3500 m) around the Basin. One of the main functions of these forests is the collection of water for the city. Thus, atmospheric pollution may have a considerable impact on the water balance on the hill slopes of the Basin, and consequently on the availability and quality of water for human consumption.

Ecological Subsidies

The rapid rise and the enormous power of the Aztec state were based on the political control of much of Mesoamerica and on the subordination of hundreds of different groups that paid tribute to the emperor. Aztec wealth depended to a great extent on the concentration of high quality goods (e.g. metals, obsidian, tropical fruits, high protein food) and labor, collected as tribute from conquered groups. The Basin of Mexico, which initially allowed the surge of Aztec culture through the appropriation and use of the highly productive *chinampa* technology, became a subsidized ecosystem receiving inputs of matter and energy from other areas.

This tradition, maintained under Spanish rule, has now reached immense proportions. Few ecosystems in the world are so far from self-efficiency as the Basin of Mexico is at present (Ezcurra and Sarukhán, 1990). With much of the forest cut, most of the *chinampa* lands turned into urban developments, practically all of the lakes dried up, the supply of raw materials and energy generated within the Basin does not suffice for even a small fraction of the 18 million residents. Thus, the Basin of Mexico imports vast amounts of food, energy, wood, water, building materials and many other products from other ecosystems that, in effect, subsidize the water and energy flows of the Basin. With 18% of the population of the country, the Basin consumes around 30% of the country's oil and one-third of its electricity.

In spite of the severe environmental problems, the Mexican model of development has given priority to improving the quality of life in large cities, where the social demand is more concentrated, at the expense of the rural areas, which have become comparatively poorer. From 1950 to 1980 the Basin experienced marked improvement in demographic and domestic indicators of quality of life, but the changes at the national level have been lower. This difference in trends is, of course, much more marked if the Basin of Mexico is compared with the depressed rural areas from which most of the immigrants come. Through this system of ecological subsidies, many of the problems generated by growth, or by sheer size, of Mexico City are in effect exported to neighboring areas. The chronic shortage of water in the Basin, for example, is in great part transferred to the Lerma and Cutzamala Basins, from which water is imported at a rate of 18 m^3/s (Bazdresch, 1986). Sewage water, on the other hand, is drained into the Tula Basin, in the State of Hidalgo. In this way, water pollution is exported to the Tula system.

Apart from the ecological interpretations of these subsidies, the urban concentration of Mexico City has also involved the concentration of wealth and an economic subsidy implicitly granted by the rest of the nation to the residents of the capital city. Public transportation in Mexico City (buses, trolley buses and the metro train) now costs approximately US$ 0.10 per trip, a fixed tariff that is independent of the distance traveled. The metro, which transports three million passengers per day (Bravo, 1986), thus generates a revenue of US$ 300 000 per day, but the real cost of operating the system is in the order of US$ 1.5 million per day (Bazdresch, 1986). The difference is ultimately met by all taxpayers, many of whom do not benefit from the service in any way. Water costs around US$ 0.30/m^3 to distribute in Mexico City. This price is largely due to the high costs of pumping water into the Basin of Mexico from the Basin of Lerma (Bazdresch, 1986). The government spends approximately US$ 450 million per year to supply water to the Basin of Mexico. The revenue obtained from the service, however, is on the order of US$ 42 million, less than 10% of the total cost. Other services, such as electricity, gas, garbage collection and road maintenance are subsidized for the whole country and not only for the Basin of Mexico. However, because the city receives these services in a higher proportion than the rest of the nation, it receives a higher share of the subsidy, as in the case of energy previously discussed. This asymmetry is, again, particularly true for rural areas that export their produce to the city, but do not benefit from the cheap urban services.

Concluding Remarks

Although most of the environmental problems in the Basin of Mexico have reached critical proportions in the late twentieth century, industrial development is not solely to blame. Urban and political centralism have been a tradition in Mexican society since the Aztec empire. The Basin of Mexico, for nearly two millennia one of the most densely populated areas of the world, has historically used its preeminent administrative and political position to obtain advantages over the other areas of the nation. But modern industrialization has exaggerated this trend to dramatic proportions, and is indeed responsible for the disproportionate urbanization and the biased distribution of population and wealth.

Resource exhaustion through inadequate land use has produced massive processes of population decline in the area in the past, showing that there are limits to population growth in a closed basin given technological level. Air pollution, water shortages, and the unbridled growth of the urban area suggest that a similar process of population curbing or even decline may occur in the near future. The Basin of Mexico is a laboratory where the many processes that drive population, natural resources and land use changes in the less developed nations are being tested. It provides both fascinating and terrible insights into what the future may hold in store for much of Latin America.

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CHAPTER 15

CONTEMPORARY PATTERNS OF LANDSCAPE CHANGE IN AREAS WITH A MEDITERRANEAN-TYPE CLIMATE IN CENTRAL CHILE

Eduardo Fuentes-Quezada, Sandra Miethke, and Reinaldo Avilés

Mediterranean-Type Landscapes in Central Chile

In Chile eumediterranean ecosystems (after di Castri, 1973) stretch across the lowlands (below 1500 m) approximately between Combarbalá (31°11') and Linares (36°00'). In this area of central Chile there are three main geomorphological elements: the coastal ranges to the west, the Andes ranges to the east, and a Central Valley between them (Fuentes, 1990). The climate is semiarid, with hot-dry summers and cool-wet winters. Rainfall is produced by fronts coming from the southwest and is very sensitive to topography (Hajek *et al.*, 1985). Consequently, the Central Valley, actually a lowered fault block, has somewhat lower winter rainfall than the two surrounding ranges.

Today, the Central Valley (or intermediate depression) is basically covered by an espino (*Acacia caven* (Mol.) Hook et Arn) savanna (Fuentes *et al.*, 1989,1990). (Savanna is used here as a physiognomical category, after Eiten [1986], and not as a geographically restricted community). The ranges surrounding the intermediate depression receive higher precipitation and are covered, in a relatively narrow belt between about 900 m and up to 1500 m, by evergreen woodlands and shrublands known as matorral (Mooney, 1977). The matorral is one of five areas around the world that have a Mediterranean-type climate and sclerophyllous vegetation associated with it (di Castri *et al.*, 1981). Above 1500 m the vegetation acquires a strong alpine character as temperatures in the winter become too low and the growing season too short (Hoffmann and Hoffmann, 1982).

Besides climate and topography, human activity is a major factor explaining the distribution of vegetation and ecosystems in the Chilean area with a Mediterranean-type climate (Fuentes, 1990). Most of the Chilean population (about 12 million) lives in the low flatland by the coast or in the so-called Central Valley. Human density in these general areas varies between 30 and 230 inhabitants per km^2.

Human influences on the landscape before the Columbian encounter are generally assumed to have been low, but after Europeans colonized the area. a large-scale transformation of the region began (Fuentes, 1990). This change included the introduction and elimination of species, increased the fire frequency and intensity, intensified the patterns of grazing and browsing, increased clearing and wood-cutting, and use of slopes for small-scale, rain-fed agriculture (Fuentes and Hajek, 1979). All these activities, but especially rain-fed agriculture, sometimes on slopes up to 30°, have drastically changed the physiognomy of the landscape. Species that had tree-like shapes, such as *Lithraea caustica* (Mol.) Hook et Arn, for example, now exhibit a shrubby multistemmed structure. Landscapes appear now as a patchwork in which different factors combine to produce alternative trajectories of vegetation change (Fuentes *et al.*, 1986; Fuentes, 1990).

It is now clear that in the past there were more woodlands than we see today. The shrublands we see are, to a large but unknown extent, human-made. The irrigated parts of the Central Valley have been converted to highly productive agricultural fields. The non-irrigated areas are now covered by the *Acacia caven* savanna. There has been some discussion as to whether the *Acacia caven* savanna is natural (e.g. Kuchler, 1977) to the Central Valley or a by-product of human use (Schmithüsen, 1956; Schlegel, 1966; Mann, 1968; Rundel, 1981), but recent experimental evidence (Fuentes *et al.*, 1989, 1990) suggests that sclerophyllous species were at least part of the flora living in this area before the arrival of humans. There is little doubt, though, that *Acacia caven* has increased its distribution due to human presence (Rundel, 1981).

In general, human effects and transformations have been largest on the low flatland of the Central Valley, generally intermediate on the coastal ranges to the west of the Central Valley, and lowest on the Andes ranges. Consequently, the better conserved sclerophyllous vegetation is currently on two mid-altitude belts on the two mountain ranges. Within these belts there are latitudinal, edaphic, and slope exposure differences that, added to human disturbances, explain current landscape patterns.

Current Vegetation Dynamics

In central Chile, human settlements frequently play the role of a "central place" from which a gradient of decreasing human-made modifications of the natural vegetation can be seen (Fuentes, 1990). This central place can be seen at scales, from 1:1 000 000 for the Central Valley at large to 1:10 000 a single house immersed in the matorral.

Current vegetation dynamics can be evaluated by comparing the position of natural or seminatural vegetation fronts in relation to human settlements and associated clearings using aerial photographs taken at different times. Comparison of aerial photographs of 1955 and 1979 show that human disturbance on the mountainous east border of the rapidly growing city of Santiago has increased during the last 25 years (Fuentes *et al.*, 1984). This centrifugal movement (in relation to the central position of the settlement) of the ecotone between the human settlement and the natural vegetation, is largely a consequence of the continually increasing size of the capital city, in turn a function of both internal growth and immigration from the provinces.

On the other side, human disturbance around smaller settlements, within the same region but peripheral to Santiago (Figure 1), decreased between 1953 and 1980 (Table 1). The number of land clearings in these rural realms actually decreased when compared to cover exhibited by those same mountainous landscapes before. There has been a decrease in the clearings between 1953 and 1980. On average, there was a significant ($p < 0.05$) decrease of 3.5% in the land surface covered by clearings. The number of sites where vegetation recovered between 1953 and 1980 is far larger (28 out of 32) than the number of sites where the vegetation deteriorated ($p < 0.002$). In addition, the total cover in all sites increased on the average by 11.6% in 30 years, significantly different from zero ($p < 0.001$).

This recovery pattern is associated with a decrease in the rural population of these areas and an increase in the proportion of their urban population between 1952 and 1982 (IGM, 1983). These increases in urban population have been from 87% to 92% for Santiago, 38% to 60% for Aconcagua, and 85% to 92% for Valparaíso. In addition, between 1960 and 1970, and probably even more since then, there has been a net migration of human population out of 14 of the 18 districts ($p < 0.02$) studied , and on the average, there was a net outmigration of 6 people/year/1000 inhabitants (IGM, 1983).

In contrast, the tendency has been just the opposite in the urban centers in these same areas: Santiago and Valparaíso have increased their population and have experienced immigration on the order of 14-37 people/year/1000 inhabitants between 1960 and 1970.

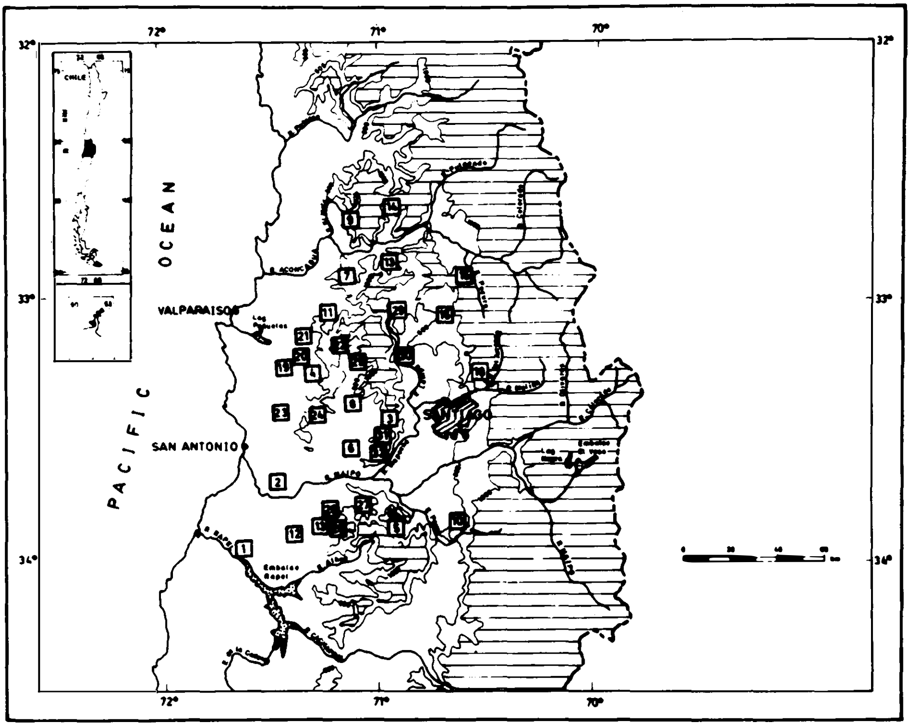

Figure 1. Map of Investigated Areas in Central Chile. The areas covered by the aerial photographs of 1953 and 1980 are shown by number in square blocks. Notice that all of them are in the coastal mountainous area west of Santiago.

Table 1. Sites with Increasing Forest Cover in Central Chile 1953-1980.

	Number of Sites	% of Total
Increased cover between 1953 and 1980	28	88
Decreased cover between 1953 and 1980	4	12
Total sites examined	32	100

Source: Comparative analysis of aerial photographs from 1953 and 1980.

These results support the idea that the current dynamics of the ecotones between the natural and human disturbed vegetation depend on population pressure and socioeconomic development. That is, the dynamics of these ecotones between human settlements and the natural vegetation around them is a function of the number of people in those areas and their activity. Less people or more involvement in urban activities as opposed to rural and, especially, subsistence activities, seem to be associated with less expansion of the ecotones than the opposite.

Trends for central Chile, in its most industrialized area, seem similar to what has been earlier described for the First World, namely that the woody vegetation tends to recover with the overall industrialization of the country. At least in places with a long human occupancy, there seems to be a reversal in the traditional degradation trend.

The history of land uses in Chile tells us that past human effects on the landscapes have been very sensitive to human actions, not only direct and desired ones, such as land clearing, but also indirect and unplanned ones, emerging as a by-product of complex interactions with other organisms and the general state of the economy (Fuentes, 1990). The results suggest that people who migrate to cities as soon as they perceive that new or better opportunities are available could be a partial explanation for the rapid centripetal ecotone movement and the recovery of the landscapes.

In contrast, the generally improved states of the economy, the increased availability of gasoline (petro), and increased local employment could also have reduced the per capita impacts on the landscapes and, therefore, partly explain the centripetal movement of the ecotone between human settlements and the surrounding natural vegetation in central Chile.

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CHAPTER 16

IMPACT OF AGRICULTURE AND LIVESTOCK PRODUCTION ON TROPICAL SOILS IN LATIN AMERICA

D. López-Hernández

Introduction

Climax soils are a consequence of environmental factors including vegetation types. Apart from seasonal changes, the characteristics of these soils remain unaffected in the short term, unless strong disturbances occur.

Many ecosystems in lowland South America were not highly disturbed at the Columbian encounter (López-Hernández, 1990).[1] The population of gatherers and hunters which originally arrived, no doubt altered some part of the landscape (Smith, this volume). Environmental changes were, however, of a minor proportion in slightly populated lowland areas (Amazon Basin and savannas), compared with the relatively heavily populated upland areas (Andes). Since soil fertility and management (technology) are typically related to population pressures among traditional land users, human populations in areas of lowly fertile rain-forest and savanna soils were constrained unless they developed appropriate soil management techniques, or found external nutrient sources (fertilizers).

Despite the increase in South American populations subsequent to the Columbian encounter, the major savanna and rain-forest ecosystems remained relatively unused until this century when dramatic changes in those environments took place, particularly in the

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1. This statement stands in contrast to the thrust of this volume. It is not meant to be contentious in an absolute sense. Rather, it reflects my sense of appropriate level of disturbance compared to areas with major human disturbance.

last 40 years, due to intensive agricultural and industrial (mainly mining) activities.

This review deals with the impact of agriculture and livestock production on the tropical soils of Latin America. Emphasis is placed on poor fertility soils of lowland areas covered by tropical rain forest and savannas, the most extended ecosystems in tropical Latin America. Because of the high variability in both fertility and production, mountainous regions and ecosystems located in parent materials derived from volcanic ash will not be considered. Two general points are addressed: (a) the changes in soil properties under slash-and-burn cultivation; and (b) the changes in soil properties when agriculture and livestock practices move toward intensive technologies.

Original Land-Use Practices and Soil Properties

Several thousand years ago, the inhabitants of American tropical forests were basically hunters and gatherers, gradually evolving to agriculture by opening clearings in the forest where species that produced food or medicines were planted. The agriculture system, common to all tropical countries, is referred to as shifting, slash-and-burn, or swidden cultivation. In Latin America different local names are used: *roça* in Brazil, *conuco* in Venezuela, *chacra* in Peru, and *milpa* in Mexico and Central America (Sánchez, 1976; Jordan, 1987). This agriculture system involves the clearing of plots for cultivation for a number of years, always less than the fallow period, in which naturally occurring successional vegetation (secondary forest) invades and regenerates the plot. Shifting cultivation can be practiced in forests and savannas, although the use in the latter is less frequent. To initiate slash-and-burn agriculture in forest, the vegetation is cleared during the dry season, with simple hand tools. The dry plant debris is then burned before the rainy season starts. Crops are grown without further removal of the tree and shrub remains. After one or two crops, the field is abandoned and a quick regrowth of the vegetation starts. The fallow period can last from 4 to 20 years before the process is repeated (Sánchez, 1976).

In savannas, shifting cultivation is practiced after the removal and burning of the scarce trees. Sánchez (1976) reported that in Africa, the grasses are removed together with the trees, whereas in South American savannas, slash-and-burn agriculture usually uses fire as the main agent of vegetation removal. Fallow should be long enough to allow rebuilding of nutrient stock. These nutrients return to the depleted soil by translocation from the deep zone of the profile through the agency of roots, weathering processes, and precipitation inputs.

Shifting cultivation in forest is ecologically sustainable because the area cleared is usually insignificant compared with the uncut forest, and the fallow period restores nutrients lost during cultivation and harvest (Jordan, 1987). In the case of savannas, the soil surface is more affected after the removal of the trees and grasses, therefore erosion problems might occur (Sánchez, 1976).

Changes in the Physical Properties of Soils under Shifting Cultivation

Soil temperature

The soil temperature profile in a tropical rain forest after burning can reach between 450° to 650°C at 2 cm above the surface, but drops at a ratio of 100°C/cm from the surface downwards. Below a depth of 5 cm, soil temperature is not greatly affected (Suarez de Castro, 1957). Burning changes the color of the plow layer due to the presence of carbon particles which, in turn, can induce a modification of the caloric capacity in sandy soils (Sánchez, 1976). After removal of the plant cover, daily soil temperatures are increased, affecting the rates of germination, emergence of plantules, and absorption of water and nutrients by crops. Temperature increases also affect the rate of organic matter decomposition. Once the *conucos* are abandoned to fallow, soil temperatures decrease.

Fires in savannas generally are not hot enough to cause direct changes in the soil (Vareschi, 1962; Frost and Robertson, 1985). Some indirect effects, however, have been reported for the soil aggregation state with a concomitant reduction in the rate of infiltration in the burnt areas (Frost and Robertson, 1985; San Jose and Medina, 1975). Because of the low thermal conductivity of savanna soils, below a depth of 2 cm, the increase in soil temperature is only 1°C. Savanna fires supposedly affect soil microbiota less.

Soil structure

In general, the literature indicates that a decrease in both the rate of infiltration and total porosity takes place after an old forest is slashed, burnt, and cropped or transformed to a derived savanna. Moura and Buol (1972) have reported that a decrease in the rate of infiltration after 15 years of cropping, of an oxisol in Brazil. The reduction in the percolation had a beneficial effect, however, due to the excessive drainage of the original soil. In the Peruvian Amazon, Seubert and colleagues (1977) observed a reduction in the rate of infiltration in a "virgin" oxisol (26 cm/h) compared to a *conuco* site (14 cm/h) which negatively affected crop production

The most important effect of the fires in savannas is also in soil aggregates. In a savanna protected from fire and grazing for nearly 30 years, Guerere (1992) found a better soil structure associated with higher water availability and lower bulk density when compared with natural savanna (Table 1).

Table 1. Bulk density, field capacity and percent of humidity in a savanna protected from fire and grazing compared with a natural savanna (means followed by different letters differ significantly, P=0.05).

Soil Characteristic	Unprotected Savanna	Protected Savanna
Bulk Density (g cm-3)	1.66 + -0.04 a	1.51 + -0.04 b
Field Capacity (g cm-3)	14.97 + -0.49 a	16.51 +-0.41 b
% Humidity	13.35 + -0.27 a	14.84 +-0.18 b

(after Guerere, 1992)

Soil erosion

Soil and nutrient losses are of minor importance in a forest soil protected by a canopy. Slash-and-burn agriculture immediately removes the natural nutrient conserving mechanism, and important losses of soil and nutrients occur in the cleared places (Jordan, 1985). The magnitude of losses depends on soil types, slope, cultivated crops, time (years) and form of cultivation. Crops which simulate the original canopy, like yuca (manioc) or bananas, protect the soil from erosion better than cereals (e.g. maize, rice) or legumes. In traditional shifting cultivation, the soil remains unprotected for only a few weeks, generally during the dry period. As such, the risks of heavy erosion are minor. This is not the case, however, where *conucos* in mountainous zones of Venezuela are worked by frontier farmers, which are not experienced with this agriculture. Heavy erosion problems often follows. Population pressures in other areas oblige a reduction in the fallow period, resulting in soil and nutrient losses (Lal *et al.*, 1975) if appropriate management does not follow.

Although many savannas present a nearly flat topography, the risks of soil loss by erosion remain important. Practically all the savannas of South America are burnt during the last half of the dry season or during brief, less rainy intervals (Sarmiento and Monasterio, 1975). The frequency of fires in tropical savannas has increased due to the use of this ecosystem for cattle raising. Erosion in savannas occurs at a higher rate than in the forest, because its use for livestock allows no fallow period and requires annual burning.

Changes in soil fertility in rain forest induced by shifting cultivation

The most important changes in soil fertility under shifting cultivation are related to the presence of important quantities of ashes produced in the burn, acting as natural fertilizers. The amount and quality of the ash is a function of the quality of the burn and the kind of vegetation which, in turn, is a function of the soil type. Table 2 compares the chemical composition of ashes of different plant materials.

Table 2. Chemical composition of ashes and partially burned materials in a mollisol cropped with sugarcane (Pulido, 1987) and in an ultisol after burning a 17-year-old forest (Sánchez, 1976).

Element	Mollisol Santa Fe, Yaracuy Venezuela	Ultisol Yurimaguas, Peru
	(%)	
N	0.23	1.72
P	0.40	0.14
K	4.72	0.97
Ca	3.60	1.92
Mg	0.72	0.41

Changes in pH, exchangeable bases and effective cation exchange capacity (ECEC)
· Soil pH increases after the burn because of the neutralizing effect of the soluble bases (K, Na, Ca and Mg), supplied by ash on soil acidity. That initial pH increment gradually decreases due to leaching, and plant and microorganism absorption. A similar trend occurs with the exchangeable bases (Sánchez and Salinas, 1983), whereas a completely different pattern is followed for exchangeable aluminum as a consequence of the liming properties of the ash.

The effective cation exchange capacity is affected by burning operations in a dual form, because of a small reduction in soil organic matter (SOM), ECEC should be reduced, however the increase of pH, in turn, slightly increases the variable charge usually dominant in these well weathered soils.

Changes in organic matter, total nitrogen and phosphorus

Although fire burns most of C, N, and S contained in the plant materials, the burn temperature is not sufficient to lead to combustion of soil carbon and nitrogen. Any reduction of surface soil organic matter in shifting cultivation is more associated with after fire mineralization (induced by higher temperature in the treeless soil) or with tilling operations. Nitrogen mineralization does not necessarily match carbon evolution: lower rates of nitrogen mineralization as compared with carbon have been previously reported (Sánchez, 1976). The reduction of soil carbon in slash-and-burn agriculture is followed by a recovery during the fallow period.

Phosphorus is a common limiting element in acid soils (López-Hernández and Burnham, 1974; López-Hernández, 1977), and after slash-and-burn in a forest the ash contributes to increase available levels in the surface horizon (Jordan, 1987; Sánchez, 1976). Perhaps one of the reasons of the peasant to abandon the *conuco* plot is the reduction of the levels of available phosphorus. Decrease in available P can be due to either phosphorus fixation in the active soil surfaces (López-Hernández and Burnham, 1974) or plant absorption.

Changes in soil fertility parameters in savanna soil induced by fire

It is impossible to find a "natural" savanna in Latin America because all savannas are deliberately burned. Burning has increased over the last 400-500 years, due to an increase in cattle activity. Sarmiento and Monasterio (1975), and López-Hernández (1990) emphasized, however, that there is no evidence to indicate that these savannas were different before 1492.

Although the subject is controversial, fires restrict the frequency of woody species in savannas. Experiments performed in fire-protected tropical savannas in Lamto (Ivory Coast) by Vuattoux (1976) and in Calabozo (Venezuela) by San Jose and Fariñas (1983) have shown that with protection, the woody component increases significantly and the associated herbaceous layer decreases.

Kellman (1979) supports the hypothesis that in absence of fire, the number of species better able to capture nutrients increases, therefore the nutrient content of biomass increases, along with an enrichment in soil microsites. This enrichment fosters the invasion of the plantules of trees, leading to a "succession" of a forest ecosystem. The litter layer remaining in a grazed and fire-protected savanna, no doubt influences the physical aggregate and fertility parameters, particularly in the surface horizon. In a work recently finished in our laboratory, Guerere (1992) compared the fertility values of soils in a "natural" (grazed and fired) savanna, with the same savanna protected for 30 years located in Estación Biológica de los Llanos (Calabozo). The nutrients immobilized in the litter layer present in the protected savanna are slowly mineralized to the surface soil, having a fertilizer effect that resembles the input of ashes in shifting cultivation.

In the protected savanna, Guerere (1992) found a small, although significant increase in pH, exchangeable bases, total nitrogen and phosphorus, and microbial carbon biomass (Table 3). Available biomass in both savannas did not differ significantly, whereas the percent of saturation of aluminum significantly decreased in the protected savanna as a consequence of the pH increment. Soil organic matter decreased in Calabozo protected savannas. The effect of fire on the content of soil organic matter (SOM) in savannas is, in general, contradictory. Various works show a decrease (Brookman-Amissah *et al.*, 1980), an increase (Frost and Robertson, 1985), and no effect (Frost and Robertson, 1985).

Table 3. Chemical properties in a savanna protected from fire and grazing compared with a natural savanna (means followed by different letters differ significantly, P=0.05.)

Properties	Unprotected Savanna	Protected Savanna
Total C (%)	1.15 + -0.02 a	1.09 + -0.01 b
Total N (ug g^{-1})	458 + -87 a	529 + -137 b
Total P (ug g^{-1})	390 + -7 a	432 + -16 b
Microbial C (ug g^{-1})	43 + -5 a	58 + -8 b
Exchangeable Bases (cmol Kg^{-1})	0.57 + -0.05 a	0.76 + -0.03 b
Al saturation (%)	65.8 + -0.45 a	56.6 + -1.6 b
pH	5.61 + -0.19 a	6.29 + -0.19 b

(after Guerere, 1992)

Changes in Soil Properties When Shifting Cultivation Moves to Continuous Cropping

From the Columbian encounter until recently, agricultural and livestock activities in lowland tropical Latin America were restricted to extensive practices that did not make profound changes in the landscape. Over the last 40 years, however, the population pressures from migrants from the mountainous region (Andes) and from the semiarid and coastal zones of northeastern Brazil, northern Venezuela, and Colombia have accelerated the rate of deforestation. In addition, an active mining operation related to oil and mineral (iron, aluminum, gold, among others) prospecting and extraction is altering the savanna and other Amazon Basin landscapes (see Smith, this volume).

Changes in Forest Soils under New Land Use

Deforestation in the Amazon Basin

Deforestation for continuous cropping or for other purposes (grazing, monoculture forest) other than traditional shifting cultivation is considered one of the most important world ecological problems. Jordan (1987) emphasizes that "although there is some disagreement about the exact rates at which the Amazon rain forests are being destroyed, most scientists concede that by the end of this century much of the primary forest in the eastern Amazon will probably be gone, and much of the western Amazon will be affected by man".

Effect of mechanized deforestation on soil properties

Comparison of the methods of deforestation have shown that the mechanized process has serious agronomic disadvantages relative to slash-and-burn, including serious impacts on soil physical properties (e.g. compaction, rate of water infiltration). There is also a significant decline in crop yields (Seubert *et al.*, 1977). Uhl and associates (1982), in an experiment at San Carlos de Rio Negro, conclude that the removal of topsoil in a bulldozed plot had major influence on the reduction of species composition and productivity of the colonizing plant community.

Continuous cropping with fertilization

Acid soils of tropical rain forests cannot support continuous cropping unless an adequate source of fertilizer is provided. Fertilization sometimes is accompanied by liming to reduce exchangeable aluminum toxicity. P. Sánchez and collaborators since the

1970s have conducted a series of experiments in the Peruvian Amazon to determine the feasibility of continuous cropping with fertilizer application as an alternative to shifting cultivation (Villachica *et al.*, 1976). The results of these experiments have shown that fertilization combined with appropriate management improve yields, and more importantly, prolong the period of good yield. A reduction of yield, even with good fertilization, is attributed to increased insect attack, insufficient rates of fertilization, poor germination and soil compaction. Micronutrients (zinc, manganese, iron, copper, boron, and molybdenum) can substantially improve the situation (Vallachica and Sánchez, 1978).

Transformation of tropical rain forest in pulpwood plantations

The best known pulpwood case is the Jari project, also considered one of the largest economic perturbations of tropical forest (Jordan, 1987). Originally the project included the purchase of 1.6×10^6 ha of old-growth Brazilian forest to establish a pulpwood plantation. Large-scale plantings of *Gmelina* commenced in 1969 on sites that were cleared by bulldozers. By 1976, clearing of the original forest by heavy machinery had to be abandoned (Russell, 1987) owing to its expense and removal and compaction of the topsoils. The conversion of the primary forest to pine plantation increased annual wood production, but at the expense of the nutrient stocks which had been stored in the above-ground biomass of the primary forest. The removal of the calcium and the potassium due to the harvest of logs constituted the most significant loss of these cations from the ecosystem. It appears that wood production during the second rotation at Jari will decline because of the lower stock of soil nutrient when compared with the first rotation (Jordan, 1987).

Changes in savanna soils under new land use

Neotropical savannas generally present soils with a low natural fertility; therefore, the actual gross productivity of these savannas is very low. In northern South America, Trachypogon savannas are one of the major ecosystems, covering vast areas of Venezuelan and Colombian llanos (San Jose and Montes, 1989). Trachypogon savannas have been extensively used for livestock, with a very low animal-unit rate (10 - 20 ha/unit animal), whereas agricultural activities in the llanos are restricted to areas with soil-water regimes. A major change in some savannas, has occurred in the last 20-30 years, however, due to the need to develop new land surfaces under intensive agricultural and cattle raising practices (López-Hernández, 1990). As a consequence of these activities, the natural herbaceous vegetation has been replaced by introduced grasses with a better nutrient quality, or by food and forest crops.

Intensive agricultural and livestock practices

High-input agriculture based on cereal crops (maize and sorghum) has replaced *Trachypogon* as the principle herbaceous component. As a consequence of liming and N-P-K fertilization, the natural fertility of savanna soils has increased, particularly in available forms of phosphorus (soluble forms of potassium have been affected only to a minor extent). Heavy liming and P fertilizer dressings have also induced depletion in the available forms of some micronutrients (e.g. zinc).

From a physical point of view, till management has been harmful to soil structure (compaction). Soil erosion problems in fragile areas have also been reported (Casanova, 1991). Management techniques using different forms of plant cover have been studied in recent years to decrease the highest losses of organic matter and plant nutrients from cropped savanna soils. Under low-input agriculture, the general tendency is to rapidly decrease soil quality, but we have no records on organic matter fraction and its associated biogenic elements (N, P, S) as a consequence of either low- or high-input agriculture.

For centuries livestock production on savannas has been extensive, with fire as the only agronomic practice used. Recently many ranches have combined traditional extensive and intensive livestock production through the use of fertilization and introduced grasses. Under heavy livestock production, soil compaction in some places has been registered (Vicente-Chandler, 1975; Alegre and Lara, 1991; Pinzón and Amezquita, 1991).

Introduction of monoculture forest

Trachypogon savannas have been replaced in large areas by pulp plantations of *Pinus caribeae* and *Eucalyptus* spp. Because of the long-term recovery of the investment, this enterprise is almost always a government operation. The resulting soil changes have not been analyzed in detail, but preliminary reports indicate a slight increase in the natural acidity of the surface soil in older plantations, and a small net loss in exchangeable calcium in the soil beneath pine trees (López-Hernández and Pomenta, 1985). Reforestation, however, can provide a better cycling of nutrients in the surface layers diminishing their loss.

Dike construction in flooded savannas

Floods are common in the clayey savannas of southern Venezuela. In order to regulate the water regime, a network of dikes, with water surfaces ranging from 2000-4000 ha, have been constructed (López-Hernández *et al.*, 1983). Dikes affect the plant community and soils in the following ways: (a) a change to aquatic grasses with high productivity and (b) an associated increase in cattle raising; (c) an increase in cation losses, particularly in potassium; and (d) a decrease in soil fertility.

Conclusions and Comments

The early hunter-gatherers of the tropical lowlands of South America probably had only localized major impact on the various ecosystem. After the Columbian encounter and during the colonial period, little clearing of the forest took place because the indigenous population declined precipitously, mostly from introduced diseases. The cleared forest returned, in many cases, as secondary succession to mature forest. In the last forty years, a new set of landscape changes has emerged in response to intensive agricultural and industrial (mining) activities. These have had profound impacts on tropical soils.

From 1965-75 food production increased at a faster rate than population in some underdeveloped tropical countries (Sánchez and Salinas, 1983), a result of the development of high-yielding varieties of crops and the elimination of soil constraints through fertilization. High-input management technology is not applied to most of the lands involved, however. Fertilizers are expensive, and so are its transportation costs. An alternative management strategy is emerging the so-called low-input soil management technology (Sánchez and Salinas, 1983). It combines the use of low fertilizer inputs with a group of conserving management practices. The future health of Latin American soils will rely on our capacity to understand and adopt these practices, some of them well-understood by the pre-Columbian Amerindian.

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CHAPTER 17

AGRICULTURAL TECHNOLOGY EXCHANGE AND DEVELOPMENT

Vernon W. Ruttan

The Columbian encounter initiated a series of dramatic changes in agricultural production and patterns of land use in both the old and the new worlds. These changes or their legacies remain with us and should be included in assessing such issues as the broader patterns of land-cover. In spite of such dramatic impacts, however, the encounter should be viewed, from an agricultural perspective, as initiating an escalation in the rate of diffusion of agricultural crops, animals, practices, and technology rather than initiating a new stage in agricultural history. Moreover, the production impacts of this escalation, while critical to assessing agricultural history, have largely run their course. The changes in agriculture in the latter half of this century have shifted the major processes at work. Unlike land-cover change, which was an important part of the encounter and remains an important component of contemporary global environmental change, agricultural change has entered a distinctive, new sphere from that associated with 1492.

The Problem

The first step in any attempt to understand the role of technology exchange in agricultural development is to abandon the view of agriculture in premodern or traditional societies as essentially static. Sustained rates of growth upwards of 0.5 % per year were feasible in many preindustrial societies. With the advent of industrialization, potentials for the growth of agricultural output shifted upward to the range of 1.5 - 2.5 %

per year.
Following the Industrial Revolution, rate of growth in this range occurred over relatively long periods in Western Europe, North America, and Japan. Since the middle of the twentieth century, the growth potential of agricultural production has again shifted upward to annual growth rates of over 4.0 %. Sustained growth rates in this range have been observed primarily in newly developing countries such as Mexico, Brazil, Taiwan, and Thailand.[1]

Any theory of agricultural development which is designed to achieve a high degree of generality must provide insight into the dynamics of agricultural growth -into the changing sources of growth- in economies ranging from those in which output is growing at a rate of 1.0 % or less to those in which agricultural output is growing at 4.0 % or more per year. In *Agricultural Development: An International Perspective* Yujiro Hayami and I outline six models of agricultural development: (a) resource exploitation; (b) conservation; (c) location; (d) diffusion; (e) high-payoff input; and (f) induced innovation (Hayami and Ruttan, 1st ed., 1971; 2nd ed., 1985). We do not regard these models as stages. Rather, we regard them as alternative models. Each society typically achieves growth in agricultural output by drawing on several, or even all six, sources of growth.

In this paper I utilize the diffusion and high-payoff input models to interpret the post-Columbian exchange and the transition to a modern science-based system of generating growth in agricultural production. The definition of technical change includes both advances in biological (or biological and chemical) and advances in mechanical (or mechanical and engineering) technology. Advances in biological technology are largely directed at enhancing output per hectare.

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1. In premodern times agriculture was characterized by the continuous, although relatively slow development of agricultural tools, machines, plants, animals and husbandry practices. The rate of development was influenced by long-run patterns of population growth, income, and prices. For a review of the state of knowledge of change in agricultural technology in prehistory and ancient civilization see: Boserup (1981); van Bath (1963); Ishikawa, (1967).

The Diffusion Model

The diffusion of better husbandry practices and of crop and livestock varieties has been a major source of growth in agricultural production. The classical studies by Carl O. Sauer (1969) and N. I. Vavilov (1949/50) indicate that interregional and international diffusion of better husbandry practices, of crop varieties and livestock breeds, and of knowledge about tool making was a major source of growth even in prehistory.[2] Such diffusion must have been an important element in the evolution of preindustrial labor- and land-intensive conservation systems.

The process of intercontinental diffusion of plants and animals, and of pests and pathogens, was dramatically accelerated after the Columbian voyages of discovery. The transfer of new crops such as potatoes, maize, and tobacco from the new continents to Europe after the discovery of America had a dramatic impact on European agriculture and European consumption patterns. The transfer of crops such as sugarcane, and animals such as the cow and the horse, created both the incentive and the means for European colonists to open up the resources of the American continents to settlement and trade. The exchange of pathogens, such as the smallpox virus and the syphilis spirochete altered demographic history in both the New World and the Old (Crosby, 1972; Dovring, 1966).

Initially this diffusion took place as a by-product of discovery, trade, and travel. Over a long gestation period, after several decades or even centuries, exotic plants and techniques were gradually adapted to local conditions. But by the last half of the nineteenth century the process of plant exploration and discovery had become highly institutionalized. In the British Empire the effort was organized through a system of botanic gardens that were developed to facilitate the transfer, testing, and introduction of plant materials (Brockway, 1979). In the United States crop exploration and introduction became a major activity of the U.S. Department of Agriculture (Klose, 1950). Similar programs became an integral part of all the leading national agricultural research programs.

A second source of the diffusion approach to agricultural development draws on the empirical observation of substantial differences in land or labor productivity among farms

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2. For an engaging nontechnical account of advances in the study of plant origins and diffusion, see Anderson (1967). For useful references to livestock adaptation and diffusion, see Phillips (1948). For a useful review, see Harris (1967).

in any agricultural region, and among the more modern to the more traditional. The men whose research contributed to the evolution of the agricultural sciences were impressed with the innovations in methods of cultivation made by farmers themselves. Arthur Young, the ideologue of the English agricultural revolution in the eighteenth century, regarded such knowledge as the only foundation on which scientific farming could be based (Nõu, 1967). Liberty Hyde Bailey, writing a century later, insisted that:

"At the present time, every intelligent farmer is an experimenter... this cumulative body of experience of the best farmer is capable of yielding better results than similar work which might be undertaken at an experiment station. . . .An experiment station, which is necessarily constituted for scientific research, cannot touch many of the most vital problems of farming" (Bailey, 1896:130-31).

Even in nations with well-developed agricultural experimental station systems, a significant portion of the total effort, until fairly recently, was devoted to the testing and refinement of farmer innovations and to the testing and adaptation of exotic crop varieties and animal species. Even in the most advanced agricultural nations this activity contributed more to the growth of agricultural productivity than the more scientific work carried on by the experiment stations until at least the middle of the twentieth century.[3]

The diffusion model of agricultural development has provided the major intellectual foundation for much of the research and extension effort in farm management and production economics since the emergence, in the last half of the nineteenth century, of agricultural economics as a separate subdiscipline linking the agricultural sciences and economics. The developments that led to the establishment of active programs of farm management research and extension occurred at a time when experiment station research was making only a modest contribution to agricultural productivity growth. This led to a heavy emphasis on the economic analysis of farmer innovations. A stimulus for refinement in survey methods, accounting techniques, and statistical methods developed by farm management economists was the desire to determine with greater precision the sources of productivity and income differentials among farmers.[4]

A further contribution to the effective diffusion of known technology was provided by the research of rural sociologists and geographers on the diffusion process. Models were developed emphasizing the relationship between diffusion rates and the personality characteristics and the educational accomplishments of farm

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3. For a specific example, see Mosher (1962).
4. For a review of these developments in the United States, see Taylor and Taylor (1952:326-446).

operators (Rogers, 1969; 1983). The insights into the dynamics of the diffusion process contributed to the effectiveness of the agricultural extension service and strengthened the confidence of agricultural administrators and policymakers in the validity of the diffusion model. The pervasive acceptance of its validity, when coupled with the observation of wide agricultural productivity gaps among developed and less developed countries and with the firm presumption of inefficient resource allocation among "irrational tradition- bound" peasants, produced an extension bias in the choice of agricultural development strategy during the 1950s.[5] These programs were expected to transform tradition-bound peasants into "economic actors" who would respond more rationally to the technical opportunities that were available to them and who would reallocate resources more efficiently in response to economic incentives.

By the early years of the twentieth century the gains in agricultural production and productivity that could be realized by the direct diffusion of plants, animals, tools, machines, and practices had largely played itself out. It became more fruitful to view diffusion as involving three phases: (a) material transfer, (b) design transfer, and (c) capacity transfer.

The first phase is characterized by the simple transfer or import of new materials such as seeds, plants, animals, machines, and techniques associated with these materials. The naturalization of plants and animals, the local adaptation of borrowed technology, and the development of new machines tend to occur primarily as a result of trial and error by farmers, blacksmiths, and mechanics.[6]

In the second phase, the transfer of technology is primarily through the transfer of certain designs (e.g. blueprints, formulas, books). During this period the imports of exotic plant materials and foreign equipment are made in order to obtain new plant breeding materials or to copy equipment designs, rather than for their use in direct production. New plants and animals are subject to orderly tests and are propagated through systematic multiplication. Domestic production of the machines imported in the

5. This extension bias was partially based on the successful experience of transfer of hybrid corn (maize) technology from the United States to Western Europe under the Marshall Plan. This transfer was successful because the climate in parts of Western Europe is reasonably close to that in corn-producing areas in the United States, and there was indigenous human capital, in the form of agricultural scientists and technicians in Europe, to conduct adaptive research (Moseman,1970:66-67).

6. See, for example, Green and Hymer (1966). The crucial innovations leading to the rapid growth of Gold Coast cocoa production "were made in the 1880s by Ghanaians, and they succeeded in spite of, not because of, the colonial department's efforts," (p. 302); Dommen (1975); Clay (1980). For a discussion of the possible strengths and limitations of informal (in contrast to institutional) research and development see Biggs and Clay (1981).

previous phase is initiated. This phase usually corresponds to an early stage of evolution of publicly supported agricultural research.

In the third phase, the transfer of technology is made through the transfer of scientific knowledge and capacity which enable the production of locally adapted technology, following the "prototype" technology which exists abroad. Increasingly, plant and animal varieties are bred locally to adapt them to local ecological conditions. The imported machinery designs are modified in order to meet the climatic and soil requirements and factor endowments of the economy. An important element in the process of capacity transfer is the migration of agricultural scientists. In spite of advances in communications, diffusion of the ideas and craft of agricultural science depends heavily on extended personal contact and association. The transfer of scientists is often of critical importance to ease the constraint of the short supply of scientific and technical manpower in the less developed countries.[7] As we approach the end of the twentieth century, it is necessary to complete the transition of these countries into the capacity transfer phase.

The High-Payoff Input Model

The limitations of the diffusion model as a foundation for the generation of productivity growth became increasingly apparent as technical assistance and community development programs, based explicitly or implicitly on the diffusion model, failed to generate either rapid modernization of traditional farms or rapid growth in agricultural output. By the early 1960s the inadequacy of policies based on the diffusion model was leading to a reexamination of the assumptions regarding the availability of a body of agricultural technology that could be readily diffused from the high-productivity to the low-productivity countries and the existence of significant disequilibrium in the allocation of resources among progressive and lagging farmers in the developing economies.

The result was the emergence of a new perspective that agricultural technology is highly "location specific" and that techniques developed in advanced countries are not, in

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7. For insight into the relationships between the transfer of ideas and the migration of individuals and groups: see Scoville (1951); Redlich (1953); Solo (1966). For the policies of governments in developing countries toward encouraging multinational firms in establishing local research and development facilities, to upgrade local production, technical and management skills, and to purchase components from local suppliers. See Mansfield *et al.* (1982:14-24; 64-107).

most cases, directly transferable to less developed countries with different climates and different resource endowments. Evidence was also accumulated to the effect that only limited productivity gains are to be had by the reallocation of resources in traditional peasant agriculture.[8]

This iconoclastic perspective was developed most vigorously by Theodore W. Schultz in his book *Transforming Traditional Agriculture* (1964). In much of the social science literature the economic behavior of peasants had been dominated by the assumption of subsistence orientation. Economic relationships in peasant society had been viewed as organized by considerations of dependence and reciprocity rather than by market relationships. Schultz insisted that peasants in traditional agriculture are rational, efficient resource allocators and that they remain poor because in most poor countries there were only limited technical and economic opportunities to which they could respond.

In Schultz's opinion, the key to transforming a traditional agricultural sector into a productive source of economic growth is investment to make modern inputs available to farmers in poor countries. We term this view the high-payoff input model. According to Schultz (1964:145-47):

"Economic growth from the agricultural sector of a poor country depends predominantly upon the availability and price of modern (nontraditional) agricultural factors. . . . The principal sources of high productivity in modern agriculture are reproducible sources. They consist of particular material inputs and of skills and other capabilities required to use such inputs successfully. . . . But these modern material inputs are seldom ready-made. They can rarely be taken over and introduced into farming in a typically poor community in their present form. . . . There are very few reproducible agricultural factors in technically advanced countries that are ready-made for most poor communities. In general, what is available is a body of useful knowledge which has made it possible for the advanced countries to produce for their own use factors that are technically superior to those employed elsewhere. This body of knowledge can be used to develop similar, and as a rule superior, new factors appropriate to the biological and other conditions that are specific to the

8. See Hopper (1965); Massell (1967); Yotopoulos (1968a, 1968b). See also the review of studies of supply response in traditional agriculture by Krishna (1967). Many of the early tests of the hypothesis of allocative efficiency in peasant agriculture drew on Asian experience. For a study drawing on African experience, see Norman (1977).

agriculture of poor communities".

This implies three types of relatively high-productivity investments for agricultural development: (a) in the capacity of agricultural experiment stations to produce new technical knowledge; (b) in the capacity of the industrial sector to develop, produce, and market new technical inputs; and (c) in the capacity of farmers to use modern agricultural factors effectively.

The enthusiasm with which the high-payoff input model was accepted and translated into an economic doctrine has been substantially the result of the success of efforts to develop high-yielding modern grain varieties suitable for the tropics (Stakman *et al.*, 1967; Brown, 1970; Moseman, 1970). The high-yielding wheat and corn varieties were developed in Mexico, beginning in the 1950s, and high-yielding rice varieties in the Philippines in the 1960s. These varieties were highly responsive to industrial inputs, such as fertilizer and other chemicals, and to more effective soil and water management. The high returns associated with the adoption of the new varieties and the associated technical inputs and management practices led to rapid diffusion of the new varieties among farmers in a number of countries, primarily in Asia and Latin America. In contrast, in most countries in Africa, agricultural research systems are only recently becoming productive sources of new technology. The impact on farm production and income was sufficiently dramatic to be heralded as a "green revolution."[9] The significance of the high-payoff input model is that policies based on the model appear capable of generating a sufficiently high rate of agricultural growth to provide a basis for overall economic development consistent with modern population and income growth requirements.

As interpreted generally, the model is sufficiently inclusive to embrace the central concepts of the conservation, location, and diffusion models of agricultural development. Advances in conservation systems of agriculture as, for example, the Norfolk crop rotation as propagated in England in the eighteenth century, represented a new high

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9. Although the term "green revolution" is used at a number of points in this study to refer to the impact of the new cereals technology, our view is essentially similar to that of Dovring (1969): "Evidently there is no general consensus on the meaning of the term 'revolution.' This term has been overused to the point of losing any distinctive meaning." The use of the term "green revolution" to describe the new high-yielding cereals technology represents an interesting footnote in history of the international diffusion of terminology. The term was first suggested by the administrator of USAID, William Gaud, in an address to the Society for International Development, Washington (1968). Later the term became widely used in popular press accounts and in the professional literature. In the interwar period the term "green revolution" was used to refer to the radical peasant political movements in Eastern Europe. See Mitrany (1951).

-payoff input in that period. The rate of diffusion of agricultural technology can be viewed as a function of the profitability of the new inputs or techniques. The impact of urban-industrial development changes the relative profitability of alternative techniques through the growth of demand and the capacity to supply the new technical inputs. The unique implications of the model for agricultural development policy are the emphasis placed on accelerating the process of development and propagation of new inputs or techniques through public investment in scientific research and education.

Sustainable Growth in Agricultural Production: Into the Twenty-First Century

The world is now undergoing the most dramatic transition in agriculture since the beginning of the Columbian exchange. By the first decade of the next century almost all of the increases in world food production must come from increased output per hectare. In most of the world, the transition from a resource-based to a science-based system of agriculture -largely a result of the Mendelian revolution in genetics- is occurring within a single century. In a few countries this transition began in the nineteenth century, but for most of the currently developed countries it did not begin until the first half of this century. For most developing countries it did not begin until after the mid-century. In this section I summarize some of the conclusions from a series of three consultations that I have organized with support from the Rockefeller Foundation, to explore the constraints on sustainable growth in agricultural production into the twenty-first century.

Biological and Technical Constraints on Crop and Animal Production

It seems apparent that the gains in agricultural production required over the next quarter century will be achieved with much greater difficulty than in the immediate past. Difficulty is currently being experienced in raising yield ceilings for the cereal crops which have experienced rapid yield gains in the recent past. The incremental response to increases in fertilizer use has declined. Expansion of irrigated area has become more costly. Maintenance research, the research required to prevent yields from declining, is rising as a share of research effort (Plucknett and Smith, 1986). The institutional capacity to respond to these concerns is limited, even in the countries with the most effective national research and extension systems. Indeed, there has been considerable difficulty in many countries during the 1980s in maintaining the agricultural research capacity that had been established during the 1960s and 1970s (Cummings, 1989).

It is possible that within another decade, advances in basic knowledge will create new opportunities for advancing agricultural technology that will reverse the urgency of some of the above concerns. Institutionalization of private sector agricultural research capacity in some developing countries is beginning to complement public sector capacity (Pray, 1983). Advances in molecular biology and genetic engineering are occurring rapidly. But the date when these promising advances will be translated into productive technology seems to be receding.

The following general conclusions are from the first consultation on *Biological and Technical Constraints on Crop and Animal Productivity* (Ruttan, 1989).

Advances in conventional technology will remain the primary source of growth in crop and animal production over the next quarter century. Almost all increases in agricultural production over the next several decades must continue to come from further intensification of agricultural production on land that is presently devoted to crop and livestock production. Until well into the second decade of the next century the necessary gains in crop and animal productivity will be generated by improvements from conventional plant and animal breeding and from more intensive and efficient use of technical inputs including chemical fertilizers, pest control chemicals and more effective animal nutrition.

The productivity gains from conventional sources are likely to come in smaller increments than in the recent past. If they are to be realized, higher plant populations per unit area, new tillage practices, improved pest and disease control, more precise application of plant nutrients, and advances in soil and water management will be required. Gains from these sources will be crop, animal, and location specific. They will require closer articulation between the suppliers and users of new knowledge and new technology. These sources of yield gains will be extremely knowledge and information intensive. If they are to be realized, research and technology transfer efforts in the areas of information and management technology must become increasingly important sources of growth in crop and animal productivity.

Advances in conventional technology will be inadequate to sustain the demands that will be placed on agriculture as we move into the second decade of the next century and beyond. Advances in crop yields have come about primarily by (a) modifying plant architecture to facilitate increased plant populations per hectare and (b) by breeding to increase the individual plant grain to straw ratio rather than by increasing total dry matter production. Advances in animal feed efficiency have come largely by decreasing the proportion of feed consumed that is devoted to animal maintenance and increasing the proportion used to produce usable animal products. There are severe physiological constraints to continued improvement along these conventional paths. These constraints are most severe in those areas that have already achieved the highest levels of productivity as in Western Europe, North America, and parts of East Asia. The impact of these constraints can be measured in terms of declining incremental response to energy inputs both in the form of a reduction in the incremental yield increases from higher levels of fertilizer application, and a reduction in the incremental savings in labor inputs from the use of larger and more powerful mechanical equipment. If the incremental returns to agricultural research should also decline it will impose a higher priority on efficiency in the organization of research and on the allocation of research resources.

A reorientation of the way we organize agricultural research will be necessary in order to realize the opportunities for technical change being opened up by advances in microbiology and biochemistry. Advances in basic science, particularly in molecular biology and biochemistry, have and are continuing to open up new possibilities for supplementing traditional sources of plant and animal productivity growth. A wide range of possibilities were discussed at the consultation ranging from the transfer of growth hormones into fish to conversion of lignocellulose into edible plant and animal products. The realization of these possibilities will require a reorganization of agricultural research systems. An increasing share of the new knowledge generated by research will reach producers in the form of proprietary products or services. This means that incentives must be created to draw substantially more private sector resources into agricultural research. Within the public sector research organization will have to increasingly move from a "little science" to a "big science" mode of organization. Examples include the Rockefeller Foundation sponsored collaborative research program on the biotechnology of rice and the University of Minnesota program on the biotechnology of maize. In the absence of more focused research efforts, it seems likely that the promised gains in agricultural productivity from biotechnology will continue to recede.

Efforts to institutionalize agricultural research capacity in developing countries must be intensified. Crop and animal productivity levels in most developing countries remain well below the levels that are potentially feasible. Access to the conventional sources of productivity growth -from advances in plant breeding, agronomy, and soil and water management- will require the institutionalization of substantial agricultural research capacity for each crop or animal species of economic significance in each agroclimatic region. In a large number of developing countries this capacity is just beginning to be put in place. A number of countries that experienced substantial growth in capacity during the 1960s and 1970s have experienced an erosion of capacity in the 1980s. Even a relatively small country, producing a limited range of commodities under a limited range of agroclimatic conditions, will require a cadre of agricultural scientists in the 250-300 range. Countries that do not acquire adequate agricultural research capacity will not be able to meet the demands that they will place on their farmers as a result of growth in population and income.

Resource and Environmental Constraints on Sustainable Growth

As we look even further into the next century, there is a growing concern about the impact of a series of resource and environmental constraints that may seriously impinge on the capacity to sustain growth in agricultural production. A second consultation on issues of resource and environmental constraints on agricultural production that included scientists involved in climate change studies, agricultural scientists, and economists was held in late November of 1989 (Ruttan, 1992).

One set of concerns explored during the consultation focused on the impacts of agricultural production practices that will be employed in those areas which have made the most progress in moving toward highly intensive systems of agricultural production. These impacts include loss of soil resources due to erosion, waterlogging and salinization, groundwater contamination from plant nutrients and pesticides, and growing resistance of insects, weeds and pathogens to present methods of control. If agriculture is forced to continue to expand into more fragile environments, such problems as soil erosion and desertification can be expected to become more severe. Additional deforestation will intensify problems of soil loss and degradation of water quality, and contribute to the forcing of climate change.

A second set of concerns stem from the impact of industrialization on global climate and other environmental changes (Parry, 1990; Reilly and Bucklin, 1989). There can no longer be much doubt that the accumulation of carbon dioxide (CO_2) and other greenhouse gasses -principally methane (CH_4), nitrous oxide (N_20), and chlorofluorocarbons (CFCs)- has set in motion a process that will result in a rise in global average surface temperatures over the next 30-60 years. And there continues to be great uncertainty about the climate changes that can be expected to occur at any particular date or location in the future. It is almost certain, however, that the climate changes will be accompanied by rises in sea level and that these rises will impinge particularly heavily on island southeast Asia and the great river deltas of the region. Drier and more erratic climate regimes can be expected in interior South Asia and North America. As a partial offset, some analysts have suggested that higher CO_2 levels may have a positive effect on yield (Rosenberg, 1986).

In this section I discuss some of the research implications that emerged from the second consultation.

A serious effort to develop alternative land use, farming systems, and food system scenarios for the 21st century should be initiated. A clearer picture of the demands that are likely to be placed on agriculture over the next century and of the ways in which agricultural systems might be able to meet such demands has yet to be produced. World population could rise from the present 5 billion level to the 10-20 billion range. The demands that will be placed on agriculture will also depend on the rate of growth of income, particularly in the poor countries where consumers spend a relatively large share of income growth on subsistence, that is food, clothing, and housing. The resources and technology needed to increase agricultural production by a multiple of 3-6 will depend on both the constraints on resource availability that are likely to emerge and the rate of advance in knowledge. Advances in knowledge can permit the substitution of more abundance for increasingly scarce resources and reduce the resource constraints on commodity production. Past studies of potential climate change effects on agriculture have given insufficient attention to adaptive change in non-climate parameters. But application of advances in biological and chemical technology, which substitute knowledge for land, and advances in mechanical and engineering technology, which substitute knowledge for labor, have in the past been driven by increasingly favorable access to energy resources by declining energy prices. There will be strong incentive, by the early decades of the next century, to improve energy efficiency in agricultural production and utilization. Particular attention should be given to alternative and competing uses of land. Land-use transformation, from forest to agriculture, is presently contributing to radiative forcing through release of CO_2 and methane into the atmosphere. Conversion of low intensity agricultural systems to forest has been proposed as a method of absorbing CO_2. There will also be increasing demands on land use for watershed protection, and biomass energy production.

The capacity to monitor the agricultural sources and impacts of environmental change should be strengthened. It is a matter of serious concern that only in the last decade and a half has it been possible to estimate the magnitude and productivity effects of soil loss even in the United States. Even rudimentary data on productivity effects of soil loss are almost completely unavailable in most developing countries. The same point holds, with even greater force, for groundwater pollution, salinization, species loss and others. It is time to design the elements of a comprehensive agriculturally related resource monitoring system and to establish priorities for implementation. Data on the effects of environmental change on the health of individuals and communities is even less adequate. The monitoring should include a major focus on the effects of environmental change on human populations.

Lack of firm knowledge about the contribution of agricultural practices to the methane and nitrous oxide sources of greenhouse forcing was mentioned at numerous times during the consultation. Much closer collaboration between production-oriented agricultural scientists, ecologically trained biological scientists, and the physical scientists that have been traditionally concerned with global climate change is essential. This effort should be explicitly linked with the monitoring efforts currently being pursued under the auspices of the International Geosphere-Biosphere Programs (IGBP).

The design of technologies and institutions to achieve more efficient management of surface and groundwater resources will become increasingly important. During the next century water resources will become an increasingly serious constraint on agricultural production. Agricultural production is a major source of decline in the quality of both ground and surface water. Limited access to clean and uncontaminated water supplies is a major source of disease and poor health in many parts of the developing world and in the centrally planned economies. Global climate change can be expected to have a major differential impact on the water availability, water demand, erosion, salinization, and flooding. The development and introduction of technologies and management systems that enhance water use efficiency represents a high priority both because of short and intermediate term constraints on water availability and the longer term possibility of seasonal and geographical shifts in water availability. The identification, breeding, and introduction of water efficient crops for dryland and saline environments is potentially an important aspect of achieving greater water use-efficiency.

A food-system perspective should become an organizing principle for improvements in the performance of existing systems and for the design of new systems. The agricultural science community should be prepared, by the second quarter of the next century, to contribute to the design of alternative food systems. Many of these alternatives will include the use of plants other than the grain crops that now account for a major share of world feed and food production. Some of these alternatives will involve radical changes in food sources. Rogoff and Rawlins (1987) have described one such system based on lignocellulose both for animal feed and human consumption.

A major research program on incentive compatible institutional design should be *initiated.* The first research priority is to initiate a large-scale program of research on the design of institutions capable of implementing incentive compatible resource management policies and programs. By incentive compatible institutions I mean institutions capable of achieving compatibility between individual, organizational, and social objectives in resource management. A major source of the global warming and environmental pollution problem is the direct result of the operation of institutions which induce behavior by individuals, and public agencies that are not compatible with societal development -some might say survival- goals. In the absence of more efficient incentive compatible institutional design, the transaction costs involved in *ad hoc* approaches are likely to be enormous.

Health Constraints on Agricultural Development

The topic of the third consultation, held in June of 1990 focused on health constraints on agricultural development. (Ruttan, 1990). One might very well ask why this topic was included in a series of consultations on agricultural research. Since the mid-1960s a number of commonly used health indicators such as life expectancy and infant mortality experienced substantial improvement for almost all developing countries. Concerns about nutritional deficiency as a source of poor health have receded in a large number of developing countries in the last several decades (BOSTID/IOM, 1987; Commission on Health Research for Development, 1990).

Yet there are a number of other indicators that suggest that health constraints could become increasingly important by the early decades of the next century. Daily calorie intake per capita has been declining for as much as two decades in a number of African countries. While dramatic progress has been made in the control and reduction of losses due to infectious disease and in the control of diarrheal disease little progress has been made in the control of several important parasitic diseases. The sustainability of advances in malaria and tuberculosis control are causing serious concern. The emergence of AIDS, combined with the other health threats, could emerge as a major threat to economic viability in both developed and developing countries.

There is also a second set of health concerns arising out of the environmental consequences of the intensification of agricultural and industrial production that were discussed in the second consultation. As the environmental impacts of agricultural and industrial intensification become clearer it appears that they are already imposing significant health burdens in some countries, particularly in parts of the USSR and

Eastern Europe, and may become more burdensome in the future.

If one visualizes a number of these health threats emerging simultaneously in a number of countries it is not too difficult to construct a scenario in which there are large numbers of sick people in many villages around the world. The numbers could become large enough to be a serious constraint on food production capacity. It was this set of concerns that guided the dialogue in the third consultation.

Issues and Priorities for the Twenty-First Century

Evidence on the question raised at the beginning of the consultation -- does health represent a serious constraint on agricultural development? -- is at best ambiguous. Scattered data from countries such as India, Indonesia and Ivory Coast indicate loss of days worked due to sickness in the 5-15 % range. In the USSR and Poland substantial numbers of days of work are lost due to respiratory disease associated with atmospheric pollution.

There have been major "plagues" in the past that resulted in mortality levels sufficient to seriously impinge on food supply. In the fifteenth century, following the Spanish conquest, the Amerindian population in the basin of Mexico declined by something like 90 %. Most of the decline was due to a series of epidemics -- smallpox, measles, typhus and plague. Famine, associated with the high dependency to working adult ratio, probably accounted for 10-15 % of the population loss (Whitmore, 1992).

The population loss from most historical plagues in Europe and Asia were concentrated in the younger and oldest age groups rather than among the adult population of working age. Many adults had survived earlier attacks and had acquired some degree of immunity. The incidence of death from the European and Asian diseases introduced into the Americas was spread more evenly across the age distribution because everyone was equally susceptible. The AIDS plague is unique in that it is killing people who would be at their most productive age. The result will be a rise in the dependency ratio -- the ratio of the old and young relative to workers in the more productive age groups. There are important questions that have not yet been sorted out in the relationships between AIDS and other diseases. One apparent consequence of AIDS in East Africa is a rise in tuberculosis. The World Health Organization has an active program of cooperation with African and other high incidence AIDS countries in estimating HIV infection and AIDS incidence. A further step should be to model the direct and interaction effects on morbidity and on mortality of the simultaneous incidence of HIV infection and tropical parasitic and viral diseases.

Specific Issues

Let me now list some of the more specific research implications that emerged from the consultation.

The capacity to design systems of health delivery that are capable of reducing the incidence of illness continues to elude health policy and planning agencies in both developed and developing countries. The systems that are in place in most countries can be more accurately described as sickness recovery systems rather than health systems. They are health care rather than health maintenance systems. A major deficiency is the lack of a system for providing families and individuals with the knowledge needed to achieve better health with less reliance on the health care system. The point was made several times during the consultation that many countries have been able to design reasonably effective agricultural extension or technology transfer systems to provide farm people with the knowledge about resources and technology needed to achieve higher levels of productivity. But we have yet to design an effective system to provide families and individuals with the knowledge in the area of human biology, nutrition, and health practice that will enable them to lead more healthy lives.

The residuals produced as a by-product of industrial and agricultural production have become an increasingly important source of illness in a number of countries and regions. The most serious impacts are occurring in China and the formerly centrally planned economies of Eastern Europe and the USSR. Levels of atmospheric, water and soil pollution have resulted in higher mortality rates and reductions in life expectancy. The effects are evident in the form of congenital malformation, pulmonary malfunction and excessive heavy metals in soils and in crops grown on contaminated soils. Many of the health effects of agricultural and industrial intensification are due to inadequate investment in the technology needed to control or manage contaminants. Rapid industrial growth in poor countries, in which investment resources are severely limited, will continue to be accompanied by underinvestment in the technology needed to limit the release of contaminants. The situation that exists in Eastern Europe presents a vision of the future for many newly industrializing countries unless better technology can be made available and more effective management of environmental spillover effects can be implemented.

Lack of location or site-specific research capacities represent a major constraint on the capacity of health systems in most developing countries. It is no longer possible to maintain the position that health-related research results can simply be transferred from developed country research laboratories or pharmaceutical companies to practice in developing countries. Local capacity is needed for the identification and analyses of the sources of health problems. It is also needed for the analysis, design and testing of health delivery systems. The international donor community has been much slower in supporting the development of health research systems than agricultural research systems in the tropics. For example, there is now in place a network of more than a dozen international agricultural research centers (IARCs), sponsored by the Consultative Group on International Agricultural Research that play an important role in backstopping national agricultural research efforts.

The only comparable international supported center in the field of health is the Diarrheal Research Center in Bangladesh. Furthermore the capacity to conduct research on tropical infectious and parasitic diseases that was supported by the former colonial countries -United Kingdom, France, Netherlands and Belgium- has been allowed to atrophy.

High birth rates are both a consequence and a cause of poor health. The demographic transition from high to low birth rates has in the past usually followed a rise in child survival rates. This suggests that improvements in health, particularly of mothers and children, is a prerequisite for decline in population growth rates. But high population growth rates, particularly in areas of high population density are often associated with dietary deficiencies that contribute to poor health and high infant mortality rates.

The issue of how to achieve high levels of health and low birth rates at low cost in poor societies remains an unresolved issue. Several very low income countries have achieved relatively high levels of health -as measured by low infant mortality rates and high life expectancy rates- but often at high cost relative to per capita income. Other societies that have achieved relatively high incomes continue to exhibit relatively high infant mortality rates and only moderately high life expectancy levels.

More effective bridges must be built, both in research and in practice between the agricultural and health communities. At present these two "tribes", along with veterinary medicine and public health, occupy separate and often mutually hostile "island empires". But solutions to the problem of sustainable growth in agricultural production and improvement in the health of rural people and the consumers of agricultural commodities requires that each of these communities establish bridgeheads in the others territory. Multipurpose water resource development projects have contributed to the spread of onchocerciasis. Successful efforts to control the black fly have reopened productive lands to cultivation. The introduction of improved cultivars and fertilization practices have helped make the productivity growth sustainable. But examples of effective collaboration either in research, or in project development are difficult to come by.

Some Generic issues

I would like to list a set of four generic issues that ran through all three consultations.

The first is that many of the problems that we have discussed are international in scope. This means that many of the institutions that will be needed to enable societies to respond to the constraints on sustainable increases in agricultural production must involve international collaboration or transnational organization. We can no longer get by with slogans such as "Think globally and act locally". We will have to institutionalize the capacity to respond to scientific, technical, resource, environmental and health constraints. In the area of health, for example, it seems clear that almost every source of illness or poor health that exists somewhere -whether the source is an infectious organism or environmental change- will exist everywhere else. This statement may be an exaggeration, but it is only a slight exaggeration.

The second is our limited capacity to design the institutional infrastructure that will be needed to sustain the required rates of growth in agricultural production as we move through the first decades of the next century. We are going to have to build institutional infrastructures that facilitate more effective collaboration among engineers, agronomists and health scientists to deal with issues of production, environmental change, and the health of food producers and consumers. The social science disciplines and related professions (law, management, social service) have not demonstrated great capacity in the area of institutional design. Plant breeders have been much more effective. They do not just analyze the sources of yield differences, but utilize the agronomic and genetic knowledge that is obtained from their analyses to design improved cultivars, that is plants and animals that are responsive to management and that are resistant to the assaults of nature. In the social sciences, once we complete our analysis we feel that our job has been finished. We tend to stop at the level of analysis. We only rarely bring the knowledge we have acquired to bear on institutional design.

The third is that much more attention needs to be given to the design of both technologies and institutions that will broaden our options for choice or action. We noted, in our discussion, that the highest incidence of AIDS is likely to occur, at least during the next several decades, in those parts of the world where the technologies and institutions needed to sustain food production are exceedingly weak. Wider technical options will be needed in both food production and utilization.

The fourth is the inadequacy of our capacity to monitor changes in the sources of productivity change, environmental change, and the insults to health. We know very little about either the levels or the trajectories. We talk about soil erosion but we do not have the monitoring capacity to know the extent to which it is weakening our capacity to produce. We are fighting a defensive battle against the health effects of the contamination of our food supply rather than anticipating the sources. One of the puzzling aspects of the data that have become available so far is that the health effects of increased use of fertilizer is less than expected in spite of high levels of nitrate in surface and ground water. Neither the developed or developing countries have in place adequate surveillance systems for disease.

Perspective

My own perspective on agricultural futures is cautiously optimistic. The challenges posed by the constraints on crop and animal productivity and by the resource, environmental and health constraints on sustainability should not be interpreted as excessively pessimistic. The global agricultural research system, the technology supply industry, and farmers are much better equipped to confront the challenges of the future than they were when confronted with the food crises of the past.

It cannot be emphasized too strongly, however, that the challenges are both technical and institutional. The great institutional innovation of the nineteenth century was "the invention of the method of invention." The modern industrial research laboratory, the agricultural experiment station, and the research university were a product of this institutional innovation. But it was not until well after mid-century that national and international agricultural research institutions became firmly established in most developing countries. The twentieth century represents, therefore, a discreet break from the pattern of diffusion of agricultural practices and technology that was given such strong impetus by the Columbian encounter. The challenge to institutional innovation in the next century will be to design the institutions that can ameliorate the negative spillover into the soil, the water, and the atmosphere of the residuals from agricultural and industrial intensification.

The capacity to achieve sustainable growth in agricultural production and income will also depend on the changes that occur in the economic environment in which developing country farmers find themselves. The most favorable economic environment for releasing the constraints on crop and animal productivity and for achieving sustainable adaptation to the resource and environmental constraints that will impinge on LDC (less developed country) agriculture is one characterized by slow growth of population and by rapid growth of income and employment in the nonagricultural sector. Failure to achieve sustainable growth in the non-farm sector could place developing country farmers in a situation in which they can make adequate food and fiber available to the non-farm sector only at higher and higher prices -reversing the long-term trend- but in which the resources available to generate the investments in resource and technology development necessary to sustain growth are inadequate.

The importance of favorable growth in the non-farm economy is particularly important for the landless and near landless workers in the rain-fed upland areas which have been left behind by the advances associated with the seed-fertilizer-water technology of the last quarter century. Rapid growth in demand arising out of higher incomes, rather than from rapid population growth, can generate patterns of demand that permit farmers in these areas to diversify out of staple cereal production and into higher value crop and animal products. It may also permit the release of some of the more fragile lands from crop production to less intensive forms of land use.

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