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SEEDS OF SUSTAINABILITY
Seeds of Sustainability
Lessons from the Birthplace of the Green Revolution

Edited by
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TIMELINE FOR AGRICULTURAL DEVELOPMENT IN THE YAQUI VALLEY, 1890–2004

1890  The Ministry of Development grants to Carlos Conant the right to open irrigation channels on the margins of the Yaqui, Mayo, and Fuerte Rivers and to launch their colonization.

1891  Conant and US investors establish the Sonora and Sinaloa Irrigation Company to execute the contract for irrigation and colonization.

1900  The Sonora and Sinaloa Irrigation Company completes 39 km of channels from the Yaqui River.

1901  The Sonora and Sinaloa Company goes bankrupt.

1902  The Sonora and Sinaloa Irrigation Company and its shareholders reach an agreement on payments. The company pays its debt with land.

1903  Conant receives a new concession from the Ministry of Development to irrigate and colonize the Yaqui Valley.

1904  Conant begins the Compañía de Irrigación del Valle de Yaqui to accomplish development work in the valley.

The Sonora and Sinaloa Irrigation Company sells its rights to the Richardson Construction Company, a California-based land development company.

1907  Conant dies at the age of 63.

The railroad reaches the point known as Esperanza Station, which, years later, gives rise to Cuidad Obregón.

1909  Richardson Construction Company forms the Compañía Constructora Richardson and negotiates a new contract with the Ministry of Development regarding construction and colonization.

David Richardson begins a new company, the Yaqui Land and Water Company, with an initial capitalization of US$15 million. Esperanza Station grows to a population of 450.
1911 Compañía Constructora Richardson establishes an agricultural experiment station and publishes a crop calendar, including recommendations for 72 crops.

1913 Civil war extends into Sonora.

1914–17 Development in the Yaqui Valley is delayed because of the war.

1920 The government and the Yaqui people sign a peace agreement, concluding fifty years of intense warfare.

1925 Irrigated area increases from 15,000 to 37,000 ha.

1926 The government cancels the concession to the Compañía Constructura Richardson and buys its shares of the Yaqui Land and Water Company, paying US$6 million. The company turns all of its shares over to the government development bank.

1927 The State of Sonora declares the creation of Cajeme County.

1928 Agricultural producers organize a research station.

1928 The National Bank of Agricultural Credit takes over the irrigation system and land.

1930 Cajeme County (including Cuidad Obregón) grows to a population of 12,000.

1936 The National Bank of Agricultural Credit assumes control of development but later transfers control to the National Irrigation Commission.

1937 The government applies the Land Tenure Law and expropriates private land to distribute among new ejidatarios. Altogether, 17,000 ha of irrigated land is distributed to ejidatarios, with 27,000 ha remaining in the private sector. An additional 34,000 ha of new land is also allocated to ejidatarios.

The government launches the construction of the Angostura Dam.

1938 Farmers harvest 53,000 ha.

1940 Cajeme County grows to a population of 28,000.

1942 Angostura Dam is completed, adding an additional 60,000 ha of irrigated area.

1943 The government and the Rockefeller Foundation launch a collaborative agricultural research program, forerunner of the International Maize and Wheat Improvement Center (CIMMYT).
1950  Cajeme County grows to a population of 63,000.
1951  Wheat yields average 1.5 t/ha.
       The government creates the Yaqui Valley Irrigation District.
1953  Oviachic Dam is completed, adding 108,000 ha of irrigated area.
1955  Farmers in the Yaqui Valley harvest 210,000 ha of crops.
1960  Cajeme County grows to a population of 124,000.
1961  The government establishes the Instituto Nacional de
       Investigaciones Agrícolas (INIA), the National Institute of
       Agricultural Research.
1963  Improved seed from CIMMYT is first released to producers.
       El Novillo Dam is completed, mostly for electricity generation,
       but also allowing total Yaqui Valley irrigated area to grow to
       233,000 ha.
1964  100% of producers use improved seed.
1966  International Maize and Wheat Improvement Center
       (CIMMYT) is formally established as an international center.
1970  Cajeme County grows to a population of 183,000.
       Wheat yields average 3 t/ha.
1975  The government expropriates 34,000 ha of private irrigated
       land, which is transferred to new ejidos. The Yaqui Valley is thus
       divided among private landowners (41%), ejidatarios (55%), and
       colonists (4%).
1980  Cajeme County grows to a population of 256,000.
1990  Wheat yields average 5 t/ha.
1994  Whitefly invades the Yaqui Valley.
2000  Wheat yields average 6 t/ha.
1997–2004  Regional drought seriously depletes reservoir levels for the
           Yaqui Valley.
ACRONYMS

AOASS  Asociación de Organismos de Agricultores del Sur de Sonora (Association of Producer Organizations of Southern Sonora)

ASERCA  Apoyos y Servicios a la Comercialización Agropecuaria (Support and Services for Agricultural Marketing, Mexico)

BANCOMEXT  Banco Nacional de Comercio Exterior (National Bank for Foreign Trade, Mexico)

BANRURAL  Banco Nacional de Crédito Rural (National Rural Credit Bank, Mexico)

CGIAR  Consultative Group on International Agricultural Research

CIMMYT  Centro Internacional de Mejoramiento de Maíz y Trigo (International Maize and Wheat Improvement Center, Mexico)

CIRNO  Centro de Investigación Regional del Noroeste (Research Center for the Northwest Region, Mexico); formerly CIANO (Centro de Investigación Agrícola del Noroeste)

CNA  Comisión Nacional del Agua (National Water Commission, [CONAGUA] Mexico)

COFEPRIS  Comisión Federal para la Protección contra Riesgos Sanitarios (The Federal Commission for Protection Against Health Risks)

CONASUPO  Compañía Nacional de Subsistencias Populares (National Company of Basic Commodities, Mexico)

ENSO  El Niño-Southern Oscillation

EPA  Environmental Protection Agency (US)

EQIP  Environmental Quality Incentives Program (US)

FERTIMEX  Fertilizantes Mexicanos (Mexican Fertilizer Company, Mexico)

FIRA  Fideicomisos Instituidos en Relación con la Agricultura en el Banco de Mexico (Trust Fund for Agriculture, Mexico)
Acronyms

**FIRCO** Fideicomisos de Riesgo Compartido (Trust Fund for Shared Risk, operated by the Ministry of Agriculture, Mexico)

**FONAES** Fondo Nacional de Apoyo para Empresas en Solidaridad (National Fund for Social Enterprises, operated by the Department of Social Development, Mexico)

**GATT** General Agreement on Tariffs and Trade

**INEGI** Instituto Nacional de Estadística y Geografía (National Institute of Statistics and Geography)

**INIA** Instituto Nacional de Investigaciones Agrícolas (National Institute of Agricultural Research)

**INIFAP** Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (National Institute of Forestry, Agriculture, and Livestock Research)

**ITSON** Instituto Tecnológico de Sonora (Sonoran Institute of Technology)

**NAFTA** North American Free Trade Agreement

**NARS** National Agricultural Research System

**OECD** Organization for Economic Co-operation and Development (Paris, France)

**OSHA** Occupational Safety and Health Administration (US)

**PAIS** Programa Agrario Integral de Sonora (Integral Agrarian Program of Sonora, Mexico)

**PEMEX** Petróleos Mexicanos (Mexican Petroleum Company, Mexico)

**PIEAES** Patronato para la Investigación y Experimentación Agrícola del Estado de Sonora (Agricultural Research and Experimentation Board of the State of Sonora)

**PROCAMPO** Programa de Apoyos Directos al Campo (Direct Farmer Support Program, Mexico)

**PROCEDE** Program de Certificación de Derechos Ejidales y Titulación de Solares Urbanos (Program for the Certification of Ejido Land Rights and the Titling of Urban House Plots, Mexico)

**SAGARPA** Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (Ministry of Agriculture, Livestock, Rural Development, Fisheries, and Food, Mexico)

**SEMARNAT** Secretaría del Medio Ambiente y Recursos Naturales (Ministry of the Environment and Natural Resources, Mexico)

**WTO** World Trade Organization
This book is being completed in the second half of 2010, but the story it tells stretches from the early part of the 1990s until the late 2000s. It is a story about an agricultural region in the very early stages of what we hope will be a sustainability transition. It is also about the interdisciplinary team effort to which we devoted our time and energy for many years, an effort that has resulted in some important things—scientific discoveries, new management tools for crop production and water resource management that are now used well beyond the Yaqui Valley itself, new perspectives on how knowledge and action can be most effectively linked, new insights into interdisciplinary research and outreach, and new insights into sustainability transitions. It is also a story about frustrations—research that didn’t get done, relationships that we struggled to develop and maintain, knowledge that we could not link with action. Despite those frustrations, this has been an exciting and useful project, and we hope the book communicates some of that.

The operational origins of the Yaqui Valley project trace to an event in 1992. During the summer of that year, Rosamond (Roz) Naylor (an economist) and I (a biogeochemist) hosted a two-week workshop at the Aspen Institute for Global Change. Each year, the Aspen Institute tackles interdisciplinary issues related to global environmental change, and among its goals is the hope of improving the interactions between natural and social scientists in order to address these issues. The focus of this particular workshop—at the interface of food, agriculture, and environmental issues—was an outgrowth of discussions at a biweekly forum of environmental faculty from all disciplines that Roz had begun at Stanford University three years earlier. The institute’s twenty plus participants included Peter Vitousek, a Stanford biologist, Walter Falcon, a Stanford economist, and Donald Winkelman, an economist who was then the director general of the International Maize and Wheat Improvement Center (CIMMYT) headquartered in Mexico. All were critical to making this project a reality. G. Philip Robertson, an ecosystem ecologist at Kellogg Biological Station (Michigan State University) with enormous experience in agricultural
systems, was also a major and influential player in these discussions, and there were many other social and biophysical scientists as well.

Discussions at Aspen were provocative and wide ranging. After amusing and sometimes exasperating interchanges, for example, on the meanings of productivity in our different professional languages, we found common cause in sustainability issues related to nitrogen fertilizer and its agronomic and environmental effects, irrigation, and agricultural policy. We also found common cause in our focus on high-productivity agricultural systems of the type that now feed most of the planet’s people, even though we realized that sustainability challenges might be more easily addressed in small, local, and even subsistence systems where decisions are less externally driven. Several research proposals were roughed out during the discussions at Aspen, but interestingly, the Yaqui Valley per se played no role in them.

The location issue was resolved in a second key meeting held at CIMMYT headquarters in Texcoco, Mexico. As a follow-up to Aspen, Winkelmann invited several of us to Mexico in 1993 to interact with members of his professional staff, especially those from the wheat program. CIMMYT was beginning to move more aggressively on environmental questions, and the head of the wheat program at the time, Anthony Fisher, felt that collaboration with Stanford might prove both scientifically and politically valuable. Soon the discussion moved to who and where questions. Those questions were answered simultaneously with the inclusion of Ivan Ortiz-Monasterio, a senior CIMMYT agronomist located in the Yaqui Valley at CIMMYT’s premier wheat experiment station. In the years that followed, Ortiz-Monasterio became the lynchpin in the leadership trio, serving as both research coleader and our most critical boundary-spanning individual, linking our research community with the farmers and decision makers of the valley, who are his friends.

Those early discussions across disciplines and across nations were critical to launching this project, but they were leavened by other critical influences that helped the project evolve. Perhaps most important for me was my involvement as a board member of the National Research Council’s (NRC) Board on Sustainable Development, starting in 1994 and extending through 2000, and then as a leader of the NRC Roundtable on Science and Technology for Sustainability through the 2000s. Those roles challenged me to see the world through the eyes of the many other member experts, all of whom represented different disciplines and walks of life related to sustainable development and environment. Most critical of those members were Robert Kates, geographer emeritus from Clark University and the
cochair of the NRC board, and William Clark, the Harvey Brooks Professor of International Science, Public Policy, and Human Development at the Kennedy School at Harvard University. Their early engagement in, and encouragement of, the Yaqui research helped lay the groundwork for much of the most integrative research that followed. Indeed, Bill Clark played an instrumental role throughout this project, especially in the knowledge systems research and vulnerability research discussed in this book. At the same time, I think it is fair to say that the Yaqui Project, a real honest-to-goodness, on-the-ground project, brought real-life experiences and perspectives to ground the board and roundtable discussions, and influenced the work of subsequent projects and committees. Ultimately, I hope that it contributed to the emergence of the field of sustainability science and encouraged others to work within place-based, human-environment systems in a quest for sustainability.

Other influences were also critical. The perspectives of the International Geosphere-Biosphere (IGBP) and Human Dimensions of Global Change Programs (IHDP) underlay much of our early interest in greenhouse gases, agriculture, and land-use change, and NASA’s land-use/landcover change program funded some of the early research. Perspectives from the Consultative Group on International Agricultural Research (CGIAR), of which Wally Falcon was a board member, influenced our perspectives on food security, food production, and sustainable agriculture. Roz Naylor and Ivan Ortiz-Monasterio brought their expertise on different dimensions of those perspectives as well as their enthusiasm for interdisciplinary problem solving. CIMMYT and its leaders made it possible to do the work.

For me personally, my husband and Stanford professor Peter Vitousek was a continuing and most important influence. He is an ecosystem ecologist and a global change scientist who has an uncanny ability to see the whole system and to identify the really important things to be done. He helped launch this project, advised throughout, read many manuscript drafts (including parts of this book), and with our kids, Mat and Liana, held down the fort at home during my many trips to the Yaqui Valley. Wally Falcon was a research team member but so much more—his savvy in the international agricultural world made many things possible, his wisdom kept us on track, and his writing abilities helped us to both find funding and get the word out. In addition to the authors of this book, Stephen Gorelick, a hydrologist, Karen Seto, a geographer, and Steven Monismith, a physical oceanographer, all professors at Stanford, brought their knowledge and expertise and ideas and great students to the project, as did Tracy Benning, Greg Asner, and many other scientist friends. José Luis Minjares
of the Mexican Water Commission and Carlos Valdes-Casillas, who was at the Monterey Technical Institute in our early years, brought management reality to much that we did, and José Luis, along with Ivan, were essential linkers of knowledge and action.

Of course, there were many other people from Mexico and the United States who made the project work; the individual chapters of this book include acknowledgments of them. My personal thanks go to Peter Jewett, who managed the Matson lab through much of the research and has played a critical role in getting this book to press, and to Tina Billow, who managed in the start-up phase and in the “buried-in-data” stage, keeping multiple projects going in the field and lab. Lori McVay was our administrative leader throughout, and Ashley Dean, our research coordinator for much of the project; without them we could not have grown and expanded in the way we did. Mary Smith helped make our meetings happen efficiently and with great fun. These, our students and post docs, and countless other people made the Yaqui Project vibrant, and its successes are thanks to them. Finally, a great many funding sources made this work possible; they are listed in individual chapter acknowledgments, and include the Packard Foundation, the USDA, NASA, NOAA, and NSF, the Ford Foundation, the Pew Charitable Trusts, the Hewlett Foundation, the Andrew Mellon Foundation, and the MacArthur Foundation (whose generous fellowship to me helped give me the freedom to start down this road). The Packard Foundation provided the critical support that allowed us to develop an interdisciplinary effort rather than a project with many disciplinary pieces, and it also supported the synthesis effort that resulted in this book as well as other outreach products.

We hope that the contributions discussed in this book are lasting ones, both to the Yaqui Valley and, more broadly, to the field of sustainability science.

Pamela Matson
PART I

The Birthplace of the Green Revolution
Chapter 1

Why the Yaqui Valley? An Introduction

Pamela Matson and Walter Falcon

There are few agricultural regions in the world more interesting and important than the Yaqui Valley in Sonora, Mexico. The Yaqui River Basin has supported agriculture for many centuries, but the story we focus on is modern. The valley is the birthplace of the green revolution, and it is now one of the most intensive agricultural regions of the world, using irrigation water, fertilizers, constantly improving cultivars, and other inputs to produce some of the highest yields of wheat anywhere. It is one of Mexico’s main breadbaskets and also a global supplier of seeds and grain. In this, the Yaqui Valley provides a story of agricultural and economic development that is emulated and reflected the world over. But over the past several decades, its story has also become one of environmental, resource, economic, and social challenges related to water resources, air and water pollution, impacts of global environmental and policy changes, human health concerns, biodiversity conservation, and climate change. As these two story lines have merged, this region has had to evolve and change. It is this story of early steps in a sustainability transition—a transition at the interface of environment and development—in which we engaged through our integrative research and outreach. It is this story that we hope to tell in this book.

Sustainability is a complex concept, one with multiple definitions and goals. In its report titled Our Common Journey, the National Research Council (NRC 1999) defined sustainability broadly as the goal of meeting
the needs of people today and in the future while (and by) protecting the life support systems of the planet. As we use it here, in the context of transitions in the Yaqui Valley, we encompass the goals of improving and enhancing food, fiber, and potentially even biofuel production, protecting the economic and social welfare of the people of the region, and sustaining its resource base and environment on land and in the sea.

Worldwide, the sustainability challenges of agriculture and food security are enormous, given the need to feed a still-growing human population that is likely to plateau at near nine billion by the middle of this century. Today, in 2010, scientific concern about this challenge can be seen in the pages and special issues of Science and Nature magazines, among many other venues. Taken together, the growing food demand associated with population growth; alleviation of hunger and increased consumption of meat and dairy; the increasing competition of agricultural lands for other uses; the increasingly clear evidence that agriculture drives negative environmental and human health changes at local to global scales; and the growing, serious concern about the effects of climate change on crop systems have called for a worldwide research effort to address agricultural sustainability and food security (for recent reviews and analyses of these issues, see IASSTD 2009; Royal Society 2009; Godfray et al. 2010; Federoff et al. 2010; NRC 2010a, to name just a few).

Agricultural sustainability challenges potentially can be addressed through a variety of approaches, including, for example, new breeding technologies, including the development of genetically modified crops; new kinds of integrative crop-livestock systems; precision agriculture (both “high tech” remote sensing and computer-based mechanized approaches as recently described in Gebbers and Adamchuk [2010] as well as lower tech approaches that use information to increase input efficiency); agroecosystem approaches that seek to use soil, water, and light resources to maximize and increase efficiency of production while reducing environmental negatives; and new, more efficient aquacultural systems. While all of these can contribute to sustainability goals, none can do the job everywhere nor be implemented overnight to achieve sustainability. In the Yaqui Valley as in most agricultural systems, sustainability is not an end point that can be defined or that is likely to be achieved in the near term, but rather a process of developing options and making choices that increasingly honor these multiple goals, and that make progress toward all of them. The Yaqui Valley is still in the early phases of its transition to sustainability, but these first steps are important.

Our story is about these seeds of a sustainability transition in an agricultural region, but the things we’ve learned—about implementing win-
win opportunities, or knowledge systems for sustainable development, or vulnerability analyses of human-environment systems, for example—are relevant to many other sustainability efforts outside of agriculture. Likewise, what we have learned about the role and contributions of multi- and interdisciplinary research in developing options and supporting implementation of them speaks to sustainability science and development efforts more generally.

The Story of Agriculture in the Yaqui Valley

In our research in the Yaqui Valley, our primary focus was the dynamic human-environment systems in irrigated agriculture and nearby land and ocean systems, as they functioned between 1993 and 2008 at the end of the green revolution and the beginning of what Gordon Conway calls the “doubly green revolution” (Conway 1997). The longer story of agriculture in the valley is, however, of importance to the more recent past; chapter 2 provides a detailed history, but an abbreviated version will be useful in this introduction to the book.

Located on the northwest coast of mainland Mexico, bound by the Gulf of California to the west and the Sierra Madre Occidental foothills to the north and east (fig. 1.1), this productive coastal plain has been inhabited for thousands of years by the indigenous Yaqui Amerindians. For centuries, the Yaquis fought against and ultimately lost to the encroachment of Spanish and Mexican colonists interested in their fertile lands and silver resources. The introduction of foreign investment and irrigation in the 1890s and early 1900s laid the foundation for what would be the most intensively irrigated agricultural land in Mexico that now covers 233,000 hectares. The establishment in the 1930s (and thereafter) of a substantial number of ejido (collective) farming units, in addition to private landowners, the Yaqui Amerindians, and foreign investors, made for unusually diverse groups and interests within the region.

In the mid-twentieth century, the Mexican government and the international development community identified the Yaqui Valley as an appropriate center for agricultural research and development, given that it is agroclimatically representative of about 40 percent of wheat growing areas in developing countries. Led by Norman Borlaug and an international team of scientists, the wheat research program promoted intensive technologies such as new high-yielding crop varieties, large-scale irrigation, fertilization, and pesticides. The results—a dramatic increase in grain production that supported Mexico’s transition to self-sufficiency in wheat production and
the direct transfer of semidwarf wheat technology to South Asia in the late 1960s—gave the valley its recognition as the home of the green revolution for wheat. However, agricultural development in the region was not the only story of change. Rapid population growth focused in cities, major development of fisheries, the engagement of the international conservation community in the adjacent oceans, the development of coastal aquaculture, and the rapid increase in livestock operations were likewise a part of the story in the valley and surrounding regions. By the time our research team entered the picture, these changes were under way.

The period of the 1990s and early 2000s, however, involved further changes, and many of them were especially challenging for Yaqui citizens, especially farmers. An eight-year drought (1997–2004), coupled with questionable irrigation procedures, literally drained the valley’s irrigation reservoirs dry, and raised questions about vulnerability of water resources in the context of future climate changes. Fertilizer use increased, but so too did nitrogen losses in the form of greenhouse gas and air pollutant
emissions to the atmosphere as well as water pollutants. Crop diseases and pests came, but rarely went, causing for example the complete loss of soybeans from cropping rotations. Major changes in Mexican macroeconomic policy, Mexico’s entry into the North American Free Trade Association (NAFTA), and booms and busts in international commodity markets created new forms of economic uncertainty in a valley that had previously led a very “policy-protected” life.

Constitutional changes expanded the ways in which ejidatarios (small communal farmers) could rent and sell their land, but also made them more vulnerable to other market-oriented policies on credit and fertilizer. Many aspects of the irrigation system were decentralized from federal to state and valley organizations, giving local farmers more authority, but also more responsibility for the ways in which water systems were managed. Agricultural extension shifted from federal hands to those of farmer unions. Attempts at diversification into fruits, vegetables, livestock, and aquaculture solved some problems, but created other ecological and economic dilemmas in the process.

These physical, economic, environmental, and social changes greatly complicated life in the Yaqui Valley. They also complicated our research efforts, but at the same time made those efforts more interesting and valuable. Change was happening so rapidly that Yaqui residents eagerly sought out the results of our studies, but the fast pace also made it difficult to establish sensible research priorities, let alone to fund them. For all of its limitations, however, the research program reported on in this volume was quite remarkable. Much place-based research is based on a single snapshot in time. We do not have a complete historical movie of the Yaqui Valley, but we do have a fairly complete ten-plus year video clip.

Integrative Research in the Valley

The choice of the Yaqui Valley as the focus of our research effort was in some ways just good luck (see the preface for more on the origins of the project), but after the fact, it proved to be an excellent choice. It is a region small enough to be understood, yet large enough to be interesting. It is a region that represents the kind of high-productivity, surplus agricultural system that is key to feeding billions of people; indeed, we explicitly chose this kind of system, in contrast to small scale, localized, or subsistence systems, even though sustainability decisions in the valley were likely to be more complicated and externally controlled. It is a region that makes
connectivity—between land and ocean, land and air, water and food, country and country, peso and dollar—very obvious.

The Yaqui Valley was also an excellent choice for our research because it has been a focus of disciplinary research, mostly agronomic, for decades. As the location of the primary field station of the International Maize and Wheat Improvement Center (CIMMYT), one of the major centers of the Consultative Group on International Agricultural Research (CGIAR) system, it has accumulated more than thirty years of knowledge. CIMMYT field research and survey data on valley farmers and on wheat technology provided a wonderful base from which to build our research. The federal government has also been conducting agricultural research through the National Institute of Forestry, Agriculture, and Livestock Research (INIFAP). INIFAP operates eight regional agricultural research centers throughout Mexico, including one in the Yaqui Valley (Research Center for the Northwest Region, Mexico [CIRNO]). CIRNO works closely with CIMMYT to further research on genetic improvement, production technology, pest management, new cropping options, and irrigation technology. Also, the farmer-owned Agricultural Research and Experimentation Board of the State of Sonora (PIEAES, known locally as the Patronato) receives breeder quality lines from CIRNO and sells them to farmer organizations who produce registered seeds. And perhaps the most important actors engaged in agriculture research are the farmers themselves—particularly a set of innovative farmers that routinely collaborate with CIMMYT and CIRNO scientists—and the credit organizations that represent them. The National Water Commission (CNA) also carries out research in support of water for irrigation, and universities such as the Sonoran Institute of Technology (ITSON) and the Monterey Technological Institute conduct research in agronomics and related areas, especially natural resources and coastal zone management.

With all this research strength, one might wonder what our multidisciplinary team of researchers from the United States and Mexico could offer. The answer, quite simply, was an integrative systems perspective. We started with a focus on the human-environment systems of the place, and an interest at the interface of crop yields, economic gains, fertilizer use, and environmental implications. Before long, as our understanding of the valley’s challenges became clear and as our team grew, we focused on irrigation management, aquaculture development, Mexican and international economic and agricultural policies as they affected the valley, environmental links between the irrigated valley and the coast and the Gulf of California, diversification of crops, and climate change and vulnerability
in the agricultural sector, and others. It did not take long to see that many if not all of these issues were connected, and that the Yaqui Valley was an excellent place to analyze and understand them as a system, perhaps doing something to help manage them sustainably. We did not start with the intention of developing a broad, decade-long analysis of sustainability in the valley, or of engaging with decision makers across such a broad range of issues, but our research took us there. Over time we saw that there is no better place to evaluate where progressive agricultural systems were headed technologically; to view the effects of globalization and the impact of NAFTA; to make the connections between agriculture, resource use, and environmental impacts; to engage in efforts to share new knowledge in decision making; and to understand those knowledge-to-action linkages, than in the Yaqui Valley.

This work was completed through the support of many different projects by many different funding organizations (see the preface for details). The need for multiple funding sources complicated the knowledge-generation process. Some critical pieces were never funded, frustrating our desire to understand a more complete story and provide more useful information. The time perspective and the long-term nature of the inquiry were crucial, but also called for an almost constant search for funding. Learning and modification of ideas took place in laboratories, at the experimentation station, on farmers’ fields, in scores of meetings with growers and other decision makers, and in regular team meetings both in the Yaqui Valley and at Stanford University. While the research elements at times appeared disjointed, they emerged logically and often built upon each other as they progressed. The individual subprojects were well done, and their outcomes have stood alone as published research papers as well as new models, tools, and management approaches. While it may be that these individual products yielding from these projects have mattered most to decision making in the valley, it is the sum total that best tells the story of the valley in transition.

In subtext, this book also tells the story of a changing and growing team of researchers trying to move from simply understanding the challenges being faced by the people and ecosystems of the valley to assisting in addressing those challenges. How, over time, did agronomists, biogeochemists, economists, ecologists, engineers, oceanographers, geographers, hydrologists, and other scientists decide to work together to analyze and help solve problems? How did we interact with farmers and other decision makers of the valley, and how did the flow of information among us all determine which problems were chosen and why? How was the research
funded as problems and funding agendas changed? And what research lessons were learned, both positive and negative, from a research effort that covered more than a decade and cost several millions of dollars?

The relatively long-term extent of the project proved the importance of working in one place continuously, and for a long time; had the inquiry stopped in 1998, or even 2002, our understanding of the interface between economics and environmental issues of the valley would have been substantially more limited. Nevertheless, it is clear that the full story of the Yaqui Valley is not ours to grasp. The valley continues to change, and some, perhaps much, of what we learned during our years of joint study and engagement has become outdated. We seek, therefore, to share through this book some of the general learning and more generally useful information, perspectives, and research approaches, along with the specific knowledge that was useful at a given time and place.

Organization of the Book

We tell the story of the last few decades of agricultural development and environment in the Yaqui Valley in several parts. In this first section, we introduce the reasons for working on these issues and in this valley, and, in chapter 2, we set the valley in historical perspective. Then, in the second part—chapters 3 through 7—we tell the interdisciplinary, integrative stories that motivated much of our work. We asked, for example, whether win-win-win solutions, for economics, agronomics, and environment, are possible in the wheat fields of the Yaqui Valley, and what would be needed to make them a reality (chap. 3). This is the project that got us started, and it eventually led to new management approaches that are perhaps first steps for this valley in terms of sustainability transitions. However, this study’s initial contribution was to show how research teams of economists, agronomists, and environmental scientists, working together, could advance science and also support decision makers. We tested the idea that intensive agriculture “spares land for nature”—that is, that carrying out agriculture very intensively (with high productivity) in some places allows and leads to less additional conversion of natural ecosystems to agriculture (chap. 4). We found that, at least when evaluated at the regional scale, intensification has direct causal links to off-site activities that have negative impacts on natural systems, and concluded that, if one is worrying about sparing land for nature, intensification is necessary but not sufficient. One has to protect land for nature purposefully, not as an assumed by-product of intensification.
We studied and evaluated the knowledge system of the Yaqui Valley, trying to understand the most critical dynamics by which new knowledge is linked to decision making, and in doing so, learned much about our own role in the knowledge system (chap. 5). We built on our knowledge of the human-environment system of the Yaqui Valley agriculture and water sectors to develop approaches by which to evaluate vulnerability (the likelihood of people and ecosystems suffering harm) to forces such as climate changes or policy changes (chap. 6). Finally, we explored the links between land and sea, including the drivers and consequences of rapid aquacultural development as well as agricultural intensification (chap. 7). These integrative, interdisciplinary studies helped us develop an understanding of the valley that went beyond what was happening to cropping systems and the producers that managed them. They also provided data and perspectives that were then generalized through comparative analyses with other places around the globe. Indeed, the development of the Yaqui Valley as a case study has had implications for understanding and managing human-environment systems that extend well beyond the valley margins.

The third major part of the book, chapters 8 through 11, provides some of the deep knowledge base that was developed about components of the Yaqui Valley system and underlies the interdisciplinary analyses about the Yaqui human-environment systems. Issues such as macroagricultural policies (chap. 8), crop management systems (chap. 9), fertilizer use and nitrogen flows from land to the sea (chap. 10), and water resource development and management (chap. 11) are dealt with in detail, representing many years of research and the involvement of many researchers; they also provide the building blocks with which the most interdisciplinary questions could be addressed. Although the chapters in this third part present research and new knowledge that cuts across sectors or institutions or landscapes and are thus themselves integrative in sometimes unique ways, they tend to be more narrowly and more disciplinarily focused than the chapters in the second part. Thus, they will be useful to students and researchers who are pursuing disciplinary analyses (for example, in agricultural policy, biogeochemistry, agronomy, or water resources research) as well as those who are interdisciplinary.

The final part of the book—chapter 12—provides a brief, retrospective glance at what we have learned, and failed to learn, in the project overall. In this chapter, we also reflect on our role as researchers in the knowledge system of the Yaqui Valley, the challenges of interdisciplinary research, and the successes, and more often the inadequacies, of our attempts to link knowledge to action for sustainability transitions in the valley.
All but one of these chapters is authored by two or more members of our research team. These author lists indicate the lead members of the research teams involved in our studies, but they are not inclusive of every participant in the research. Indeed, it is fair to say that every author of this book was involved, in one way or another, in every aspect of the research described here, and many important players are not listed as authors at all. Acknowledgments in each chapter attempt to recognize the many contributors, but we no doubt have missed some.

We have endeavored in this book to tell a coherent story of our substantive findings. To do so, we chose to write new chapters from scratch, rather than simply compiling previously published articles. Each of these chapters is meant to contribute to the broad, overarching view of transitions in the Yaqui Valley, but each can also be read alone, depending on the reader’s interest. Whether the reader chooses to read part or all, we hope that our experiences in the valley provide ideas, insights, and knowledge that will be useful to those interested in transitions to sustainability.