Integrative Analyses of Human-Environment Systems

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Integrative Analyses of Human-Environment Systems:

Intensive Agriculture, Environmental Change, and Sustainability in the Yaqui Valley, Mexico

Team members:

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Wally Falcon, Amy Luers, David Lobell, Lee Adamms, Greg Asner, Karen Seto, Esther Cruz, Jose Luis Minjares, Steve Gorelick, John Harrison, Mike Beman, Bill Riley, Ellen McCullough, Jeanne Panek, Toby Ahrens, Steve Monismith, David Battisti, Peter Jewett, and many others
Roz’s perspective (in 1990):
Food production and rural poverty

Ivan’s perspective:
Yields and input efficiency in developing world agriculture

Pam’s perspective:
Understanding global environmental change
Global Environmental Changes Resulting from Human Activities

- Atmospheric changes
- Climate change
- Land cover and land use changes
- Biodiversity loss
- Loss of ecosystem services
- Water resources limitations
- Soil degradation
- Change in biogeochemical cycles
Consequences for nitrogen and carbon cycling??
What about tropical agriculture and fertilizer use?
Measured Changes in GHGs

- Carbon Dioxide (ppm)
- Nitrous Oxide (ppb)
- Methane (ppb)

IPCC (2001)
Roz’s perspective (in 1990):
Food production and rural poverty

Ivan’s perspective:
Yields and input efficiency in developing world agriculture

Pam’s perspective:
Understanding global environmental change
“Food, Conservation, and Environment: Is Compromise Possible?”

Aspen Global Change Institute  1992

ecologists, biogeochemists, atm scientists, geographers, economists, ag development, agronomists, etc
Agricultural Sustainability in the Yaqui Valley
The Yaqui Valley --
“the home of the Green Revolution”

Figure 3. Comparison of world wheat yields to the Yaqui Valley.
Source: FAO Production Yearbook, CIMMYT.
Area sown to variety\textsuperscript{a}  

Yaqui Valley, Mexico

\begin{itemize}
  \item Jupateco-73
  \item Nacozari-76
  \item Ciano-79
  \item Genaro-81
  \item Seri-82
  \item Opata-86
\end{itemize}

\textsuperscript{a} Bread wheat varieties only. Durum area was important in the late 1980s.
Rate of Nitrogen Application on Wheat

Uso de Nitrogeno en Trigo

Kg N/ha

Year - Ano


64% 84% 100% 100%

Percentage represents the proportion of the area that is fertilized
DEVIATION FROM MEDIAN RESERVOIR INFLOW (MCM)
(1965-2003)
1992

2003
Our first question:
Can fertilizer be managed to maintain yields but reduce environmental degradation in the Yaqui Valley?

What are the biogeochemical consequences?

How and why do farmers fertilize as they do?

What alternatives are possible win-wins?
Fertilizer Use and Loss

Urea

Soil Organic Matter

NH$_4^+$

NO$_3^-$

NH$_3$ → NO → N$_2$O → N$_2$

NH$_4^+$ → NO$_3^-$ → N$_2$O → N$_2$

Nitrification

Denitrification
Nitrogen trace gas losses during the wheat season

Simulated Farmer’s Practice

-- 1995
-- 1996

Matson et al 1998
Nitrification produces half of trace N flux

Panek et al 1999
20-50 kg/ha/6 mo wheat cycle x area of wheat = N flux in solution

Riley et al 2001
Irrigation events

Chlorophyll

Sea Surface Temp

Residual Chlorophyll
Run-off of fertilizer nitrogen causes coastal over-enrichment and phytoplankton blooms

Beman, Arrigo and Matson 2005
Archaeal amoA

- From 2 sequences to 400++ and counting
- Ubiquitous in the ocean
- Diverse
- Found where nitrification is known to be important

Francis et al 2005 PNAS
Nitrogen Interactions

NH4 and NO3⁻ Input to Marine Ecosystems

Marine Ecosystems

NO3⁻ in Surface and Groundwater

NO3⁻ Input to Marine Ecosystems

N₂O (Global Impact)

Downstream

NO

Urban

NOx

N Deposition

Downwind

Ecosystems of the Sierra Madre

Cropping Systems
Why do farmers do what they do?

- Changes in the policy environment
- Misperceptions about fertilizer timing
- Aversion to risk....
- Machinery constraints...
- Experience says it works...
Are there win-win alternatives?
Best alternative reduces losses >10 fold, maintains yields and grain quality and saves money.

Simulated Farmer’s Practice

-- 1995
-- 1996
Best Alternative 1996

Matson et al 1998
Rate of Nitrogen Application on Wheat

Percentage represents the proportion of the area that is fertilized.
Knowledge --> action???
What drives fertilizer management decisions?

credit union advice --
And risk aversion under uncertainty due to variability
Reduce fertilizer use by reducing uncertainty… and work with farmers and credit union advisors to test and incorporate new approaches.

Real-time measurements of plant N relative to fertilized strips
Vulnerability of Wheat Yield to Temperature Variability and Change

\[ V = \int \left| \frac{\delta Y}{\delta t} \right| \frac{Y}{Y_0} P_t dt \]

WHERE

\( Y \) = Yield
\( t \) = temperature
\( P_t \) = Probability of temperature

Sustainability Challenges in the Yaqui Valley Human-Environment System

Trop ozone Δ  Climate Δ  PoliciesΔ  Technology & Resources Δ
CO2 Δ  (sea level, temp, precipitation)

“natural” lands — Water — Agriculture — Aquaculture

Urban — Estuaries + Fisheries — Wetlands

Industry — Fisheries + Marine

Note: institutions for each , but no institutions for integrated system
Water Resources in the Yaqui Valley

Aquifer vs reservoir use?
Climate history -- how frequent are droughts?
Sustainable management of water resources?

Jose Luis Minjares
Lee Adamms
Steve Gorelick
Wally Falcon
David Battiste
Reservoir and Aquifer Allocation Models for Sustainable Water Use

Crop Decisions

Irrigation Decisions

Crop Yield

GW Pumping

Infiltration to GW

DISTRICT ALLOCATION

Production Costs

Yield Potential

Energy Costs

Pumping Capacity

Crop / Irrigation Scheduling

Infiltration to GW

Crop Prices

Land Resources

Drainage Constraints

Distribution Efficiency

Lee Adamms Steve Gorelick, Wally Falcon (Stanford) and Jose Luis Minjares (CNA)
Shrimp farm development

1986 Landsat TM

2001 Landsat TM
Shrimp Aquaculture in Southern Sonora

Government program
- 1988 PAIS

National policy
- 1986 Fishing Law
- 1992 Fishing Law
- 1992 Article 27 (Agrarian Reform)

Source: Luers et al. YEAR and field surveys 2001
Our integrated research perspective?

A sustainability perspective

Meeting the needs of people and Sustaining atmosphere, water, climate and species and ecosystems
Lesson 1 -- Interdisciplinary research takes extra time and “matrix” money
Yaqui Valley Project’s Model
for knowledge to action

Biogeochemistry  
Hydrology  
Marine science  

Ecology  
Economics  
Political Science  
Microbiology  
Conservation Biology  
History  

Infectious Disease  
Law  
Climatology  
Geography  
Sociology  

Decision Makers

Interdisciplinary research, focused on problems, in dialog or partnership with decision makers and linking orgs
Lesson 2 -- a different kind of research

Improved understanding

Existing understanding

(modified from Stokes, 1997)
Improved understanding

Existing understanding

Improved technology, management

Existing technology

(modified from Stokes, 1997)
Improved understanding

Improved technology, management

Basic research

Existing understanding

Applied R&D

Existing technology

(modified from Stokes, 1997)
Use-inspired basic research ("Sustainability Science")

- Improved understanding
- Improved technology, management
- Existing understanding
- Existing technology

(modified from Stokes, 1997)
Use-inspired basic research
(Sustainability Science)

Improved understanding

Existing understanding

Existing technology

Improved technology, management

Decision makers

(modified from Stokes, 1997)
Lesson 3 -- Understanding the knowledge system is critical if we want to link knowledge to action
Linking Knowledge to Action ("Knowledge Systems for Sustainability"):

1) Gap between what decision makers want from S&T and what S&T is offering ⇒

2) In effective knowledge systems, the problem to be solved is defined in a collaborative but ultimately user-driven manner ⇒ Need to foster institutions and procedures for initiating and sustaining such dialogues

Results from KSSD Project and Roundtable on S&T for Sustainability
3) Need “supply chain” perspectives on the design of decision support systems

4) “Boundary organizations” that link the R&D community to decision making community are critical (must be trusted, credible, legitimate)
What will it take for a transition to sustainability?

- integrative knowledge, tools, approaches
- purposeful linking of knowledge to action
What will it take for a transition to sustainability?

- integrative knowledge, tools, approaches
- linking knowledge to action
- learning from experience
- public understanding
- new ethics
- hope, inspiration, and motivation
- the will to change
- leadership by corporations, citizens, governments, non-profits, universities…
Major Funding for the Yaqui Project

**USDA** - Ag fertilization and GHG
**NASA** - Drivers and consequences of Land Use Change
**Packard Foundation** - Integrated Land-Sea interactions
**Packard Foundation** - Sustainability in Yaqui
**NSF** - Vulnerability in human-environment systems
**NOAA** - Knowledge Systems for Sustainable Development
**Ford Foundation** - Ag Development in Latin America
**Bechtel Foundation** (Stanford) - Integrated Studies in Yaqui
**Rockefeller, MacArthur and other Foundations**
**Graduate student fellowships** (NSF, NASA, EPA, Switzer, Stanford Graduate Fellowships, etc)
How can universities encourage interdisciplinary research focused on problem solving as well as new understanding?

• Encouragement and valuing of collaborative, interdisciplinary research
• Innovation research funds
• Awards and rewards
• Lower barriers across disciplines or units
• Encourage “uncommon dialogues”
• Educational opportunities
• Research on how we learn and work interdisciplinarily
• For tenure evaluation, an interdisciplinary community
• Help create new publication venues
## Quadrant Model of Scientific Research

<table>
<thead>
<tr>
<th>Research inspired by...</th>
<th>Considerations of use?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quest for fundamental understanding?</td>
<td>No</td>
</tr>
<tr>
<td>No</td>
<td>Pure applied research (Edison)</td>
</tr>
<tr>
<td>Yes</td>
<td>Pure basic research (Bohr)</td>
</tr>
</tbody>
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(rewritten from Stokes, 1997)