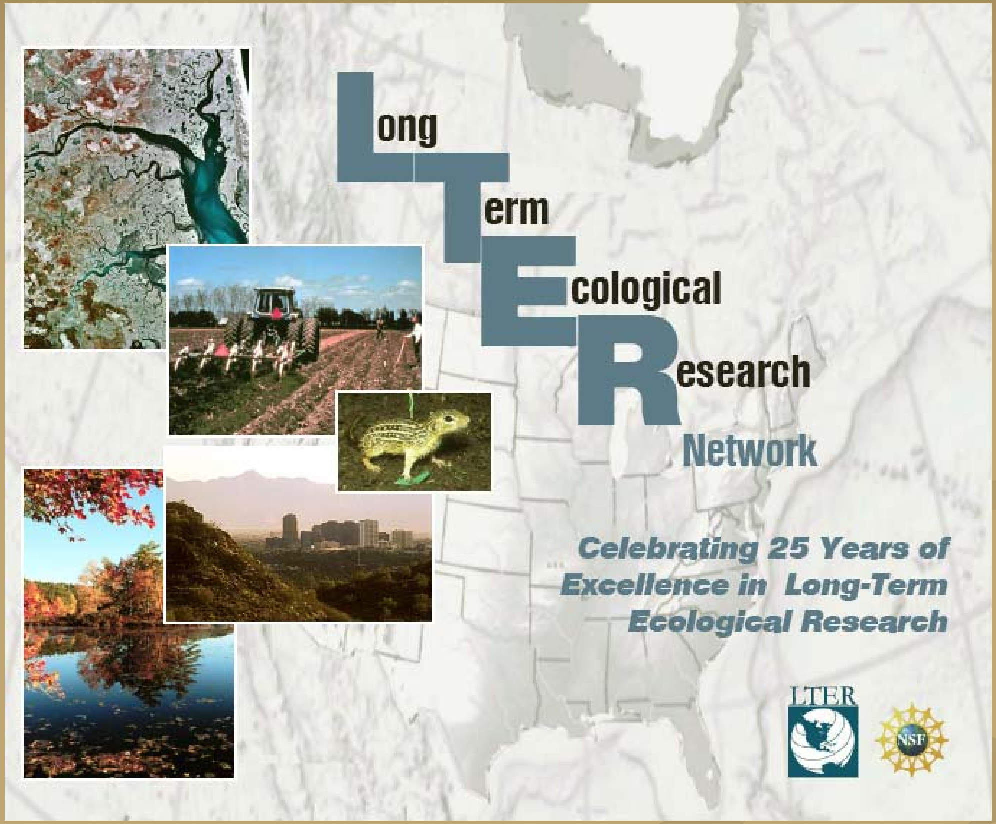
New Directions for U.S. LTER Research



G. Philip Robertson
W.K. Kellogg Biological Station
Michigan State University

US LTER Sites

AND – H.J. Andrews Experimental Forest LTER, Oregon

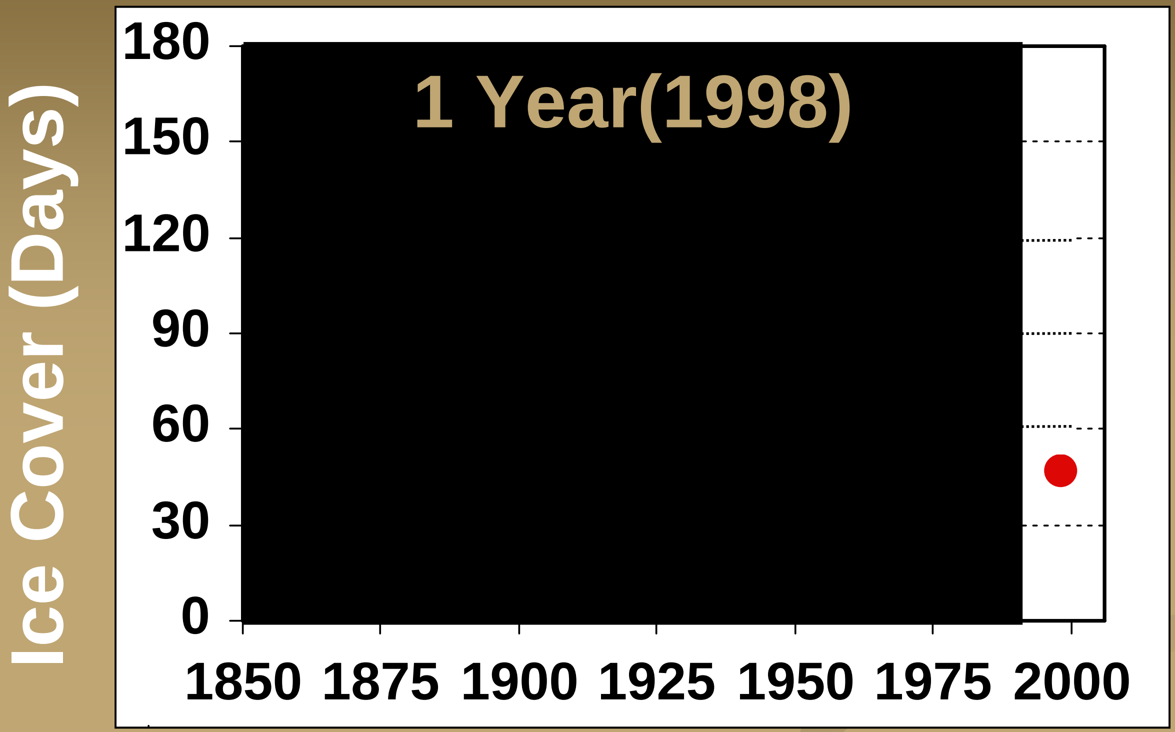
CWT – Coweeta LTER, North Carolina

JRN – Jornada Basin LTER, New Mexico

KNZ – Konza Prairie LTER, Kansas

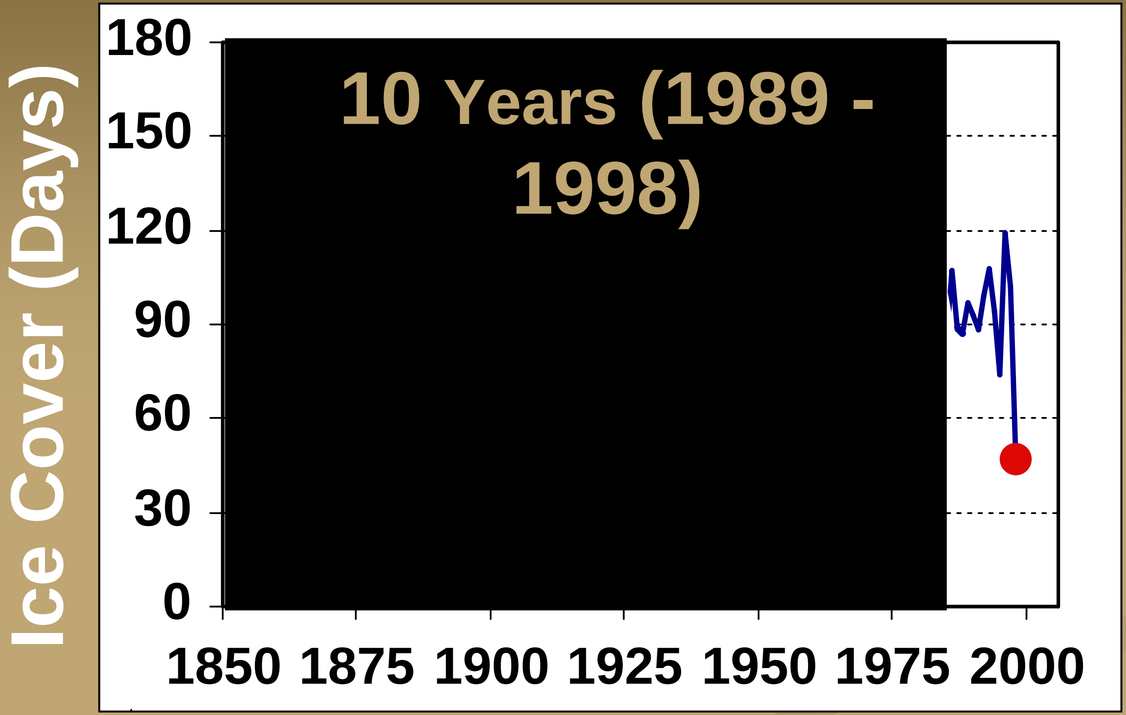
NTL – North Temperate Lakes LTER, Wisconsin

Lake Mendota, Wisconsin



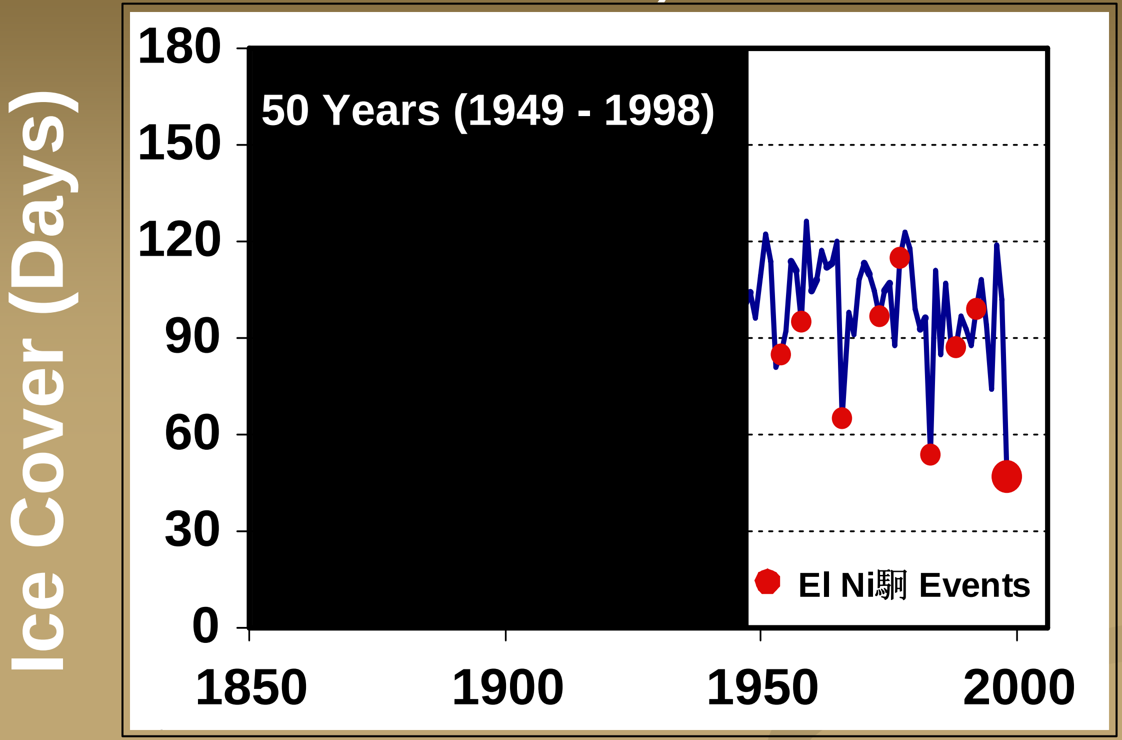
Lake Mendota, WI is an example of how long-term research provides insights not evident from short term studies. The graph above shows how long the lake was covered with ice in 1998. A study taken over one year (short-term) does not reveal much.

Lake Mendota, Wisconsin



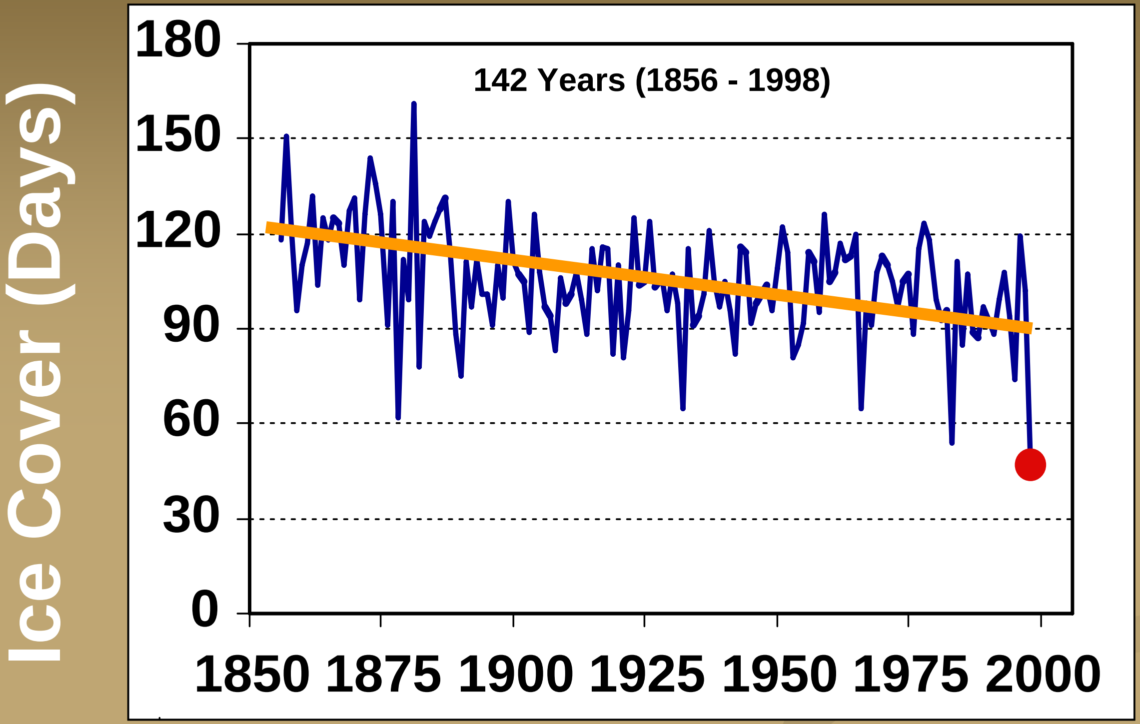
Research conducted over a decade reveals that duration of ice cover was unusually short in 1998.

Lake Mendota, Wisconsin



Research over half a century reveals patterns in the lake’s ice cover that coincide with global weather patterns and natural phenomena.

Lake Mendota, Wisconsin

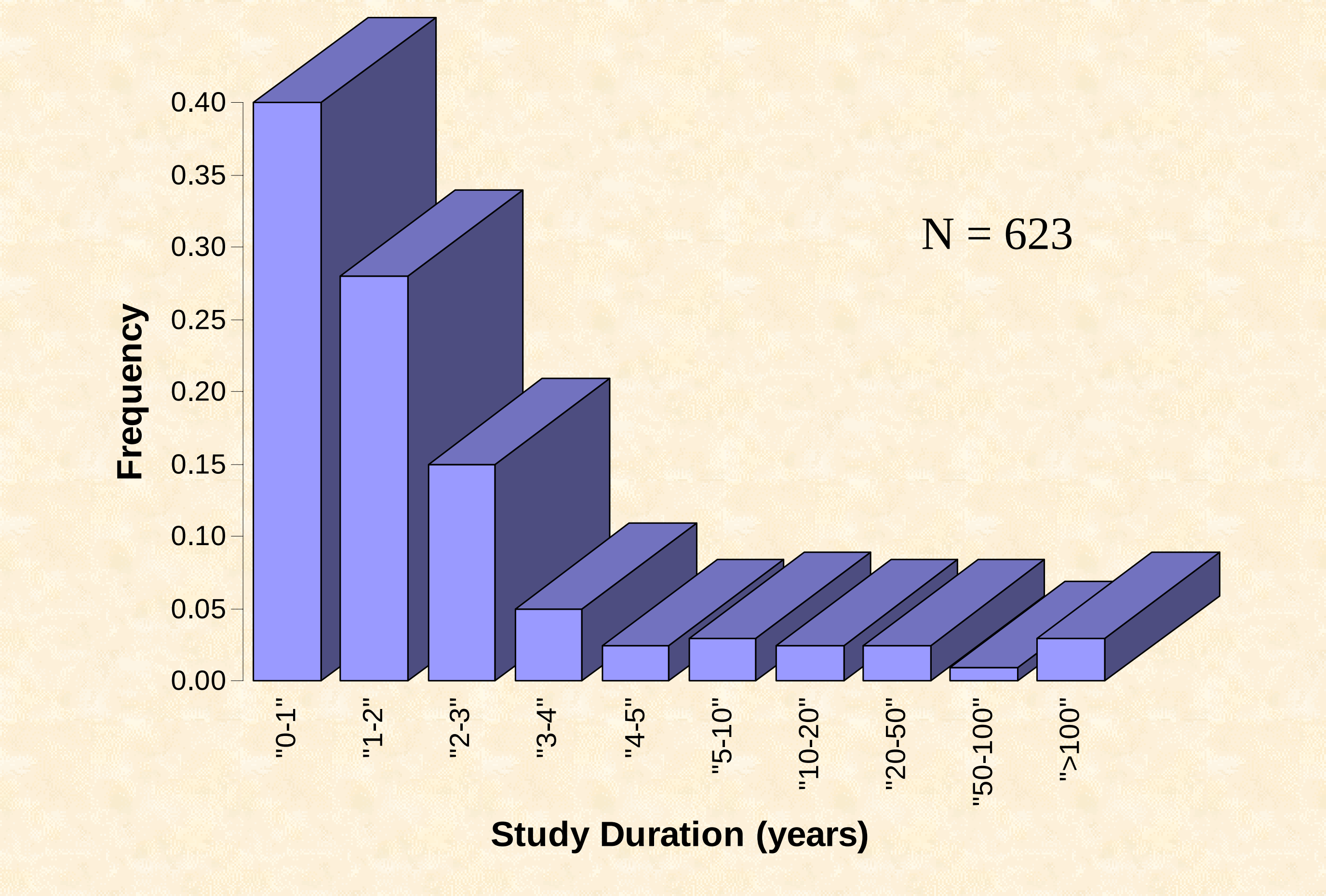


Data for the past 142 years suggests a trend that is not evident from shorter data sets.

Long-term research is required to reveal:

- Slow processes or transients
- Episodic or infrequent events
- Trends
- Multi-factor responses
- Processes with major time lags

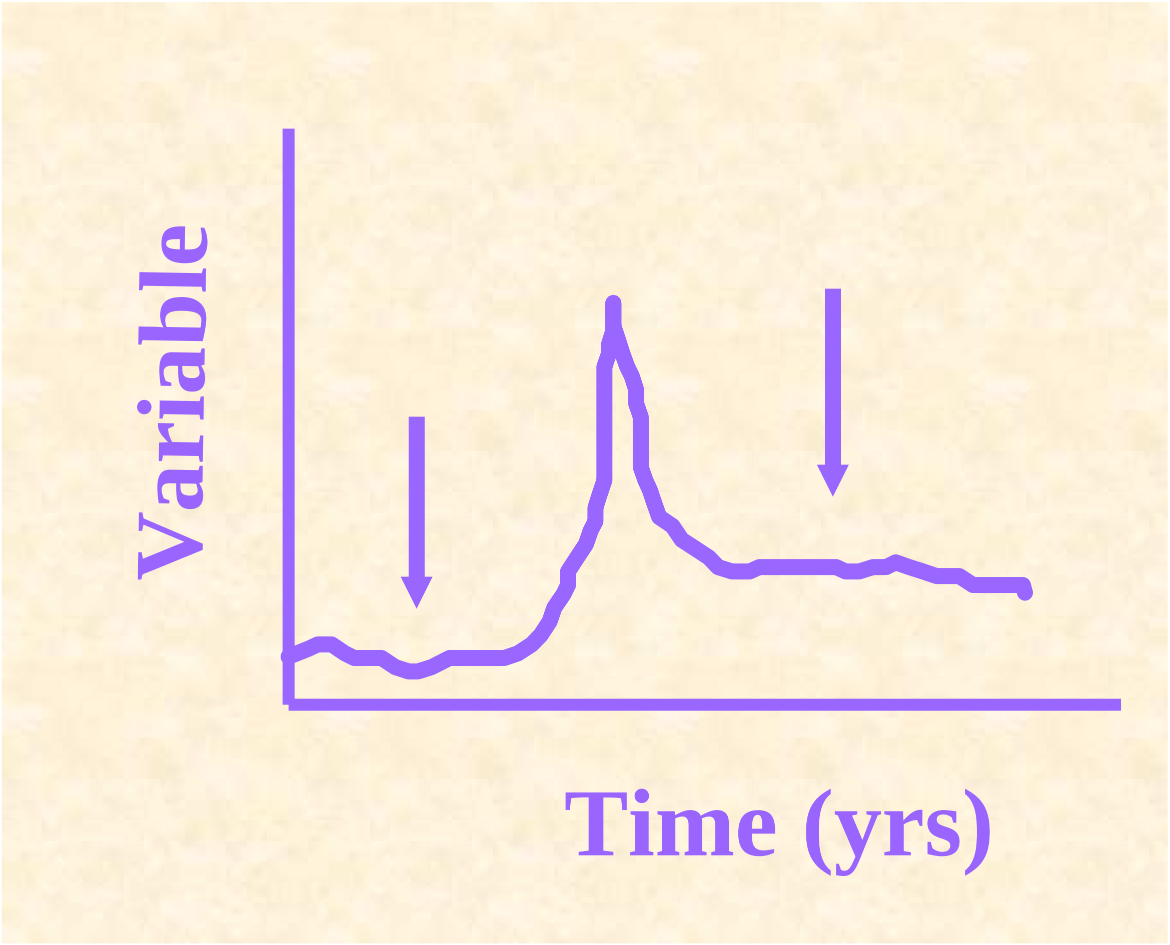
Duration of all observational and experimental studies



Eighty percent of studies in the ecological literature last less than three years

Source: Tilman (1989). In Likens, G.E. (ed). Long-Term Studies in Ecology. Springer-Verlag, New York.

Only 10 percent of studies capture unusual events



Unusual events reset systems. Short-term studies initiated before and after a rare event are viewing different system states.

LTER research covers time scales from months to centuries

YEARS		RESEARCH SCALES	PHYSICAL RESET EVENTS	BIOLOGICAL PHENOMENA
10^5	100 MILLENNIA	PALEO ECOLOGY & LIMNOLOGY	Continetal Glacition	Evolution of Species
10^4	10 MILLENNIA			Bog Succession Forest Community Migration
10^3	MILLENNIUM		Climate Change	Species Invasion Forest Succession
10^2	CENTURY	**LTER**	Forest Fires CO_2 Climate Warming	Cultural Eutrophication
10^1	DECADE		Sun Spot Cycle El Nino	Hare Population Prairie Population
10^0	YEAR		Prairie Fires	Annual Plants
10^{-1}	MONTH		Lake Turnover Ocean Upwelling	Plankton Succession
10^{-2}	DAY	MOST ECOLOGY	Storms Diel Light Cycle Tides	Algal bloom Diel Migration
10^{-3}	HOUR			

The time scales addressed by the LTER Program fall outside the range of those typically addressed in other ecological research programs

Current US LTER Sites

AND – H.J. Andrews Experimental Forest LTER, Oregon

ARC – Arctic Tundra LTER, Alaska

BES – Baltimore Ecosystem Study LTER, Maryland

BNZ – Bonanza Creek Experimental Forest LTER, Alaska

CAP – Central Arizona-Phoenix LTER, Arizona

CCE – California Current Ecosystem LTER, California

CDR – Cedar Creek Natural History Area LTER, Minnesota

CWT – Coweeta LTER, North Carolina

FCE – Florida Coastal Everglades LTER, Florida

GCE – Georgia Coastal Ecosystem LTER, Georgia

HBR – Hubbard Brook LTER, New Hampshire

HFR – Harvard Forest LTER, Massachusetts

JRN – Jornada Basin LTER, New Mexico

LNO – LTER Network Office, New Mexico

KBS – Kellogg Biological Station LTER, Michigan

KNZ – Konza Prairie LTER, Kansas

LUQ – Luquillo Experimental Forest LTER, Puerto Rico

MCM – McMurdo Dry Valleys LTER, Antarctica

MCR – Moorea Coral Reef LTER, French Polynesia

NWT – Niwot Ridge LTER, Colorado

NTL – North Temperate Lakes LTER, Wisconsin

PAL – Palmer Station LTER, Antarctica

PIE – Plum Island Ecosystem LTER, Massachusetts

SBC – Santa Barbara Coastal Ecosystem LTER, California

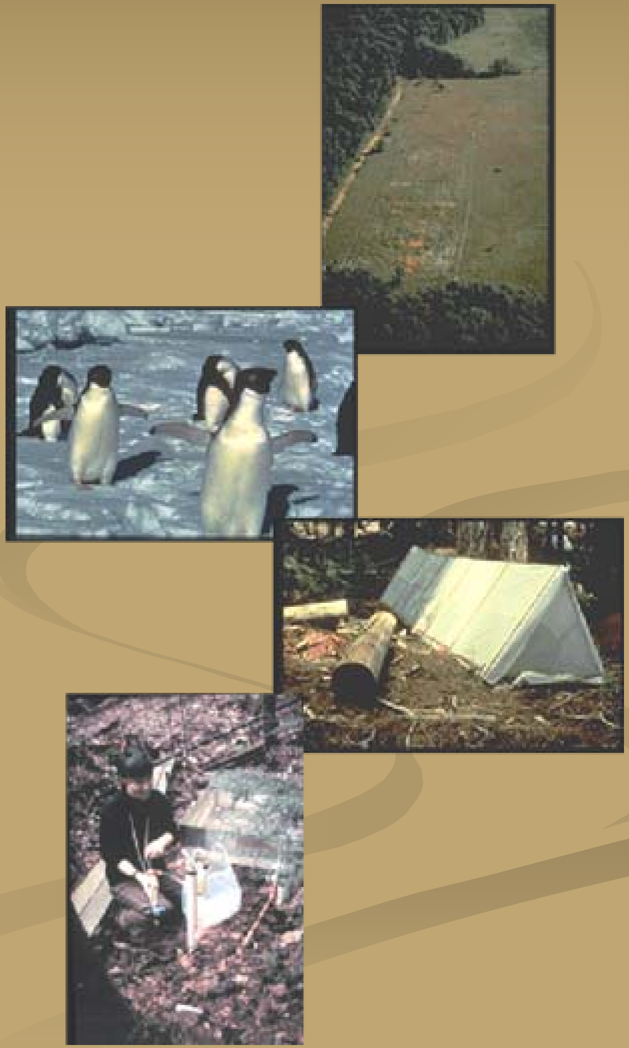
SEV – Sevilleta LTER, New Mexico

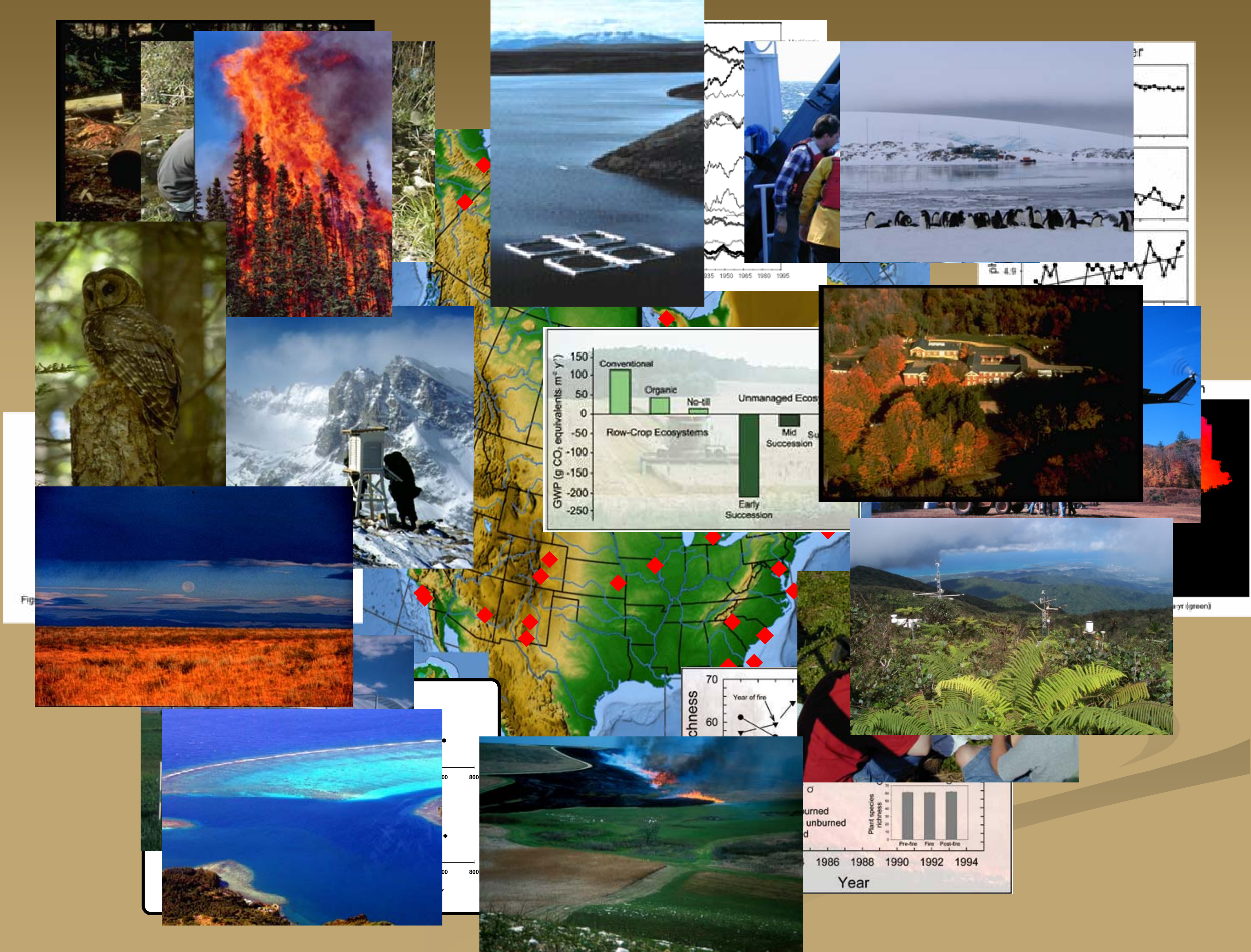
SGS – Shortgrass Steppe LTER, Colorado

VCR – Virginia Coast Reserve LTER, Virginia

LTER sites share a common commitment to long-term research on core topics:

- Pattern and control of primary production
- Spatial and temporal distribution of populations selected to represent trophic structure
- Pattern and control of organic matter accumulation in surface layers and sediments
- Patterns and movements of inorganic inputs through soils ground- and surface waters
- Patterns and frequency of disturbance

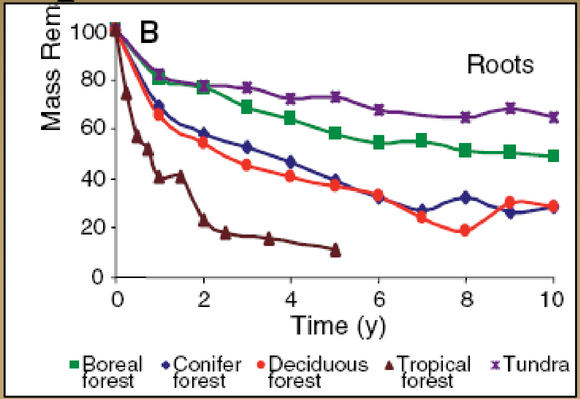



GWP (g CO2 equivalents m-2 y-1)
150
100
50
0
-50
-100
-150
-200
-250
Conventional
Organic
No-till
Unmanaged Ecos
Row-Crop Ecosystems
Mid Succession
Early Succession
Su
35
1950
1965
1980
1995
Year of fire
70
60
chness
urned
unburned
Plant species richness
Pre-fire
Fire
Post-fire
1986
1988
1990
1992
1994
Year
800
800
Fig

- Site science volumes

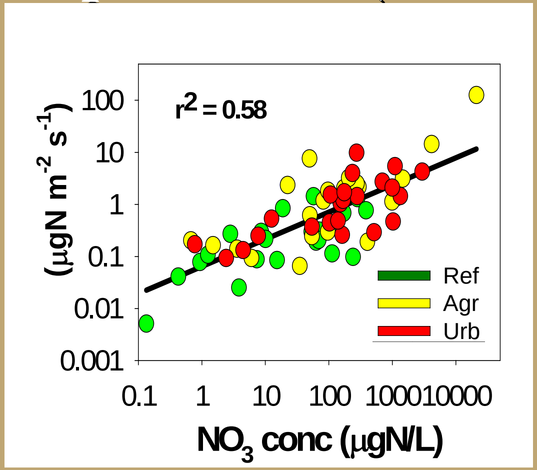
Recent Cross-Site Syntheses

- Long-term Intersite Decomposition Experiment (LIDET)



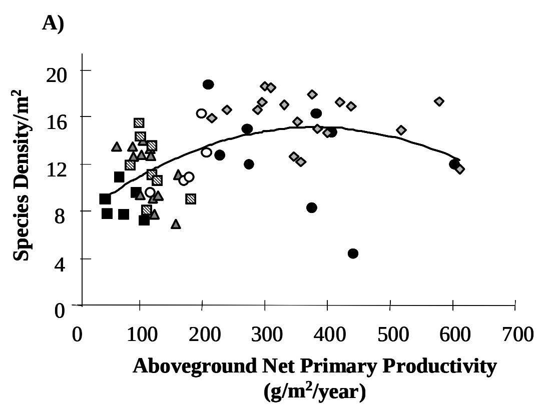
Parton et al. 2006 *Science* 315: 361

- Lotic Intersite Nitrogen Experiment (LINX)



Peterson et al. 2001 *Science* 292: 86

- Productivity Diversity Traits Network (PDNet)



Suding et al. 2005 *PNAS* 102: 4387

THE IMPORTANCE OF CROSS-SITE SYNTHESIS

“The power of the network approach of the LTER program rests in the ability to compare similar processes (e.g., primary production or decomposition of organic matter) under different ecological conditions. As a result, LTER scientists should be able to understand how fundamental ecological processes operate at different rates and in different ways under different environmental conditions.”

(US LTER 10-y Review, 1993)

LONG-TERM ECOLOGICAL RESEARCH NETWORK

LTER CORE AREAS

- Net Primary Production
- Organic matter cycling
- Nutrient cycling
- Population dynamics
- Disturbance

CHARACTERISTICS:

- Long-term
- Ecological
- Site-based

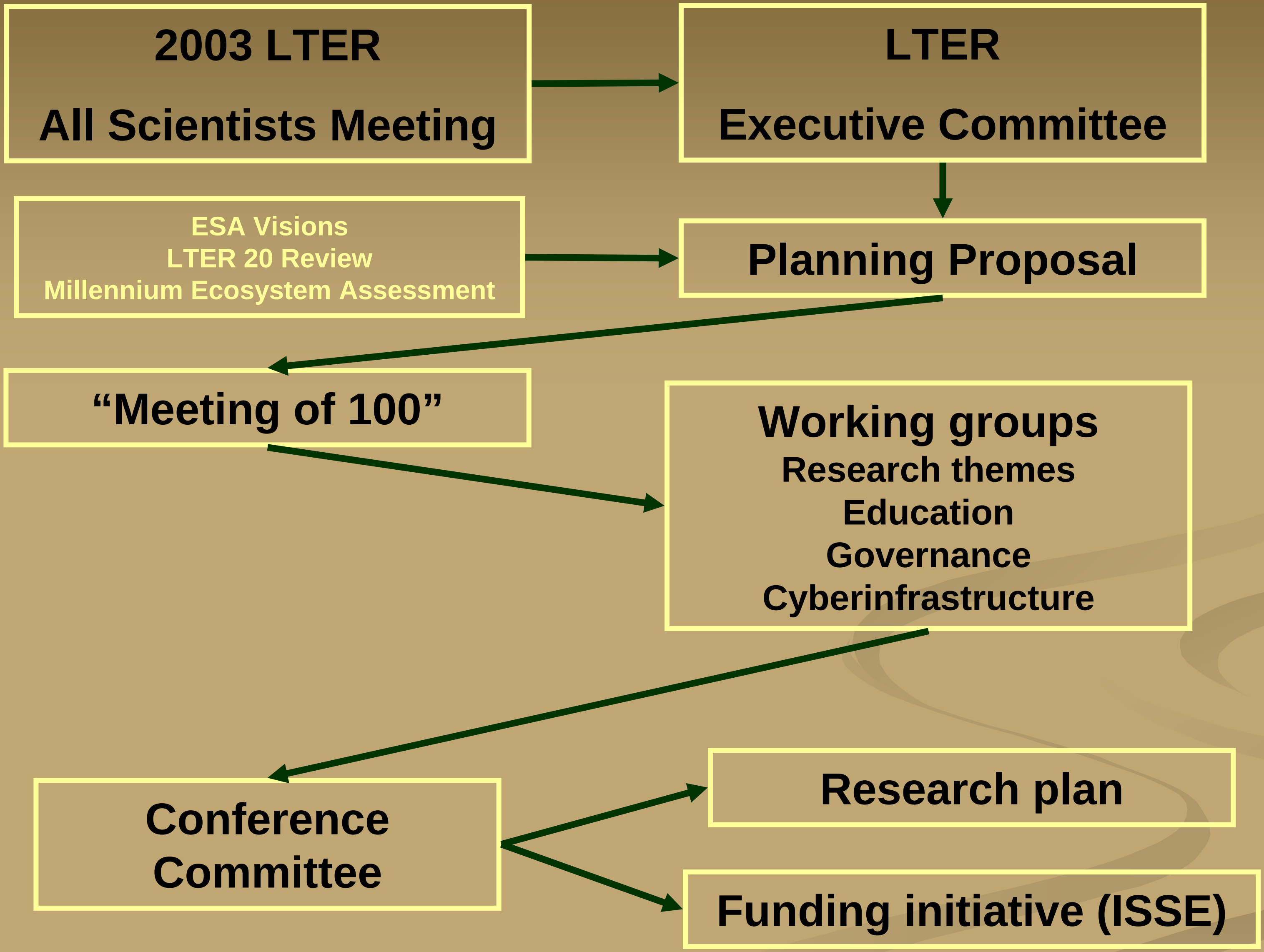
TOWARD INTEGRATION AND SYNTHESIS: GOALS OF THE LTER PLANNING PROCESS

A new LTER science agenda that will take LTER science to a higher level of research collaboration, synthesis, and integration.

- **Objective 1:** **establish activities that will lead to multi-site, highly collaborative, integrated research that explicitly includes synthesis components coupled with novel training opportunities in graduate and undergraduate education.**

- **Objective 2:** **evaluate LTER Network governance structure and further stimulate the culture of collaboration within the LTER Network.**

- **Objective 3:** **envision and develop education and training activities that will infuse LTER science into the K-12 science curriculum.**



2003 LTER

All Scientists Meeting

LTER

Executive Committee

ESA Visions
LTER 20 Review
Millennium Ecosystem Assessment

Planning Proposal

“Meeting of 100”

Working groups
Research themes
Education
Governance
Cyberinfrastructure

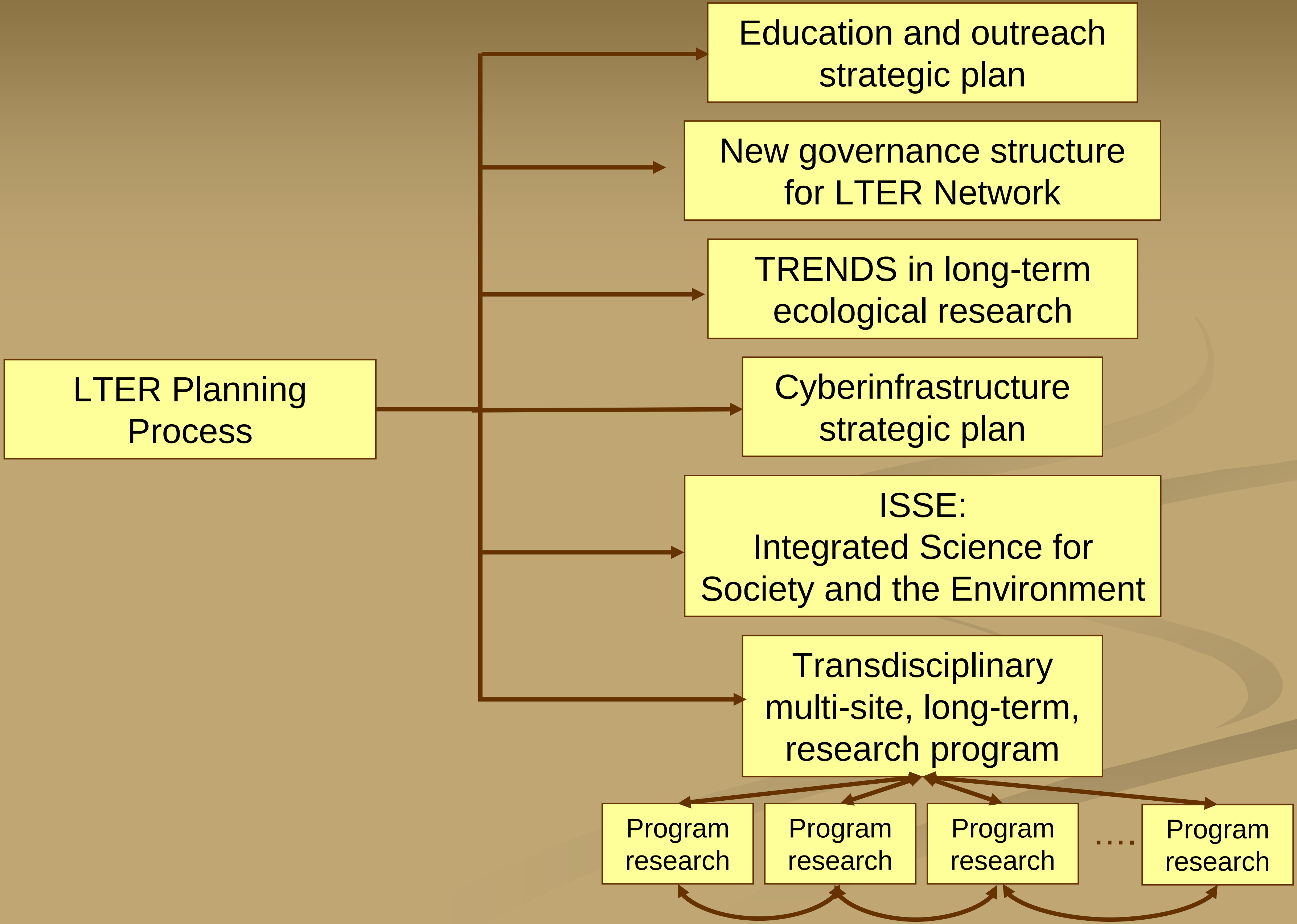
Conference Committee

Research plan

Funding initiative (ISSE)

Three year planning process

OUTCOMES OF THE PLANNING PROCESS



LTER Planning Process

Education and outreach strategic plan

New governance structure for LTER Network

TRENDS in long-term ecological research

Cyberinfrastructure strategic plan

ISSE:
Integrated Science for Society and the Environment

Transdisciplinary multi-site, long-term, research program

Program research

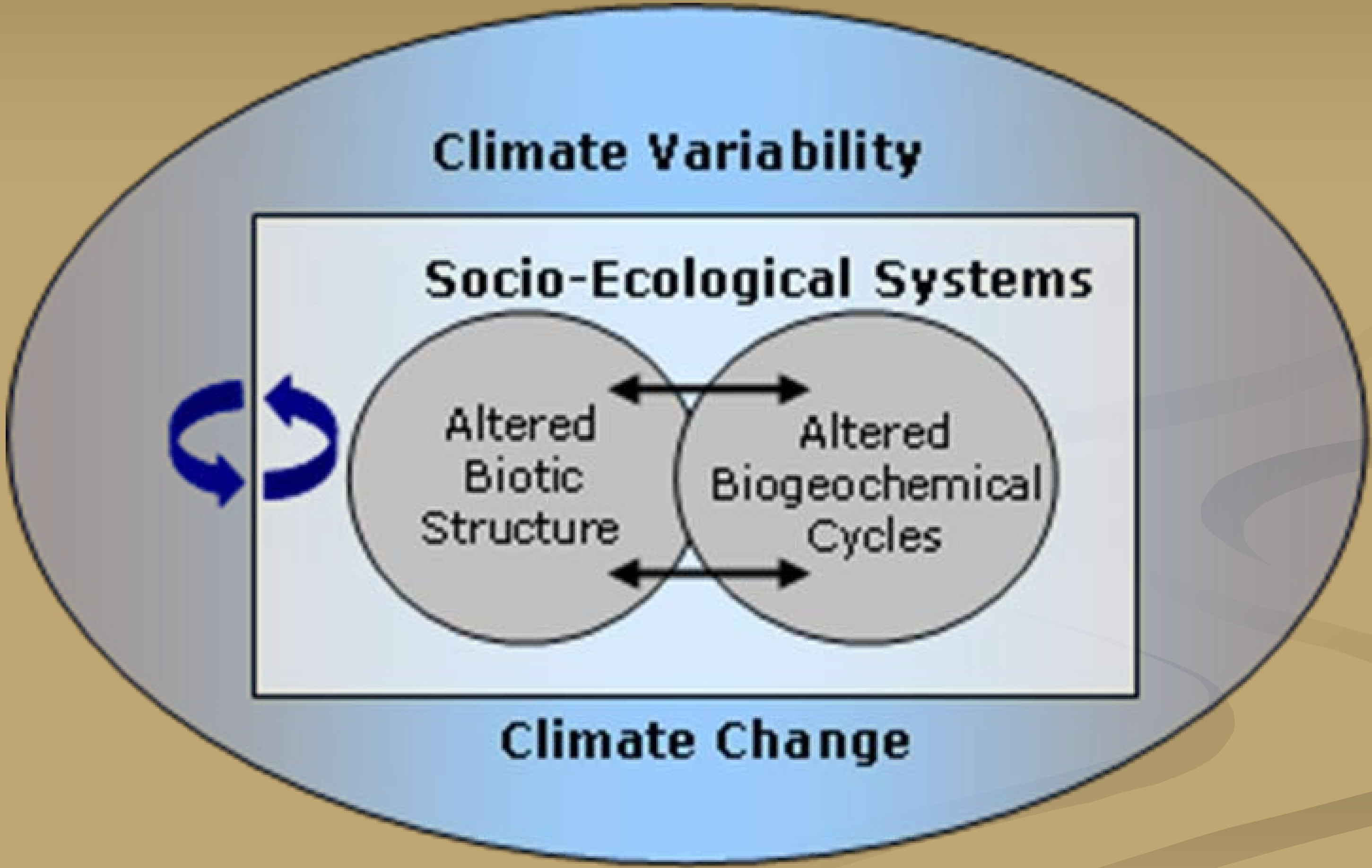
Program research

Program research

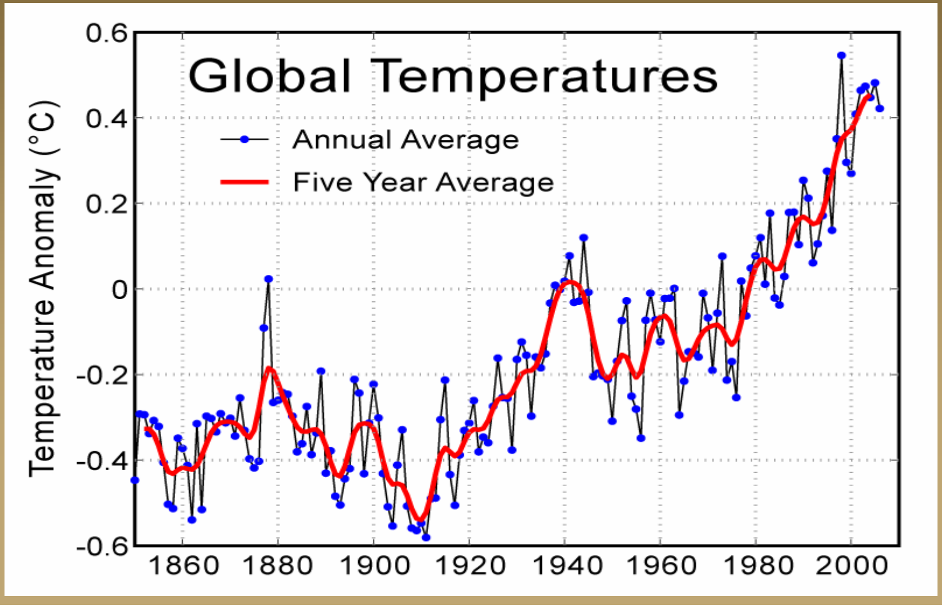
….

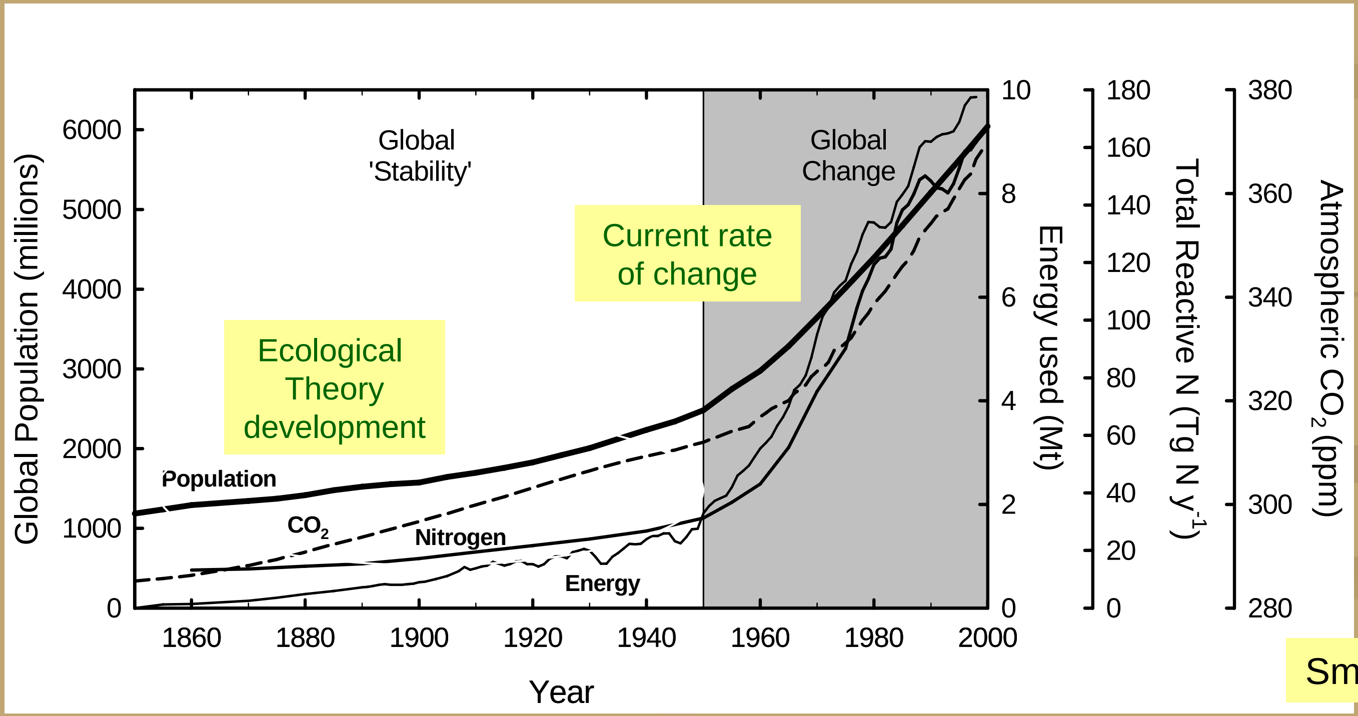
Program research

INTEGRATED SCIENCE FOR SOCIETY AND THE ENVIRONMENT



SOCIO-ECOLOGICAL PRESSES

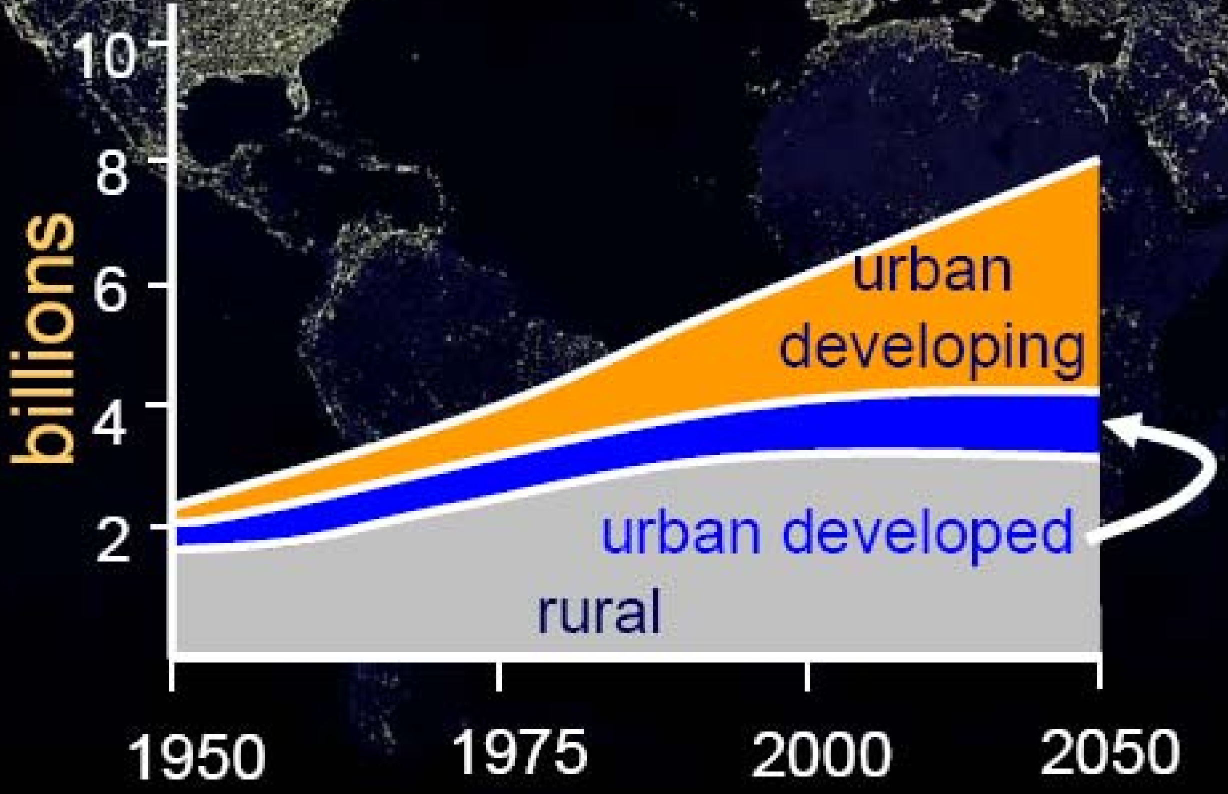



Ecological Theory development

Current rate of change

Smith, Knapp & Collins, in review

The problem of urbanization: the future



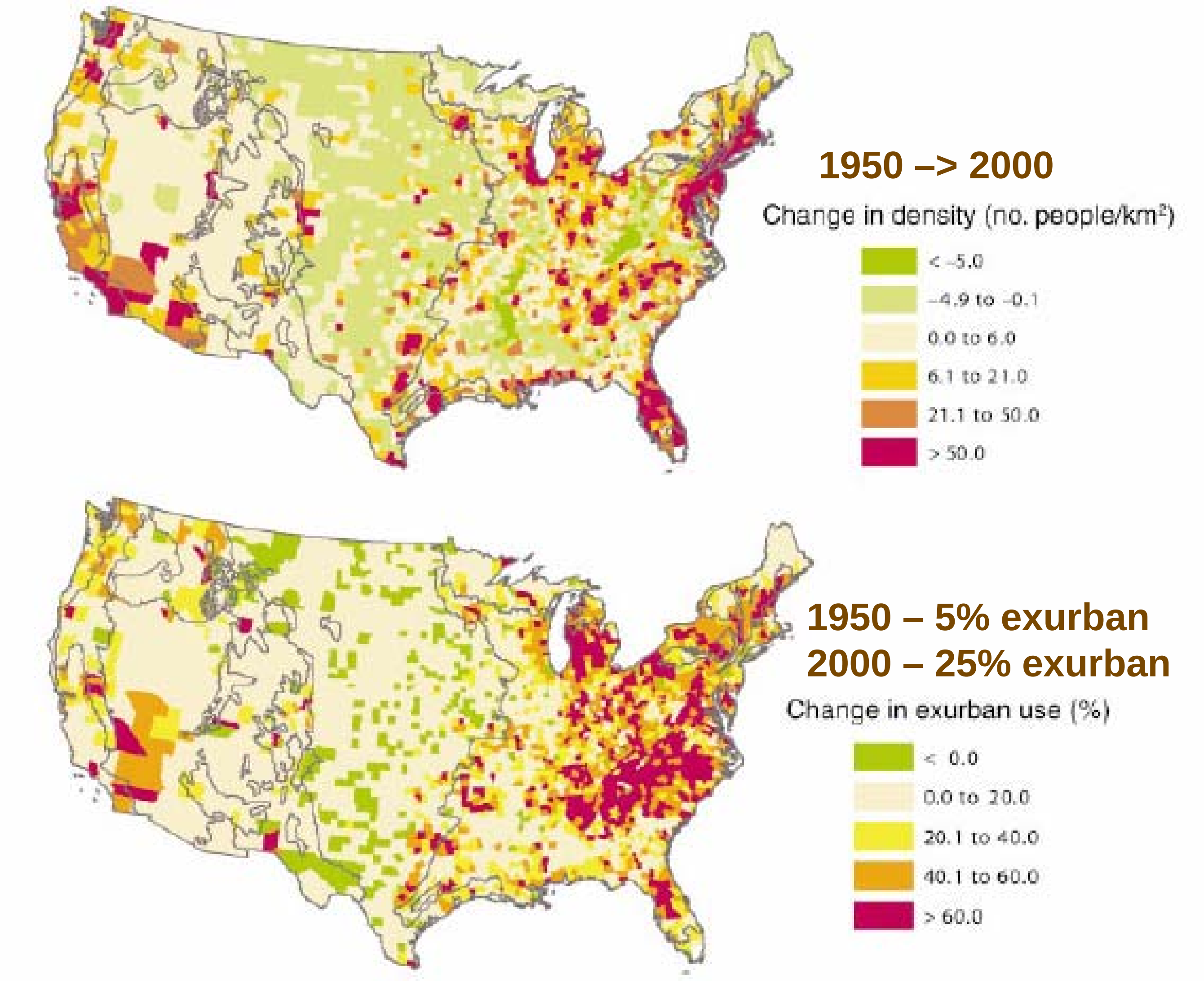
Source: World Resources Institute 1996

Urban population[1]:
1800 – 2%
1900 – 12%
2000 – 47%
2050 – 60%

Megacities[2]:
1950 – 1
2000 – 19
2015 – 60

Sources: [1] Cohen 2003 *Science*
[2] IHDP Report 2005

POPULATION EFFECTS VARY SPATIALLY
Requires a broad-scale comparative approach



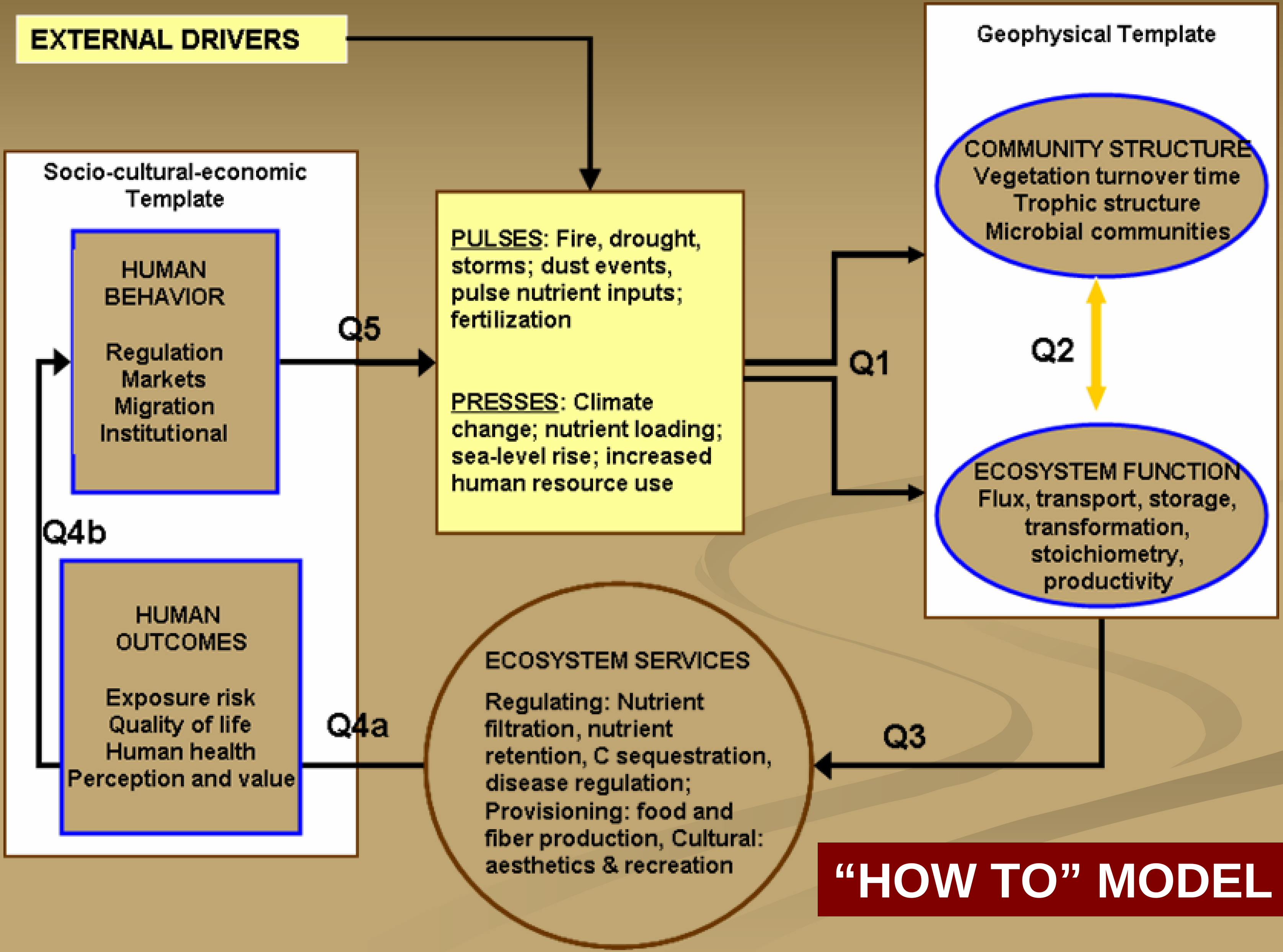
1950 –> 2000

1950 – 5% exurban
2000 – 25% exurban

Brown et al. 2005 Ecological Applications


ARC
BNZ
PAL
MCM
CDR
NTL
HBR
HFR
PIE
SGS
KBS
BES
SBC
NWT
CCE
CAP
LNO
SEV
KNZ
VCR
CWT
JRN
GCE
FCE
LUQ
MCR
Tahiti
C

ITERATIVE CONCEPTUAL FRAMEWORK



EXTERNAL DRIVERS

Socio-cultural-economic Template

HUMAN BEHAVIOR

Regulation
Markets
Migration
Institutional

HUMAN OUTCOMES

Exposure risk
Quality of life
Human health
Perception and value

PULSES: Fire, drought, storms; dust events, pulse nutrient inputs; fertilization

PRESSES: Climate change; nutrient loading; sea-level rise; increased human resource use

Geophysical Template

COMMUNITY STRUCTURE
Vegetation turnover time
Trophic structure
Microbial communities

ECOSYSTEM FUNCTION
Flux, transport, storage, transformation, stoichiometry, productivity

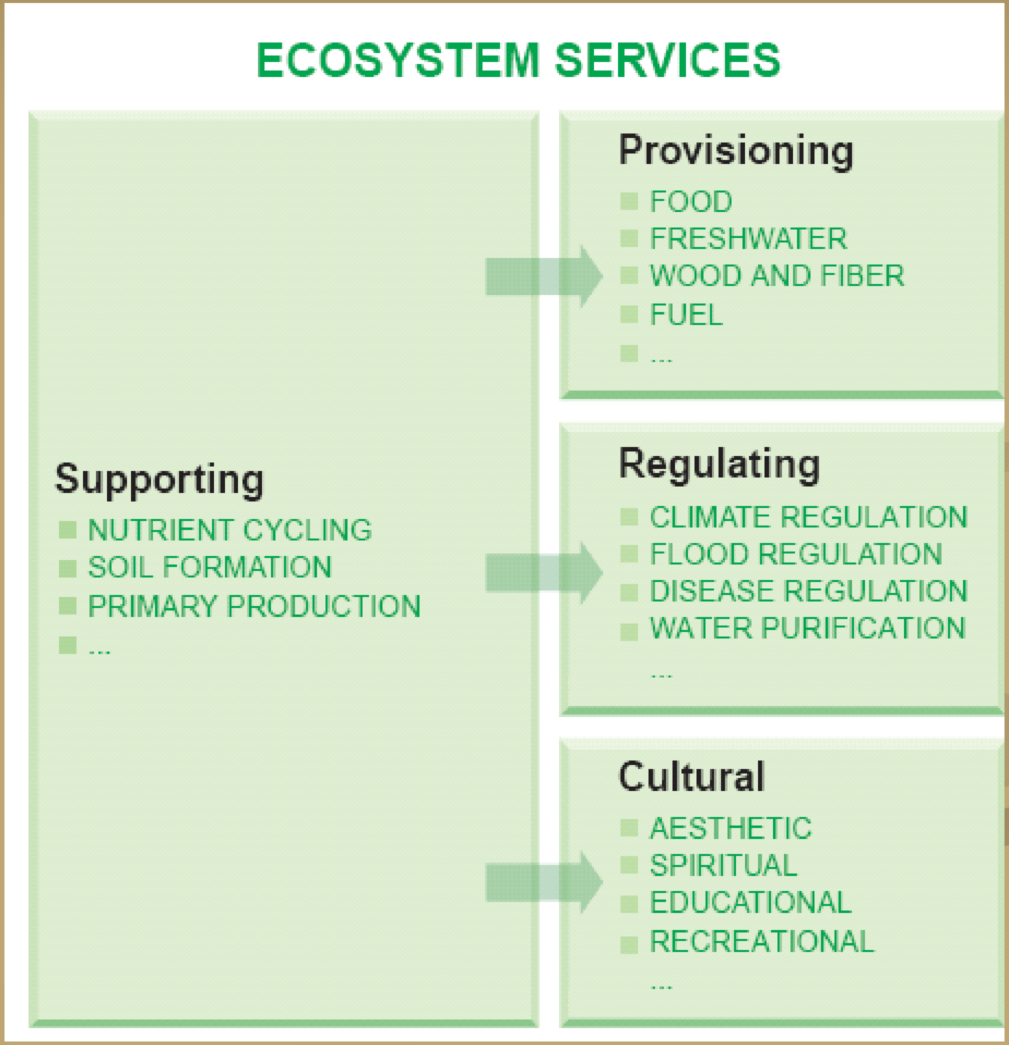
ECOSYSTEM SERVICES

Regulating: Nutrient filtration, nutrient retention, C sequestration, disease regulation; Provisioning: food and fiber production, Cultural: aesthetics & recreation

“HOW TO” MODEL

Ecosystem Services
The benefits people obtain from ecosystems

Millennium Ecosystem Assessment:



ECOSYSTEM SERVICES

Supporting
- NUTRIENT CYCLING
- SOIL FORMATION
- PRIMARY PRODUCTION
- ...

Provisioning
- FOOD
- FRESHWATER
- WOOD AND FIBER
- FUEL
- ...

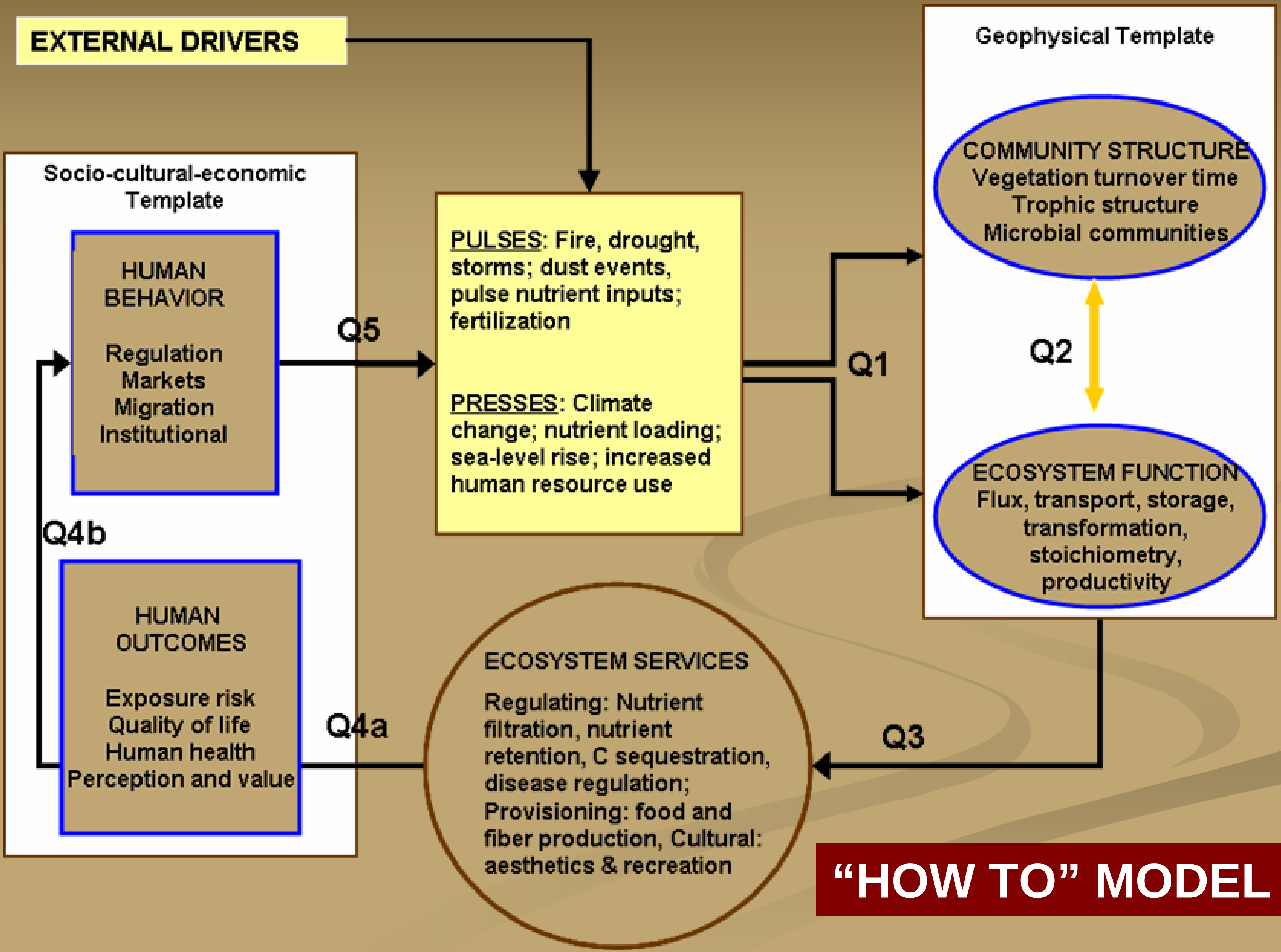
Regulating
- CLIMATE REGULATION
- FLOOD REGULATION
- DISEASE REGULATION
- WATER PURIFICATION

...

Cultural
- AESTHETIC
- SPIRITUAL
- EDUCATIONAL
- RECREATIONAL

...

ITERATIVE CONCEPTUAL FRAMEWORK



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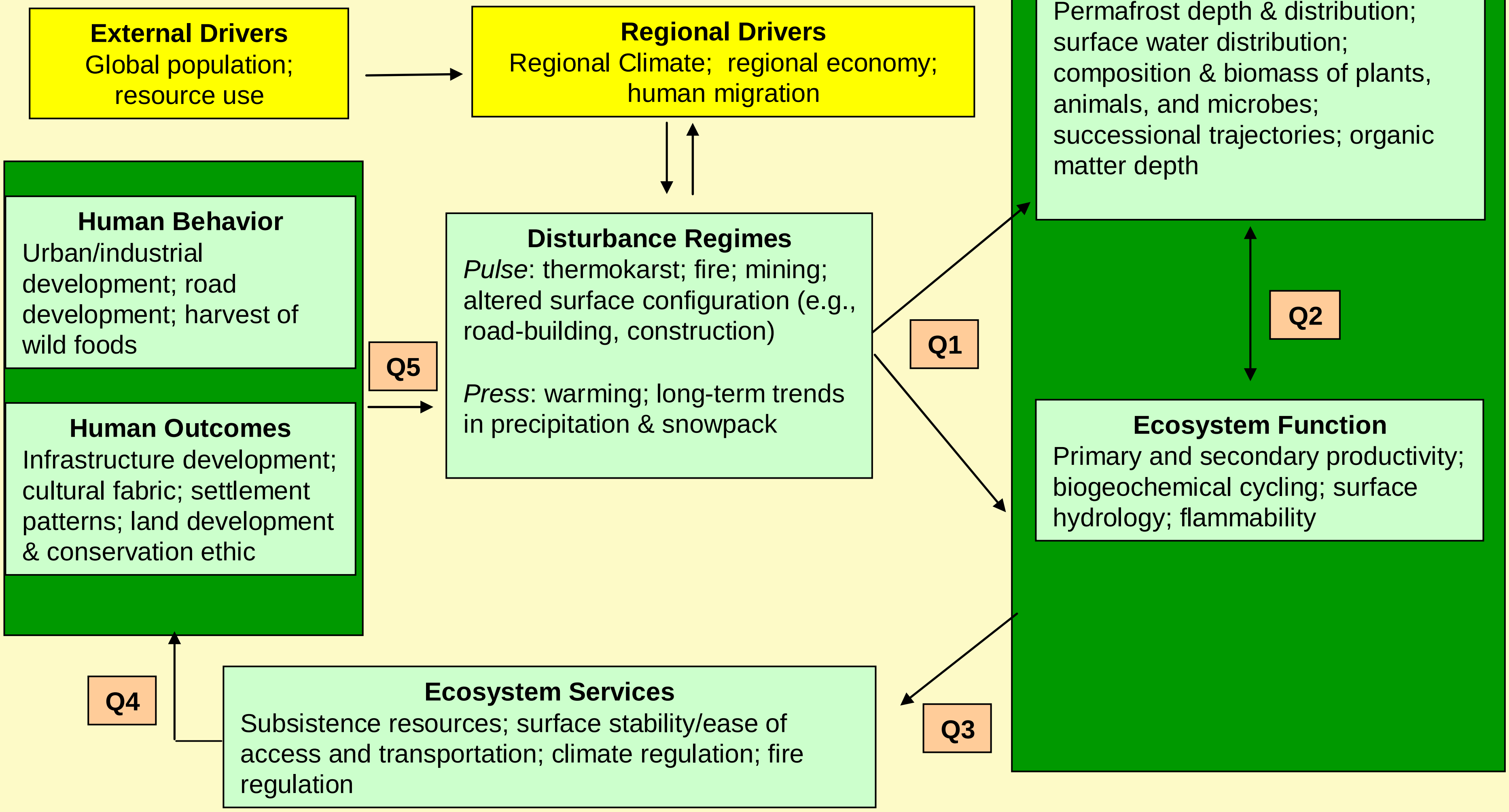
"HOW TO" MODEL

FRAMEWORK QUESTIONS

- **Q1:** How do long-term press and pulse drivers ***interact*** to alter ecosystem structure and function?
- **Q2:** How can biotic structure be both a ***cause and consequence*** of ecological fluxes of energy & matter?
- **Q3:** How do altered ecosystem dynamics affect ecosystem services?
- **Q4:** How do changes in vital ecosystem services ***feed back*** to alter human behavior?
- **Q5:** Which human actions influence the frequency, magnitude, or form of press and pulse disturbance regimes across ecosystems, and how do these change across ecosystem types?

Bonanza Creek Permafrost Impacts



External Drivers
Global population; resource use

Regional Drivers
Regional Climate; regional economy; human migration

Biotic Structure
Permafrost depth & distribution; surface water distribution; composition & biomass of plants, animals, and microbes; successional trajectories; organic matter depth

Human Behavior
Urban/industrial development; road development; harvest of wild foods

Disturbance Regimes
Pulse: thermokarst; fire; mining; altered surface configuration (e.g., road-building, construction)

Press: warming; long-term trends in precipitation & snowpack

Human Outcomes
Infrastructure development; cultural fabric; settlement patterns; land development & conservation ethic

Ecosystem Function
Primary and secondary productivity; biogeochemical cycling; surface hydrology; flammability

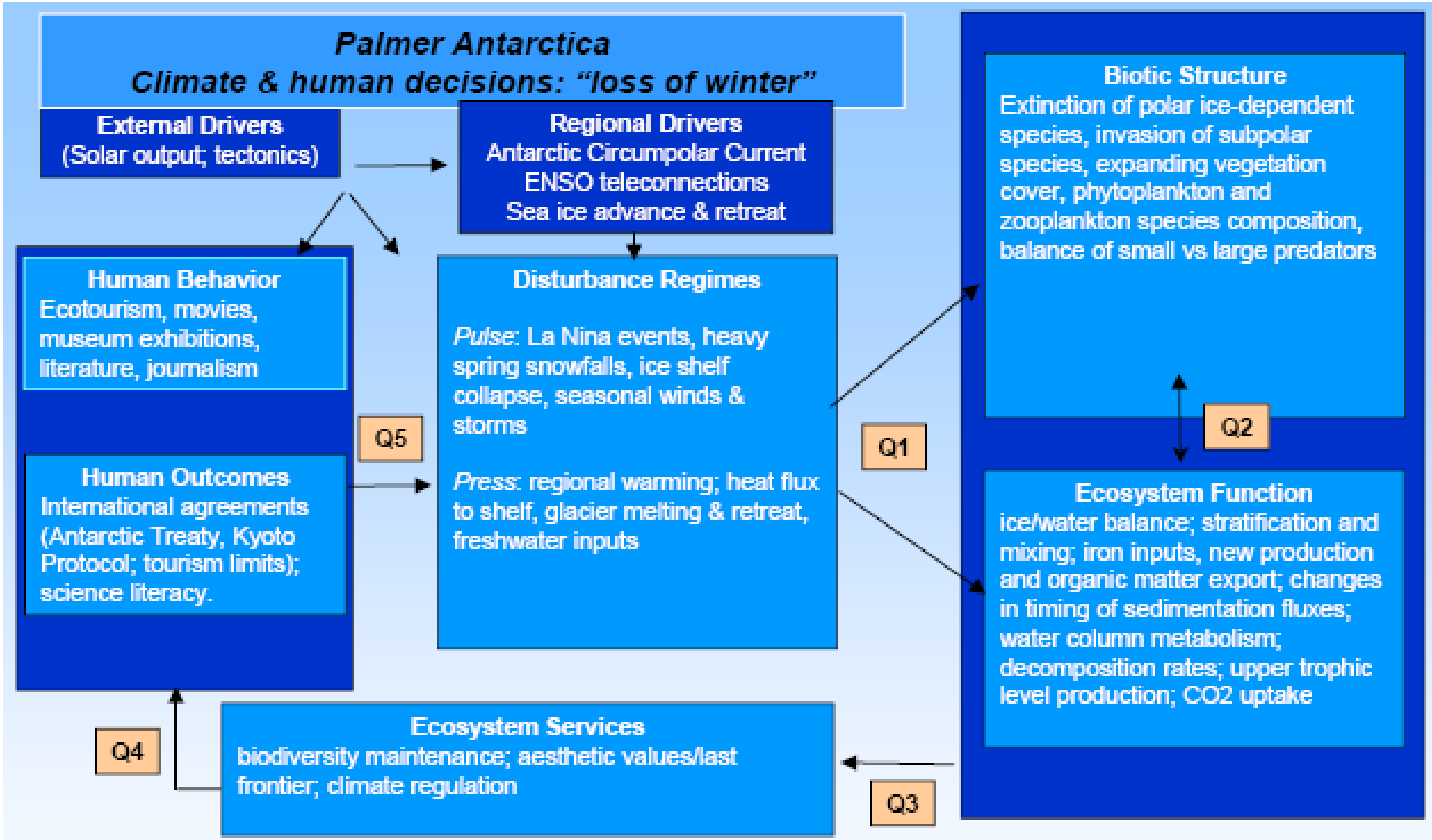
Ecosystem Services
Subsistence resources; surface stability/ease of access and transportation; climate regulation; fire regulation

Q1. How do long-term trends in climate interact with disturbance to the land surface to affect the structure & function of the boreal forest in interior Alaska?
Q2. How are feedbacks between community structure and ecosystem function affected by changes in permafrost?
Q3. How do ecological changes associated with warming permafrost affect subsistence resource use, the ease of accessing landscapes, and flammability/fire regulation?
Q4. How will the human population respond to landscape changes associated with warming permafrost?
Q5. How will human actions/decisions affect the dynamics of permafrost thaw in interior Alaska?

Questions Q4-5: Bonanza Creek, Alaska

- **Q4.** How will the human population respond to landscape changes associated with warming permafrost?
- **Q5.** How will human actions and decisions affect the dynamics of permafrost thaw in interior Alaska?

Palmer Antarctica
Climate & human decisions: "loss of winter"



External Drivers
(Solar output; tectonics)

Regional Drivers
Antarctic Circumpolar Current
ENSO teleconnections
Sea ice advance & retreat

Human Behavior
Ecotourism, movies, museum exhibitions, literature, journalism

Human Outcomes
International agreements (Antarctic Treaty, Kyoto Protocol; tourism limits); science literacy.

Disturbance Regimes

Pulse: La Nina events, heavy spring snowfalls, ice shelf collapse, seasonal winds & storms

Press: regional warming; heat flux to shelf, glacier melting & retreat, freshwater inputs

Biotic Structure
Extinction of polar ice-dependent species, invasion of subpolar species, expanding vegetation cover, phytoplankton and zooplankton species composition, balance of small vs large predators

Ecosystem Function
ice/water balance; stratification and mixing; iron inputs, new production and organic matter export; changes in timing of sedimentation fluxes; water column metabolism; decomposition rates; upper trophic level production; CO2 uptake

Ecosystem Services
biodiversity maintenance; aesthetic values/last frontier; climate regulation

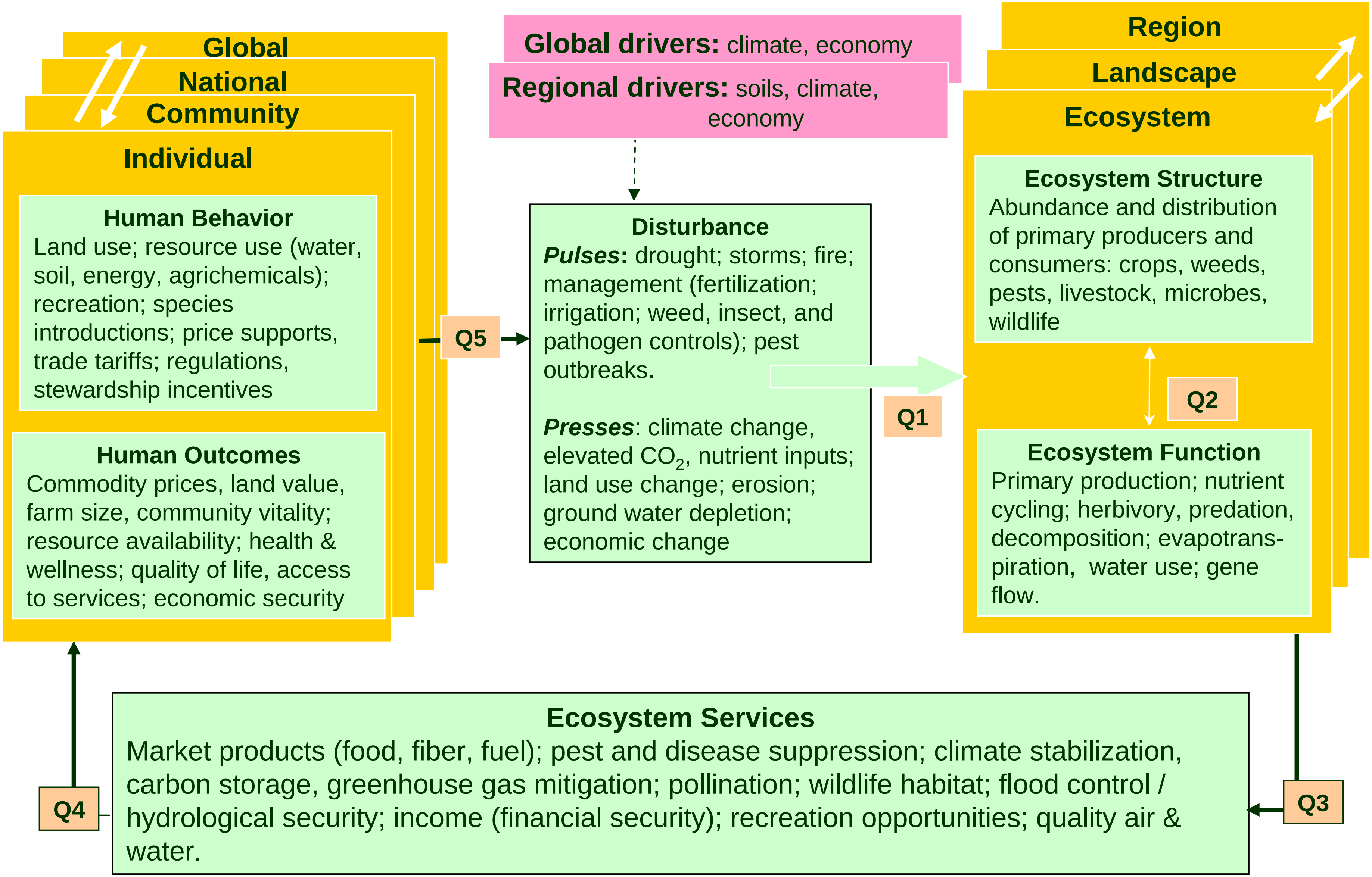
Q1: How do long-term climate warming and short term weather, sea ice and oceanographic events influence life history adaptations of ice-dependent and independent species and lower trophic level dynamics?
Q2: How are feedback interactions between upper trophic level predators (top-down controls) and biogeochemical functions (bottom-up) affected by changing climate and sea ice over the long and short term?
Q3: How will loss of typical polar species (e.g., penguins) affect tourism and cultural values of Antarctica?
Q4: How does the human population (tourists, students, moviegoers, policy makers) respond to warming-related changes in the Antarctic environment?
Q5: How do human decisions and actions (more or less tour business; Treaty structures, pressure to control carbon emissions) affect pace and results of climate change?

Questions Q4-5: Palmer Antarctica

- **Q4.** How does the human population (tourists, students, moviegoers, policymakers) respond to warming-related changes in the Antarctic?

- **Q5.** How do human decisions and actions (more or fewer tourists, treaty structures, pressure to control carbon emissions) affect the pace and results of climate change.

Working Lands Socio-Ecological Systems: KBS, SGS, AND, etc.



Global
National
Community
Individual

Human Behavior
Land use; resource use (water, soil, energy, agrichemicals); recreation; species introductions; price supports, trade tariffs; regulations, stewardship incentives

Human Outcomes
Commodity prices, land value, farm size, community vitality; resource availability; health & wellness; quality of life, access to services; economic security

Global drivers: climate, economy

Regional drivers: soils, climate, economy

Disturbance
Pulses: drought; storms; fire; management (fertilization; irrigation; weed, insect, and pathogen controls); pest outbreaks.

Presses: climate change, elevated CO_2, nutrient inputs; land use change; erosion; ground water depletion; economic change

Region
Landscape
Ecosystem

Ecosystem Structure
Abundance and distribution of primary producers and consumers: crops, weeds, pests, livestock, microbes, wildlife

Ecosystem Function
Primary production; nutrient cycling; herbivory, predation, decomposition; evapotranspiration, water use; gene flow.

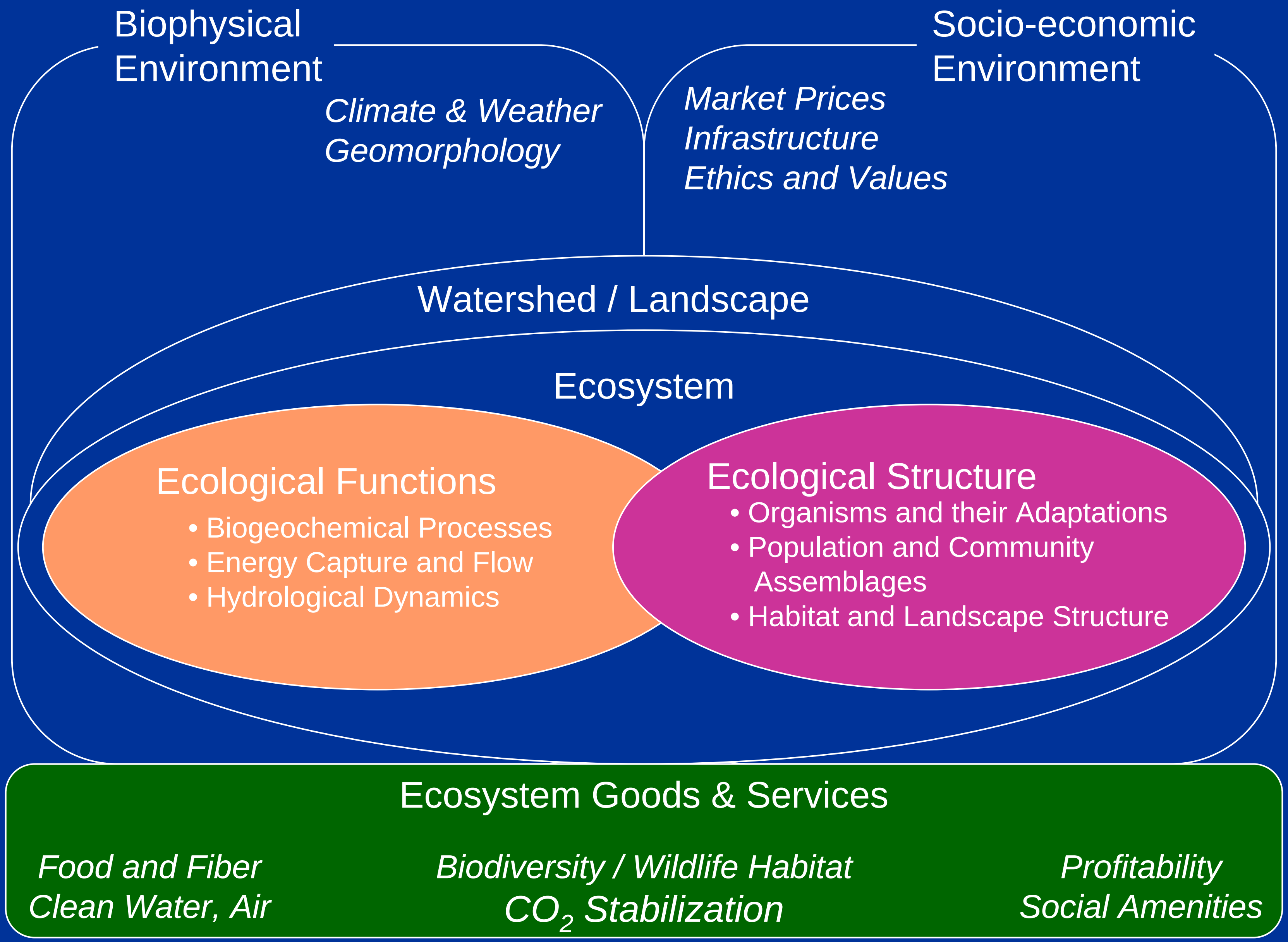
Ecosystem Services
Market products (food, fiber, fuel); pest and disease suppression; climate stabilization, carbon storage, greenhouse gas mitigation; pollination; wildlife habitat; flood control / hydrological security; income (financial security); recreation opportunities; quality air & water.

Questions Q4-5

- **Q4.** How do humans perceive changes in ecosystem services, and how do these perceptions influence market and policy behavior, rural migration, resource availability, personal and community health and well-being, environmental attitudes, and economic growth and security?

- **Q5.** How do social structural, institutional, and economic factors affect human decisions about ecosystem management (e.g. grazing pressure, pesticide and fertilizer use).

KBS: The Row Crop Ecosystem



Biophysical Environment

Climate & Weather
Geomorphology

Socio-economic Environment

Market Prices
Infrastructure
Ethics and Values

Watershed / Landscape

Ecosystem

Ecological Functions

- Biogeochemical Processes
- Energy Capture and Flow
- Hydrological Dynamics

Ecological Structure

- Organisms and their Adaptations
- Population and Community Assemblages
- Habitat and Landscape Structure

Ecosystem Goods & Services

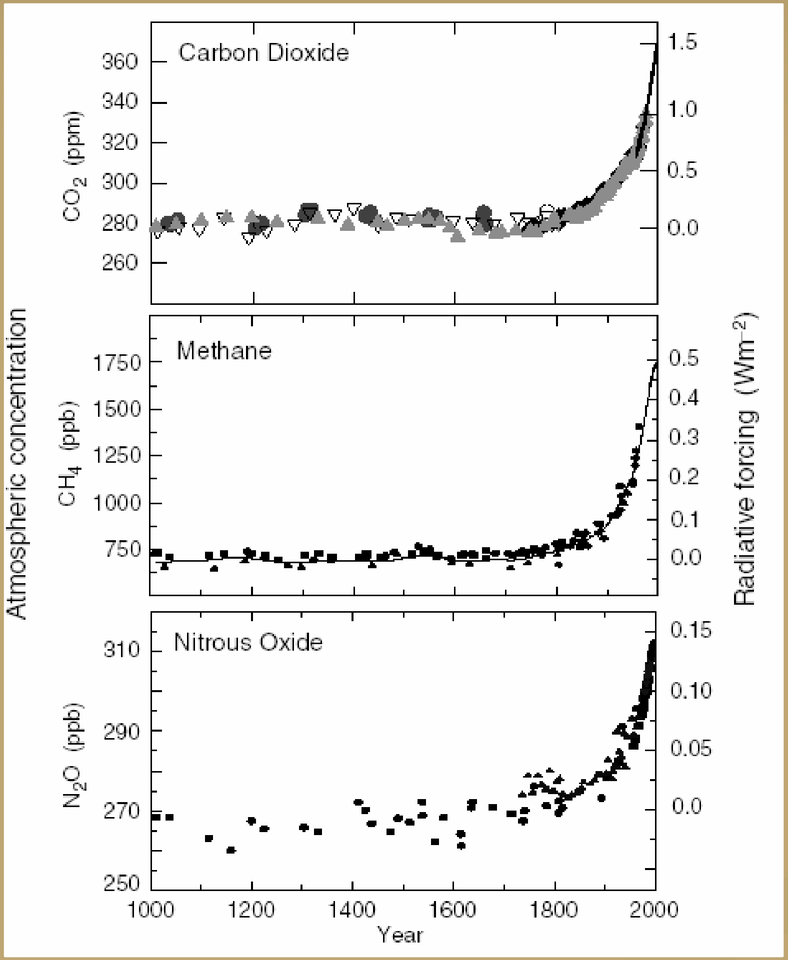
Food and Fiber
Clean Water, Air

Biodiversity / Wildlife Habitat
CO_2 Stabilization

Profitability
Social Amenities

Agricultural Systems as Greenhouse Gas Mitigators

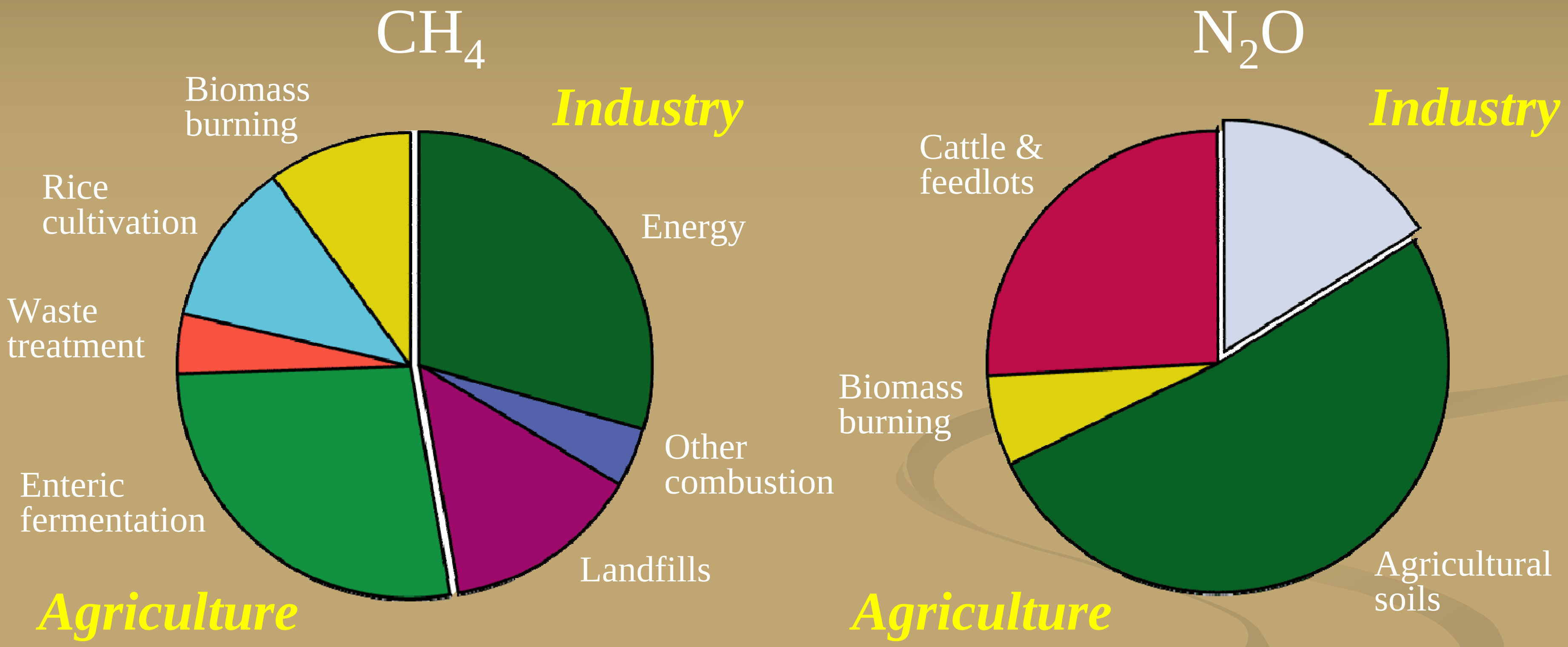
Atmospheric Concentrations of the Biogenic Greenhouse Gases (CO_2, Methane, and Nitrous Oxide) from 1000 A.D.



	Atmospheric Lifetime (yr)	Global Warming Potential
CO_2	variable	1
Methane	12	23
Nitrous Oxide	114	296

From IPCC (2001)

Anthropic Sources of
Methane and Nitrous Oxide Globally



Total Impact 2.0 Pg C_{equiv} 1.2 Pg C_{equiv}

(compare to fossil fuel CO_2 loading = 3.3 PgC per year)

Source IPCC 2001; from Robertson 2004

Major Potential Sources of Global Warming Impact in Field Crop Ecosystems

- Soil carbon change
- Fuel use
- Nitrogen fertilizer
- Lime (carbonate) inputs
- N_2O flux
- CH_4 flux (oxidation & emission)

KBS LTER Site

Ecosystem Type	Management Intensity
Annual Crops (Corn - Soybean - Wheat)	
Conventional tillage	High
No-till	
Low-input with legume cover	
Organic with legume cover	
Perennial Crops	
Alfalfa	
Poplar trees	
Successional Communities	
Early successional old field	
Mid successional old field	
Late successional forest	Low

Full Cost Accounting:
GWP Impact of Field Crop Activities

	Soil-C	N-Fert	Lime	Fuel	N_2O	CH_4	Net
				g CO_2 -equiv / m^2 / y			
Annual Crops							
Conventional tillage	**0**	**27**	**23**	**16**	**52**	**-4**	**114**

Soil carbon is at equilibrium (no annual change)

N_2O is largest source of GWP impact

Full Cost Accounting:
GWP Impact of Field Crop Activities

	Soil-C	N-Fert	Lime	Fuel	N_2O	CH_4	Net
	g CO_2 -equiv / m^2 / y						
Annual Crops							
Conventional tillage	0	27	23	16	52	-4	114
No-Till	-110	27	34	12	56	-5	14

No-till soil carbon gain provides substantial mitigation

Importance of N_2O does not change with no-till

Full Cost Accounting:
GWP Impact of Field Crop Activities

	Soil-C	N-Fert	Lime	Fuel	N_2O	CH_4	Net
				g CO_2 -equiv / m^2 / y			
Annual Crops							
Conventional tillage	0	27	23	16	52	-4	114
No-Till	-110	27	34	12	56	-5	14
Organic with cover	-29	0	0	19	56	-5	41

Some C gain with organic management

Some other sources of impact drop out

No N_2O change with organic management

Full Cost Accounting:
GWP Impact of Field Crop Activities

	Soil-C	N-Fert	Lime	Fuel	N_2O	CH_4	Net
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Organic with cover	-29	0	0	19	56	-5	41
Perennial Crops							
Alfalfa	-161	0	80	8	59	-6	-20
Poplar trees	-117	5	0	2	10	-5	-105

Substantial C gain with perennial crops, especially legume

No N_2O change with legume; substantial change with poplar

Full Cost Accounting: GWP Impact of Field Crop Activities

g CO_2 -equiv / m^2 / y

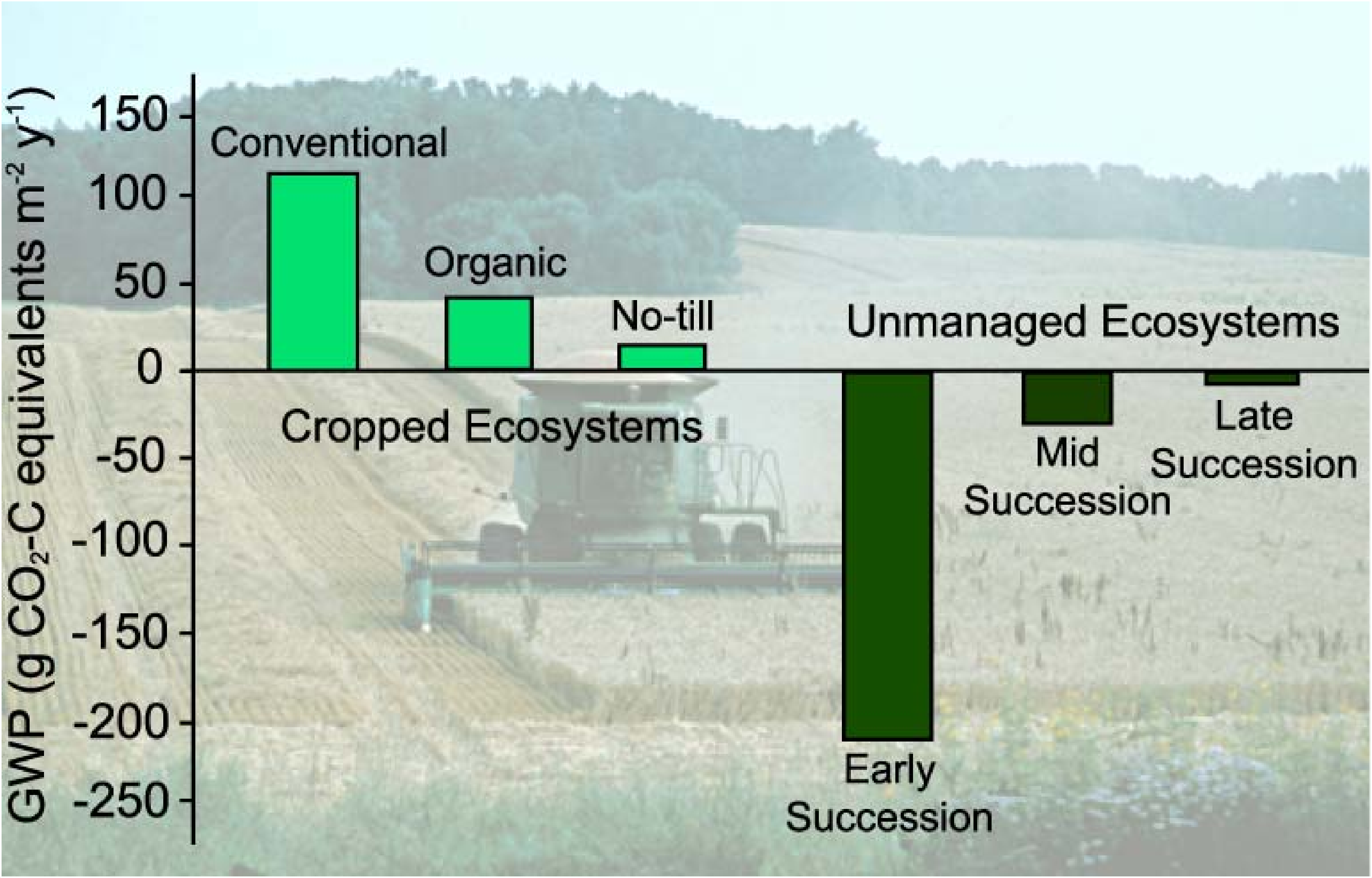
	Soil-C	**N-Fert**	**Lime**	**Fuel**	**N_2O**	**CH_4**	**Net**
Annual Crops							
Conventional tillage	**0**	**27**	**23**	**16**	**52**	**-4**	**114**
No-till	**-110**	**27**	**34**	**12**	**56**	**-5**	**14**
Organic with cover	**-29**	**0**	**0**	**19**	**56**	**-5**	**41**
Perennial Crops							
Alfalfa	**-161**	**0**	**80**	**8**	**59**	**-6**	**-20**
Poplar trees	**-117**	**5**	**0**	**2**	**10**	**-5**	**-105**
Successional Communities (CRP)							
Early successional	**-220**	**0**	**0**	**0**	**15**	**-6**	**-211**
Mid-successional	**-32**	**0**	**0**	**0**	**16**	**-15**	**-31**
Late successional forest	**0**	**0**	**0**	**0**	**21**	**-25**	**-4**

Huge C gain in natural system early, no gain later (at equilibrium)

Methane oxidation significant only in unmanaged systems

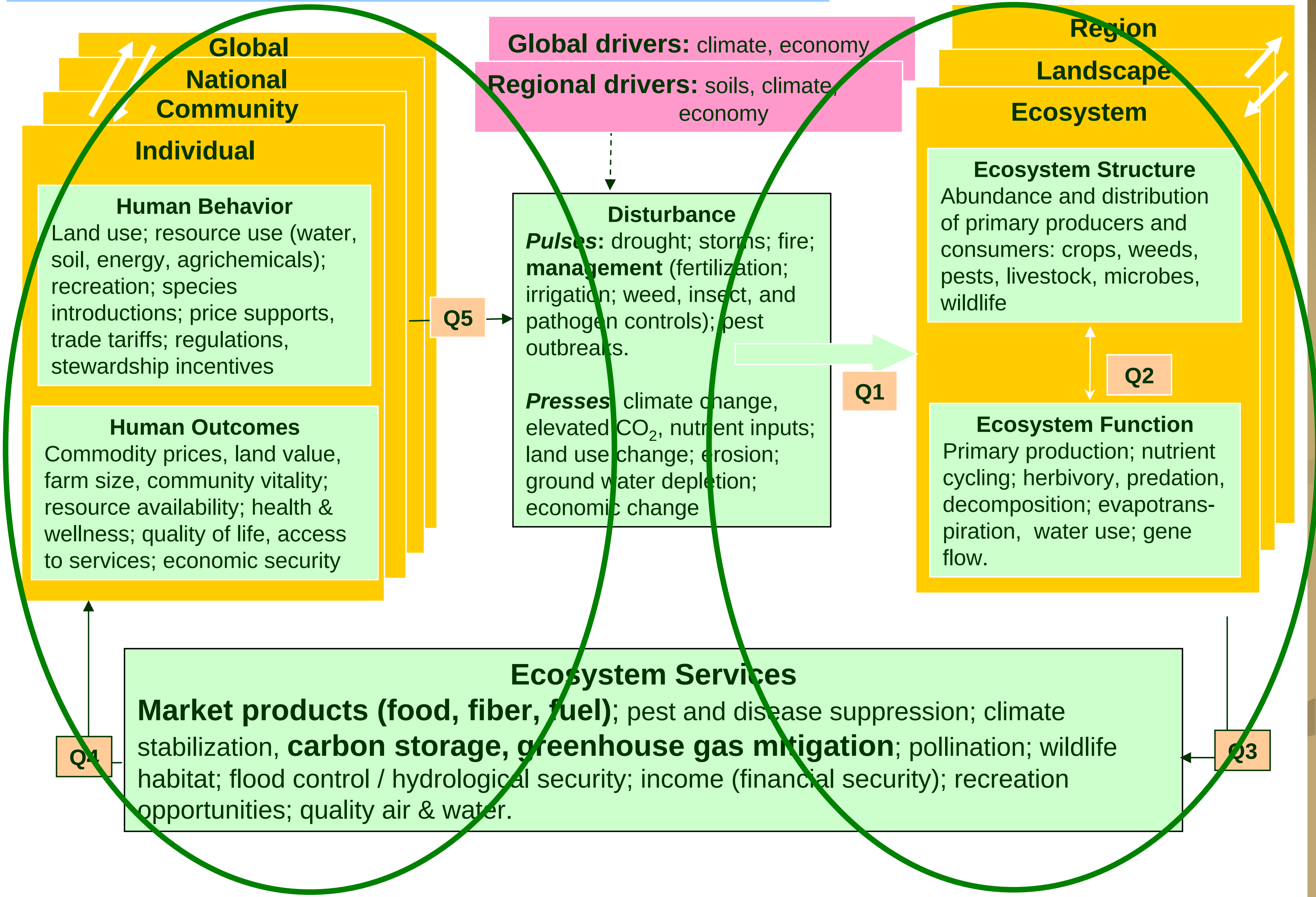
Robertson et al. *Science* 289:1922

Net Global Warming Impact of Managed and Unmanaged Ecosystems at KBS



Robertson et al. *Science* 289:1922

Working Lands Socio-Ecological Systems: KBS, SGS, AND, etc.



Global

National

Community

Individual

Human Behavior
Land use; resource use (water, soil, energy, agrichemicals); recreation; species introductions; price supports, trade tariffs; regulations, stewardship incentives

Human Outcomes
Commodity prices, land value, farm size, community vitality; resource availability; health & wellness; quality of life, access to services; economic security

Global drivers: climate, economy

Regional drivers: soils, climate, economy

Disturbance
***Pulses*:** drought; storms; fire; **management** (fertilization; irrigation; weed, insect, and pathogen controls); pest outbreaks.

***Presses*:** climate change, elevated CO_2, nutrient inputs; land use change; erosion; ground water depletion; economic change

Q5

Q1

Region

Landscape

Ecosystem

Ecosystem Structure
Abundance and distribution of primary producers and consumers: crops, weeds, pests, livestock, microbes, wildlife

Q2

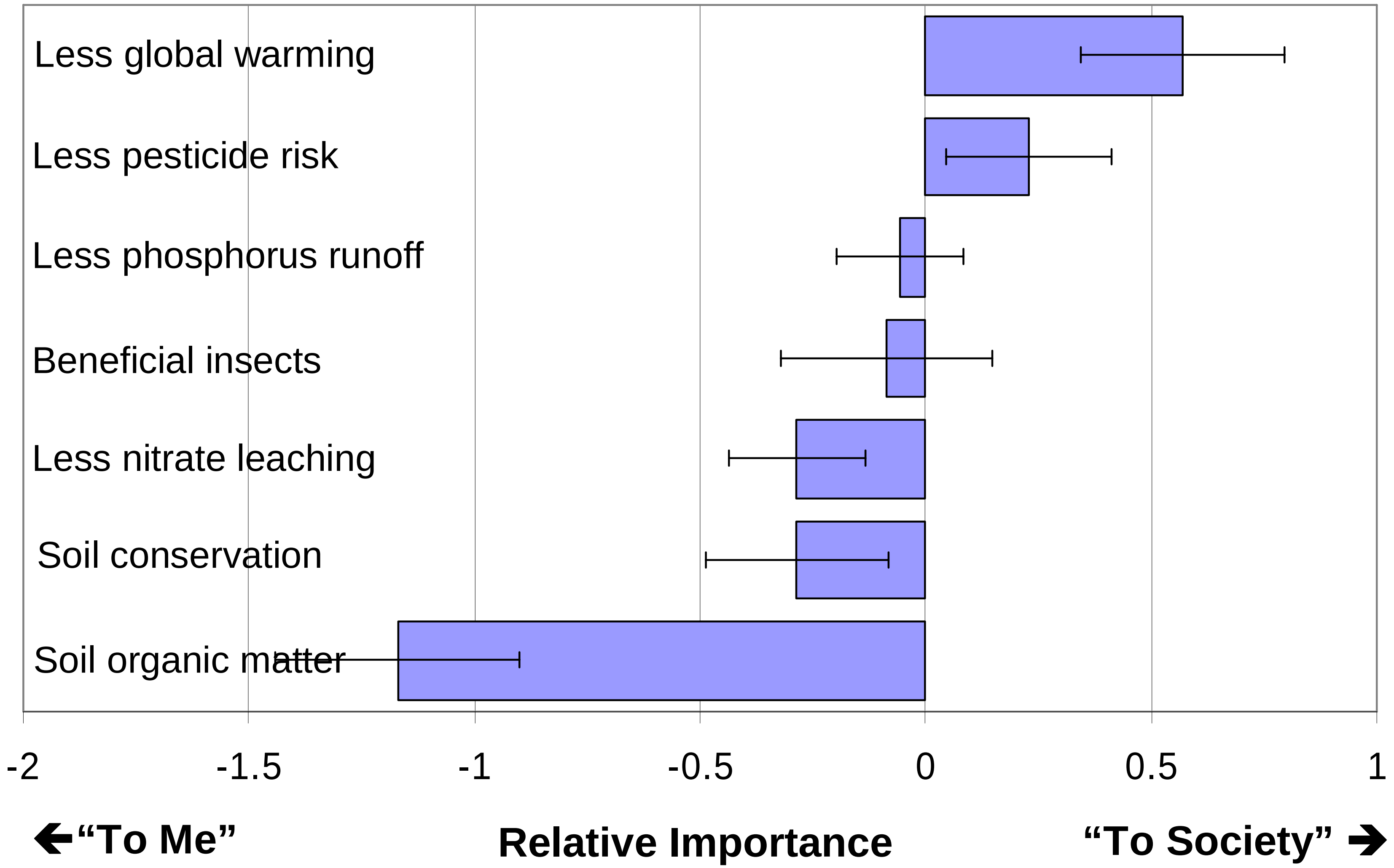
Ecosystem Function
Primary production; nutrient cycling; herbivory, predation, decomposition; evapotranspiration, water use; gene flow.

Q4

Q3

Ecosystem Services
Market products (food, fiber, fuel); pest and disease suppression; climate stabilization, **carbon storage, greenhouse gas mitigation**; pollination; wildlife habitat; flood control / hydrological security; income (financial security); recreation opportunities; quality air & water.

Michigan farmers’ perceptions of the value of different ecosystem services :



Source: Swinton et al. in review

Questions Q4-5

- **Q4.** How do changes in the valuation of services influence human outcomes such as market and policy behavior, rural demographics, resource availability, personal and community health and well-being, environmental attitudes, and economic growth, wealth, and security?

- **Q5.** How do social structural, institutional, and economic factors affect human decisions about ecosystem management.

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