Scheduled Events

Symposium Agenda

Business Meeting Agenda
THE ASSOCIATION OF ECOSYSTEM RESEARCH CENTERS
Invites you to a symposium entitled

ECOLOGICAL TIPPING POINTS

Ripley Center, Smithsonian Institution, Washington, DC, Room 3035

THURSDAY, November 16, 2006

****

Presentations may be accessed by clicking on the links below. Information from these presentations should only be used with proper citation to the authors and images from the presentations should only be used with permission of the authors.

****

11:30a - 1:00 p  Buffet Lunch

1:00p - 1:15p  Welcome and AERC Overview
Knute Nadelhoffer (President) and AERC Board

1:15p - 1:30p  The National Ecological Observatory Network (NEON)-Will NEON Forecast Tipping Points?
Dr. James A. MacMahon, Chair, NEON Inc. & Utah State University

1:30p - 2:00p  Recent Changes in the Arctic Freshwater Cycle and Impacts on Global Climate
Dr. James McClelland, University of Texas

2:00p - 2:30p  Northward Movement of Forests in the Arctic: Why Changing Arctic Ecosystems Matter
Dr. Andrea Lloyd, Middlebury College

2:30p - 2:45p  Coffee Break

2:34p - 3:15p  Could Warming and Increased CO2 Concentrations Lead to Tipping Points in Coral Reef Ecosystems?
Dr. Chris Landgon, University of Miami

3:15p - 3:45p  Detecting Changes in Highly Variable Environments - Lessons from the Western United States
3:45p - 4:15p  Dr. Kris Havstad, New Mexico State University

Desertification and Societal Uncertainty

4:15p - 4:45p  Dr. David Mouat, Desert Research Institute

4:45p - 6:30p  Discussion

Please join us for a reception! Room 3112
THE ASSOCIATION OF ECOSYSTEM RESEARCH CENTERS
2006 Annual Business Meeting

Ripley Center, Smithsonian Institution, Washington, DC, Room 3112

FRIDAY, November 17, 2006

8:00a – 9:00a    Buffet Continental Breakfast
9:00a – 11:30a  Business meeting

Agenda for Business Meeting

I.  Welcome and Review of Hill Briefing – Knute Nadelhoffer

II. Secretary Report from 2005 Annual Business Meeting – Robin Graham

III. Treasurer Report – Amy Ward

IV. Old Business – Knute Nadelhoffer
   a. Brochure Update
   b. Election of Officers for 2007
      i. President- Elect
      ii. Member at Large

V. New Business – Tom Jordan
   a. Discussion of proposal to change duration of Officer terms, stagger Secretary and Treasurer terms, make Past President a voting member of the Board of Directors
   b. Discussion of proposed Tipping Point article for Bioscience
   c. 2007 Annual Symposium and Business Meeting – Nov 15-16, Washington, DC
The United States National Ecological Observatory Network (NEON):
Science, Education, and Enabling Infrastructure
NEON

What is it?
Where is it?
So What !?

James A. MacMahon
Ecology Center, Utah State University &
NEON Board of Directors
NEON’s Mission

• The NEON mission is to:
  – discover and understand the fundamental ecological principles that govern the responses of the biosphere.
  – provide the capacity to forecast future states of ecological systems.
NEON in the space-time continuum

- eons
- epochs
- millennia
- centuries
- decades
- years
- days
- cells
- organisms
- communities
- landscapes
- biomes
- continents
- planets

- Paleo studies
- Ecosystem manipulations
- NEON
- Eddy flux
- Global satellite missions
- Land surface experiments

Time

Space
Fundamental NEON Science Challenges

• How will ecosystems and their components respond to changes in natural- and human-induced forcings?
• What is the pace and pattern of these responses?
• How do the internal responses and feedbacks of ecosystem processes and components interact with changes in climate, land use, and invasive species?
• How do these feedbacks vary with ecological context and spatial and temporal scales?
Grand Challenges

- Biodiversity
- Biogeochemical cycles
- Climate change
- Hydroecology
- Infectious disease
- Invasive species
- Land use
What is it?
What is NEON?

- A continental-scale research instrument,
- Geographically distributed infrastructure,
- Networked state-of-the-art communications system,
- Cutting edge lab and field instrumentation,
- Site based experimental infrastructure,
- Natural history archive facilities,
- Computation, analytical, and modeling capability,
- Wall-to-wall remote sensing coverage,
- A linked computational network.
What is NEON?

• A continental-scale research instrument,
• Geographically distributed infrastructure,
• Networked state-of-the-art communications system,
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NEON Fundamental Instrument Unit
FY07 MREFC: Cyberinfrastructure and Sensor Integration

Sensor to cyberinfrastructure  
Cyberinfrastructure to archive
Where is it?
NEON Climate Domains

1. Northeast
2. Mid Atlantic
3. Southeast
4. Atlantic Neotropical
5. Great Lakes
6. Prairie Peninsula
7. Appalachians / Cumberland Plateau
8. Ozarks Complex
9. Northern Plains
10. Central Plains
11. Southern Plains
12. Northern Rockies
13. Southern Rockies / Colorado Plateau
14. Desert Southwest
15. Great Basin
16. Pacific Northwest
17. Pacific Southwest
18. Tundra
19. Taiga
20. Pacific Neotropical
BioMesoNet

- PAR—photosynthetically active radiation
- UV; solar radiation
- IR up/down
- Profiles (d[ ]/dz)
  - Temperature, Moisture, CO2, Soil temperature, Soil moisture
- Air temperature (1.5m, 9m)
- Relative humidity (1.5m)
- Wind speed and direction (2m, 9m, 10m)
- Barometric pressure
- Rainfall
- Soil temperature (10 cm below both natural sod cover and bare soil)
- Soil temperature (5 and 30 cm)
- Soil moisture (5, 25, 60 and 75 cm)
Enabling Facilities & Platforms
Organism Tracking System

- Mobile animals as bio-sentinels for environmental change, forecasting biological invasions, emerging disease spread
- Individuals tagged with radio transmitters
  - Lightweight VHF tags (0.3g)
- Towers poll, detect, localize
  - Handheld and fixed (tower-based)
Airborne Observation

• High-fidelity imaging spectroscopy
  – Vegetation indices
  – Leaf area index
  – Canopy characteristics
  – Diversity

• Wave-form LIDAR
  – Vegetation height
  – Ground topography
  – Biomass
  – Life form diversity
NEON: a launch pad for ecological studies

- fire
- grazing - CO₂
- invasives
- hanta virus
- urbanization and water
- GSL as paleorecorder
THRESHOLDS & NEON
Conclusion

NEON will transform the way we do ecological research and education and will provide information of importance to society.
(Small) Organism tracking systems

Science questions:
- mobile animals as bio-sentinels for environmental change
- forecasting biological invasions and emerging disease spread
- education, outreach and conservation

Deployment:
- 50 terrestrial, 20 aquatic grids
- 200 terrestrial/aquatic single sites

Leveraging:
- BioMesonet, MicroSensornet, cell towers, radar stations
- Combine with large animal tracking (FWS) into “Bio-bank”

Cost:
- Installation: $5.5 M terrestrial, $2 M aquatic (~5K individuals/yr)
- Annual: $0.8 M terrestrial, $0.6 M aquatic
Recent Changes in the Arctic Freshwater Cycle and Impacts on Global Climate

Jim McClelland
University of Texas at Austin
Marine Science Institute
Collaborators

Bruce Peterson
Marine Biological Lab
Robert Holmes
Woods Hole Research Center
Ruth Curry
Woods Hole Oceanographic Institute
John Walsh
International Arctic Research Center
Knute Aagaard
University of Washington
OUTLINE

• Connections between Arctic freshwater cycle, ocean circulation, and climate
• Changes in the arctic/subarctic freshwater system over the latter half of the 20\textsuperscript{th} century
• Relevance to climate change modeling
Predicted interactions between global warming and the hydrologic cycle

1. Increased atmospheric transport of water vapor toward the poles
2. Increased high latitude precipitation and river discharge
3. Melting of glaciers and sea ice
4. Increased export of fresh water from the Arctic Ocean to the North Atlantic Ocean
5. Decreased North Atlantic Deep Water formation
6. Alteration of global ocean circulation patterns, including decreased transport of warm ocean water northward in the Atlantic
7. Relative cooling in the northern hemisphere and enhanced warming in the southern hemisphere
North Atlantic Deep Water (NADW) Formation Occurs Primarily at Two Sites (GIN Sea and Labrador Sea)

- NADW formation is major engine for global ocean circulation
- NADW formation strongly influenced by salinity & temperature
- Increased freshwater inputs to the North Atlantic weakens, and potentially shuts down, NADW formation.
Global Ocean Thermohaline Circulation

From Rahmstorf, Nature, 2002
Adapted from Broecker
Modeled Changes in Surface Air Temperatures Resulting from a Shutdown of North Atlantic Deepwater Formation

From Rahmstorf, Nature, 2002
HadCM3 Model
A New Ice Age

Oceanographers have discovered a huge river of freshwater in the Atlantic formed by melting polar ice. They warn it could soon bury the Gulf Stream, plunging North America and Europe into frigid winters.

Researchers Predict Europe Could Turn Icy Cold

Posted on Fri, 01 Mar 2002 17:40:07 GMT

Written by Becky Orfinger, Staff Writer, DisasterRelief.org, with news reports

A new study by a group of Oregon State University (OSU) scientists explores the possibility that Europe's generally mild average temperatures could soon become more like Alaska's. The scientists used computer models to analyze the potentially paradoxical effect of global warming on an ocean temperature phenomenon called "thermohaline circulation" that moderates Europe's climate, and published their findings in the scientific journal Nature this week.

The Heat Before the Cold

By Terrence Joyce

This week's unexpected heat wave across much of the Northeast and Midwest, coupled with recent reports about the surprisingly fast collapse of an Antarctic ice shelf the size of Rhode Island, has heightened fears of a long-term rise in temperatures brought about by global warming. But this fear may be misguided. In fact, paradoxically, global warming could actually bring colder temperatures to some highly populated areas like Eastern North America and Western Europe.

Could global warming produce a big chill?

By David Arnold

WOODS HOLE — In what would be a surprising byproduct of global warming, average temperatures in North America and Europe could drop by 5 to 10 degrees Fahrenheit in the coming decades as melting polar ice and increased water evaporation profoundly alter the ocean currents that keep both regions warm, say researchers at the Woods Hole Oceanographic Institution.

Terrance Joyce, chairman of the
Eurasian River Discharge to the Arctic Ocean

Yenisey, Ob’, Lena, Kolyma, Severnaya Dvina, Pechora

Average discharge anomaly for 5 year increments
Cumulative volume anomaly from river inputs

Discharge anomaly relative to 1936-1955 baseline (km³/y)
Cumulative volume anomaly (km³)

Years


-2000 -1000 0 1000 2000 3000 4000

-200 0 50 100 150 200
Volumetric Dilution of Nordic Seas and Subpolar Basins Through Time (Curry and Mauritzen 2005)

Full Water Column

Fresh Water Anomaly (m) rel to 1950_59 .0_bottom
Potential Sources of Freshwater

- Net Precipitation (P-E) including river runoff
- Sea Ice net melt
- Glacier net melt
- Greenland Ice Sheet net melt
Average freshwater source anomalies for 5-year intervals

Flux anomalies for freshwater sources (km³/y)

P-E Arctic Ocean
P-E HBCA
P-E Nordic Seas
P-E Subpolar Basins
Rivers Arctic Ocean
Rivers HB

Glaciers
Sea Ice

Graph showing flux anomalies for various freshwater sources over time from 1950 to 2005.
Freshwater Anomalies in the Nordic Seas and the North Atlantic Subpolar and Subtropical Basins

![Graph showing freshwater anomalies](image-url)

- **T1**: FW Anomaly NSSB
- **T2**: Combined
- **T3**: Subpolar
- **T4**: Nordic
- **Subtropic (>1500 m)**

**Graph Details**
- **Net flux anomaly (km³ yr⁻¹)**
- **Storage anomaly (km³)**
- **Year**: 1950 to 2000
Comparison of Ocean Storage and Cumulative Input Anomalies

Fresh water anomaly (km³)

Year


T1 T2 T3 T4

Glacier melt
Sea ice attrition
P-E remote
P-E local

Cumulative input
Cumulative storage
Global air temperature and the North Atlantic Oscillation Index (NAO)

- Global SAT anomaly is relative to 20th century average
- NAO Index reflects the difference in sea level pressure between Iceland (Icelandic Low) and the Azores (Azores High).
Increasing Melt of the Greenland Ice Sheet

Current Greenland Summer Melt

- 2002 all-time record melt area
- Melting up to an elevation of 2000 m
- 16% increase from 1979 to 2002

130,000 years ago, Greenland may have melted by 2/3rds in 500 years or less

Net Ice Sheet Water Balance ~ -80 km³/yr during 1990s.

(Box et al. 2004)

Courtesy J. Overpeck and ARCSS
# Average Anomalies for 1990s

<table>
<thead>
<tr>
<th>Source</th>
<th>Average anomaly (km³/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small glaciers and ice caps</td>
<td>38 ± 13</td>
</tr>
<tr>
<td>Greenland ice sheet</td>
<td>81 ± 38</td>
</tr>
<tr>
<td>Rivers, Arctic Ocean</td>
<td>164 ± 34</td>
</tr>
<tr>
<td>Rivers, Hudson Bay</td>
<td>-59 ± 16</td>
</tr>
<tr>
<td>Net precipitation, Arctic Ocean</td>
<td>124 ± 72</td>
</tr>
<tr>
<td>Net precipitation, HBCA</td>
<td>81 ± 33</td>
</tr>
<tr>
<td>Net Precipitation, Nordic Seas</td>
<td>67 ± 28</td>
</tr>
<tr>
<td>Net Precipitation, Subpolar Basin</td>
<td>336 ± 73</td>
</tr>
<tr>
<td>Sea ice</td>
<td>817 ± 339</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1649</strong></td>
</tr>
</tbody>
</table>

Shut down of NADW formation in model simulations happens with a sustained freshwater input between 0.06 and 0.15 Sv.

0.052 Sv
Summary

- For 1955 to 2000 the freshwater sources in order of importance were:
  - Net precipitation (including river discharge)
  - Sea Ice
  - Glaciers

- Changes in these sources largely explain the changes in freshwater storage in the northern North Atlantic Ocean
Summary

• Warming coupled with the North Atlantic Oscillation appears to be driving the observed changes in freshwater sources and storage

• Average freshwater input anomalies during the 1990s approached values that model simulations identified as sufficient to shut down NADW formation
Northward movement of forests in the Arctic: Why Changing Arctic Ecosystems Matter

Andrea Lloyd
Middlebury College
November 16, 2006
Fig. 2.8. Seasonal land-surface air temperature trends for the period 1966 to 2003 calculated using the GHCN dataset (updated from Peterson and Vose, 1997). (ACIA, 2004)
Summer temperature, northwestern Canada (1800-present)

Szeicz & MacDonald 1994
Treeline (upper/northern limit of spruce) in 1850

Treeline, ca. 1900

Treeline, ca. 1950

Treeline, ca. 2000

Treeline (upper/northern limit of spruce) in 1850
The diagrams illustrate the changes in forest and forest-tundra areas over time.

- **Forest**: The graph shows an increase in forest area from 1800 to 2000, with a notable rise in the middle of the 20th century.

- **Lower forest-tundra**: The area increased significantly from 1890 to 1930, with a peak in the middle of the 20th century.

- **Middle forest-tundra**: There was a notable increase in the early 20th century, followed by a decline and then a slight increase in recent years.

- **Upper forest-tundra**: The area showed a steady increase from 1800 to 1930, with a peak in the early 20th century and a slight rise in the late 20th century.

The data points indicate significant changes in the distribution of forest and forest-tundra areas, reflecting environmental and human impacts over the centuries.
Decade that spruce populations established in tundra:
Conclusions:

• Spruce density and areal extent has increased since the late 1800s in Alaska.
• Expansion of forests is correlated with warming in the late 19th and 20th centuries.
1949

Chandler River, 50 miles S. of Umiat: Sturm, Racine and Tape: Fifty Years of Change in Arctic Alaskan Shrub Abundance
Fig. 1  (a) Location of studies (numbers in brackets) related to shrub expansion in the Arctic. These same numbers in brackets appear in the text associated with relevant studies. The smaller rectangle indicates the area where repeat aerial photography was available (see (b)) (background map: CAVM Team, 2003). (b) The Col photo study area showing the 24 flight lines and 19 river systems along which photos were rephotographed. Color codes indicate relative change in shrub cover (RSC, relative change in shrub cover) (red: RSC = 50–80%; orange: RSC = 30–50%; orange–yellow: RSC = 15–30%; yellow: RSC = 0–15%; black = photos not suitable for this type of analysis). There was almost no negative change (loss of shrubs).
Conclusions:

• Spruce density and areal extent has increased since the late 1800s in Alaska.

• Expansion of forests is correlated with warming in the late 19th and 20th centuries.

• Shrub size, density, and areal extent has increased since at least the 1950s in Alaska.
Summer albedo across a tundra-forest transition

Herbaceous tundra
Low shrub tundra
Tall shrub tundra
Forest-tundra
Forest

Vegetation type

Winter/spring albedo

Herbaceous tundra
Low shrub tundra
Tall shrub tundra
Forest-tundra
Forest

(Data from Sturm et al. 2005)
Figure 11. Cumulative shortwave solar heating for five land surfaces ranging from tundra to forest. Results highlight the differences due to the long polar night at 75°N versus year-round sunlight at 50° and indicate that differentiation by vegetation begins later in the winter at higher latitudes.

Figure 12. Solar heating factor as a function of latitude. The solar heating factor is the ratio of shortwave solar energy absorbed by one type of land surface vegetation divided by the energy that would have been absorbed if the site had been shrub-free tundra. Note that for a shrubland (our woodland site), the increase ranges from 69 to 75% (latitude 75°N and 70°N, respectively).

(Figures from Sturm et al., 2005, JGR)
**Atmospheric heating (W/m²)**

<table>
<thead>
<tr>
<th></th>
<th>Observed</th>
<th>Potential maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrub expansion</td>
<td>0.08</td>
<td>6.37</td>
</tr>
<tr>
<td>Forest expansion</td>
<td>0.11</td>
<td>24.54</td>
</tr>
</tbody>
</table>

(Figure and data from Chapin et al. 2005, Science)
high-latitude warming

↑ Shrub & tree growth & cover

↓ albedo

↑ Atmospheric heating
Tundra with thin snow

Drift snow

Downwind edge of shrub patch

(photo courtesy of Matthew Sturm, from Sturm et al. 2005)
Conclusions:

• Spruce density and areal extent has increased since the late 1800s in Alaska.
• Expansion of forests is correlated with warming in the late 19th and 20th centuries.
• Shrub size, density, and areal extent has increased since at least the 1950s in Alaska.
• Shrub and tree expansion initiates positive feedbacks-- associated with increased atmospheric heating, and increased snow trapping-- that have the potential to measurably increase the rate of local and regional-scale warming.
Thank you!!

**Funding:**
NSF-OPP
Bonanza Creek LTER
Middlebury College

**Collaborators:**
Matthew Sturm
Terry Chapin
& other
ATLAS P.I.s and
LTER investigators
COULD WARMING AND INCREASING CO2 LEAD TO TIPPING POINTS IN CORAL REEF ECOSYSTEMS?

Chris Langdon

Rosenstiel School of Marine and Atmospheric Science, University of Miami, USA
Correspondence between pCO₂ and temperature over last 140 years
Rising Atmospheric Carbon Dioxide

Current CO₂ highest in 650,000 years of ice core data and 24 million years from soil data.
Build up of atmospheric CO$_2$ is causing warming

This warming may have an adverse effect on organisms such as corals that tolerate only a narrow range of environmental temperature (stenothermal).

Buddemeier et al. (2004)
Effect of temperature on rate of coral growth

![Graph showing the effect of temperature on coral growth rate.](image)

- **Normal seasonal range in temperature**
- **Bleaching threshold**
- **Relative calcification rate**
- **Temperature, °C**

Key:
- M. capitata
- M. capitata
- P. lobata
- G. fascicularis
- S. pistilata
- Acropora sp.
- P. damicornis
- Topt=25.0 PW=10
- Topt=26.0 PW=4
Bleaching

(loss of algal symbionts and/or pigmentation from reef corals and other invertebrates)

Bleaching leads to mortality if thermal stress is prolonged and/or severe, i.e. if temperature exceeds the normal summer maximum by $>1^\circ$C for 4-8 weeks.
A 2°C warming could push corals to a tipping point where they would bleach each summer, a situation that would be unsurvivable in the long term.
Bleaching events are predicted to be more frequent and severe as the climate warms

Hoegh-Guldberg (1999)
Research is now focusing on understanding:

- Rates and mechanisms of adaptation and acclimatization
- Strategies for increasing reef resilience in the face of projected climate change

Hughes et al. (2003)
The other \( \text{CO}_2 \) problem – the oceans are taking up the \( \text{CO}_2 \) and becoming more acidic.

\[ \approx 48\% \text{ of anthropogenic } \text{CO}_2 \text{ taken up by the ocean} \]
Rising atmospheric CO$_2$ is changing the chemistry of the oceans

\[
\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{HCO}_3^- + \text{H}^+ \\
\text{CO}_3^{2-} \rightleftharpoons \text{HCO}_3^- + \text{H}^+
\]

"business as usual" IS92a scenario (IPCC, 1995)

After Wolf-Gladrow et al., 1999
End Result of CO₂ flux into the Global Oceans

↑ CO₂ aqueous
↑ HCO₃⁻
↓ pH (ocean acidification)
↓ CO₃⁻² (decreased Ω)

How do these changes affect coral reefs?
Coral calcification depends on $\Omega$

$$\Omega = \frac{[\text{Ca}^{2+}][\text{CO}_3^{2-}]}{K_{sp}}$$

$\Omega_{\text{arag}} > 1$ promotes precipitation  
$\Omega_{\text{arag}} < 1$ promotes dissolution

Falling $[\text{CO}_3^{2-}]$ means that $\Omega$ also falls.
Projected change in $\Omega_a$ as ocean takes up $CO_2$

Reef growth is associated with $\Omega \geq 3.2$

Kleypas, J.A. et al, 1999
Latitudinal changes in $\Omega_a$

As the oceans take up CO$_2$, this curve is keeping the same shape but shifting downwards.

By the year 2100 the maximum is projected to be 2.6.

Biogeography of coral reefs and carbonate saturation state

Kleypas et al., 1999
Shrinking range where $\Omega_a$ is conducive to reef development

Pre-industrial (1870)
$pCO_2 = 280$ ppmv

2000 – 2009
$pCO_2 = 375$ ppmv

2020 – 2029
$pCO_2 = 415$ ppmv

2040 – 2049
$pCO_2 = 465$ ppmv

2060 – 2069
$pCO_2 = 517$ ppmv

Aragonite saturation state

Saturation state in the tropics may decrease by 30% over the next century with a proportional reduction in calcification rates
Controlled temperature and CO$_2$ aquaria system at UM
Effect of CO$_2$ on vertical extension of *P. lobata*

Elevated CO$_2$ causes an immediate but reversible 45-80% reduction in skeletal extension
Coral calcification declines with declining saturation state
(symbols represent data for 12 different coral species)

\[ G = -4.5 + 22.7\Omega_a, \quad r^2 = 0.67 \]
Effect of CO$_2$ on the calcification of the Biosphere 2 coral reef mesocosm
(each of these points is the average over a 4 month period)

$y = 62373.77x^{-1.24}$

$R^2 = 0.61$

Langdon et al. 2000
Saturation state controls calcification

At one point in the study the $\Omega_{a}$ was held between 2-2.5 for 2.5 years. The rate of calcification never increased over this period indicating that the organisms had little capability to acclimate.
At what point will a reduction in coral skeleton building become critical?

- Coral reefs are found where the rate of production of carbonate framework exceeds the rate of removal.
- Physical removal processes play a role but the dominant process is biological.
- If we can get an estimate of the spatially averaged rate of bioerosion then we can identify the critical rate of reef-building that must be exceeded to sustain a coral reef in the long term.
Bioerosion happens on many scales by bivalves and sponges.
by polychaete worms
by endolithic phototrophs and fungii
(photomicrographs show resin casting of the galleries bored by endolithic algae and fungii)
Net reef accretion may not be sustainable if atmospheric CO$_2$ exceeds 500 ppm.
Two possible tipping points identified for coral reef ecosystems

If warming exceeds 2°C bleaching events could become an annual occurrence. This would likely lead to a loss of coral cover and phase shift to a macroalgal dominated system.

If atmosphere CO$_2$ exceeds 500 ppm the saturation state could fall below the level needed to sustain reef framework.

We need to improve our scientific understanding of adaptation and acclimatization

We need to take immediate action to control greenhouse gas emissions….
Ecosystems in the tropics and at the poles are experiencing rapid change.
Detecting Changes in Highly Variable Environments - Lessons from the Western United States

Kris Havstad for Scientists with the US Department of Agriculture Agricultural Research Service Jornada Experimental Range Las Cruces, NM
Overview

- Well documented evidence of change
- Change not always gradual
- Change may be irreversible (a post threshold world)
- Landscape heterogeneities mitigate and accelerate
- Dynamics underlying thresholds includes socio-political influences on these landscapes
Changes in the world’s rangelands – many examples, all continents…
Gravelly, shallow carbonatic relict fan
(water limited, prone to shrub dominance)

Gravelly active fan
(shifting mosaic of grass and shrubs)

Limestone hills (resistant grassland)

Calcareous loamy (susceptible to water erosion)

Clay bottom
(receives water, highly resistant grassland)

Landscapes interpret the drivers

Interpreting a Landscape Mosaic
(will show this figure again)

Landscapes interpret the drivers
Changing scientific underpinnings of dry land ecology (Research Centers have been crucial to reshaping these views)

<table>
<thead>
<tr>
<th>Old view</th>
<th>“Landscape” view</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Uniform degradation mechanisms</td>
<td>Spatial variability in degradation</td>
</tr>
<tr>
<td>B₁. Stability, linearity, and reversibility</td>
<td>Thresholds, “regime shifts”</td>
</tr>
<tr>
<td>B₂. Small-scale processes</td>
<td>Cross-scale interactions</td>
</tr>
<tr>
<td>C. The ivory tower, intradisciplinarity</td>
<td>Socio-ecology, transdisciplinarity</td>
</tr>
</tbody>
</table>
Examples from the Chihuahuan Desert

Prediction of variations and/or transitions requires location-specific data.
Three kinds of vegetation/soil dynamics observed

“Resilient variation within states”

1) Reversible changes in plant abundance with changes in rainfall or disturbance pattern (grazing, fire) ~ patch dynamics

“Transition between states”

2) Changes in plant abundance that cannot be reversed until competitors or fire-adapted species are removed

3) Changes in plant abundance that cannot be reversed until erosion is stabilized and soil fertility, soil physical properties, or previous hydrology is restored.
Why is change so variable?

Grass dynamics via repeat aerial photography 1936-1996

Probability of grass persistence

Bestelmeyer et al., Ecology, 2006
Fine-scale soil patchiness governs vegetation pattern

Patchiness in calcium carbonate is inversely related to grass cover.
Regional patterns of degradation on different geomorphic units

Grass dynamics in 123 trend plots: ca. 1970-2003

Dynamics differ predictably on different soils

Bestelmeyer et al., J. Arid Env., 2006
The effects of geomorphic position on vegetation dynamics:

Active alluvial fan (gravelly soils)

Relict, dissected alluvial fan (gravelly soils)

Erosion and deposition processes depend on landscape context.
Distinguishing resilience vs. regime shifts (thresholds)

Is this grassland at risk of desertification?
Thresholds as sequences of events, changes, and feedbacks

- **Pattern threshold**
  - grass connectivity
  - shrub density
  - habitat fragmentation

- **Process threshold**
  - erosion rate
  - fire spread/frequency
  - dispersal/colonization rate

- **Degradation threshold**
  - soil depth
  - nutrient availability
  - habitat occupancy

**Classification thresholds**
- recognized to prevent a transition
- recognized for restoration

Bestelmeyer, Restoration Ecology, 2006
Pattern thresholds exist that can be quantitatively related to process

- Measures initiation of process that produces a transition
- Can be detected with cover values, stubble height, gap size

Ludwig et al., Ecological Indicators, in press
Pattern may also be linearly related to process rates

- The lower the cover, the greater the erosion rate

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**Figure 6.4.** Water budgets and amount of interrill erosion, runoff, and interception from oak, bunchgrass, sodgrass, and bare ground dominated areas, Edwards Plateau, Texas. Based on 10 cm of rainfall in 30 minutes (from Blackburn et al. 1986).
Altered process rates have gradual or discrete environmental consequences

- Process rates \times \text{duration} = \text{degree of change} (\text{e.g., in organic matter content})

Nickel series, MLRA 42, typic aridic Calcareous Gravelly

Recent grassland loss, A horizon present

Crossed a pattern-process threshold

Grassland absent for decades, A horizon lost

Has this crossed a degradation threshold?
At some critical values of an environmental/resource factor, the site becomes degraded, autogenic recovery does not occur, degradation may spread.
Geographic position may override local properties

Grassland preserved

Grassland lost

3 km
Geomorphic position: Aeolian deposition

1984

1988

1997

2003

Basin floor: Loamy site adjacent to degrading loamy sand site

- 25 cm of fine sand accumulation abrading and burying tobosa
- Landscape-driven dynamics
People drive and respond to ecological change

- Policies, economics, and motivations govern the intensity and spatial distribution of disturbances.

- Education coupled with science-based models and indicators enable people to respond to ecological change.

- Ecologists are only beginning to understand linkages between ecological and social processes: this is the newest frontier.
Policy drivers of rangeland ecosystem change

- Homestead Acts (1862 and later): 160+ acres to settlers too small in the arid western U.S, un-owned open range free-for-all (initial pulse of widespread degradation)
Policy drivers of rangeland ecosystem change

- Taylor Grazing Act (1934): “stop injury to the public grazing lands”; grazing allotments formed; solidified grazing as primary use of public lands (*introduced present spatial structure of human effects*)
Interpreting a Landscape Mosaic
(Landscapes interpret the drivers)

Gravelly, shallow carbonatic relict fan
(water limited, prone to shrub dominance)

Limestone hills (resistant grassland)

Gravelly active fan
(shifting mosaic of grass and shrubs)

Calcareous loamy
(susceptible to water erosion)

Clay bottom
(receives water, highly resistant grassland)

...location, location, location...
Lessons for interpretation of variations or regime shifts/thresholds

1. Recognize spatial heterogeneity of land units given vegetative/soil potentials

2. Describe threshold behaviors of those units into sequences of events and processes

3. Characterize landscapes of units and their cross-scale interactions involved in threshold behaviors

4. Integrate ecological and sociological/economic data to further explain local variation

…Location, Location, Location,…

Note: in many (but not all) cases we are already in a post threshold world
Desertification and Societal Uncertainties

David Mouat
Desert Research Institute, Reno NV
November 2006
Drylands:

- Occupy 41% of the earth’s land surface
- Are populated by over 2 billion people
- Up to 20% of drylands are suffering from some degree of desertification
Desertification:

“Land degradation in arid, semi-arid and dry subhumid areas resulting from various factors, including climatic variations and human activities”

UNCCD, Article 1.
Causes of desertification:

• Inherent vulnerability of dryland areas
• Inherent variability in climate
• Human activities such as cash-cropping, fuel wood cutting, irrigation, overgrazing
Desertification is a cumulative process, exacerbated by:

- Increasing human population in dryland areas
- Climate change/variability
- Global economics
- Social inequalities
Environmental impacts of desertification include:

- Soil nutrient depletion
- Salinization
- Lowered water tables
- Vegetation change
- Erosion
- Over exploitation of resources
In human terms desertification results in:

- Increasing distance to water
- Depletion of fuel wood
- Poor animal health
- Reduced crop yields
- Increased human misery
- Migration
Desertification

• Results in a loss of ecosystem services
• Reduces land use and alternative livelihood options for humans
• Increases societal uncertainty
Some impacts of land degradation

- Decrease in productivity
- Loss of cropland
- Loss of biodiversity
- Out-migration
Tipping Points in Desertification

- Vegetation change
- Increases in areas of bare ground
- Differences in landscape patterns
- Change in surface and groundwater systems
“Global Warming Hits ‘Tipping Point’”

- Siberian study
- Upward revisions of predictions for future global temperatures

New Scientist, August 2005
Recent studies show that climate change will increase the risk of desertification in Africa – which is already severely affected.
Rainfall and surface water in Africa

de Wit and Stankiewicz, 2006
Global circulation models + greenhouse-gas emissions + anthropogenic CO$_2$ input = significant decrease in perennial surface runoff
Effect of a 10% drop in rainfall on perennial drainage density

- 25% increase
- no change
- 25% lost
- 50% lost
- 75% lost
- no drainage

Annual rainfall in a region [mm]

de Wit and Stankiewicz, 2006
In most drylands, predicted increases in temperature are not likely to be offset by precipitation increases; drylands will become more arid, intensifying the potential for desertification.
Do desertification processes follow non-linear trajectories?

- Westoby et al., state and transition, 1989
- Tausch et al., plant community thresholds, 1993
- Whisenant, transition thresholds, 1999
- Reynolds and Stafford-Smith, thresholds and human adaptation, 2002
Desertification state and transition

• Grass-dominated systems change to shrub-dominated

With implications for resource distribution, and increased bare ground
Faced with salinization, soil erosion, declining productivity, and other consequences of desertification

what do people do?
Will a cascade of changes in the human environment system transform that system from sustainable to unsustainable -- or vice versa?
Impact and intensity of desertification in Senegal reduced by human behavior

Bradley and Grainger, 2004
Social resilience expressed by:

- Reducing herd size
- Diversifying livestock type
- Diversifying crops

Then, in times of greater need:

- Gathering forest products
- Trade
- Traveling spiritualism
- Migration to urban areas

Bradley and Grainger, 2004
Are interventions possible?

- While there are still options
- Before degradation is too severe
- While people are still motivated
- Costs increase dramatically with increased degradation
- At appropriate scales
- Both top-down and bottom-up
UN Convention to Combat Desertification

“The Convention aims to promote effective action through innovative local programs and supportive international partnerships”
Desertification “opportunities”

- Identification of areas and peoples at greatest risk
- Finding effective ways to take advantage of local knowledge
- Improving communication
- Reducing redundancy
We need a global perspective – recognizing that some countries, peoples, and regions are “out of the loop” and therefore particularly vulnerable.
In order to frame policies which can be effective in both temporal and spatial contexts we need to understand the range of possible futures for drylands.
The MA developed four scenarios.
“Negative” futures can be ameliorated by local and regional studies that investigate alternative options and involve and empower people.
Are tipping points always negative?

- Awareness
- Preparedness
- Communication
- Social institutions
- Community organization
SUMMARY -- 1

- Desertification – land degradation in drylands – is the most threatening ecosystem change on all continents & impacts livelihoods of the poor and land productivity
  - 10-20% of drylands are already degraded
  - A much larger area is currently under threat
- Desertification is a result of a long-term failure to balance demand for and supply of ecosystem services in drylands
- Dryland populations on average lag far behind the rest of the world in human well-being & development indicators
This is attributed to:
- human factors: indirect factors like population pressure, socioeconomic and policy factors, and globalization phenomena, and direct factors like land use patterns and practices
- Climatic factors of concern include droughts and projected reduction in freshwater availability due to global warming

Threats due to water scarcity, intensive use of services and climate change are much greater for drylands:
- Greatest threats in sub-Saharan Africa and Central Asia

Desertification processes in drylands cause adverse impacts on non-drylands areas:
- Biophysical impacts: dust storms, downstream flooding, impairment of global carbon sequestration capacity, and regional/global climate change
- Social impacts: human migration and economic refugees
Desertification and Societal Uncertainty

A race for survival?