

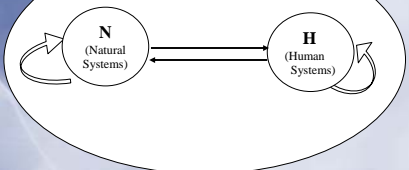
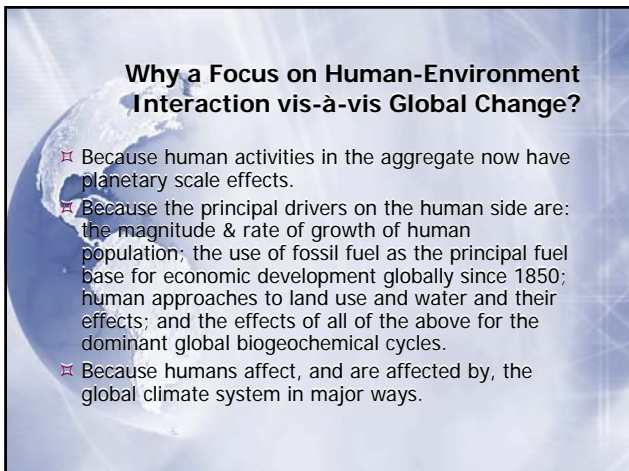


**Policy Design for Dealing with Multiple Environmental Stresses, Nonlinearities, & Critical Thresholds**

*Policy and Management Responses to Global Environmental Change*  
*Edward Miles*  
*SMA/CSES/JISAO/UW*

*Figure 1 implies that while humans are part of nature, they are also independent actors on nature as much as they are subject to natural cycles and events. So what is important is the dynamic interaction between the two at all space/time scales across all human activities. SMA puts the focus on the marine environment which is defined to extend from coastal watersheds to the open ocean as they are connected by river run-off, tropospheric transport, and the conduct of human activities on-shore and in the marine environment. Humans also affect themselves via culture, patterns of social organization, and institutional design and performance in both public and private spheres. Nature affects itself and humans as well via seasonal, inter-annual, decadal, centennial, and millennial cycles, biogeochemical cycles, biological evolution, weathering of the physical and social environment over time, stochastic cataclysmic events, and the like. What is now particularly salient is the extent to which humans by themselves have the capacity to generate effects on nature at all space scales, including the planetary one. This capacity creates opportunities as well as challenges, some of them severe. Many of these opportunities and challenges are evident in the ocean environment which is our focus of study.*

**Dynamics of Change in the Marine Environment**

**Why a Focus on Human-Environment Interaction vis-à-vis Global Change?**

- ✘ Because human activities in the aggregate now have planetary scale effects.
- ✘ Because the principal drivers on the human side are: the magnitude & rate of growth of human population; the use of fossil fuel as the principal fuel base for economic development globally since 1850; human approaches to land use and water and their effects; and the effects of all of the above for the dominant global biogeochemical cycles.
- ✘ Because humans affect, and are affected by, the global climate system in major ways.



**Why the Particular Interest in Multiple Stresses, Nonlinearities, & Critical Thresholds?**

- ✘ Because the planet is a fully coupled system (atmosphere/ocean/terrestrial biosphere/cryosphere/humans), environmental stresses usually emerge in multiple suites, even though the tendency of social decision systems is to treat them singly.
- ✘ The global system, and the subsystems thereof, give rise to nonlinear interactions & feedbacks which produce unexpected effects.
- ✘ These effects often produce thresholds which either amplify rates of change and/or shift subsystems, and even the whole system (e.g., 100Kyr Milankovitch cycles), into new states.
- ✘ The management of nonlinear change and critical thresholds present severe policy and management challenges.

## Framing the Problem: The NRC Workshop Report

- ❏ The Puzzle:
- ❏ Both ecosystems & humans often face suites of multiple environmental stresses generated by a combination of external physical forcing & internal forcing. Multiple environmental stresses produce more than additive effects. They create synergies through interaction and produce quantitatively & qualitatively different outcomes from single influences.
- ❏ Outcomes are derived from nonlinear processes operating on multiple spatiotemporal scales which lead to critical thresholds or points at which either rates of change shift dramatically and/or the system shifts into a different state.
- ❏ However, many (most?) nonlinearities are unknown and gaps in understanding these phenomena lead to gaps in knowing how to respond to them in terms of design of policy & management approaches.

## Purpose of NRC Workshop: How to proceed to remedy lack of control generated by gaps in understanding?

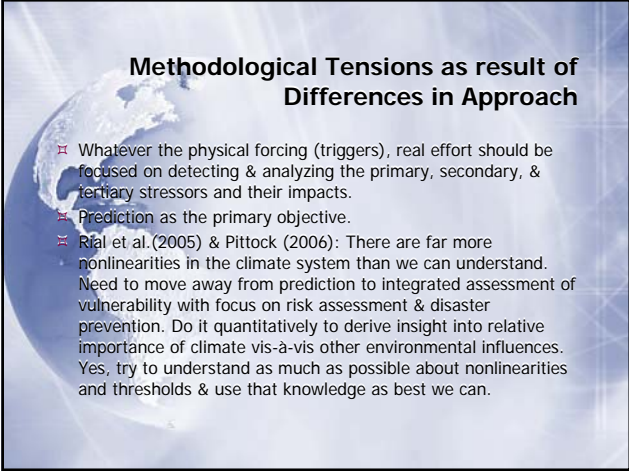
- ❏ Workshop buying into Barron's formulation that the ability to "anticipate" (i.e., predict) the future is what makes knowledge powerful.
- ❏ Decision to focus first on the physical drivers (climate, land use/cover, waste products & streams) & trace interactions in place-based fashion.
- ❏ Note that impacts & societal decisions are place-based, but drivers operate on much larger scales.

## Remedy for Lack of Control, cont'd.

- ❏ What stands in way of understanding this level of complexity?  
Need:
- ❏ Integrated regional web of sensors linking observations into coherent framework.
- ❏ Integrated & comprehensive regional information systems widely accessible to researchers, managers, & stakeholders.
- ❏ Directed process studies designed to examine specific phenomena through field investigations.
- ❏ Complex coupled system models at appropriate spatiotemporal scales integrating biologic, hydrologic, & socioeconomic systems.
- ❏ Strong connections to significant regional issues & stakeholders.
- ❏ Progress linked to implementing all 5 principles above.

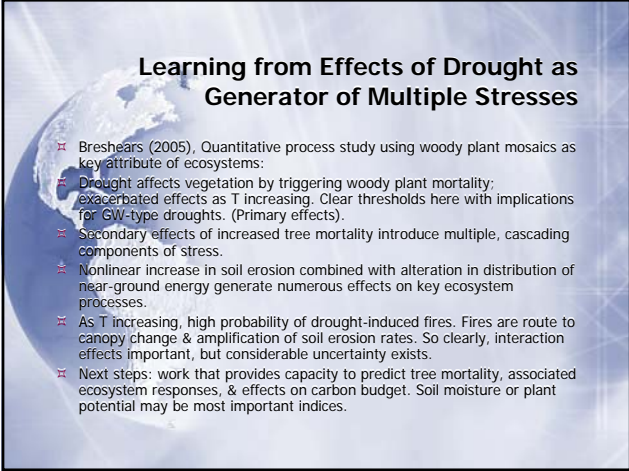
## Approach, cont'd.

- ❏ Observation that nonlinearities & multi-scale, interactive complexities trigger threshold changes in ecosystems & human social systems & these thresholds affect the vulnerability & resilience profiles of both.
- ❏ Further observation that there are two types of change: 1. Slow-onset natural phenomena, like drought, where the longer & the more intense the event, the wider the scope (magnitude & intensity) of impacts. Vulnerability of social systems then increased by effects of multiple stressors--absence of risk-based planning, existence of marginalized social groups with limited mitigation capacity, dependence on overexploited natural resources, high levels of poverty, & violent social conflict.
- ❏ Type 2: Abrupt change precipitated by fast-moving internal nonlinearities & feedbacks, moving the system closer to, and over, the edge.



## Methodological Tensions as result of Differences in Approach

- ⌘ Whatever the physical forcing (triggers), real effort should be focused on detecting & analyzing the primary, secondary, & tertiary stressors and their impacts.
- ⌘ Prediction as the primary objective.
- ⌘ Rial et al. (2005) & Pittock (2006): There are far more nonlinearities in the climate system than we can understand. Need to move away from prediction to integrated assessment of vulnerability with focus on risk assessment & disaster prevention. Do it quantitatively to derive insight into relative importance of climate vis-à-vis other environmental influences. Yes, try to understand as much as possible about nonlinearities and thresholds & use that knowledge as best we can.



## Learning from Effects of Drought as Generator of Multiple Stresses

- ⌘ Breshears (2005), Quantitative process study using woody plant mosaics as key attribute of ecosystems:
- ⌘ Drought affects vegetation by triggering woody plant mortality; exacerbated effects as T increasing. Clear thresholds here with implications for GW-type droughts. (Primary effects).
- ⌘ Secondary effects of increased tree mortality introduce multiple, cascading components of stress.
- ⌘ Nonlinear increase in soil erosion combined with alteration in distribution of near-ground energy generate numerous effects on key ecosystem processes.
- ⌘ As T increasing, high probability of drought-induced fires. Fires are route to canopy change & amplification of soil erosion rates. So clearly, interaction effects important, but considerable uncertainty exists.
- ⌘ Next steps: work that provides capacity to predict tree mortality, associated ecosystem responses, & effects on carbon budget. Soil moisture or plant potential may be most important indices.



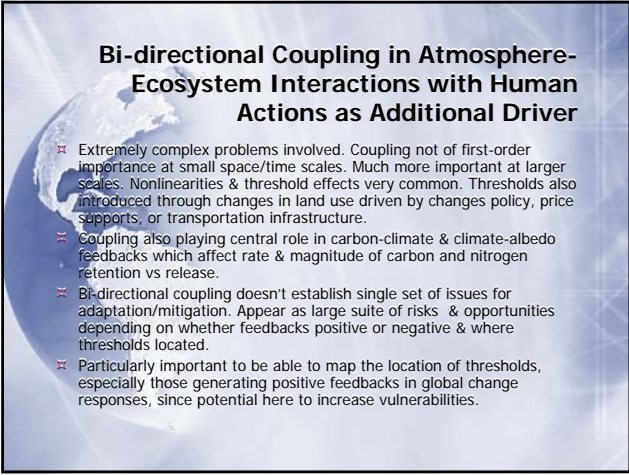
## So How Approach Policy/Management Design Problem re Drought?

- ⌘ Drought different from other natural hazards. Slow-onset, creeping phenomena, effects increasingly widespread. Best addressed through multiple indicators. Impacts non-structural & spread over large areas. Poorly documented. Result is adoption rate for drought mitigation lagging behind other natural hazards.
- ⌘ Drought the most costly US natural disaster. Conflicts between water users increasing; impacts increasing, becoming more complex, & expanding beyond agriculture, but so far no systematic assessment done. Crisis management characteristic response. Has U.S. Congress reduced or increased vulnerability to drought? System only moving from disaster to disaster.
- ⌘ Need to change approach to emphasize drought risk management, *but drought prediction central to risk management approach*. Focus on vulnerability to try to understand risk, but realize that vulnerability is dynamic because society is. Therefore need updated vulnerability indices.




## Changing the Policy/Management Approach to Drought in U.S., cont'd.

- ⌘ Federal assistance programs numerous, poorly coordinated & reactive. People rewarded for poor planning. Need good information coupled with plans for drought mitigation. Response per se may be less important than clear focus on mitigation. But need reliable seasonal-interannual forecasts, more timely water supply assessments, & design of new kinds of informational products designed to fit needs of real decision-makers in specific places.
- ⌘ Need also to improve monitoring and early warning, knowledge of drought hazard, & expand assessments of economic, environmental, & social impacts. Educate end-users & increase awareness of drought impacts & trends.
- ⌘ Changes in spatial & temporal distribution of rainfall, soil moisture, runoff, frequency & magnitudes of drought events not explicitly included in current response planning. Some things foreseeable but not acted upon. Need to ask also whether adaptive practices adopted in past contribute to multiple stress in future & whether management lessons learned in past applicable to future.




## Bi-directional Coupling in Atmosphere-Ecosystem Interactions with Human Actions as Additional Driver

- Extremely complex problems involved. Coupling not of first-order importance at small space/time scales. Much more important at larger scales. Nonlinearities & threshold effects very common. Thresholds also introduced through changes in land use driven by changes policy, price supports, or transportation infrastructure.
- Coupling also playing central role in carbon-climate & climate-albedo feedbacks which affect rate & magnitude of carbon and nitrogen retention vs release.
- Bi-directional coupling doesn't establish single set of issues for adaptation/mitigation. Appear as large suite of risks & opportunities depending on whether feedbacks positive or negative & where thresholds located.
- Particularly important to be able to map the location of thresholds, especially those generating positive feedbacks in global change responses, since potential here to increase vulnerabilities.



## Bi-Directional Coupling: What do we need to know about the human dimensions?

- How do human decisions re cropping, land-use/cover change, & urbanization influence atmosphere-ecosystem interactions & what are the costs in ecosystem services of converted land?
- How do greenhouse gas increases & associated warming, land use, & air pollution interact with biodiversity?
- How do drivers relate with stresses to produce particular vulnerabilities or adaptive capacities?
- How do socio-economic, institutional, and environmental processes influence environmental change and adaptive capacity?
- How can societal resilience to multiple stresses be improved? How can adaptive management approaches be developed & implemented?



## One Significant Methodological Innovation

- Ron Prinn (MIT). Integrated Global System Model (IGSM) systematically integrating physical, biological, chemical, economic [John Reilly] dimensions.
- Objectives: discovery of new atmosphere-ecosystem interactions; objective assessment of uncertainty; critical & quantitative policy analysis.
- Since uncertainties large, need comprehensive studies of sensitivity of conclusions to critical input assumptions plus calculations of probability distributions of critical variables.
- If GEC seen as problem in risk mgmt, linking physical & biological environments with social requires avoiding focus on single policy issues & recognition that socioeconomic systems complex & dynamic. Interactions affect efficiency & effectiveness of policy instruments. Must always be concern for future consequences of policy choices.



## On Thresholds

*The Heinz Center Workshop*

### Where We Ended: The Melillo/Miles Research Agenda

- ⌘ What are thresholds?
- ⌘ Do thresholds operate in ecological & social systems? Can we predict the likelihood of a threshold happening? (What indices? What tools?)
- ⌘ Can we manage systems to reverse or halt their movement toward thresholds?
- ⌘ What are the consequences of crossing thresholds? How do we manage to minimize negatives & maximize positives? (Deal with multiple stresses & scale).
- ⌘ Are there management impediments to optimal responses?
- ⌘ What kind of partnership between environment & social services is needed?

### Peter Kareiva: Taking Thresholds to the Next Level

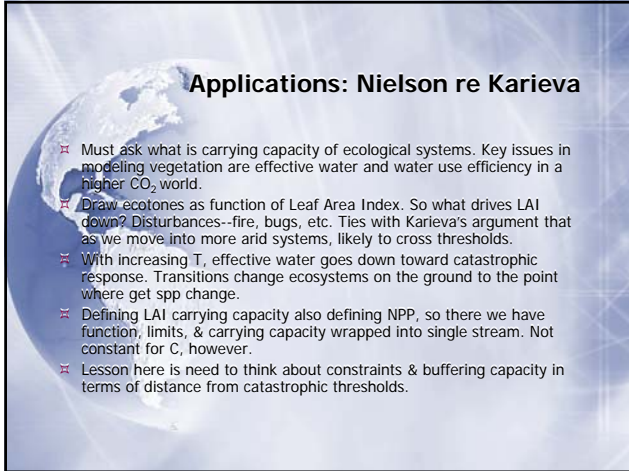
- ⌘ Need to be able to make predictions. What? Where?
- ⌘ Need to be able to do something about it. How manage for resilience?
- ⌘ What kinds of systems most susceptible? Arid vs Wet; Rivers vs Estuaries, etc.
- ⌘ What kinds of ecosystem services most susceptible/resilient?
- ⌘ Identify key sets of processes common to all to regulate resilience: NPP (includes inherent fertility + P); Residence time; Connectivity; Spp or functional diversity; Socio-economic & political factors; plus
- ⌘ Are there different processes for different ecosystem services?

### Kareiva, cont'd.

- ⌘ Some Recommended Research Topics:
- ⌘ Scale: Links between slow & fast and large and small.
- ⌘ Reversibility: Can we identify key variables that determine if scale changes reversible?
- ⌘ Are those the same variables that regulate resilience?

### Comments & Questions by Roger Pulwarty

- ⌘ Noting a tension in the room re framing. Objective risk vs context matters. How manage thresholds? What is awareness of finite time for response and how differ re conditioning factors & types of resource use, etc.?
- ⌘ How do thresholds themselves change over time and what are the dynamics of emergent properties?
- ⌘ How much flexibility is there in the legal system?
- ⌘ What are the key processes leading up to thresholds?
- ⌘ What produces criticality? Where are the buffers?
- ⌘ How much precision is required in what we need to know?
- ⌘ What is the spatiotemporal quality of the threshold and how does that relate to societal decision-making systems?



### Applications: Nielson re Karieva

- ✘ Must ask what is carrying capacity of ecological systems. Key issues in modeling vegetation are effective water and water use efficiency in a higher CO<sub>2</sub> world.
- ✘ Draw ecotones as function of Leaf Area Index. So what drives LAI down? Disturbances--fire, bugs, etc. Ties with Karieva's argument that as we move into more arid systems, likely to cross thresholds.
- ✘ With increasing T, effective water goes down toward catastrophic response. Transitions change ecosystems on the ground to the point where get spp change.
- ✘ Defining LAI carrying capacity also defining NPP, so there we have function, limits, & carrying capacity wrapped into single stream. Not constant for C, however.
- ✘ Lesson here is need to think about constraints & buffering capacity in terms of distance from catastrophic thresholds.



### 2 Last Applications re Lessons

- ✘ Coral Reefs.
- ✘ Peters et al. 2004. Re the Mt. Pine Bark Beetle in Canadian Forests.