Regime Shifts in Social-Ecological Systems
Impacts on Ecosystem Services & Human Well-Being

Dr Reinette (Oonsie) Biggs
Prague, 26 June 2012
I. THEORY
- Why care about regime shifts?
- Understanding mechanisms
- Detecting regime shifts
- Predicting regime shifts – early warnings
- EXERCISE: Group exercise 1

II. RESEARCH RESULTS
- Regime Shifts Database
- Regime Shifts Analysis Framework
- Some initial results
- EXERCISE: Group Exercise 2
WHY CARE ABOUT

REGIME SHIFTS?
Over the past 50 years, humans have changed the Earth more rapidly and extensively than in any comparable period of time in human history.

*Millennium Ecosystem Assessment 2005*
Changing functioning of the planet

24% of Earth’s terrestrial surface has been converted to cropland

Man-made reservoirs hold 3-6X volume of all rivers on Earth

Source: Millennium Ecosystem Assessment
We live on a human-dominated planet

Need to understand the integrated dynamics of intertwined Social-Ecological Systems (SES)
The Challenge

Increased well-being for many people
  – Through use of **ecosystem services**: fresh water, food production, timber, fiber & fuel, climate regulation, water purification

BUT current trajectory appears unsustainable
  – Many **ES** are degrading or insufficient for projected future demand
    • eg climate regulation, fresh water (MA 2005, IPCC 2007)
Regime Shifts are of particular concern

Large, persistent changes in system structure and function associated with crossing a tipping point/critical threshold

Coral Reefs

Coral dominated reef  Algae dominated reef
Why are regime shifts important?

• Large impacts on ecosystem services and society

• Non-linear phenomena:
  – Often come as a surprise; difficult to predict
  – May be difficult or impossible to reverse

• Appear to be increasing in frequency (MA 2005)
Ecosystem services

‘The benefits people obtain from ecosystems’

**Provisioning**
- Food
- Freshwater
- Fiber
- Biochemicals
- Genetic resources

**Regulating**
- Water purification
- Water regulation
- Climate regulation
- Disease regulation
- Pollination

**Cultural**
- Spiritual & religious
- Recreational
- Aesthetic
- Educational
- Sense of place

**Supporting**
- Soil formation
- Nutrient cycling
- Primary production

Biodiversity is a necessary underlying condition

*Millennium Ecosystem Assessment 2003*
Regime shifts also exist in social systems

- Political change
  - Eg South Africa

- Medieval – Industrial era

- Changes in value systems

Transformations or positive changes can also be regime shifts
UNDERSTANDING

REGIME SHIFTS

(multiple understandings from different fields)
Regime shifts are a feature of complex adaptive systems

Resilience (in this context): Magnitude of change that a system can absorb without undergoing a regime shift

Alternate regimes created and maintained by various feedback loops

All systems contain multiple feedback loops

Different feedbacks can dominate & structure the system

Different configurations drive the system to different attractors

Limited number of possible dominant feedback configurations – or regimes

Dominant feedback in clear water regime

Dominant feedback in turbid regime

Amplifying feedback that reinforces turbid regime

Lake ecosystem

Turbid regime

Clear regime

Amplifying feedback that reinforces turbid regime
What causes regime shifts?

Shock

Regime 1 Regime 2

Biggs et al. 2012.

Dominant feedbacks are overwhelmed

Change in underlying variables

Dominant feedbacks are slowly eroded

Biggs et al. 2012.
Regime shifts are typically indicated by jumps in time series data.

Moist to dry conditions in the Sahara

Duration of shift is rapid relative to time in each regime.
Must define focal output variable (shift with respect to x?)

Not all big changes are regime shifts!

Change must persist for some time

Several mechanisms can lead to such "jumps"
Hysteresis

Scheffer et al. 2001. Nature 413
Not all regime shifts show “jumps”

Depends on strength of feedbacks

Different regime shifts occur at specific characteristic scales.

The diagram illustrates the relationship between time scale (centuries, decades, years) and spatial scale (field, watershed/landscape, subcontinental) over which the shift occurs. Different environmental phenomena are categorized based on their time and spatial scales, such as River channel position, Wet savanna – Dry savanna, Cloud forests, Soil salinization, Eutrophication, Coastal hypoxia, Coral reef degradation, and Soil structure.
Regime shift at one time scale may just be a disturbance at another

Vostok Ice Core
DETECTING

REGIME SHIFTS
Detecting Regime Shifts

Often difficult to know if an observed change is a regime shift or not

Detecting Regime Shifts:

Statistical approaches – detect patterns
1. Temporal data (time series)
2. Spatial data

Mechanistic approaches
3. Experiments
4. Modelling
1. Time series data

Moist to dry conditions in the Sahara

Baltic sea

Statistical tests: Principle Components Analysis (PCA), t-tests
2. Spatial Data

Space can substitute for time:
some places in regime 1; others in regime 2

Patchy landscapes may indicate alternate regimes
At a variety of scales

GLOBAL MAP / VEGETATION (Percent Tree Cover)
Multi-modal distributions


Forest & Savanna Biomes

Forest

Savanna

Map showing distribution of deterministic low tree cover, bistable, currently low tree cover, bistable, currently forest, and deterministic forest in different regions around the world.
3. Experiments

1. Large disturbance triggers a permanent shift
2. Sensitivity to initial conditions

_Scheffer & Carpenter 2003 TREE_
Hysteresic effects

Lake Veluwe, Netherlands

Scheffer et al. 2001 Nature 413: 591-596
4. Modelling

Fish-habitat model


Adult piscivore (A)

Planktivore (F)

Juvenile piscivore (J)

Angling
harvest (qE)

Shoreline development
hide (h)

\[
\frac{dA}{dt} = -qE \cdot A
\]

\[
\frac{dF}{dt} = D_F(F_R - F) - c_{FA}F \cdot A + \sigma \frac{dW}{dt}
\]

\[
\frac{dJ}{dt} = -c_{JA}JA - \frac{c_{JF}vFJ}{h + v + c_{JF}F}
\]
Piscivore dominated

Planktivore dominated

Angling

Shoreline development
Critical values: Angling (qE)

Location of “tipping point” is a function of piscivore population, angling pressure (qE) & shoreline development (h)

Critical values: Shoreline development (h)

At low piscivore populations resilience is very low: Very small or no domain in which Piscivores dominate
Large lag between tipping point and actual regime shift

Attractor switches in year 556, at $q_E = 1.78$

Regime shift: years 637 – 651 (>10% increase per year in planktivore population) (i.e. regime shift only occurs ~80 years later)
PREDICTING REGIME SHIFTS
Early warning indicators

Variety of indicators

- Increasing variance
- Increasing skewness
- Increasing slowness (rate of return)
- Increasing autocorrelation

Change in underlying variables
Time series data

Also detectable in spatial data

Limitations: Early warning indicators

• Can only warn of regime shifts brought about by slow changes in underlying variables (not for regime shifts due to shocks)

• Signal may be noisy and difficult to interpret

• May provide warning too late to do anything about it
Setting safe boundaries

Examples:
Safe pollutant concentrations
Safe harvest levels
Planetary boundaries

System thresholds can move as other drivers change!

Biggs et al. In prep.
GROUP EXERCISE 1
Group Exercise 1

- Break into groups of 4
- Discuss criteria for identifying regime shifts
- Based on criteria identify:
  - 1 example of a social-ecological regime shift
  - 1 example of a large change that is not a regime shift
- Report back
Coffee Break!

Be back at 15:30
REGIME SHIFTS DATABASE

www.regimeshifts.org

RESEARCH RESULTS
Purpose

1. To provide a high quality synthesis of different types of regime shifts documented in SES

2. To facilitate comparison of different social-ecological regime shifts

**Focus:** Regime shifts that have large impacts on ecosystem services i.e. **matter to people**

**Target audience:** Scientists, assessment processes, lecturers, students, practitioners, policy-makers
Regime Shifts DataBase
Large persistent changes in ecosystem services

The Regime Shifts DataBase provides examples of different types of regime shifts that have been documented in social-ecological systems. The database focuses specifically on regime shifts that have large impacts on ecosystem services, and therefore on human well-being.

Latest additions

**Kelp Transitions**
Kelp forests may undergo regime shifts to turf-forming algae and urchin barrens. This shift leads to loss of habitat and ecological complexity. Shifts to turf algae are related to nutrient input, while shifts to urchin barren are related to trophic-level changes. The consequent loss of habitat complexity may affect commercially important fisheries. Managerial options include restoring biodiversity and installing wastewater treatment plants in coastal zones.

**Browse all regime shifts**

- Bush Encroachment
- Coral Bleaching
- Collapse of the thermohaline circulation
- Beaches Collapse

www.regimeshifts.org
Aims to address critical research gaps

1. What regime shifts can occur in different SES?
2. What are the major drivers of regime shifts?
3. What are the impacts of regime shifts on ecosystem services and human well-being?
4. How are different regime shifts interconnected?

Carpenter et al 2006, 2009, Reid et al 2010
### REGIME SHIFTS

<table>
<thead>
<tr>
<th>Regime shift name</th>
<th>Ecosystem</th>
<th>Mechanism &amp; feedbacks</th>
<th>Ecosystem impacts</th>
<th>Impacts on HWB</th>
<th>Management options</th>
<th>Etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshwater Eutrophication</td>
<td>Freshwater</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Salinization</td>
<td>Drylands</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Etc.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### CASE STUDIES

<table>
<thead>
<tr>
<th>RS Type</th>
<th>Case name</th>
<th>Country</th>
<th>Local particulars</th>
<th>Etc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshwater eutrophication</td>
<td>Lake Mendota</td>
<td>USA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freshwater eutrophication</td>
<td>Lake Washington</td>
<td>USA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Etc</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AQUATIC SYSTEMS</td>
<td>TERRESTRIAL SYSTEMS</td>
<td>STRONG SOCIAL FEEDBACKS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------</td>
<td>----------------------------------------------</td>
<td>---------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Floating plants</td>
<td>19. Salinization - snowgeese</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Hypoxia</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CLIMATE SYSTEM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Ice sheet collapse</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Summer Arctic sea ice</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Thermohaline</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Monsoon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>YOUR EXAMPLES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

~20 Examples based on literature
Regime Shift Analysis Framework

Biggs et al, in prep.
Biggs et al, in prep.

Human-centered operational definition

Large, persistent (and usually abrupt) shift in the set of ecosystem services produced by an SES

Abruptness affects capacity to adapt to the change

Biggs et al, in prep.
Criteria for selecting regime shifts

1. Large shift in the set of ecosystem services produced by a social-ecological system

2. Persists on a timescale that matters to people

3. Established or proposed feedback mechanisms that reinforce the different regimes
Step 1: Define system

Identify relevant social-ecological system

Example:
Submerged to Floating Plants
Step 2: Identify different regimes

Water body dominated by submerged plants

Water body dominated by floating plants

As reported in the literature
Step 3: Identify key ecosystem services

Identify ecosystem services associated with each regime & the stakeholder groups that benefit and lose

<table>
<thead>
<tr>
<th>Submerged Plants</th>
<th>Floating Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Fisheries</td>
<td>- Impeded navigation</td>
</tr>
<tr>
<td>- Biodiversity</td>
<td>- Impeded recreation</td>
</tr>
<tr>
<td>- Water purification</td>
<td>- Pollutant absorption</td>
</tr>
<tr>
<td>- Disease regulation</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Beneficiaries</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Ecotourism sector</td>
</tr>
<tr>
<td>- Fishery sector</td>
</tr>
<tr>
<td>- Urban dwellers</td>
</tr>
</tbody>
</table>
Step 4: Identify key feedbacks

Identify key feedback mechanisms that maintain each regime

Step 5: Identify key drivers

Direct drivers
(eg nutrient input)

Indirect drivers
(eg fertilizer in agriculture)

Shocks (eg rainstorms)
Step 6: Identify management options

Identify key feedbacks and drivers to bolster or weaken

**Enhance resilience of desired regime**
(eg reduce nutrient runoff)

**Reduce resilience of undesired regime**
(eg harvest floating plants)
Step 7: Other information

• Spatial scale
• Time scale
• Reversibility

• Land use
• Ecosystem type

• Sources of evidence
  (models, experiments, observations etc)
• Level of confidence
  (about regime shift & mechanisms)
Summarized online

www.regimeshifts.org
Freshwater Eutrophication

Main Contributors: Juan Roote, Rehnette (Onsie) Biggs
Other Contributors: Garry Peterson, Steve Carpenter

Summary
Freshwater eutrophication refers to the build-up of nutrients in freshwater ecosystems such as lakes, reservoirs and rivers, leading to excessive plant growth or algal blooms. The main driver of freshwater eutrophication is nutrient pollution in the form of phosphorus from agricultural fertilizers, sewage effluent and urban stormwater runoff. Beyond a certain threshold of phosphorus accumulation, a recycling mechanism is activated which can keep the system locked in a eutrophic state even when nutrient inputs are substantially reduced. Fisheries and aesthetic values are among the ecosystem services affected by freshwater eutrophication.

Drivers
- Key direct drivers:
  - Vegetation conversion and habitat fragmentation
  - External inputs (e.g. fertilizers)
  - Species introduction or removal
  - Soil erosion & land degradation

- Land use:
  - Urban
  - Large-scale commercial crop cultivation
  - Intensive livestock production (e.g. feedlots)
  - Fisheries
  - Mining
  - Land use impacts are primarily off-site (e.g. dead zones)

Impacts
- Ecosystem type
  - Freshwater lakes & rivers

- Key Attributes
  - Typical spatial scale
    - Local/landscape

Library of figures & images
Searchable summary of key attributes
### Impacts

**Ecosystem type**
- Freshwater lakes & rivers

**Key Ecosystem Processes**
- Primary production
- Nutrient cycling

**Biodiversity**
- Biodiversity

**Provisioning services**
- Freshwater
- Fisheries

**Regulating services**
- Water purification
- Pest & Disease regulation

**Cultural services**
- Recreation
- Aesthetic values

**Human Well-being**
- Food and nutrition
- Health (eg toxins, disease)
- Livelihoods and economic activity
- Cultural, aesthetic and recreational values
- Social conflict

### Key Attributes

**Typical spatial scale**
- Local/landscape

**Typical time scale**
- Years
- Decades

**Reversibility**
- Irreversible (on 100 year time scale)
- Hysteretic
- Readily reversible

**Evidence**
- Models
- Paleo-observation
- Contemporary observations
- Experiments

**Confidence: Existence of RS**
- Well established – Wide agreement in the literature that the RS exists

**Confidence: Mechanism underlying RS**
- Well established – Wide agreement on the underlying mechanism

**Links to other regime shifts**
- Hypoxia

---

*View more info & key references*  
*View resources*  
*View case studies*
Introduction

The shift from oligotrophic to eutrophic conditions occurs when a body of water—a lake, river, or reservoir—accumulates excessive nutrients. This process can happen naturally over several centuries as a lake ages and accumulates sediments and nutrients from the surrounding landscape. Nowadays, however, human activities cause freshwater eutrophication to occur much more rapidly and extensively than in the past.

Alternate regimes and feedbacks

CLEAR WATER REGIME In one regime, phosphorous inputs, phytoplankton biomass (algae), and phosphorous recycling from lake or river sediments are typically low, and the water is clear. Such systems are called oligotrophic.

EUTROPHIC REGIME In the other regime, phosphorous inputs, phytoplankton biomass, and phosphorous recycling from sediments are usually high, and the water is turbid or murky. Such systems are called eutrophic (Smith 1993, Carpenter 2003, Smith & Schindler 2009).

Because freshwater ecosystems are usually phosphorous limited, freshwater eutrophication is typically related to over-enrichment by phosphorous rather than other nutrients. Even if nutrient input levels are subsequently decreased, the system may remain locked in a eutrophic state. The mechanism that keeps the system eutrophic is the activation of a phosphorous recycling feedback (local - well established). In shallow lakes and rivers, the sediments on the lake or river floor typically contain high levels of phosphorous that have accumulated from the setting out of decomposing algae and other organisms. Under eutrophic conditions, the loss of the rooted plants means that the sediments can easily become resuspended due to wave action or the activities of bottom-feeding fish. The resuspended nutrients then become reavailable, promoting further growth of algae, and thereby reinforcing the eutrophic state (Schaeffer 1997, Schaeffer et al. 1993).

In deep lakes, the eutrophic state is maintained by a different mechanism. In deep lakes temperature gradients create different layers of water; the epilimnion or upper layer is warm and well oxygenated, while the hypolimnion is a lower and colder water layer (Carpenter 2003). When the hypolimnion is oxygenated, phosphorous is captured by iron molecules in an insoluble form. Thus, it is not available to primary producers such as algae. However, algal blooms lead to the depletion of oxygen levels in the lower water layers through the decay of organic matter. When oxygen levels become depleted, phosphate is released in a soluble form that can be used by algae. Algal blooms thereby trigger the recycling of phosphorous in a way that reinforces the eutrophic state (Carpenter 2003).

Drivers that precipitate the regime shift

Excess phosphorous inputs to freshwater systems typically derive from fertilizers applied to agricultural lands, urban storm water runoff, and untreated sewage disposal (Carpenter 2003). Deforestation and poor agricultural management can accelerate, in magnitude and frequency, the runoff of phosphorous from agricultural lands (Smith & Schindler 2009). The accumulation of phosphorous in the water column usually triggers excessive production of phytoplankton (i.e., algal blooms) in faster-flowing rivers, phytoplankton tends to be washed downstream, and excessive growth of plants such as water hyacinth (Eichhornia), duckweed (Lemna) or water fern (Azolla) may be stimulated instead (Schaeffer 1997).
The Regime Shifts DataBase provides examples of different types of regime shifts that have been documented in social-ecological systems. The database focuses specifically on regime shifts that have large impacts on ecosystem services, and therefore on human well-being.

Latest additions

Kelp Transitions
Kelp forests may undergo regime shifts to turf-forming algae and urchin barrens. This shift leads to loss of habitat and ecological complexity. Shifts to turf algae are related to nutrient input, while shifts to urchin barrens are related to trophic-level changes. The consequent loss of habitat complexity may affect commercially important fisheries. Managerial options include restoring biodiversity and installing wastewater treatment plants in coastal zones.

Browse all regime shifts

Perform various searches
Preliminary results

Biggs et al, in prep.
Main drivers of regime shifts

Climate change and agriculture-related drivers dominate

- Global climate change
- External inputs
- Harvest and resource consumption
- Species introduction or removal
- Disease
- Adoption of new technology
- Soil erosion and land degradation
- Environmental shocks
- Habitat conversion and fragmentation
- Infrastructure and development

Biggs et al, in prep.
Impacts of regime shifts

Most affected ecosystems

- Marine and coastal
- Freshwater lake and rivers
- Tundra
- Grasslands
- Drylands and deserts
- Moist savannas and woodlands
- Polar
- Planetary
- Tropical forest
- Temperate and boreal forest

Fraction of examples in database

Ecosystem Processes & Biodiversity

- Biodiversity
- Primary production
- Nutrient cycling
- Water cycling
- Photosynthesis
- Soil formation

Fraction of examples in database
Impacts on ecosystem services

Provisioning Services

- Fisheries
- Wild animals and plant foods
- Freshwater
- Other crops
- Timber
- Livestock
- Woodfuel
- Foodcrops

Regulating Ecosystem Services

- Water purification
- Regulation of soil erosion
- Climate regulation
- Natural hazard regulation
- Water regulation
- Pest and disease regulation
- Pollination
- Air quality regulation

Fraction of examples in database
What does it mean for people?

Human Well-being

- Livelihoods and economic activity
- Food and nutrition
- Cultural, aesthetic and recreational values
- Security of housing and infrastructure
- Health
- Social conflict
- No direct impact

Fraction of examples in database
More in-depth analyses
Drivers of Regime Shifts

Juan Rocha
PhD student

Network analysis of global change drivers of regime shifts

Linkages and cascades between regime shifts
Ecosystem service impacts of 12 agriculturally-driven regime shifts

Comparison of the sets of ecosystem services in each regime, and how impacts 6 different user groups

Christine Hammond
MS student
Clear decline in ecosystem services & human well-being from less (green) to more (orange) anthropogenically impacted regimes.

Agribusiness is least impacted, subsistence farmers are most impacted by regime shifts.
Leverage points for enhancing ecological resilience to climate change

Effect of climate change on feedback mechanisms

Use CLDs to analyze impacts of climate change on resilience

Temperature, Precipitation
Droughts, Floods

Disappearance of Arctic summer sea-ice
Leverage points for enhancing ecological resilience to climate change

Use CLDs to analyze impacts of climate change on resilience & identify potential leverage points for 10 regime shifts

Rolands Sadauskis  
MS student
Leverage points for breaking poverty traps in smallholder agricultural systems

Use CLDs to identify leverage points for addressing social-ecological poverty traps

Small-holder agriculture: Nutrient depletion poverty trap
Leverage points for breaking poverty traps in smallholder agricultural systems

<table>
<thead>
<tr>
<th>Small-holder livestock keeping systems</th>
<th>Small-holder agriculture systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Informal social livestock insurance</td>
<td></td>
</tr>
<tr>
<td>Property rights and land tenure</td>
<td></td>
</tr>
<tr>
<td>Credit arrangements</td>
<td></td>
</tr>
<tr>
<td>Health and nutrition</td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td></td>
</tr>
<tr>
<td>Alternative income sources</td>
<td></td>
</tr>
<tr>
<td>Enabling institutions &amp; policy</td>
<td></td>
</tr>
</tbody>
</table>
Demand for information

- UN Secretary-General Ban Ki-moon’s High Level Panel on Global Sustainability
- IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation
- Convention on Biological Diversity (Perreira et al 2010 Science 330)
- Planet under Pressure Conference (March 2012)
- European Environment Agency (EEA)
Caveats

• Based on what has been reported in the literature
  – may or may not reflect reality
    – Concept has been around for longer in aquatic sciences
    – Under-reporting in developing/low population areas
    – Ecosystem service and human well-being impacts often not directly reported; inferred from related literature

• Definition of regime shifts varies in different fields
  – Challenge to collate in a standard framework
Reflection on strengths

- Ecosystem service focus useful
  - Directly connects social and ecological systems
  - Focuses on policy-relevant changes
  - Integrated response across different system components

- Identify new regime shifts arising purely from interaction of social and ecological factors – ie social-ecological feedbacks
  - Eg Forest – cropland; Ecosystem management approaches

- Highlights internal forces that provide resilience to change or promotes change, rather than external drivers of change
GROUP EXERCISE 2
Group Exercise 2

• Break into groups of 4

• Select a regime shift

• Identify
  – 2 alternate regimes
  – 1-2 key feedbacks that maintain each regime
  – 1-2 key drivers that shift the system between regimes
  – 3 ecosystem services that are lost/gained
  – Main user group that benefits in each regime
  – Main user group that loses in each regime

• Report back in 3 min
Thank you

www.regimeshifts.org