Exactly how resilient are ecosystems?

Beth Fulton | Head of marine ecosystem modelling, CSIRO Australia
2014
Competing use of space & pressures
Planetary Boundaries

- Socioecological universal theory requires unification of cognitive science, psychology, economics, ecology, biogeochemistry, mathematics, physics...
Resilience & Complex Adaptive Systems

- One facet of complex systems science

Joshua Epstein
Benoît Mandelbrot
Buzz Holling
Stuart Kauffman
Charles Darwin
John Conway
Edward Lorenz
Karl Ludwig von Bertalanffy
Jay Forrester
John von Neumann

... plus economists, anthropologists and many more
“Lies for children”

They're not exactly lies, but are, nevertheless, untrue.... It's close enough to true, for everyday things.

Terry Pratchett, Jack Cohen and Ian Stewart (2000)

- Diet matrix (feeding relationships)
- Species concept
- Resilience
Ecological vs Engineering Resilience

- Engineering resilience = stability around equilibrium
Ecological vs Engineering Resilience

- Engineering resilience = return time
- Can’t really cope with changing systems as equilibrium concept
Ecological vs Engineering Resilience

- Ecological resilience = absorb shocks & retain ‘same’ structure & function
- Related to concepts of vulnerability & robustness
Ecological vs Engineering Resilience

- Ecological resilience = different in each dimension (& variable)
- Due to external drivers and internal processes
How Resilience Fails
Cascading failure most obvious

- Overfishing
- Nutrient loading
- Storms
- Parasite infection

- High reef cover
- Diverse habitats
- Stressed
- High algal cover

Cascading effect → VERY resilient final state

Hughes 1994; deYoung
Cross scale interactions

- Hierarchy of change (cross scale interactions)
- Path dependency

<table>
<thead>
<tr>
<th></th>
<th>Patch</th>
<th>Local</th>
<th>Regional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecological</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social/Cultural</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Cross scale interactions

<table>
<thead>
<tr>
<th></th>
<th>Patch</th>
<th>Local</th>
<th>Regional</th>
<th>Global</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ecological</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social/Cultural</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Cross scale interactions

<table>
<thead>
<tr>
<th></th>
<th>Patch</th>
<th>Local</th>
<th>Regional</th>
<th>Global</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ecological</td>
<td>Infection, Competition, Feeding</td>
<td>Storm</td>
<td>Weather &amp; Climate</td>
<td>Climate</td>
</tr>
<tr>
<td>Economic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social/Cultural</td>
<td>Families</td>
<td>Land use</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Infection, Competition, Feeding**
- **Storm**
- **Weather & Climate**
- **Climate**
- **Fishing**
- **Economy**
- **Trade**

- **Land use**

---

(ChartData)
How resilient are ecosystems?

- Literature search & www.regimeshifts.org

n = 230

- Anoxia/hypoxia
- Eutrophication
- Low flushing
- Overfishing
- Fish-pred-prey switch
- Jellies
- Invading species
- Kelp forest transition
- Bivalve collapse
- Reef transition
- Marsh transition
- Other Seagrass transitions
- Climate
How resilient are ecosystems?

- Gets the attention in the stories
- Less resilience to “plenty”
Model evidence – Balanced Harvest

- Spread the pressure = ecologically sustainable (resilient)

- Technically feasible?
- Possible culturally and economically?

Garcia et al 2012
Model evidence – Future projections

- Potential futures in SE Australia
Not as dire with acclimation

- No acclimation
  - Squids boom/bust
  - Jellies & non-calcifiers win
  - Weedy & pelagic
  - Fast turnover system

- With acclimation & evolution
  - While system copes, little gross change (some turnover in dominant spp)
  - Tipping point exists (~550-700 ppm)
Ecosystems

An ecosystem composes of physical-chemical-biological processes active within a space-time unit
Lindeman 1942

- Humans too
Barriers to adaptation

① Biological and ecological
   – distribution, composition & productivity change; thresholds

② Behavioural, cognitive and social
   – flexibility & personality; intuition & perception; cultural influence

③ Governance and regulation
   – supportive vs constraints & delays (hardship potential)

④ Economic and markets
   – compound barriers; larger operators typically have more capacity

⑤ Technological
   – facilitate change vs lock in maladaptive behaviour; info access

⑥ Scientific
   – remaining gaps; more change focus needed
Measuring Resilience

... key components and relationships (networks) and their continuity through space and time.

... by no means obvious what leads to resilience in a complex system, or which variables should be measured in a given study of resilience

Cummings et al 2005

- Components (& drivers) abiotic, ecological, habitats, human actors
- Processes nutrient cycles, flows, economics, social
- Networks (linkages) food webs, trade, friendship
- “Innovation” diversity, movement, learning
- Continuity (buffers) longevity, seed banks, rules, repositories

Also identify surprises & potential alternative states

Cummings et al 2005
Monitoring & indicators

- Multiple groups looking at indicators (national, international)
- PICES S1, ICES, SCOR
- Indiseas ([www.indiseas.org](http://www.indiseas.org))
  - Biomass
  - Community indices (size, age)
  - Vulnerability index
  - Trophic level (biodiversity proxy)
  - Abiotic indices (system-specific)
  - Economic indices
  - Human community dependency
  - Reference levels for each
  - Harvest control rules

Shin et al 2012
Monitoring & indicators

- Essential Ocean Variable (EOVs)
- 726 indicator recommendation (>100 documents)
  - General types known (relative biomass of key groups, habitats, structure, longevity, productivity, abiotic, social & economic)
  - Desire universal set
  - System specific

Hayes et al in prep
Monitoring & indicators

- Loss resilience = regime shift
  - Early warning indicator = shift in variance or skew

- Muffling & magnification (due to how components interact & how correlated to the shock)
  - Monitor bits with different vulnerabilities and responses
Critical management variables

- Effective management has “Rule of hand”
- 3-5 key variables (aggregate ones now preferred, pros & cons)
- Psychology? Back to “lies for children”?
Aggregate indices & the cringe response

- Aggregate indices now preferred (integrate information)
  - Scoring -> simple composite (sensitive to correlations & weighting)
  - Multicriteria decision analysis (transparent, but sensitive to rules)
  - Multidimensional space (math robust, intuitive understanding lost)

Shin et al 2012; Rochet et al 2005
Aggregate indices & the cringe response

- Model based indicators
  - Can produce resilience indices
    “provided that a parameterization for disturbance events was available”

- Performance can be poor
  - Difficult to collect data
  - Model formulation
  - Lack of transparency
  - Need good systems understanding

Mumby et al 2007; Fulton et al 2005
Adaptive Monitoring

Climate change
- Physical features impacted
  - Species composition changes
    - Bias, design, coverage, representativeness affected
    - Adaptive sampling? Avoid inconsistencies?
  - Consistent core + serendipitous supplements?
Managing for resilience

① Manage for multiple potential configurations & multiple scales

② Manage for diversity, paying attention to slow variables (as they dictate thresholds, responses, adaptive capacity)

③ Accept fore-gone short-term efficiency (but less long-term crisis management costs; trade-off between time periods or scales)

④ Strategic interventions can work, but timing dependent

⑤ Understand underlying mental models, increasing overlap provides adaptive capacity

⑥ Adaptive governance (vulnerability can not be eliminated)

Anderies et al 2006
Marrying resilience & optimal control

- Management comfortable with optimal control principles
- Modification possible, so that keep successful aspects, but get flexibility (resilience) needed in changing systems?
Summary

- Multiple stressors
- Resilience = means of understanding system state & cycles
  - understanding cross-scale complex systems
- Biology can take care of itself... mostly (don’t forget humans!)
- Indicators
  - Basic needs known in general terms (avoid “physics envy”)
  - more data, but how deal with it?
  - How remain adaptive?
- Managing for resilience might be possible
Thank you

CSIRO Division of Marine and Atmospheric Research
Beth Fulton
Head of Ecosystem Modelling

+61 3 6232 5018
beth.fulton@csiro.au
www.csiro.au