SUPPLEMENT 2

General comments:

For the purpose of these exercises students will be assigned to groups. Ideally, each group contains five to seven students with a diversity of backgrounds. At a minimum, all groups should contain social and ecological or forestry expertise. Instructors typically “float” among groups during the exercises, thus participating in all discussions.

Each group is provided with a map showing the location and boundaries of the study area, typically a single stand with some information about surrounding forests. Also, groups are provided with existing forest inventory data, previous management plans and other documentation available describing proposed or past interventions (including natural disturbances such as past major insect outbreaks, fires, wind storms, etc., or historical human occupation). Students are encouraged to visit the forest (repeatedly) and take any additional data as they see fit.

We also provide access to information about the broader context of the study forests. This information includes ecological information, such as biogeoclimatic zone, natural disturbance regimes, and climate information. In addition, the study forest is set in social and economic context. Ideally, we use the real world setting and students can gather actual information about marketing options (e.g., distances to sawmills) or social settings (e.g., recreational visitors from an adjacent urban areas). Similarly, we prefer to use the actual management objectives of the landowner in our exercises. However, in cases where this is too narrow, more common ownership objectives can be assumed (e.g., when the land is managed by a foundation with a narrow focus on conservation or education).

Note, that the exercises below are presented as examples that hopefully will make it easier for other instructors to teach such theoretical concepts in a field setting. Interested instructors should consider whether all of them are useful and how they need to be adjusted for a specific class or workshop. Also, these exercises assume familiarity with basic theoretical concepts (see reading list in Supplement 1).

Exercise 1

Objective:

To develop a formal conceptual dynamic model of your forest.

Learning outcomes: Students should be able to:

1. Understand key components (processes and actors) of ecosystems and social systems as they affect a forest,
2. Gain experience in step-by-step model formulation,
3. Organize key elements and processes into a model structure,
4. Appreciate connections and interactions among elements (across scales), and
5. Identify key features driving ecosystem responses to perturbation.

Procedure:

1) “A forest is composed of diverse and numerous human and environmental components”. As a first step in understanding the forest ecosystem with which you are working, provide a description of the:
- human actors or stakeholders who interact with the forest: describe each and briefly explain their goals and objectives with regards to their interactions with the system
- physical location, soil type(s) and any other remarkable physical characteristics of the region (e.g., rivers, ponds, rocky outcrops)
- ecological community: describe the main species present and any other pertinent features of the forest (e.g., forest successional stage, non-native or invasive species, endemic species, endangered species, etc.)
- history: provide a brief summary of any relevant events in recent or geological time that have influenced the way the forest is today (e.g., glaciation, flooding, use by ancient civilizations, fire events, recent management history).

You may illustrate your text with photographs, maps and diagrams as necessary.

2) Go through the following steps to develop a formal dynamic system model structure of your forest. First, use the questions listed in Table 1 (see below; based on Bennett et al. 2005) to characterize and get a basic understanding of your forest. The questions are separated into five steps:
   1. Assessment and system definition
   2. Components and system drivers
   3. Network structure
   4. Feedback processes
   5. Using the information to understand system behavior

   These questions are supposed to guide you through the process. There may be other information that is pertinent and should be included into your description of the forest. Provide your answers to these questions and other pertinent information to the instructor.

3) Next, provide a graphical presentation of your ecosystem model structure (for examples of such figures, see Bennett et al. 2005 and resalliance.org).

Table 1: Guidance for development of model structures. These questions facilitate collection of baseline data that can provide the basis for development of a model. Modified from Bennett et al. 2005.

<table>
<thead>
<tr>
<th>Step</th>
<th>Question</th>
<th>Answer defines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>What aspect(s) of the system should be sustained (stable)?</td>
<td>System boundaries, criteria for building system model</td>
</tr>
<tr>
<td>1</td>
<td>What kinds of changes are likely to impact sustainability?</td>
<td>External drivers, disturbances, desired state of system</td>
</tr>
<tr>
<td>2</td>
<td>What processes and drivers are producing these changes?</td>
<td>System drivers</td>
</tr>
<tr>
<td>2</td>
<td>What external forces control processes that are generating change?</td>
<td>&quot;Outside&quot; impacts on system</td>
</tr>
<tr>
<td>2</td>
<td>What are the key components of the system?</td>
<td>Detailed list of system components</td>
</tr>
<tr>
<td>3</td>
<td>How do the key components interact?</td>
<td>Connections among processes and components</td>
</tr>
<tr>
<td>4</td>
<td>What positive and negative feedback loops exist?</td>
<td>Identifying loops in model</td>
</tr>
<tr>
<td>4</td>
<td>Which variables connect the feedback loops?</td>
<td>Identifying variables driving loops in model</td>
</tr>
<tr>
<td>4</td>
<td>What (if anything) moves the system from being controlled by one feedback loop to another?</td>
<td>Identifying thresholds and leverage points in loops</td>
</tr>
<tr>
<td>5</td>
<td>As indicated by feedback loops, what are possible threshold values of the state variables?</td>
<td>Threshold conditions</td>
</tr>
<tr>
<td>5</td>
<td>How far are the state variables from the threshold values?</td>
<td>Compare current state to threshold values</td>
</tr>
<tr>
<td>5</td>
<td>How fast are the variables moving towards or away from the thresholds?</td>
<td>Is system become more vulnerable or more stable?</td>
</tr>
<tr>
<td>5</td>
<td>How do external shocks and controls and affect the state variable?</td>
<td>How sensitive is the system to external influences</td>
</tr>
<tr>
<td>5</td>
<td>How likely are the shocks and controls?</td>
<td>Uncertainty</td>
</tr>
<tr>
<td>5</td>
<td>How are slow variables changing and how do they affect thresholds?</td>
<td>Impact of slow changes in the system on increasing or decreasing stability</td>
</tr>
<tr>
<td>5</td>
<td>What factors are controlling the change in slow variables?</td>
<td>Controls of stability</td>
</tr>
</tbody>
</table>
**Exercise 2:**

After establishing a conceptual dynamic model structure and a basic understanding of the forest system, the next step is to expand the system’s analysis to include scales and develop an appreciation of the challenges when managing across multiple hierarchical scales (modified from Burke and McQuinn 2011).

**Objective:**

To emphasize the importance of scales in understanding and managing forest ecosystems

**Learning outcomes:** Students should be able to:

1. Understand the importance of scale and cross-scale interactions,
2. Determine “scale-misfits”, i.e., where social scales and ecological scales (time, spatial, functional) don’t match, and
3. Understand how scale misfits and gaps (in governance, see Ekstrom and Young, 2009; http://hdl.handle.net/10535/5404) can be overcome.

**Procedure:**

1) To start, develop a list of the:
   - main ecological factors that influence your forest. These should include components, ecosystem processes that drive internal dynamics, external stressors, and
   - main social factors that influence your forest. This should include goods and services provided by the ecosystem and which are in demand by the human community, management tools, human values, anthropogenic stressors.

2) For each factor in the list, assign the appropriate scale (spatial, temporal, and hierarchical), e.g., from individual plant or animal to populations to community to ecosystem level, from short to long term, from microsite to landscapes.

3) After making the table, list ecological and social factors on both the x and y axis in a matrix (see example in Table 2). For each box (each x and y axis combination), highlight whether the factors are connected (scales match), whether they are not connected (scales don’t match or scale misfit), or uncertainty exists regarding the connections.

4) Write up a summary about the major scale-misfits your analysis has revealed. What concerns or potentially unsustainable processes or actions originate from these misfits? Can you think of any management options to deal with these misfits?

Table 2: Example of an ecosystem matrix used to investigate scale misfits (modified from Burke and Quinn 2011). Key ecological and social components at multiple scales are derived from the literature. Table values identify the relationship between these variables in terms of scale connectedness.

<table>
<thead>
<tr>
<th></th>
<th>Blister Rust Resistance</th>
<th>White bark pine</th>
<th>Ribes</th>
<th>Dispersal</th>
<th>Competition</th>
<th>Pine beetle</th>
<th>Aesthetics</th>
<th>Recreation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genetic</td>
<td>Blister Rust resistance</td>
<td>-</td>
<td>c</td>
<td>nc</td>
<td>c</td>
<td>nc</td>
<td>nc</td>
<td>nc</td>
</tr>
<tr>
<td>Species</td>
<td>White bark pine</td>
<td>-</td>
<td>-</td>
<td>c</td>
<td>c</td>
<td>c</td>
<td>c</td>
<td>c</td>
</tr>
<tr>
<td></td>
<td>Ribes shrub species</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>nc</td>
<td>nc</td>
<td>nc</td>
<td>nc</td>
</tr>
<tr>
<td>Ecosystem processes</td>
<td>Dispersal</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>nc</td>
<td>c</td>
<td>nc</td>
</tr>
<tr>
<td></td>
<td>Competition</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>c</td>
<td>nc</td>
</tr>
<tr>
<td></td>
<td>Pine beetle</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>c</td>
</tr>
<tr>
<td>Human values</td>
<td>Aesthetic</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>c</td>
</tr>
<tr>
<td></td>
<td>Recreation</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

- c = scale connected, nc = scale not connected, ? = uncertain
**Exercise 3:**

To explore impacts of uncertainties in social-ecological systems, develop and evaluate management prescriptions and strategies, and generate knowledge about ambiguous developments. Expand the findings from Exercises 1 and 2 into a broader setting organized to evaluate a broader set of management constraints and opportunities.

**Learning outcome:** Students should be able to:

1) Gain an appreciation for uncertainties in future social, environmental, economic and technical conditions,
2) Understand the impacts that uncertainties have on the outcome of management decisions,
3) Understand how selected management scenarios can provide information for future management decisions, and
4) Develop strategies to accommodate uncertainty in development and assessment of management prescriptions and strategies.

**Procedure** (modified from Rose and Starr 2013) (feel free to utilize results from Exercises 1 and 2, but you can also expand your work to include, e.g., new management goals):

1) Establish an overall long-term management goal.
2) Describe the major challenge or issues that you are exploring in this exercise.
3) Identify critical factors, variables, trends, and uncertainties that affect #1 and #2 above. Use information from the previous exercises to determine external causes that influence whether you can achieve your goals or not. Think broad, these causes should include social, economic, technical, logistics conditions.
4) Evaluate factors, etc. under # 3 in terms of available information and degree of confidence about direction and magnitude of future developments.
5) Use information from # 4 to develop three to four future scenarios. Note, that the choice of important factors (e.g., climate change impact and demand for forest products in figure 1 below) should not reflect what you think is most likely (they are not predictions of the future). Instead, they should be chosen with the goal to maximize what you learn about dealing with future uncertainties. Also, to maximize the learning potential, try to maximize the difference between the scenarios. Thus, pay special attention to factors with high uncertainties, low probability, and high impact which lead to scenarios that can stimulate creative and innovative ideas. Define your scenarios in terms of scale (e.g., scenarios applicable a variety of owners across the region are preferable to scenarios that are limited to one owner). Also, make sure the scenarios relate to forestry practices, such as weed control, prescribed burning, harvesting, or other silvicultural decisions (avoid scenarios that deal with larger scale issues, such as land use change).

6) Identify the implications of each future scenario for your forest (# 1 and # 2 above).
7) For each scenario, develop a list of actions you would implement or stop implementing.

8) Evaluate actions in terms of their success under the various scenarios. Special attention should be paid to identify actions (current and future) that perform well under all or only a single future scenario.

9) Discuss the implications of #8 on current management strategies and plans. This is the time, where you consider the probabilities of different scenarios and prioritize actions. Also, discuss whether sufficient information exists to make these decisions or whether actions should be delayed.

10) Develop a monitoring strategy to assess the impacts of your actions in the future. Discuss indicators (measures), critical threshold, and future flexibilities if thresholds are reached.


Figure 1: Example of four possible future scenarios. Adapted from Kaslo and District Community Forest Long Term Strategy. Final Report.
**Exercise 4:**

**Objective:**
To develop a conceptual model that represents your forest dynamics as nested, adaptive cycles and can provide the basis for the development of a simulation model.

**Learning outcomes:** Students should be able to:

1) Integrate various information levels (e.g., understanding of scale-misfits and uncertainty from exercises 1 and 2, forest dynamics) into a graphical model that represents forest dynamics as a panarchy cycle.

2) Utilize all information from previous exercises to develop nested panarchy cycles for a forest system.

3) Describe their understanding of ecosystem dynamics, including nested aspects of the panarchy cycle, in a modeling and verbal context.

**Procedure:**

1) To view your system as a nested panarchy cycle (as an “archetype” model) convert the table from the scale (misfit) from exercise 2 into a table similar to Table 3 (based on Soane et al. 2012).

   *(Reminder: The panarchy cycle is viewed as a “nested sets of adaptive cycles”, i.e., cycles which interact across scales. “Larger, slower cycles generally constrain the smaller, faster ones and maintain system integrity, but, during the Ω and α phases, critical cross-scale interactions can operate, particularly “Revolt” connections, in which an Ω phase collapse on one level triggers a crisis one level up, and “Remember” connections, in which the α phase of a cycle is organized by a higher-level K phase” [http://www.ecologyandsociety.org/vol12/iss1/art24/])*

2) Develop a graphical model highlighting the main “basins of attraction” and transitions possible for your system (e.g., building on your results from Exercise 1).

3) Investigate how the dynamics of your model can be represented best graphically. For example, a graphical model could be twisted into the 3-dimensional panarchy cycle, using the information from Table 3 (for examples, see Figure 2 in Soane et al. 2012).

4) Discuss the relevance of the panarchy cycle to your system. Integrate what you have learned about scale-misfits and uncertainty in exercises 1 and 2 with the concept of nested panarchy cycles. Describe which scale-misfits (in exercise 1) and failures (in exercise 2) can be triggered (or exaggerated) by cross-scale interactions (e.g., “revolt” in the nested panarchy cycle)? Which ones can be overcome (or reduced) by cross-scale interactions (e.g., “remember” in the nested panarchy cycle)?

Table 3: Example of a table used to organize information for development of nested panarchy cycles. Table headings from Soane et al. 2012.

<table>
<thead>
<tr>
<th>Measure of capital</th>
<th>Factors decreasing capital and connectedness</th>
<th>Factors contributing to reorganization</th>
<th>Factors involved in re-establishment of capital and connectedness</th>
<th>Driving forces towards system shift</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fast cycle</strong></td>
<td>Amount of biomass</td>
<td>Overharvesting</td>
<td>Harvest regulations</td>
<td>Higher wood demand due to increased population</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Medium cycle</strong></td>
<td>Late successional habitat</td>
<td>Invasion of exotic weeds</td>
<td>Weed control Avoidance of disturbances</td>
<td>Ecological knowledge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Increased trade and tourism</td>
</tr>
<tr>
<td><strong>Slow cycle</strong></td>
<td>Forest cover</td>
<td>Change in land use laws</td>
<td>Subsidies for landowners</td>
<td>Education of community and politicians</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Shift in economic and political agendas</td>
</tr>
</tbody>
</table>