Ecosystem Recovery and Resilience to Large Disturbances (based on review articles in science primary literature).

Joe Connell and Slater (1977, *American Naturalist*) summarized the ways that organisms act in the colonization and development of a biological community (aka succession):

1) facilitation: The activities of organisms that first colonize a disturbed or newly opened area, modify the environment in ways that make the area habitable for other organisms. Since then, facilitation has been broadly documented as an ecological phenomenon. Most of these modifications involve lessening the severity of physical stresses such as desiccation, heat, exposure etc. A production system would be a model of a facilitation interaction with humans making better conditions for the algae to grow.

2) tolerance: Organisms which have longevity through transitions passively become major parts of the community that develops. This is well documented in temperate, terrestrial systems and the examples of old field succession.

3) inhibition: Organisms which are early colonists can hold space and prevent the recruitment of new species even if the latter might fit better into the community or cause the community to be more productive. This is well documented in rocky shore communities.

Eric Berlow (1997, *Ecological Monographs*) added to the above by describing the three models of the outcomes of succession:

1) canalization: The outcome of the recovery or succession is always the same. This is the textbook example of temperate plowed field to forest. In this scenario, there is a very strong attractor for a single trajectory in community space (n-dimensional space where n=the number of species in the community). This is the main motivating idea for letting nature take it’s course and restoration by benign neglect.

2) externally driven succession: The environment determines the outcome of recovery. Coral reefs become covered with seaweeds when the nutrient concentrations in the water are elevated by not when they are low. This also applies to changes in the biotic environment such as the removal of predatory animals.

This is also called a phase shift. Environmental degradation, pollution, global climate change etc. change ecosystems according to this model of succession.

3) contingency: Chance events or “historical accidents” determine the outcome of recovery such that a different community could persist in the same the place, under the same conditions if it had different initial conditions. These are called alternative stable states. There are relatively few, but some, documented examples of alternative stable states because the global context is changing rapidly. This is currently a popular paradigm in ecology research.

Susan Williams and collaborators (2009, *Proceedings of the National Academy of Sciences*) refuted the idea that individual species losses or additions in ecosystems do have effects on overall productivity when the losses not random but as they occur in ecosystems. After a disturbance that reduces the number of species in an ecosystem, recovery of productivity requires replacement of diversity as well as numbers of organisms.

Dudgeon and collaborators (2010, *Marine Ecology Progress Series*) give a critical review of evidence and claims for alternative stable states in marine systems including algal growth on coral reefs. They clarify that the switch to algal dominated tropical reefs is an environmentally driven phase shift rather than a stochastic, stable change. Another key conclusion is that the rate of recovery is related to the lifespans (longevity) of the organisms involved. The recovery after the Yellowstone fire, for example is on the track predicted by the age at which trees reach maturity, 80 - 100 years for recovery to a closed forest canopy.

Overall, the direct recovery of a previous healthy ecosystem after a big disturbance relies on there being “pristine” or unchanged conditions and community members which hare not stressed by external factors. Alternatively, in degraded conditions, another organism (like us, for example) can facilitate the recovery by making conditions suitable for other species. To develop a stable long lasting system, it is important to get in early and also be tolerant of small changes (robust).

For examples of production systems, which attempt to recreate ecosystem effects, I looked into integrated multitrophic aquaculture systems (IMTAs) that include algae. From terrestrial systems, there is the literature on permaculture and integrated agriculture including integrated pest management.

Troell and colleagues (2009, *Aquaculture*) summarize the state of the field of Ecological Engineering for aquaculture in the open ocean, with reference to tank and nearshore systems. There are many difficulties in establishing the balance of intensity of production of a few species within a larger ecosystem. Off shore systems have huge scale but are subject to storms. Most IMTA is derived from attempts to mitigate the environmental impacts of finfish aquaculture by adding seaweed grown on nets downstream and filter feeding shellfish below fish pens. I’m pretty sure this is a dead end for us. De Paula Silva and colleagues (2008, *Aquaculture*) take a more ecosystem inspired approach to integrating algae in land-based aquaculture ponds, in tropical conditions. They choose species which self-recruit in flow through ponds and which form algal blooms in nature. Those species tolerated fluctuating chemical conditions in the ponds and effectively remediated the nitrogen supply. At least one of the species they used, *Ulva sp*. is a food species (aka sea lettuce).

Conversations with colleagues at University of Washington and University of Maine regarding aquaculture of Porphyra sp. (the nori seaweed) pointed out the freezing tolerance of this commercially produced organism. Nets “seeded” with the seaweed can be frozen for later use. I thought this was interesting in terms of the possibility of starting the growth of a crop at the time that the power goes out.