Cultivation-Depensation Model – Q2 Management and Hysteresis

1. Ecosystems often can exhibit multiple stable states; aquatic ecosystems have provided classic examples of this. Scheffer et al. (2003) describe alternative stable states moving between floating and submerged plant dominance in freshwater ecosystems. Using experiments, field data, and models they describe the self-stabilizing nature of these states and how the system may be pushed from one state to the other through large disturbances. Typically, ecosystems have some ability to absorb these disturbances without much change to the current dominant state. Over time though, with repeated disturbances, the ability of an ecosystem to overcome these is diminished to the point that the next disturbance to occur will drastically alter the ecosystem and cause it to shift to a new stable state.
2. The transition between these states is often non-linear and may come with little warning as the buffering capacity of system is slowly eroded over time. These dynamics make it particularly challenging to see how close a system may be to flipping and recognizing this in time to take meaningful action that prevents a stable state shift. Hindsight is in many cases the only way researchers are able to understand the dynamics that produce stable states and regime shifts (Sheffer and Carpenter 2003). Newfoundland northern cod stock collapse and subsequent efforts to restore the stock are an example of hindsight revealing the shift in stable state. When the stock first collapsed, the fishery was closed in 1991, with the common assumption that a simple reduction in fishing mortality would allow the stock to recover. To date, recovery has yet to be realized leading researchers to explore potential causes, like environmental changes leading to declines in prey supply for cod and variability in natural mortality through time, which were not initially considered (Rose and Walters 2019). **Describe an example of hindsight illustrating a regime shift here, not sure if I picked the best example but it’s a start I think.**
3. Because of this, keeping ecosystems in a safe operating space is crucial to buffering against disturbances and preventing regime shifts to undesirable states (Carpenter et al. 2017). These abrupt changes are likely to have major implications for both the ecology of the system and the human users of it, resulting from changes in energetic pathways (Xu et al. 2014). Regime shifts in coral reefs, due to increases in algae and coral bleaching, lead to reductions in fish biomass and a subsequent loss of food security and employment for the communities around these reefs (Norstrom et al. 2009, Crepin et al. 2012). How biological communities respond to disruptions in their dynamics will determine to what extent, if any, the stable regime changes.
4. Ecosystems transition between stable states resulting from changes in community dynamics. This can occur either through slow moving changes to underlying abiotic factors that favor some species over others (nod to Hansen climate change work, nutrient input) or through direct impacts by humans on the species themselves. The focus of ecosystem-level drivers of regime shift primarily focus on changes to hydrological processes, such as climate change and cultural eutrophication, and management strategies to maintain stable states of a system in light of ecosystem change (Carpenter, 2003; Davis et al. 2010; Liu et al. 2015). Alternatively, management of ecologically driven regime shifts tend to focus on identifying the underlying cause of change, and, in many cases, adapting to those changes (Magee et al., 2019) or mitigating the effects of those changes through increased systemic resilience (Carpenter et al. 2017). Fisheries are a prime example system because humans impact the system directly through fishing and indirectly through climate change. Large-scale anthropogenic impacts, such as climate change, can drive regime shift in inland freshwater systems, resulting in a projected shift in the dominance of certain fish over others (Hansen et al., 2017). However, the scale at which these indirect drivers occurs makes them difficult to manage or mitigate.
5. Humans can also directly alter species interactions, resulting in reinforcement or destabilization of the stable state of the system. For example, increased angling pressure on certain fish species can result in changes in the relative abundances of species in the system, resulting in harvest-driven regime shifts between states where different species dominate over others. While harvest is tied to angler preference and behavior, the ultimate result can be emergent shifts in the stable state of the system. Harvest of more ‘desirable’ species may result in decreased dominance of those species in favor of other species within the system. Harvest driven regime shifts have been studied in commercial and marine fisheries when ecosystem-based management has been implemented (Oken and Essington 2016; Essington et al. 2015). The recognition of the role of inter-specific and trophic interactions between species, and the hysteretic behavior that may follow, has helped foster the adoption of ecosystem-based management (Walters and Kitchell 2001; Blackwood, Hastings, and Mumby 2012). Crowder et al. (2008) has also explored the simultaneous influences of multiple fished species on marine systems. This stands in contrast to more traditional management decisions which take a linear view of the system (e.g., fish population is overexploited, so managers attempt reduce mortality rates through regulations or stock in response) (Sass et al. 2017). Instances where these simple solutions have had no effect, or even a negative effect, are abundant and demonstrate a need to consider alternative stable states and the hysteretic behavior that is often present in complex aquatic communities (Pine et al. 2009).
6. Fisheries managers have the challenge of maintaining or shifting the stable state of a system in order to provide desired opportunities for anglers. The ultimate result of this is that, with the right tools, managers are uniquely positioned to use specific techniques to control the stable state of the system that they manage. Using traditional management techniques, such as stocking or harvest-control limits, and intimate knowledge of system dynamics, managers have the ability to directly influence the state of system. A central theme of these management strategies is a holistic view of the ecosystem and the rejection of single species management strategies applied broadly in favor of flexibility that allows managers to consider the full context of the systems they work in and tailor their actions appropriately (Collie et al. 2016; Camp and van Poorten 2019?). Stocking and harvest control can allow managers to compensate for harvest-driven regime shifts in order to maintain a desired stable state, or to shift from an undesirable state to one that is more desirable. While harvest-driven regime shifts are likely not a major consideration for anglers that produce them, managers must be aware of the probable results of these regime shifts. Through the actions of anglers and managers alike, humans can have direct impacts on fisheries in addition to the indirect impacts discussed earlier.
7. Here we explore direct human influence on an ecosystem, through a modeled recreational fishery, to show why understanding the complex interactions between species is necessary to either maintain or rehabilitate an ecosystem using multispecies recreational fisheries as an example. To better understand the dynamics and interactions of multi-species recreational fisheries, we expand on the model presented in Biggs et al. (2009) and present a two species, stage-structured fisheries model. In keeping with the tenets of ecosystem-based management, our model moves away from a single harvested species management scenario and towards a more realistic system where multiple harvested sportfish species interact (trophically) with each other. The outcome of this trophic interaction affects and is affected by the effects of humans on the ecosystem through fishing *activities*. Adults and juveniles of both species trophically interact with each other and are simultaneously harvested, but to different degrees. We parameterized our model to represent largemouth bass (*Micropterus salmoides*) or a generalized centrarchid complex (bluegill *Lepomis macrochirus*, black crappie *Pomoxis nigromaculatus*) and walleye (*Sander vitreus*) trophic interactions in north temperate lakes. Multiple lines of evidence have suggested that centrarchids and walleye negatively interact through various mechanisms including lake warming due to climate change, habitat loss, and overexploitation (Craig Kelling paper, J. Hansen et al. 2015, Gretchen Hansen papers, Carpenter et al. 2017 SOS, Embke et al 2019). Our model is unique in that it examines hysteresis and management in: (1) a freshwater ecosystem; and (2) a multi-species system where both species and/or species complex are sport fish targeted by anglers. The goals of our modeling exercises were to: (1) better understand the role hysteresis plays in the type and magnitude of management responses necessary to maintain a system in a desired state; and (2) to investigate the role management responses can play in reverting to an alternative configuration. We accomplish this by modeling species-specific responses to regulations and stocking in a system where hysteresis is present or absent. We perform our modeling experiments in systems where a manager’s goal is to either maintain a desired, walleye dominated, stable state or push the system to the desired stable state from an undesired, centrarchid dominated, state.