Physics to Fish: Nature's rules, Biological loopholes, and the mid-trophic ladder

Ecosystem modeling developed over the last few decade as either being forced by environmental variability or as feeding back to the environment after the ecosystem-biogeochemical interactions are already formulated. We will need a new paradigm: further advances in ecosystem modeling can only be achieved by treating the climate-ecosystem interactions as a synergistic system with a continuum of space and time-scales. The advantages of disciplinary boundaries have already been exploited to their maximum and any deficiencies in the current generation of ecosystems should only be viewed in the context of their interactions and feedbacks with the climate system together with the contribution of the deficiencies in the representation of climate to perceived shortfalls in the ecosystem simulations. The scales of these interactions run the gamut from internal to subseasonal to decadal and longer time-scales and from mesoscale to global scales.

There are notable similarities in the Pacific, Atlantic, Indian Oceans despite the large dissimilarities in their zonal and meridional extents. The western boundary currents, subduction and upduction zones, tropical and subtropcal fronts have clear impacts on the preformed and regenerated nutrients and oxygen at all time-scales determining the mean-picture of the ecosystems and trophic interactions. Closer scrutiny raises issues of meridional asymmetries in SSTs, winds, etc. that have clear implications for coupled climate variability. It is clear that the asymmetries in the biological vs. solubility pump is not just a response but has a potential role to play in maintaining the asymmetries and may be an important factor in the species composition across the equator. Do these large-scale mean patterns in important dynamical and thermodynamical structures depend on ecosystem interactions and feedbacks for their existence? What are the implications for trophic interactions at the level of microbes to primary production to forage to fisheries? Do they have any role to play in the endemic pathogens of human health impacts? How will the distribution evolve under global warming?

Internal variabilities in the ocean are well known for the western boundary current systems but even tropical mesoscale variabilities generate non-deterministic conversion of baroclinic and barotropic instabilities to eddy kinetic energy which affects near surface turbulence. This has potential implications not only for low-frequency rectifications in physical fields but also in ecosystem responses and biogeochemical variables. The cascades to grazing, zooplankton, primary production, forage, and upper trophic levels is completely unexplored. Signal to noise ratios in our 'observations' are difficult for dynamical and thermodynamical variables but nearly impossible for ecosystem and biogeochemical fields of importance.

At intraseasonal or subseasonal time-scales, MJOs are the most robust atmospheric oscillations which bridge weather to climate and have widespread consequences in terms of rainfall variability. MJOs are also known to organize ecosystem response in the ocean with putative feedbacks that could affect convection onsets/breaks with implications for particular attention to ecosystem responses to MJOs including species composition and species succession, and the cascade of the MJO-influence up the food chain to top predators amounting to a typical Physics-to-Fish system that with intimately interacting components. It is thus impossible to consider trophic interactions without considering the role of MJOs in forcing them and the potential feedbacks from the ecosystems to the MJOs. Does the ecosystem organize SSTs to feedback to MJOs?

ENSO is the largest natural interannual mode with extensively recorded consequences for ecosystem variability and trophic interactions. Much recent work has begun to fill-in the gaps in our understanding of how the radiative and dynamic processes translate the simple light-to-heat conversion by microscopic algae to regional or even global-scale coupled ocean-atmosphere response. It is quite evident now that fundamental processes such as the mixed layer-thermocline interactions in such crucial regions as the eastern Pacific cold-tongue, equatorial Atlantic, and the Arabian Sea are significantly affected by the heat source provided by ecosystem response. It is also obvious now that the annual cycle and the interannual variability in the global tropics are tightly coupled and ecosystem variability and trophic interactions are an integral part of this waltz. Parameterizations of C:Chl, grazing, nutrient uptake, etc. are intimiately tied to the zonal/meridional dynamics and thermodynamics including the physical and biological impacts of islands, Indonesian throughflow, and the skewness in cold/warm ENSOs, and the potential for ferricline/nutricline decoupling due to iron sources. Bio-climate feedbacks not only affect ENSO amplitude and frequencies but also determine the response of the upper trophic levels by integrating preformed and regenerated nutrients with their own cold-to-warm and warm-to-cold ENSO recharge-discharges. This synergy is integral part of the competition for nutrients/light, species composition/succession, and energy transfers up the food web. ENSO-teleconnected regions offer unique phasing (Indian Ocean leading and the Atlantic lagging) information that must be exploited for trophic interaction studies and ecosystem responses in models also provide singlularly unique information on model deficiencies.

Decadal variability has emerged as the new frontier but trophic interactions have been instrumental in introducing the concept of regime shift. While it is widely-accepted that ENSO displays decadal clustering the canonical decadal patterns remain a mystery in terms of their genesis (ENSO rectification?) and origin (tropical or extra-tropical?). While regime shifts in ecosystems are demonstrably statistically significant, no such statistical significance is quantifiable for the climate “shifts”. The uniqueness of the ecosystems is in their ability to integrate trend-like forcing to generate a shift-response offering a clear advantage for ecosystem modeling at decadal time-scales. Modulation of the Subtropical Cell has a detectable fingerprint on the preformed and regenerated nutrients and oxygen among other biogeochemical fields. The seductive aspect of this process is that it is independent of the exact mechanism(s) responsible for the decadal modulation of ENSO and offers an unparalleled opportunity to focus the ecosystem modeling efforts as offering totally new information on the phasing of the decadal ecosystem and biogeochemical responses and highlight physical model deficiencies that could otherwise go undetected. While decadal recharge-discharge in the physical system may be too small for detection/attribution, ecosystems offer unrivaled tracers that need to be part of any trophic interaction parameterization. This has obvious implications for detection and attribution of climate variability and change including the invasion of anthropogenic greenhouse gases and spread of human pathogens.

Each of these time-scales (subseasonal to interannual to decadal and longer) in the climate-ecosystem interactions also offer exciting new avenues for designing synergistic observational programs to bridge the knowns to the unknowns such as the role of aeolian dust, ENSO variability under global warming, cascades of climate signals through the food web, and the variability of carbon sources and sinks. Coupled climate modeling has all but transformed itself into Earth System modeling beckoning the ecosystem modelers to step up to the plate to answer the call about Earth System interactions and predictability. Parameterization of trophic interactions are at the threshold of being an indispensible part of this Earth System modeling revolution. It must be remembered that just as important as going up the foodweb is to consider going down the foodweb from photosynthesizers to microbes and marine pathogens. Even if we fish down the foodweb, the role of the ocean in transmitting human pathogens such as cholera and helicobacter will not diminish and the impact of climate change needs to be considered not only in terms of the ocean’s ability to sequester carbon but also in terms of continuing to be mostly benign for human health. While nature will continue to set the rules, biological loopholes are a moving target that must be part of our parameterization portfolio.

The climb from physics to fish requires the mid-trophic ladder and this ladder has already been constructed. Well-established allometric scaling laws allow us to relate the energy supply at the bottom of the food chain, namely primary production to the biomass of the upper trophic levels by deriving the energy transfer coefficients empirically. The allometric scaling between habitat temperatures and metabolic rates are turned into models for population dynamics via energy consumption in general for growth, temperature regulation, movement, and somatic and gonadic maintenance. The remarkable self-similarity of these scaling laws from molecules to mammals thus allow us to go from molecular reactions to spatially explicit population dynamics to achieve the goal of going from physics to fish with what can be called minimum realistic models; models up to the task now for making decisions.