

Across the land-sea boundary with an IOOS informed seascape ecology supporting ecosystem management

John P. Manderson¹ and Josh T. Kohut²

The co-authors contributed equally to the development of this white paper

¹NOAA/NMFS/NEFSC James J. Howard Laboratory, Highlands, NJ 07732

²Rutgers, The State University of New Jersey, New Brunswick, NJ 08901

“..comparison of marine and terrestrial dynamics has more than theoretical interest. As we utilize marine and terrestrial environments, the consequences, deliberate or accidental, depend on [ecosystem] responses to physical and chemical change. The imposition of terrestrial standards for marine problems may produce too strict or too lax criteria--or most likely quite inappropriate ones” (Steele, 1991)

1. Introduction

Ecosystem assessment and management in the sea is holistic, based upon interdisciplinary science that considers physical, chemical and biological processes, including feedbacks with human ecological systems, that structure and regulate marine ecosystems. Space and time based tools for the management of human activities in the sea need to be informed by a broad scale habitat ecology that reflects the dynamic realities of the ocean. Current spatial management strategies including marine spatial planning (MSP) and ocean zoning are based upon the patch-mosaic paradigm of terrestrial landscape ecology modified to consider principles of dispersal ecology, primarily for pelagic early life history stages. This modification is not enough because fundamental differences in the role fluid properties and processes play in controlling ecological processes on land and in the sea makes the blanket

application of paradigms developed on land to the problems of ocean management fundamentally flawed.

The rapid evolution of the Integrated Ocean Observation System (IOOS) made possible through interdisciplinary partnerships and networked data sharing provides descriptions of coastal ocean hydrography and hydrodynamics at fine scales of space and time and regional spatial extents. This allows hydrography and hydrodynamics to be placed at the foundation of a seascape ecology in the

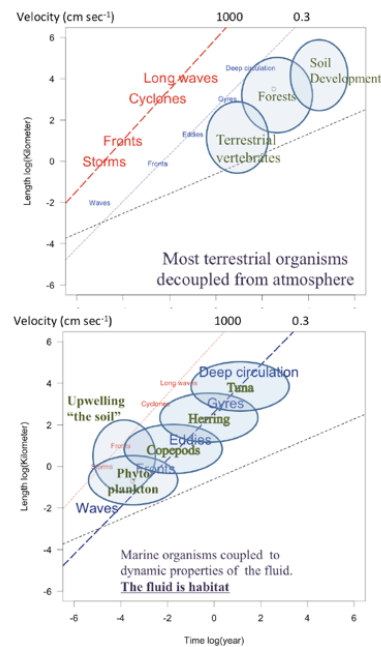


Figure 1. Ecosystems on land (above) operate at space-time scales orders of magnitude slower than turbulent features of the atmosphere while variability in marine ecosystems (below) matches the scales of variability of turbulence in the ocean fluid. (From Steele, 1991 and Mamayev, 1996)

way that geography and geophysics appropriately serve as the foundation of terrestrial landscape ecology. IOOS not only provides the ocean data required to develop seascape ecology but also the infrastructure and expertise to operationalize it for regional ecosystem assessment and adaptive co-management. Finally, regional IOOS associations are cooperative partnerships of academic, government and private industry experts from diverse fields and interests. As a result the IOOS "culture" can foster the collaborative development of an interdisciplinary seascape science that is more likely to lead to effective and less adversarial strategies of regional ecosystem co-management that operate at space-time scales more closely matching those of the ecosystem itself.

2. Seascapes are not landscapes

In 1984 Risser et al summarized deliberations of a workshop held to develop a modern framework for the science of landscape ecology based upon theoretical and empirical underpinnings of a broad scale spatially explicit ecology useful for the management of terrestrial resources. The foundations of this synthesis rested on (1) developments in satellite remote sensing that allowed researchers to place fine scale ecological studies in broader spatial contexts; (2) advances in ecological theory that elucidated the role of dispersal and connectivity in determining regional community dynamics; and (3) the advent of modern computing that allowed researchers to store, analyze, and model large amounts of spatially and temporally explicit data and explore relationships between the changing landscape patterns and the processes potentially causing them. Landscape ecology rests primarily upon the patch

mosaic paradigm of habitat in which patches are defined by sharp gradients in vegetation and geomorphology. Geography and geological processes, particularly soil development, that control fundamental processes including primary productivity in terrestrial ecosystems are the foundations of landscape classification. In terrestrial ecosystems, many of the most important organisms and processes are decoupled from the atmosphere by gravity and physiological adaptation to extreme variations in atmospheric properties, including temperature. As a result the primary features of terrestrial habitats and ecosystems are physical structures created by landform and plant communities that can be modified by disturbance. Community compositions are determined by climate. However, the role of the atmospheric fluid is of secondary importance and the space-time scales of terrestrial ecosystems are much slower than the atmosphere (Fig 1).

In contrast, the ocean is highly viscous and has a density close to that of living tissues. Most marine organisms are therefore nearly buoyant in a fluid that has dynamics that control their motions and those of other important particles. Since the basic processes of cellular metabolism evolved in the sea, most living tissues are also nearly isosmotic with seawater. This contrasts starkly with terrestrial organisms whose intracellular concentrations of solutes and water are dramatically different than the surrounding atmosphere. Finally the specific heat capacity and thermal conductivity of seawater are about four and twenty-three times that of atmosphere, respectively. As a result, marine organisms experience much slower rates and ranges of temperature

change than do terrestrial organisms. Warm-blooded organisms are rare in the ocean where the required oxygen is limited and the temperature of the fluid regulates critical rates across all levels of ecological organization from the cell to the ecosystem as a whole.

Processes that control primary productivity on land and the sea are also fundamentally different. In the ocean nutrients required by plants are constantly falling out of sunlit surface waters where photosynthesis is possible. As a result, tiny fast living plants with high surface to volume ratios are entirely dependent on the plumbing of the ocean to deliver nutrients into the sunlit surface layers from sometimes remote land or deeper waters sources. As a result phytoplankton have very fast population dynamics to which other members of marine food webs must respond. In contrast, primary productivity on land depends on slow and local nutrient regeneration processes in the soil at the interface with a nearly transparent atmosphere where sunlight is rarely in short supply. As a result plants at the base of terrestrial food web are often immobile, long lived, and have slow population dynamics which higher trophic levels respond to.

Due to the tight coupling of physiology, movement of organisms and other critical ecological processes to the oceans fluid, the fluid is the primary driver that structures seascapes and regulates seascape processes. As a result the space-time scales of marine ecosystems match those of the turbulent oceans fluid (Fig. 1).

3. The role of IOOS in seascape ecology

The presence of IOOS, including its infrastructure, data, models and the

expertise of its diverse partners, now allows for the development of seascape ecology with a regional spatial scope that reflects the realities of the ocean. Like landscape ecology's modern synthesis (Risser, 1984), an IOOS informed seascape ecology could provide the theoretical and empirical underpinnings for the broad scale spatially and temporally explicit ecology required for the regional assessment and management of ocean resources. Seascape science will integrate the fields of fisheries oceanography, marine habitat ecology, and ecosystem science with hydrography and hydrodynamics at its foundation, just as terrestrial landscape ecology rests appropriately on the foundation of geography and geophysics.

4. Toward an IOOS informed seascape ecology

We took advantage of the IOOS collaborative culture to form an interdisciplinary workgroup of habitat scientists, oceanographers, fishery managers, social scientists, and fishermen from academia, government and industry to develop ecologically informed habitat models for the purpose of addressing issues of the by-catch of butterfish (*Peprilus triacanthus*) in the longfin squid (*Doryteuthis pealeii*) fishery. We held workshops to combine scientists' and fishermen's knowledge into a single model of butterfish habitat made using National Marine Fisheries Service (NOAA/NMFS) surveys of organisms and hydrography, and satellite and high-frequency radar measurements of ocean properties and processes provided by the Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS), a regional component of IOOS

(Manderson et al., 2011). During the workshops scientists and fishermen each made “mental models” that included environmental variables each group considered important in defining habitat. Over lunch the two models were constructed and evaluated using cross-validation in a butterfish “smackdown”. Following lunch we discussed results of the “smackdown” and the ecological mechanisms potentially responsible for habitat associations described by scientists and fishermen. Following the workshops we developed the model that combined the ecological expertise of fisherman and scientists.

Once the combined model was complete, we worked with fishing industry partners to design an at-sea model evaluation using dynamic habitat model nowcasts provided by MARACOOS. The combined model was adjusted slightly to include variables that were static (bottom rugosity) and dynamic variables that could be delivered in real-time by the ocean observing system.

During an 8-day trip on the F/V Karen Elizabeth, captained by Chris Roebuck, we transmitted updated dynamic butterfish habitat model nowcasts to the vessel (Fig 2). Our survey design involved sampling areas the nowcasts predicted “habitat suitability” would be “high” and “low”. In each 3 station set we also included a site where the fisherman, Captain Roebuck, predicted butterfish would be abundant. We sampled station sets for fish and the environment during the day and night in three canyon hotspots identified by the model along the edge of the Mid Atlantic Bight continental shelf. Using this approach we were able to formally incorporate fishermen’s knowledge into the design of our field

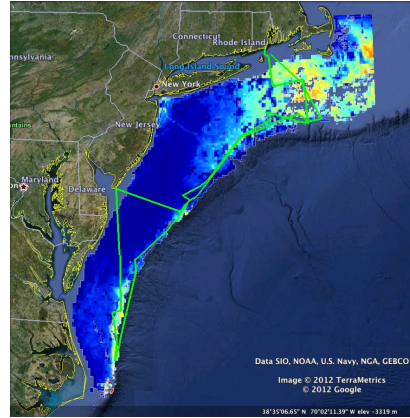


Figure 2. Butterfish habitat preference predicted by the model during our 8-day evaluation. The warmer colors indicate areas of preferred habitat. The vessel track is shown in green.

evaluation survey. Throughout the evaluation the crew on board the Karen Elizabeth sent reports of preliminary results back to shore which we published on an online blog.

The evaluation survey showed us that the combined model could be used to identify regions and times when butterfish concentrations were likely to be high at scales of 10s of kilometers. We learned that fishermen understood species-habitat associations at scales much finer than could be described by the data used to construct the model and thus the model itself. Fishermen also knew locations and times where the animals were likely to occur that are not typically sampled on scientific surveys.

We are further refining our mesoscale model with the help of the fishing industry for the recalibration of indices of population trend based upon the amount of habitat actually sampled in fisheries independent surveys. We also intend to use the refined model for industry based population surveys of dynamic habitat intended to supplement fishery-independent surveys. These applications may prove especially useful for estimating population trends of

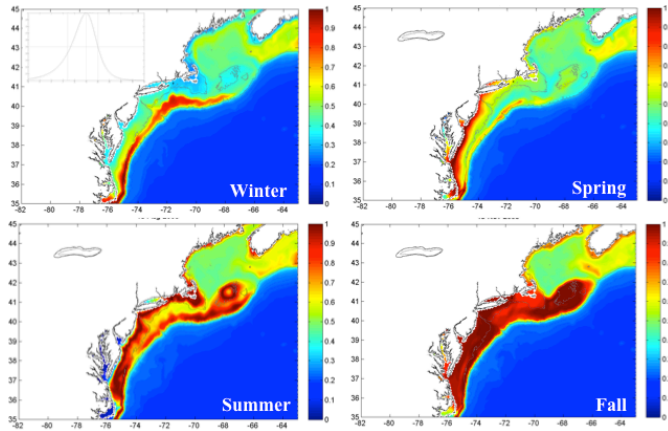


Figure 3. Spatial maps of thermal habitat “suitability” for butterfish during the winter, spring, summer, and fall based on IOOS temperature fields and abundance responses of butterfish.

ecosystem keystone species when rapid changes in climate are causing dramatic changes in fluid properties and processes and thus in the spatial dynamics of ocean habitats.

5. The Next Decade

We are beginning to move beyond empirical ecological models based upon regional fisheries data and observations toward mechanistic ecological models that can be coupled to IOOS assimilative oceanographic models describing critical features of ocean habitats (Fig. 3). Coupled mechanistic biophysical models will allow us to describe dynamic ocean habitats throughout the water column and avoid pitfalls associated with using correlative empirical models for forecasting. Using oceanographic models will also allow us to investigate the role of advection in delivering key habitat building blocks from sometimes remote sources to locations and times where/when ocean habitats form. Mechanistic seascape models that rest on the foundations of assimilative hydrodynamic models will be particularly useful if climate change produces ocean conditions we have never before observed.

We intend to continue to work with fishermen within the context of the

IOOS collaborative culture. Integrating their practical ecological knowledge with academic knowledge of the sea should result the rapid development of accurate seascape models. These models will first be considered hypotheses that can be adaptively tested within ocean observing systems. Once vetted in this way they can be easily operationalized as tools for the space and time management of human activities in dynamic ocean ecosystems. We believe this adaptive, iterative, collaborative approach is the cost effective way to develop a seascape ecology with a scope broad enough to meet requirements for resource management in the sea.

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