



Delineating ecological regions in marine systems: Integrating physical structure and community composition to inform spatial management in the eastern Bering Sea



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ABSTRACT

Characterizing spatial structure and delineating meaningful spatial boundaries have useful applications to understanding regional dynamics in marine systems, and are integral to ecosystem approaches to fisheries management. Physical structure and drivers combine with biological responses and interactions to organize marine systems in unique ways at multiple scales. We apply multivariate statistical methods to define spatially coherent ecological units or ecoregions in the eastern Bering Sea. We also illustrate a practical approach to integrate data on species distribution, habitat structure and physical forcing mechanisms to distinguish areas with distinct biogeography as one means to define management units in large marine ecosystems. We use random forests to quantify the relative importance of habitat and environmental variables to the distribution of individual species, and to quantify shifts in multispecies assemblages or community composition along environmental gradients. Threshold shifts in community composition are used to identify regions with distinct physical and biological attributes, and to evaluate the relative importance of predictor variables to determining regional boundaries. Depth, bottom temperature and frontal boundaries were dominant factors delineating distinct biological communities in this system, with a latitudinal divide at approximately 60°N. Our results indicate that distinct climatic periods will shift habitat gradients and that dynamic physical variables such as temperature and stratification are important to understanding temporal stability of ecoregion boundaries. We note distinct distribution patterns among functional guilds and also evidence for resource partitioning among individual species within each guild. By integrating physical and biological data to determine spatial patterns in community composition, we partition ecosystems along ecologically significant gradients. This may provide a basis for defining spatial management units or serve as a baseline index for analyses of structural shifts in the physical environment, species abundance and distribution, and community dynamics over time.

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1. Introduction

Spatial classification of patterns in biogeography provide a practical approach to understand ecosystem dynamics. This has useful application to conservation (Lourie and Vincent, 2004; Spalding et al., 2007) and resource management (Marasco et al., 2007; Levin et al., 2009; Livingston et al., 2011; Link and Auster, 2011). Oceanographic processes, bathymetric structure and environmental conditions regulate

system organization and productivity (Speckman et al., 2005) and influence competitive and predatory interactions (Kildaw et al., 2005). By recognizing and explicitly characterizing spatial heterogeneity in marine systems, we are able to define and better explain distinct regional patterns (Bailey, 1998).

There is an extensive history of classifying biogeographic patterns in the marine environment (Forbes, 1856; Ekman, 1953; Hedgpeth, 1957a,b). Hierarchical approaches are often used, scaling from geographical realms (continental or oceanic scales), to provinces (seas or basins), ecosystems (self-contained systems), and regional-scale processes. To distinguish boundaries, classification systems have employed species endemism (Briggs, 1974), bathymetry (Allen and Smith, 1988), biogeochemical processes (Longhurst, 1998), oceanic production (Bailey, 1998), thermogeography (Adey and Steneck, 2001)

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and physiographic and oceanographic patterns (Piatt and Springer, 2007). Such classification systems have also used functional considerations such as utility and parsimony (Spalding et al., 2007). As part of this process, the concept of large marine ecosystems (LME) was established to define the continental margins according to ecological criteria (e.g. bathymetry, hydrography, productivity, and trophic relationships) and to facilitate transboundary and ecosystem-based management (Morgan, 1987; Sherman and Alexander, 1989; Sherman, 1991). LMEs are also widely used as distinct units of analysis in comparisons of marine systems (Branch et al., 2010; Pinsky et al., 2011). Due in part to the emphasis on Ecosystem-Based Fishery Management (EBFM) in the reauthorization of the Magnusson-Stevens Act, LMEs were also adopted by the US National Oceanic and Atmospheric Administration (<http://www.lme.noaa.gov>) and currently provide the basis for assessing and managing discrete fish stocks. While LMEs provide a robust and useful designation of distinct marine areas, there is increased interest in higher resolution understanding of ecosystem processes and regional phenomena relevant to both conservation (Dinerstein and Olson, 1997; Ford, 1998; Banks et al., 1999; Spalding et al., 2007) and natural resource management (Fogarty and Murawski, 1998; Fogarty and Keith, 2009; <http://bsierp.nprb.org>). This is recognized by international (UN FAO, 2003) and national authorities (Ecosystem Principles Panel, 1996; National Marine Fisheries Service, 1999; US Commission on Ocean Policy, 2004). As distinct units within LMEs, ecoregions serve this purpose. We define an ecoregion as an ecologically and geographically defined area characterized by distinct assemblages of biological communities and environmental conditions.

1.1. Purpose and intent

Both spatial and multispecies management approaches require robust methods to synthesize physical and biological data to identify regional structure within ecosystems, and determine the relative impacts of various environmental and biological drivers. We illustrate an approach to integrate data on species distribution with data on

environmental variables and physical structure to distinguish regions with distinct biogeography and ecology (i.e. ecoregions).

1.2. Regional Delineation

LMEs are defined using broad-scale patterns of biodiversity, productivity and hydrographical features (Hempel and Sherman, 2003; Murawski, 2007). These boundaries distinguish ecosystem processes, food web and trophic interactions, and commercially exploited stocks. The criteria distinguishing ecoregions is less clear. Most approaches have been synthetic (consensus and expert opinion) and largely qualitative (Piatt and Springer, 2007; Ortiz, 2012). Past efforts to apply quantitative methods have typically focused on physical variables alone (Allen and Smith, 1988), used aggregate biomass without consideration of the composition of the ecological communities represented (Fogarty and Keith, 2009; Livingston et al., 1999; Pepin et al., 2010; Zwanenburg et al., 2010) or included anthropogenic and political considerations (Spalding et al., 2007).

Hard boundaries rarely exist in marine systems (Murawski, 2007). Ecological processes and species distributions fluctuate along gradients, often dictated by a relatively limited group of covariates (e.g. temperature, depth, salinity, stratification, nutrient availability, substrate type, productivity). Identifying how distinct biological communities organize across environmental gradients offers one means to differentiate ecoregions.

1.3. Study system: eastern Bering Sea

Our analyses focus on the eastern Bering Sea (EBS), a highly productive system that generates roughly half of US fish and shellfish landings and supports important populations of seabirds and marine mammals (National Research Council, 1996). It is characterized by a broad coastal shelf and a deep-sea basin, extending from the Alaska Peninsula to the Bering Strait. The Bering Sea shelf extends 800 km from Norton Sound to the

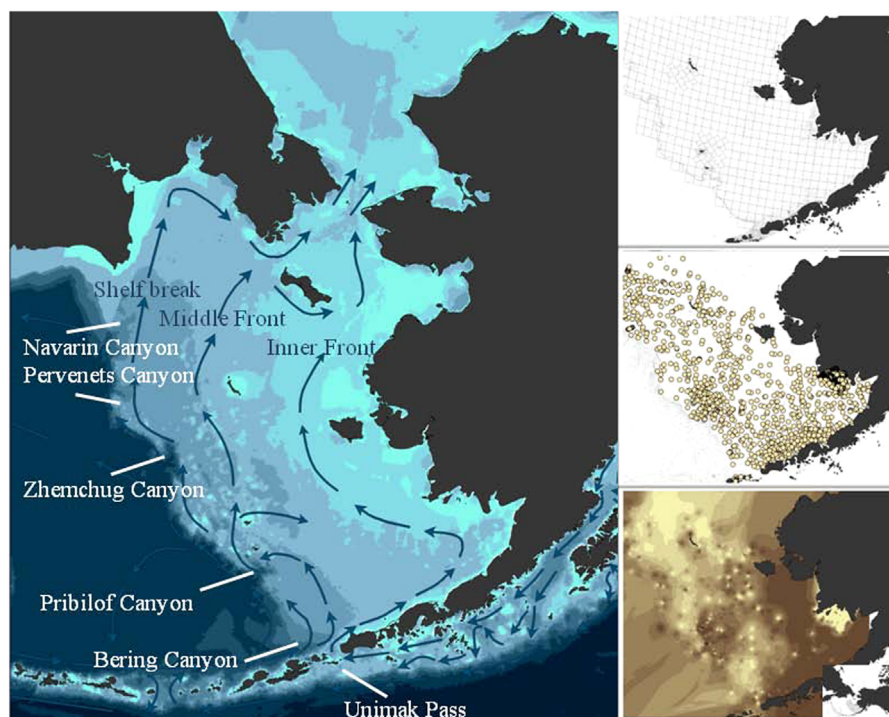


Fig. 1. Eastern Bering Sea shelf. Main panel displays depth, predominant currents, fronts and canyons. Side panels display fixed grid survey stations for survey biomass (top right), sampling locations for sediment (middle right) and inverse distance weighting of surficial sediments (darker shades indicate coarser substrates, bottom right).

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