LIMNOLOGY
and
OCEANOGRAPHY

Limnol. Oceanogr. 62, 2017, S272–S291

doi: 10.1002/lno.10537

Ecosystem variability along the estuarine salinity gradient: Examples from long-term study of San Francisco Bay

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Abstract

The salinity gradient of estuaries plays a unique and fundamental role in structuring spatial patterns of physical properties, biota, and biogeochemical processes. We use variability along the salinity gradient of San Francisco Bay to illustrate some lessons about the diversity of spatial structures in estuaries and their variability over time. Spatial patterns of dissolved constituents (e.g., silicate) can be linear or nonlinear, depending on the relative importance of river-ocean mixing and internal sinks (diatom uptake). Particles have different spatial patterns because they accumulate in estuarine turbidity maxima formed by the combination of sinking and estuarine circulation. Some constituents have weak or no mean spatial structure along the salinity gradient, reflecting spatially distributed sources along the estuary (nitrate) or atmospheric exchanges that buffer spatial variability of ecosystem metabolism (dissolved oxygen). The density difference between freshwater and seawater establishes stratification in estuaries stronger than the thermal stratification of lakes and oceans. Stratification is strongest around the center of the salinity gradient and when river discharge is high. Spatial distributions of motile organisms are shaped by species-specific adaptations to different salinity ranges (shrimp) and by behavioral responses to environmental variability (northern anchovy). Estuarine spatial patterns change over time scales of events (intrusions of upwelled ocean water), seasons (river inflow), years (annual weather anomalies), and between eras separated by ecosystem disturbances (a species introduction). Each of these lessons is a piece in the puzzle of how estuarine ecosystems are structured and how they differ from the river and ocean ecosystems they bridge.

Estuaries are transitional ecosystems between land and ocean. Their defining feature is the salinity gradient, a spatial pattern in the mixture of water from two distinctly different sources: seawater, and freshwater delivered as land runoff. The salinity gradient is a fundamental reason why the estuary is not just an ecotone—a transitional zone between two separate biomes—but rather an ecosystem class of its own, with unique species assemblages and transport processes. As a result, patterns of water properties and biota along the estuarine axis from freshwater to sea seldom represent the simple passive mixing of two water sources. Here, we examine the nature of and reasons for patterns along the salinity gradient of San Francisco Bay, "…a classic example of a coastal plain estuary in which terrestrial freshwater mixes with salt water entering the estuary from the ocean" (Schoellhamer et al. 2016).

Since the beginning of estuarine science, we have recognized the importance of the salinity gradient, using it as a frame of reference for understanding spatial structure and its variability in the form of property vs. salinity plots, or "mixing diagrams" (Stefánsson and Richards 1963; Ketchum 1967; Wollast and De Broeu 1971; Liss and Pointon 1973). The approach is informative and appealing because of its simplicity, exploiting differences in the chemical and physical properties of seawater and freshwater. When end-member concentrations vary more slowly than estuary flushing time and there are no intermediate transformations or sources, then spatial structure is determined primarily by mixing of the two end-members, and properties should vary linearly (conservatively) along the salinity gradient. Nonlinear patterns along the salinity gradient, on the other hand, often imply estuarine processes of transformation and non-conservative behavior (Boyle et al. 1974; Sharp et al. 1984).

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Special Issue: Headwaters to Oceans: Ecological and Biogeochemical Contrasts Across the Aquatic Continuum
Edited by: Marguerite Xenopoulos, John A. Downing, M. Dileep Kumar, Susanne Menden-Deuer, and Maren Voss