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Fisheries Ecosystems and Hypoxia: A Future Informed by the Past

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The California Current Ecosystem (CCE) contains some of the most productive marine fisheries in the world. As global climate moves outside the established range of historical precedent, the physical structure of this ecosystem is shifting precipitously. Rapid change to environmental states that have no analogue in modern history is confounding to ecosystem scientists and managers: How do we plan for and manage ecosystems that are configuring to physical, chemical, or biological states that we have never seen or measured before? These environmental challenges require the incorporation of new toolkits, especially when managing resources that have such a direct impact on human economic vitality and traditional livelihoods such as marine fisheries.

Large-scale physical processes uniquely structure the CCE. Equatorward winds and the Coriolis Effect drive surface waters offshore and suction deeper water upwards along the shallow continental margin. This physical process seeds surface ecosystems with nutrients from the deep ocean; in a sense, upwelling fertilizes surface waters, much like you would fertilize your own garden to increase plant productivity. These nutrients drive spectacular surface blooms, which in turn support extensive and productive fisheries (e.g., salmon, rockfish, pandalid shrimp, and Dungeness crab) and large cetacean, pinniped, and seabird populations.

Surface productivity (i.e., algal blooms, organismal body parts, fecal matter, etc.) has to go somewhere, and it does—it sinks down through the water column. Bacteria in deeper, darker waters, where photosynthesis and thus oxygen replenishment can no longer occur, consume the surface-derived carbon. These microbial communities that feed upon the surface carbon rain consume dissolved oxygen for their respiratory requirements and, therefore, the greater the surface export of carbon, the greater the oxygen consumption at depth. These zones of acute oxygen consumption, and thus lowered dissolved oxygen concentrations, are called "oxygen minimum zones" (OMZs). They are essentially the low-oxygen shadow of the adjacent productive surface ecosystems, with upper and lower boundaries that delineate three-dimensional ecosystems and physical barriers. OMZs create substantial physical boundaries within fisheries ecosystems; fish and crustaceans are especially intolerant of low-oxygen conditions and exhibit avoidance behaviors of only mildly hypoxic waters.

The most recent deglaciation (18,000–10,000 years ago), an event of ~3.5°C of global warming and ~120 m of sea level rise, is an ideal laboratory to ask questions regarding how marine fisheries ecosystems undergo dramatic physical reorganization during events of global climate change. Deglaciation in the CCE, an event only a blink of an eye ago in the geologic past, can be investigated using shallow sediment cores from the continental margin. These sediment archives, much like tree rings or ice cores, reconstruct environmental and climatic change. Paleoceanographers use geochemical, microfaunal, or sedimentary toolkits to ask questions of these archives and to build cohesive chronologies that can be compared to other types of climate archives from distant parts of the globe. Though the deglaciation is not analogous to how we humans are currently changing the planet, it is nonetheless a rich source of data for how marine ecosystems are disturbed through rapid global warming. OMZs leave striking evidence in sediment archives of their presence; therefore, it is relatively easy to assess where, both geospatially and vertically, OMZs impinged upon the continental margin. Marine sediment cores provide clear warning of how rapidly and comprehensively oceanographic change can occur. Globally, the upper ocean (i.e., the primary location of the majority of fisheries ecosystems) rapidly lost dissolved oxygen during the deglaciation event, with heretofore unknown consequences to upper surface ocean ecosystems (Jaccard and Galbraith 2012). The catastrophic melting of North American ice sheets occurred at ~14,700 years ago, coincided with very rapid warming, and serves as the best analogue for what is occurring in the twenty-first century. During this event the continental margin of the CCE rapidly deoxygenated; from ~1,100 to 300 m below sea level, the water column became severely hypoxic (Moffitt et al. 2014). Therefore, this recent event of global warming was accompanied in the CCE by the deoxygenation of greater than 900 m of the water column.

What OMZs and the physical structure of the CCE mean for fisheries is this: there is a finite volume between the surface ocean and the upper boundary of the OMZ where oxygen-dependent fisheries ecosystems can flourish. In the modern CCE, this upper boundary of OMZ waters sits at ~600 m water depth. However, the key for fisheries planning in a nonanalogue future is that this low-oxygen boundary is not static. Already, modern anomalous events of severe upwelling-driven hypoxia have been documented on the continental shelf of the CCE (Chan et al. 2008), causing ecosystem-level disturbances and mass die-offs of fish and invertebrates (Grantham et al. 2004). Investigations of the recent deglaciation show that the CCE OMZ can expand vertically by hundreds of meters on decadal timescales, rapidly compressing oxygenated shallower water and volumetrically reducing fisheries ecosystems (Moffitt et al. 2014). Climate models reveal that deoxygenation of the surface ocean is an inherent component of a rapidly warming planet (Keeling et al. 2010). For fisheries, this means that, among the panoply of current ecosystem threats, from ocean acidification and coastal degradation to invasive species, expanding OMZs and the compression of oxygenated surface waters should be of primary concern to CCE fisheries managers. It also means that as habitat volume is reduced, the potential fisheries take from that habitat will be reduced, with downstream effects on fishing communities and coastal economies. The fishing communities of the North American coastline, already beleaguered by decades of fisheries closures and reductions, should be informed of how their livelihood is at risk in a future of rapid climate warming. OMZ expansion not only degrades potential fisheries habitat but removes that habitat from fisheries use; no oxygen means no fisheries, plain and simple.

Interactions between climate, upwelling systems, and fisheries ecosystems are critical to understanding how sustainable CCE fisheries will be in a warm, carbon-rich future. Ocean, climate, and fisheries scientists all bring critical knowledge of this system to bear and these sometimes disparate fields of study need to foster intellectual connections to meet the resource management and scientific needs in the coming century.

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