COMMENTARY

Human impacts on fisheries across the land–sea interface

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A long-held paradigm is that estuaries are important to the welfare of estuarine-dependent coastal fisheries, providing spawning areas, suitable salinity gradients for development, protection from predators, and food. Many publications link the beneficial nature of estuaries with fisheries production and decry human activities that modify habitat, and therefore potentially decrease fisheries production. However, what if the water quality of the estuary, often human-driven, results in less than suitable habitat for coastal fisheries productivity, both in the estuary and in the adjacent offshore waters? Finding the data to support relationships (positive and negative) among estuaries and coastal fisheries production is difficult because of inadequate data, highly variable data, or data with no clear linkages to processes. Hughes et al. (1), however, amassed a dense and multifaceted database of declining estuarine water quality in the form of worsening hypoxia to declines of fish diversity, reduced estuarine habitat suitability, and declines in offshore fisheries. The authors defend a plausible mechanism across the land–sea interface.

Relationships among hypoxic waters and fisheries productivity (either catch per unit effort or landings) remain as elusive as relationships of nitrogen loading and fisheries productivity. Efforts to understand these ocean trophic models shifted over the 20th century from agricultural models of food stimulated by nutrients that feed higher primary producer standing stocks and secondary production to concerns of higher N and P loads into water bodies, excess phytoplankton biomass, and the deleterious effects of eutrophication, including harmful algal blooms and hypoxia (Fig. 1) (2–6).

A meta-analysis by Micheli (7) of 47 food webs (natural and experimental) verified a relationship between nitrogen loading and primary production but not necessarily standing stocks of secondary consumers in the form of fisheries. Breitburg et al. (8) followed with a broad global analysis of 30 estuaries and semienclosed seas and found few strong relationships between N loading and fisheries production and hypoxia and fisheries production. Their divisions for fisheries were pelagic planktivores, benthopelagics, and benthics. Fisheries landings were positively related to N loading only for the benthopelagics and pelagics. None were related to the percent of the bottom water that was hypoxic.

On more local or regional scales, however, there are documented decreases in landings or catch per unit effort with increase in area of hypoxia. Cod landings in the Baltic decline with an increase in stratification that affects the buoyancy of cod eggs so that they do not reach suitable habitat for development and with an increase in volume of hypoxic bottom-water that negatively affects survivability (9, 10). A similar decrease in cod landings in the western Atlantic is potentially related to increasing nutrient loads in the St. Lawrence River estuary and subsequent hypoxia (11, 12).

Fig. 1. A fish kill at Grand Isle, Louisiana, caused by a hypoxic water mass from offshore moving onto the barrier island. Image courtesy of K. St. Pé (photographer).

The bottom-waters of the northern Gulf of Mexico west of the Mississippi River delta are severely low in dissolved oxygen on an annual basis through much of the spring and summer, and are related to increased N and P loading and shifting nutrient ratios (13–15). Two analyses (16, 17) found significantly negative relationships ($P < 0.05$) over the period from 1985–1997 and 1985–2004, respectively, when the brown shrimp catches from both Louisiana and Texas fisheries were combined and compared with the area of bottom-water hypoxia in midsummer. No statistically significant relationships were found between hypoxic zone area and white shrimp annual catch. White shrimp spawn at the time of year and location of the severest hypoxia. Brown shrimp are emigrating from the estuaries into severely hypoxic water at a different time of the year, and offshore migration is halted by the physical geographic location of the "dead zone." These life history characteristics may explain part of the differences between the white and brown shrimp, but many other factors are equally important, such as fishing effort, timing of fishing effort, distance from port × price of fuel × small/large boat fishery, salinity of the nursery areas, economic impact of imported shrimp on the market, human-induced loss of habitat because of increased nutrient loads, and acreage of nursery area, which is proportional to the shrimp landings (18). Chesney and Baltz (19) further argue that the penaeid shrimp fishery is highly resilient to environmental stress and speculate that it is likely that other quantifiable impacts of greater magnitude may currently have more significant effects than hypoxia on the community structure and secondary production of nekton populations in the northern Gulf of Mexico.

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Hughes et al. (1) focused their attention on Elkhorn Slough, a central California estuary characterized by increasingly and highly eutrophic waters and worsening conditions of hypoxia. This environmental degradation is driven by high nutrient loads from adjacent agricultural lands in its watershed. Elkhorn Slough, like many estuaries, is also home to many commercially, recreationally, and aesthetically important organisms. Among these are two flatfishes, the English sole (*Parophrys vetulus*) and speckled sanddab (*Citharichthys stimmaeus*), which use demersal habitats in Elkhorn Slough as nursery areas (refs. 20 and 21, as cited in ref. 1). The English sole is an important commercial species, and Lassuy (ref. 22, as cited in ref. 1) estimated that the majority of adults that are captured in the offshore Monterey Bay region used Elkhorn Slough as juveniles. Datasets of fish, water quality, climatology, and regional oceanographic data of 40-y length for Elkhorn Slough and >20 y in adjacent offshore waters provided a unique opportunity to examine water quality (dissolved oxygen conditions) and flatfish abundances of the target species: English sole and speckled sanddab.

Absence or lower abundance of the target flatfishes occurred when hypoxic conditions were present in the estuary, and dissolved oxygen concentration was the only variable that suggested a negative impact on flatfish presence in either the deep channels (2–10 m depth) or the shallow flats (<2 m depth). Temperature variability was not consistent with flatfish abundance. Species richness was also lower in hypoxic waters than in normoxic waters, but differences in combined samples of 0.5–1.5 are hardly staggering.

If hypoxia negatively affects abundance of flatfishes in the estuary, which are primarily age 0–1, then a reduction in catch in the offshore region would be manifested in the following year. As predicted, cross-correlation analysis did detect a 1-y lag effect in decline in the catch of English sole in National Marine Fisheries Service trawl surveys in the Monterey Bay region. The offshore fisheries data from several trawl surveys were combined to examine the relationships of English sole abundance with offshore dissolved oxygen, El Niño Southern Oscillation, Pacific Decadal Oscillation, North Pacific Gyre Oscillation, and upwelling. Nursery area dissolved oxygen was a significant predictor of declines in the English sole fishery but upwelling with its lower dissolved oxygen concentrations was also a significant predictor of English sole declines.

Variations in climatology (not equated by this author to climate change) can affect precipitation and runoff to estuarine and coastal waters, while alleviating conditions of hypoxia or worsening the conditions of hypoxia (23). Hughes et al. (1) identified that increases in El Niño conditions resulting in increased precipitation, decreased salinity, and flushing of the upper estuary and relaxed upwelling intensity with warmer ocean waters could alleviate the detrimental effects of low-oxygen conditions. Under non-El Niño conditions, hypoxia occurred throughout the estuary with declines in flatfish abundance.

The linkages seem clear. Lower dissolved oxygen in the estuary equates to lower flatfish abundances in the estuary and a subsequent 1-y later lower abundance of flatfish in the offshore fishery. Negative and positive effects of El Niño fluctuations on flatfish abundance in the estuary were repeatable across five of six other estuaries of the northeast Pacific, indicating that climatological factors could alleviate conditions of worsening hypoxia, or alternatively cause more problems.

Still, what are the proportional effects across longer temporal scales of fluctuating dissolved oxygen conditions in the estuaries, and longer-term fisheries production in the offshore coastal waters? And, how will these effects be manifested in climate change that would affect the dissolved oxygen conditions of the estuary and coastal ocean and the oxygen and circulation patterns that affect larger scale dynamics, such as El Niño Southern Oscillation? Climate change and ocean warming will affect estuaries and nearshore coastal oceans differently, in some cases alleviating hypoxic conditions and in other cases worsening the situation. Hughes et al. (1) identify Elkhorn Slough as the most southerly range for English sole, and indicate that conditions of temperature stress and hypoxia stress (interactions of temperature) may worsen. However, consider the larger climate scenario of habitats opening up in more northerly waters as they warm. Consider the potential for shifting coastal currents to minimize upwelling of lower dissolved oxygen conditions onto the shelf.

Clearly the increase of N and P loads to estuaries and costal offshore waters is occurring and will expand to developing countries as their symptoms of eutrophication follow a similar but lagged timeline to developed countries (23, 24). The negative impacts of poor water quality and hypoxia are evident in many areas. Hughes et al. (1) combined multiple, long-term datasets from Elkhorn Slough and the adjacent offshore waters to identify estuarine hypoxia impacts on juvenile English sole that resulted in lower offshore abundance of a commercially important flatfish. The evidence for estuarine hypoxia and offshore fisheries effects is clear in their data analysis, but otherwise has been sparse or equivocal. The increase of nutrient loading to aquatic systems, freshwater and saltwater, is or is perceived as a threat to water quality and the living resources that depend upon the habitat. Reduction in N and P loadings is a highly recommended course of action (25).

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