Effects of Toxic Contaminates on Trophic Levels Within Puget Sound Estuarine Habitats

Within an estuary, nutrients and bioavailability are diverse and innumerable. Estuaries provide principal habitats for various animal species, including shorebirds, waterfowl, invertebrates, fish, and mammals. Supplemented by a nutrient-dense environment, plant growth is elevated, and zooplankton, a food source for many species, is abundant. The hydrographic features of an estuary allow for fine particles and sediments carried by rivers to the estuaries to act as nutrient sinks, offering surface area for nutrients to suspend and settle out. Additionally, estuaries contain seawater under freshwater, trapping nutrients underneath. The complex trophic web that occurs within estuaries is an indicator of the ecosystem's health. The features of an estuary that allow nutrients to be confined and readily available also, unfortunately, allow pollutants to be trapped. The food webs that rely on estuarine environments are vulnerable to human-caused disturbances, especially pollutants (Carefoot,1983). This essay examines the consequences that human-caused contaminates have on estuarine habitats and the subsequent trophic-level effects that can occur.

Contributing factors to contamination of Puget Sound

The second-largest estuary in the United States, Puget Sound is unique in its characteristics that contribute to its biologically productive habitats. The growth in human population in the Sound has led to negative impacts on water quality, coastal habitats, and fish and wildlife populations (Pacific Coastal and Marine Science Center, 2024). Pollutant sources within Puget Sound include industrial waste, stormwater drainage, chemical spills, wastewater treatment facilities, and agricultural runoff. Detected pollutants produced by these sources in estuaries include polychlorinated biphenyl (PCBs), dichloro-diphenyl-trichloroethane (DDT), metals including arsenic, lead, copper, and mercury, polycyclic aromatic hydrocarbons (PAHs), pesticides, and various industrial chemicals (Meador, 2014). Climate change has led to ocean warming, deoxygenation, and ocean acidification, intensifying pollutant bioaccumulation rates and producing toxic algal blooms within the Sound (Trainer & King, 2023).

Trophic level vulnerability of estuarine systems

Organisms living within estuarine environments are generally very tolerant of unstable conditions, as an estuary is a constantly changing environment. However, the food web of an estuary is more sensitive due to its limited structure and less diversity than that of a more extensive marine system. Removing just one species can disrupt a food web, leaving an empty niche. This disruption influences the flow of energy throughout the entire system. Depending upon a few key organisms capable of utilizing the detritus and micro-algae available in the estuarine systems of the Sound, the loss of critical organisms, or by extension, the contamination of those organisms, can cause a trophic cascade and collapse a system (Odum, 1970). Puget Sound has explicitly a food web driven by phytoplankton and phytoplankton detritus, supporting a bottom-up ecosystem model. However, seabirds such as Bald Eagles (*Haliaeetus leucocephalus*) and gulls also play a significant role in the food web structure and act as possible keystone species due to their high consumption rates of crucial forage fish, invertebrates, and even benthic primary producers (Harvey et al., 2012).

Phytoplankton and detritus drive energy flow for the pelagic and benthic estuarine communities of Puget Sound (Harvey et al., 2012). As primary producers, phytoplankton can initiate a contaminant's entry into a food web. For example, DDT, introduced in 1945 as an effective insecticide, can contaminate fish, birds, invertebrates, and other predators that consume phytoplankton exposed to it. DDT is soluble in lipids and rapidly accumulates when it becomes concentrated in an organism's fatty tissues. Bioaccumulation occurs as DDT transfers along the food web, eventually reaching top carnivores like eagles. Marine birds such as Bald Eagle populations were affected significantly by DDT toxicity, as its residues block nerve functions in vertebrates and interfere with the formation of egg shells in birds from calcium degradation (Sumich, 1992).

Impact of Puget Sound estuarine contaminates on human health, economics, and culture

Human-caused toxic contaminates within Puget Sound have detrimental impacts not only on wildlife but also on human health, safety, commercial and recreational harvests, and culture. Contaminates found in Puget Sound fishes notably impact human commercial and sport fishing. Because of their higher position in the food web, popular sport and commercial fish such as rockfish (*Sebastes spp*), Pacific cod (*Clupea pallasii*), and salmonids can bioaccumulate a higher concentration of contaminants and pass toxins on to humans. Flatfishes such as starry flounder (*Platichthys stellatus*) also have the means to move contaminants from sediments to humans that consume them because flounder feed on bottom-dwelling benthic invertebrates that use sediments as habitat (West et al., 2001). Fine sediments have been shown to concentrate contaminates such as petroleum byproducts and pesticides, sometimes at an alarming rate. It has been found that DDT levels in estuarine sediments are 100,000 times higher than in estuarine water (Odum, 1970). The negative impact of human-caused contaminants on juvenile salmon populations is an additional concern, as first-year survival is the most critical period in the salmon life cycle. A significant sustenance and economic source for human communities within the Sound, salmon can spend considerable time in estuaries as juveniles, which increases their chances of exposure to harmful contaminants. This exposure can impair growth, alter behavior, negatively affect their immune system, and cause physiological homeostasis, leading to higher mortality rates. Although some types of toxic contaminates have declined over the years, such as DDT, others are increasing with the rise in urbanization in Puget Sound (Meador, 2013).

Fish and wildlife of the Sound, including salmonids, shellfish, and seabirds, are directly impacted by pollutants on all levels of the food web. Higher-trophic-level organisms, however, face an increased risk of mortality and health impacts as the bioaccumulation factor is intensified. As a member of the food web and a high-trophic-level organism, humans are directly impacted by the contaminants in the ecosystem they feed off of (Alava et al., 2018). Human health is seriously affected by a variety of harmful toxins found in shellfish that cause paralytic amnesic, diarrhetic, and azaspiracid poisoning. Although naturally occurring, this toxic algae consumed by the shellfish is encouraged to bloom due to changing environmental conditions of the Sound, such as increasing water temperatures and changing salinity. The toxins in these algae become concentrated in shellfish and planktivorous fish tissues as they feed, and toxins are transferred up the food web to humans and wildlife. High concentrations of some toxic algae species can cause mass mortalities in avian, fish, and shellfish populations. With over 900 shellfish farms in Washington and over 300,000 people participating in recreational shellfish harvesting on Washington's beaches yearly, the impact on human subsistence, ceremonial practices, and commercial and recreational harvest is threatened by the rise in aquatic toxins (Trainer & King, 2023). Programs like The SoundToxins Program enable the management of toxic algal blooms within Puget Sound, providing early warning of harmful algal blooms to aquaculture producers and tribal and state natural resource managers to prevent risk to human health, fewer harvest losses, and reduce shellfish recalls (Trainer & King, 2023).

Effects of climate change on bioaccumulation of toxins within an estuarine food web

Climate change is among the challenges the Northeastern Pacific faces, and by extension, Puget Sound. Climate change has been found to amplify the bioaccumulation of some contaminants, such as mercury, in the food web. Ocean warming, deoxygenation, and ocean acidification intensify pollutant bioaccumulation rates. Lower trophic-level organisms can play an essential role in the bioaccumulation of mercury, as climate change can increase exposure and intensify mercury concentrations in zooplankton by a factor of 2 to 7 (Alava et al., 2018). In Puget Sound, harmful algal blooms have become a substantial risk to the ecosystem and human health. Climate change, which causes intensifying pollutant bioaccumulation rates, is associated with increased temperatures in marine waters that favor the growth of some harmful algal blooms (Trainer & King, 2023).

Conclusion

The consequences of human-caused contaminates on estuarine habitats are loss of wildlife and viable habitats, risk to human health and safety, and the subsequent impact on sensitive food webs caused by bioaccumulation of toxins. Historically, higher trophic-level organisms are significantly impacted by contaminants. Due to their hydrographic features, estuaries act as natural buffers to trap toxins. These trapped toxins increase the risk of disrupting the sensitive food webs that rely upon estuaries for subsistence, habitat, and, in the case of humans, cultural, social, and economic well-being. With the population of humans that reside along Puget Sound, a large estuary, expected to continue increasing, the rise of human-caused pollution and contaminants and the increase in toxic algal blooms pose a significant threat to water quality, coastal habitats, and fish and wildlife populations. Human health and subsistence from coastal food sources are also at risk, with the communities in Puget Sound relying on marine life for commercial and recreational harvests. As climate change progresses, warmer temperatures, ocean acidification, changes in oxygen levels, and increased nutrient runoff are expected to increase the risk of toxic events that threaten higher trophic-level organisms, such as wildlife and humans.

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