Written Testimony of
Dr. Kevin G. Sellner
Executive Director
Chesapeake Research Consortium, Inc.

for the
Committee on Resources
Subcommittee on Fisheries and Oceans
U.S. House of Representatives

Hearing on
Scientific Review of Ocean Systems

" Harmful Algal Blooms
A Function of Natural Circulation Processes and Human Alterations of Ocean Chemistry"

(provided in advance of Oral Testimony to be delivered on June 8, 2005)

Harmful algal blooms (HABs) are a global phenomenon, resulting from natural processes (general circulation, ocean currents, and mixing in surface layers of the ocean) and ambient or human-derived nutrients that include nitrogen, phosphorus, silicon, and trace elements such as iron, copper, and other elements needed in lower concentrations for growth. HABs generally consist of photosynthetic algae but can include non-photosynthetic organisms (protozoa), similar to their photosynthetic relatives but without chlorophyll and therefore more like small animals. HABs can result from growth of these organisms as well as physical concentration of these cells through unique circulation or mixing patterns in the open and coastal ocean, estuaries, and even freshwater lakes and reservoirs.

I am providing the following testimony to inform the honorable members that HABs can result from two processes, 'natural' (implying without human influence) and 'human-induced' or anthropogenic intervention. In either case, researchers must observe, identify mechanisms responsible for growth or accumulation of the species, use this information to inform or forecast transport and delivery of the species to coastal areas, and then try to reduce impacts of the HABs on coastal populations, living resources, and regional economies. Observation, research, modeling, and mitigation are integral to the information I am providing the subcommittee as well as future abilities to protect US and other nations' coastal citizens and resources from these events.
HABs result from local growth and/or accumulation of problematic species in an area. We are familiar with 'red tides' and associated fish kills, manatee and porpoise deaths, and coughing beach residents along Florida's beaches, deaths of birds, sea lions, and otters along California's coast, and closed shellfish harvests for Indian tribes, recreational clammers, and commercial harvestors in the Pacific Northwest and NH-Maine coastlines. These closures are a result of oceanic conditions that deliver populations of toxic algae to these areas, independent of human influence. That is, general circulation patterns (ocean currents) common to these regions lead to the growth and transport of the harmful species to inshore areas where accumulation can lead to mass mortalities, aerosolized cells and their toxins, and normal filtering of these cells from the water by mussels, oysters, and clams. This latter process, the natural feeding of the shellfish, concentrates toxins of the harmful species in the shellfish tissue which, when ingested by local citizens, leads to intoxication and temporary or permanent illness and in some cases, death.

The species delivered in this manner in US waters include the red tide organism Karenia breve in the Gulf of Mexico, responsible for neurotoxic shellfish poisoning (NSP); several species of Pseudo-nitzschia, responsible for amnesiac shellfish poisoning (ASP) and permanent short-term memory loss or death (birds, mammals, including humans) along the nation's West coast; and Alexandrium species in the Gulf of Maine, West coast, and Alaska responsible for paralytic shellfish poisoning (PSP) and public health threats. In the Gulf of Mexico, regional currents deliver Karenia to the west coast of Florida where it slowly grows and accumulates, to be transported horizontally via wind-induced movement of surface waters containing the cells. It can move north to the Florida panhandle and beyond, even to Texas, in established ocean currents and aperiodically formed gyres, resulting in mass fish kills and dolphin mortalities. For the diatom Pseudo-nitzschia on the West coast, two common circulation processes result in its proliferation and delivery to coastal areas. One is the upwelling of deeper, nutrient-rich bottom waters resulting from southerly coastal winds moving surface waters offshore, to be replaced by deeper waters. These cooler, nutrient-rich waters then support growth of algal populations including the toxin-producing Pseudo-nitzschia which is ingested by local shellfish and sardine and anchovy populations. These, in turn, are food for sea otters and sea lions, respectively, transferring the toxins of the Pseudo-nitzschia to the mammals and irreparably damaging the hippocampus of the brain, leading to seizures and in some cases, death. Of concern is the ingestion

of shellfish that have concentrated Pseudo-nitzschia from the surrounding waters in that subsequent human consumption can lead to permanent memory loss and death, as recorded in eastern Canada when the toxic species were first identified in the late 1980's.

Another circulation feature also results in potential delivery of toxic Pseudo-nitzschia species to shellfish and possible human consumers in the Pacific Northwest. There is a recurrent oceanic gyre, the Juan de Fuca eddy, a circulating water mass, off Vancouver. This gyre fosters growth of the diatom and depending on regional winds and the surface ocean currents they drive, may transport gyre populations to the coast of Washington. Once onshore, toxic Pseudo-nitzschia populations can be filtered from the overlying water by resident razor clam populations, vectors for poisoning recreational clammers and native American tribal communities dependent on these local shellfish. In both California and Washington, delivery of toxic populations to the coast is a function of natural meteorology and ocean currents, with no human influence responsible for growth or delivery of the HAB species.

The paralytic shellfish producing species of the genus Alexandrium is delivered to the Maine, NH, and Massachusetts coastline as a function of regional circulation patterns, again with no human responsibility or influence. Ocean currents from Nova Scotia enter the Bay of Fundy in New Brunswick, Canada and transport resident populations southwestward along the coast of Maine and New Hampshire. Depending on regional winds, the populations can be carried inshore to rocky, shellfish-rich coasts or mouths of small river systems or alternatively, it can form a resting stage (cyst) that settles to the bottom to act as a seed bank for future population growth; new populations of the toxic species emerging from the settled cysts can then be delivered/transported through normal wind-current patterns to shellfish in the shallow areas of the New England coastline. Thus, the growth and delivery of Alexandrium in the Gulf of Maine is solely a function of regional winds, ocean circulation patterns, and the unique life cycle of the toxic species.

For these three toxic harmful algae, natural processes govern growth and delivery to inshore areas. Hence, there is little control possible for growth and delivery of the species. Mitigation of impacts from these species requires effective observation of regional wind patterns, detection of upwelling or surface current directions, detection of the harmful species or its toxin, and then intervention in delivered populations as they enter an area. Observations can be assured through research or monitoring vessels, remote sensing of surface temperatures, plant biomass, or individual species (all now possible and likely more probable through ocean observing systems), forecasting surface current trajectories and species landfall (now in place in several areas), and managing coastal activities to assure minimal exposures to incoming populations (through relocating fish pens, harvesting shellfish prior to exposure, placing surface booms offshore, monitoring shellfish toxicity, measuring aerosolized toxin content to prevent inhalation, and direct intervention of the HAB by applying agents such as clay particles to remove toxic populations from surface waters).

A second set of HABs that impact US coastal oceans, estuaries, and freshwaters are also a function or natural currents and mixing processes but may be stimulated through human-derived nutrients entering these systems. One of the species identified above, i.e., Pseudo-nitzschia, can be stimulated by human activities that lead to greater nitrogen and phosphorus loads to and altered silicon availabilities in coastal areas. In California, growth of toxic Pseudo-nitzschia australis populations appears to be enhanced through local runoff events delivering elevated levels if silicon, a product of altered land use patterns and weathering in coastal areas. Further, the most dramatic example of human-induced HAB development in US waters is also Pseudo-ntizschia, but off Louisiana where soluble nitrate from mid-west agriculture enters the Mississippi River and are carried to the northern Gulf of Mexico. The tremendous increase in soluble nitrate concentrations delivered to waters off Louisiana in recent decades and an accompanying altered ratio of nitrate-nitrogen to available silicon in the loads has selected for several Pseudo-nitzschia species as well as elevated phytoplankton biomass in general. A surface plume of less dense, fresher, nutrient-rich water from the Mississippi River moves into and over the higher salinity, more dense waters of the northern Gulf of Mexico, fueling the production of this species and other accompanying phytoplankton species as well. Fortunately, no toxic species of Pseudo-nitzschia have been detected in the area yet. However, concern over future toxicities and the expanding hypoxia zone in the Gulf from sinking phytoplankton cells derived from the elevated Mississippi River nitrate loads warrants strong considerations of better basin-wide nutrient controls; the mixing patterns typical of river discharge into high salinity oceanic areas could foster growth of the harmful, toxic species in the future.

Natural estuarine circulation can also foster HAB growth if the tributaries entering an estuary are enriched with nutrients from altered land use. Freshwaters from rivers meet the ocean in estuaries and override the more dense, salty ocean waters, creating vertical stratification with fresher waters in the surface and saltier waters at depth. Additionally, due to the earth's rotation, salty oceanic waters flow into estuaries on the eastern side of estuaries and freshwaters leave estuaries on the western side of the systems. This circulation pattern can result in vertical and horizontal separation of waters and the algae they carry, including harmful species. Depending on the flows entering in the rivers, the length of time that the algae being carried by the two water masses remain in the estuary can vary. This time and space variation effectively provides some HA species optimal growth conditions particularly when nutrients entering the estuary are elevated.

The Chesapeake Bay provides a good example of the potential for harmful algal growth and impacts on living resources

and coastal inhabitants and economies. The natural circulation in the Chesapeake involves two-layered flow described above: fresher, less dense water from its rivers flows seaward while Atlantic Ocean water moves up the bay in deeper depths. Because human activities in the watershed have resulted in huge increases in nitrogen and phosphorus entering the estuary since colonial times, some species including several toxic or rapidly growing species can better utilize the abundant nutrients, leading to toxic events or massive blooms which on sinking, decompose to consume available oxygen and cause fish kills or 'crab jubilees' (crabs leave the water). Species carried down-bay can be entrained in ocean water moving back up the bay and carried back to remain in the estuary, ensuring additional blooms. This 'entrainment' insures long exposure to abundant nutrients entering the system. Species include Prorocentrum cordatum, a species which on occasion reduces oyster survival and regularly depletes waters of available oxygen, Karlodinium veneficum and Pfiesteria species, both fish killers at low to moderate numbers, and Microcystis aeruginosa, a colonial species capable of producing liver and neurotoxins in fresh to low salinity areas. These species are cosmopolitan and likely cause similar impacts in many other US and non-US estuaries.

Two other examples indicate the importance of water movement/circulation and nutrient additions from human activities on the landscape and harmful algal bloom development. Elevated nitrogen loading from human activities of surface and naturally flowing groundwaters along Florida's eastern coast has been suggested as the primary cause for elevated macroalgae in coral reef ecosystems in the area. Similar suggestions have been offered for macroalgal overgrowth of reefs in Caribbean and tropical waters. This continuous nutrient enrichment of nutrient-poor, oceanic waters off Florida and the tropics appears to 'select' for rapid growing seaweeds that are now fluorishing in the region. Storms and hurricanes can displace these beds of algae, driving them on to beaches leading to rotting masses of material on recreationally important systems, depressing tourism and fostering economic hardships for the state and islands as well as potentially impacting coral reef growth and recruitment.

Although not because of salt, the circulation and mixing processes described for estuaries also holds for freshwater lakes and reservoirs but through natural solar heating. As surface waters of lakes and reservoirs warm from spring to summer, they become less dense and are thermally distinct from the underlying colder, dark bottom waters. If surrounding landscapes are developed or farmed with little management of nutrient runoff, elevated nutrient levels can run into the lighted, surface waters and provide near optimal conditions for species that can most effectively use the nutrients and the available sunlight. These systems are often dominated by bloom-forming buoyant cyanobacteria, including the species identified earlier for the Chesapeake, Microcystis aeruginosa, as well as other species that synthesize other toxins. If these freshwater systems serve as drinking water supplies, human health impacts can result, visible as temporary illness to tumor enhancement to death.

This second group of HABs, like the first, respond to circulation and mixing for delivery and presence in a system, whether coastal ocean, estuary, or freshwater lake. However, elevated nutrient levels (and in some cases, even types of nutrients present from land uses in a basin) that accompany human occupation and use of the landscape, can provide optimal growth conditions for some harmful species, including those producing toxins and those accumulating to such high levels that their death strips the water of oxygen causing fish kills and other mortalities. Again, circulation and mixing are natural processes generally beyond human control so these cannot be very effectively manipulated to reduce bloom species. But elevated nutrients from human activities in a watershed that lead to the proliferation of some species can be controlled, thereby providing some ability to reduce the development of the HAB species and their accompanying nearshore impacts.

I thank you for this opportunity to inform the Subcommittee's members of the role of natural processes and human activities in HAB development. Ocean currents, mixing, and turbulence are the primary controls for the growth and accumulation of all algae as they determine access to nutrients and sunlight. For some harmful algae impacting the US coast, these processes alone determine landfall and impacts; the blooms are independent of human inputs and the bloom impacts can only be reduced through observations, forecasts, and intervention in the bloom. For some other species, elevated nutrient inputs arising from increased human alterations of the landscapes (agriculture, suburbanization, urbanization, industrial development, etc.) coupled with currents, mixing, and turbulent conditions provide optimal growth conditions. It is these species that we can effectively control before blooming, by reducing nutrient loads to the systems by better managing landscapes to limit nitrogen and phosphorus loading to our aquatic ecosystems.