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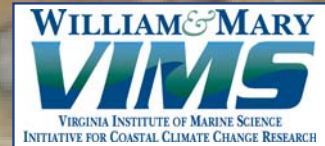
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Climate Change and Aquatic Animal Health in Virginia: Effects and Responses



Environmental Conditions and Aquatic Disease

Climate change, with concomitant increases in sea level, temperature, greenhouse gases and alterations in precipitation, is a major environmental challenge for the future management of Virginia's valuable marine resources. Hidden costs of climate change may include unforeseen perturbations of the natural balance between environmental variables and host-pathogen relationships moderated by these variables. New environmental stressors associated with climate change may facilitate the spread of known diseases into fish and shellfish populations not previously affected, exacerbate disease where it already exists, or result in the emergence of novel pathogens.

Aquatic animal disease specialists use the "triad of causality" (Figure 1) to help explain how disease outbreaks occur in wild populations. Disease arises in an individual or population as a result of the interactions between environment, pathogen, and host. Outbreaks occur when one component of the triad shifts, enhancing the overlap of conditions in the

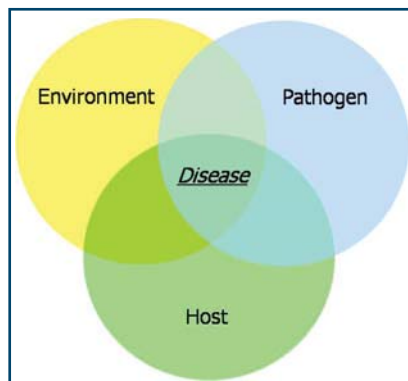


Figure 1. Triad of causality.

center of these processes. Regional climatic variability can be viewed conceptually as a shift in the multiple environmental drivers that may lead to enhanced or reduced risk of disease outbreaks because of the shift of overlapping factors, both pathogen and host-derived. Environmental stressors can include salinity changes, temperature fluctuations, low dissolved-oxygen concentrations, harmful algal blooms, habitat alterations, fishing pressure, and introduced species; they can result in epidemics of morbidity and mortality¹ and increased rates of disease transmission, susceptibility to opportunistic infections, and severity of disease through the suppression of immune responses.^{2,3}

There are limited data on the specific impacts that climate change will have on disease outbreaks in aquatic species important to Virginia. However, it is likely that climate variability coupled with other anthropogenic stressors will lead to significant future disease issues in our fisheries resources.

Disease in Oysters and Clams

Molluscs like oysters (Figure 2) and clams are ecologically and economically important to the Mid-Atlantic region, but are impacted by several destructive protozoan parasites. Climate change may exacerbate at least one of these parasitic diseases. Range expansion northward of oyster parasite and lethal "dermo disease" agent *Perkinsus marinus*

Additional Concerns

Human Health Concerns

- Bacterial species *Vibrio vulnificus* and *Vibrio parahaemolyticus* inhabit estuarine waters and are associated with acute wound infections and seafood-borne illnesses that are sometimes fatal. While the threat of these human pathogens is greatest in summer in the Gulf States, warming water temperatures would elevate risk in the Mid-Atlantic.

Harmful Algal Blooms (HABs)

- Besides being toxic to humans in some cases, harmful algal blooms can seriously damage fish and shellfish stocks. Warming water temperatures and increasing eutrofication could favor blooms by harmful species like *Karlodinium veneficum* and *Alexandrium monilatum*.



Figure 2. A healthy oyster reef on Virginia's Eastern Shore.

The dynamic interactions among molluscan populations, pathogens, and myriad environmental stressors in the context of a changing physical environment simply cannot be known in advance, and will only be revealed over time.

Mitigating Marine Disease

- Reduce nutrient inputs to coastal waters to restore water quality, including healthy dissolved oxygen levels.
- Conserve populations of fish and shellfish, preserving both abundance and genetic diversity, to maintain a maximum capacity for adaptation to changing climate and disease challenges.
- Adopt fisheries management strategies that facilitate the evolution of disease resistance in natural populations; for example, by protection of older survivors of multiple disease challenges as key broodstock.
- Prevent or minimize the amplification and translocation of pathogens, or the introduction of new disease agents, that may occur through aquaculture activities.
- Improve diagnostic tools and conduct research to better understand the factors, such as climate and anthropogenic influences, that drive disease in fish and shellfish.

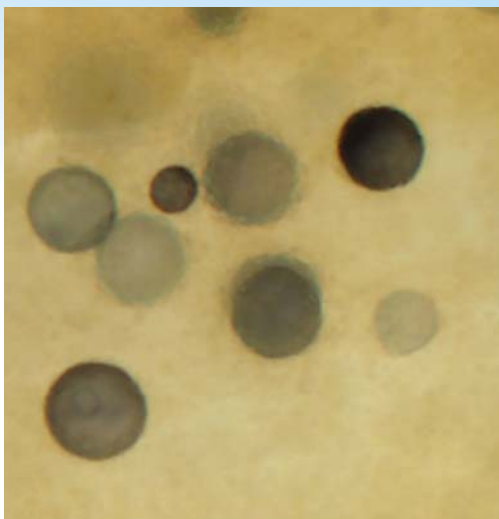


Figure 3. Cells of *Perkinsus marinus*.

(Figure 3) has already been attributed to warming water temperatures, particularly in winter.⁴ In Virginia, intensification of dermo disease began in the 1980s with the onset of serious drought, which reduced stream-flows and elevated bay salinities.⁵ Continued warming and increasing salinities, because of drought and sea level rise, are envisioned for the coming decades,^{6,7} and elevated temperatures in particular will increase *P. marinus* activity: extending its seasonal period of peak activity (when temperatures exceed 20°C) and increasing parasite abundance (warmer winters result in higher levels of the parasite⁵).

However, climate change may also have ameliorative effects on molluscan disease. Some climate models predict an increased intensity of summer storms, including tropical storms and hurricanes. The pulses of low salinity caused by these storms may lessen impacts from dermo disease and from MSX disease, caused by *Haplosporidium nelsoni*, as well. Also a mortal oyster pathogen, *H. nelsoni* is intolerant of even short pulses of salinity less than 10. Further, the hard clam parasite, QPX, is already at its southern distributional limit in Virginia, and may recede in significance or disappear from Virginia with warming climate.

Emergence of new molluscan disease problems with changing climate is impossible to predict. The dynamic interactions among molluscan populations, pathogens, and myriad environmental stressors in the context of a changing physical environment simply cannot be known in advance, and will only be revealed over time.

Disease in Blue Crabs

The iconic blue crab, *Callinectes sapidus*, has a number of serious pathogens, but most are limited to high salinity waters.⁸ The protozoan parasite *Hematodinium* sp. occurs in summer and fall epidemics in high salinity waters along the Delmarva Peninsula (Figure 4). Infected crabs become lethargic and often die, in which case

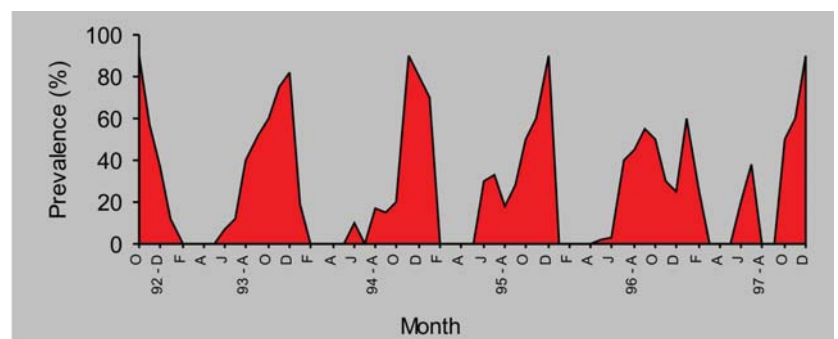



Figure 4. Seasonality of *Hematodinium* in blue crabs from coastal bays on the Delmarva Peninsula. The sharp autumnal peaks are distinctive features of the outbreaks.



they are lost to the fishery. Epidemics occur in peak periods of juvenile recruitment. Increases in salinity due to rising sea levels will result in *Hematodinium* sp. moving into new habitats in Chesapeake Bay, increasing the risk of epidemics in the blue crab stock.

Blue crabs also host a number of potentially lethal viruses and bacteria (Figure 5). The viruses occur mostly in higher salinity areas of Chesapeake Bay,⁸ and perturbations in the environment and crab population may increase risk of the emergence of viral diseases. Studies on bacterial infections in blue crabs often indicate a strong increase in the prevalence of infections during spring and summer. The seasonal flux in intensity of infections occurs in the spring and mortalities are associated with rapid warming trends in overlying waters. It is unclear how temperature operates to induce infections, but increases in water temperature, particularly during sensitive periods in the life history of the crab, could result in mortalities induced by bacterial pathogens.

Disease in Finfishes

Diseases in finfishes have become notorious in our region. The striped bass, *Morone saxatilis*, forms the basis for large recreational and commercial fisheries in Chesapeake Bay, and its recovery following major declines in the 1970s is a testament to the conservation efforts of state and federal management agencies. A chronic bacterial infection called mycobacteriosis (Figure 6), however, is a major threat to striped bass in Chesapeake Bay. Associated with a suite of mycobacteria, and causing tissue destruction and scarring of fish organs, this disease is now endemic to the Bay, with >70% of the resident bass infected. Epidemiological modeling has provided evidence of mortality in striped bass associated with this disease.⁹

A predominant hypothesis put forward to explain the emergence of mycobacteriosis identifies accelerating eutrophication in Chesapeake Bay as an important anthropogenic stressor for striped bass.^{10,11} Adult bass have an upper thermal tolerance level that may be exceeded in surface waters of Chesapeake Bay during the summer. Deeper, cooler portions of the Bay are believed to have served as traditional summer thermal refugia for resident striped bass. However, because of increasing nutrient inputs and resulting eutrophication, the summer thermal refuges become hypoxic or anoxic.¹² This forces resident bass into shallower, warmer physiologically stressful waters during the summer months leading to immune function compromise and increasing disease expression.^{10,11} Climatic factors that increase the frequency and duration of hypoxic episodes may exacerbate mycobacteriosis. A future climate that includes warmer summers with weak summer winds, highly variable precipitation, and rising sea level with increasing salinities in the Bay¹³ may have such an effect.

The Atlantic menhaden, *Brevoortia tyrannus*, another ecologically and economically important finfish, has experienced large recent population declines, possibly due to overfishing, increased predation pressures by striped bass, and poor recruitment



Figure 5. Bacterial shell disease of a captive blue crab. Shell disease is more prevalent in winter months.



Figure 6. Skin ulcers in a striped bass from Chesapeake Bay caused by an emerging bacterial disease called mycobacteriosis.

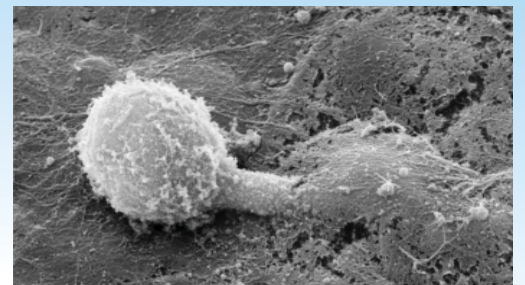
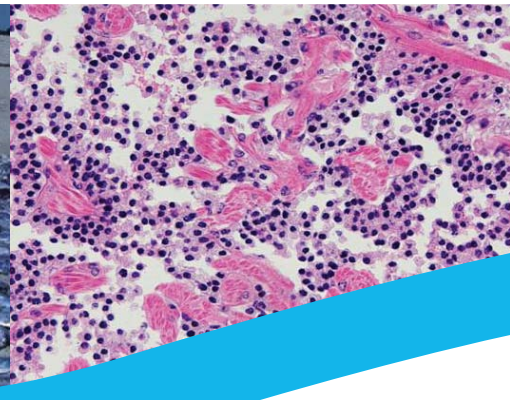


Figure 7. Infectious *Aphanomyces invadans* zoospore penetrating a skin cell of an Atlantic menhaden.



Figure 8. Ulcerative mycosis in Atlantic menhaden causing a single ulcer near the anal fin.



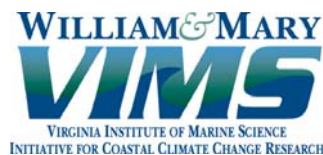
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by juvenile fish. Juvenile menhaden feeding in summer in the freshwater reaches of Chesapeake Bay tributaries acquire infections of the water mold, *Aphanomyces invadans*⁴ (Figure 7). Infected fish develop deeply penetrating ulcerous lesions that often involve the visceral organs¹⁵ (Figure 8), from which the fish do not recover. Infective stages, zoospores, are only infectious at salinities lower than 1,¹⁶ and outbreaks of lesions on menhaden are associated with summer rainfall events, which reduce upper estuarine salinities. Thus, it can be hypothesized that under certain scenarios of increasing temperature and more frequent and severe summer rainfall events, climate change may adversely impact the menhaden stocks by exacerbating the impacts of this disease on juvenile recruitment into the fishery.

Responding to Aquatic Diseases in the Face of Climate Change

The uncertainties and scale of climate change impacts make it difficult to develop strategies for mitigation and adaptation. In addition, there are a number of anthropogenic stressors such as nutrient and contaminant pollution that can contribute to disease processes, and which may intensify with sea level rise and increased temperatures or salinities. A better understanding of the environmental influences on pathogen and host biology and the expression of all of these diseases is needed. Marine animal health management in our region can reasonably begin, however, with restoration of healthier natural systems. Reducing the role of anthropogenic stressors in Chesapeake Bay and our coastal sounds will be fundamental to disease-mitigation strategies.



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