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Factors Influencing Zooplankton Distribution in the Chesapeake and Delaware Bays

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ABSTRACT

The Chesapeake and Delaware Bays are well known and extensively studied for their commercial value and environmental quality. There have been multiple studies based on salinity and temperature in these bays, but little is known about the influence of these factors on zooplankton distribution. Salinity has an effect on physiological processes, and, as a result, species have adapted for certain salinities. Temperature impacts both species physiology and primary productivity, which, in turn, impacts feeding rates of zooplankton. Based on previous studies on zooplankton distribution and current knowledge of physical variables, it was expected that salinity is the major variable in species distribution. The study demonstrates that salinity was indeed a factor in decapod distribution, and it suggests temperature may have been a regulator in copepod distribution. Temperature and salinity, however, were most likely not the only factors in total regulation of species distribution because of the visible disparity between chaetognath abundance in the Chesapeake and Delaware Bays, regardless of temperature or salinity.

INTRODUCTION

The Chesapeake Bay is one of the most extensively studied coastal ecosystems in the world (Boesch, 2001). Its tidal waters encompass an area of 11,000 km^2, and more than six states are part of the watershed (Boesch, 2001). Runoff from across the watershed flows into one of the nine tributary rivers of the Bay, where it then flows out into the Atlantic Ocean. Water from the Chesapeake Bay meets the waters of the Delaware Bay and forms an area of the Atlantic Ocean called the Middle Atlantic Bight

(Epifanio & Garvine, 2001). The Delaware Bay is considerably smaller, with one major tributary, and tidal waters of approximately 3,000 km^2 (Cronin, 1962).

The Chesapeake and Delaware Bay are home to a number of various animal species, ranging in size from small zooplankton (<200 µm-2 mm) to large nekton (> 3-4 cm). Many species thrive in these waters, but the object of many research studies, including this one, are the primary consumers that span from the mesozooplankton such as the calanoid copepods, *Acartia tonsa* and *Eurytemora affinis*, to the larval forms of the Chesapeake blue crab, *Callinectes sapidus* (Kimmel, 2004). These organisms are major primary consumers in the Chesapeake and Delaware Bays food web (Park & Marshall, 2000); thus, they are important for understanding the ecology of these coastal ecosystems. Spatial distribution of these zooplankton species varies based on different physical factors (e.g. temperature, salinity, turbidity, and currents) and nutrient availability (Breitburg, 1997; Boesch, 2001; Epifanio & Garvine, 2001; Kimmel et al., 2006). Of the multiple physical and chemical factors that influence zooplankton distribution, salinity and temperature are two of the more easily quantified factors.

SALINITY

Salinity varies in estuaries such as the Chesapeake and Delaware Bays because of the variability in freshwater contribution to the estuarine ecosystem. In the Chesapeake Bay, there are nine major tributaries that flow into the Bay from the surrounding watershed, and the Delaware Bay has one main tributary, the Delaware River. Tributary water mixes with ocean water to create zones of varying salinity. Euhaline waters, which have a salinity range from 30 to 35, are in the oceanic regions off the coast of the United

States. In estuaries, such as the Chesapeake and Delaware Bays, euhaline water mixes with freshwater from the tributaries and forms brackish waters where salinity ranges from 0.5 to 29 (Nybakken, 2003). Euhaline waters in the Chesapeake and Delaware Bays are found at the mouths of the bays where they meet the ocean, and the waters progressively become more brackish the closer they are to the tributaries (Park & Marshall, 2000).

The input of freshwater changes the salt composition of the seawater, and contributes to the growth and maintenance of a species population (Epifanio & Garvine, 2001; Kimmel et al., 2006; Park & Marshall, 2000). The Susquehanna River is the major tributary that feeds freshwater into the Chesapeake Bay (United States Geological Survey). When the freshwater input is low from the Susquehanna River from diminished precipitation rates, more saline waters are present in the Chesapeake Bay.

There is a large interannual variability in the volume of freshwater that enters the Chesapeake Bay from the Susquehanna River. For example, the years 2003 and 2004 were considered extremely wet due to high rates of precipitation, and the flow from the Susquehanna River was higher than normal. In the years 2001 and 2002, however, the flow was lower than average (Solomon, 2006, United States Geological Survey).

TEMPERATURE

In the Chesapeake Bay, a temperate estuary, water temperatures change seasonally and can range from 7.3 °C to 27.7 °C. Temperatures can also vary spatially from the upper to lower regions of the Bay (Solomon, 2006), and vertically from the surface to the bottom of the water column (Nybakken, 2003).

Waters in the Bays are colder than water in the outlying oceanic areas, with temperature variation of up to 5 ºC (Park & Marshall, 2000). Vertical variations in temperatures are visible at salt wedges (where the freshwater from the tributaries meet the euhaline waters from the ocean), and often there is a difference between surface and bottom waters. The strength of the halocline (the area at which there is a shift in salinity) at the salt wedge will also be influenced by the temperature of the freshwater. Seasonal air temperatures influence water temperatures, as do melting snow that enters in the spring from the tributary rivers (Nybakken, 2003). The stronger the halocline at the salt wedge, the more difference in temperature there will be between the surface and bottom layers.

Temperature impacts zooplankton abundance on multiple levels. Primary production, or the conversion of carbon dioxide into carbohydrates using energy from sunlight by phytoplankton, is regulated by temperature (Nybakken, 2003).

Positive relationships between phytoplankton production and zooplankton abundance and metabolism have previously been found in the Chesapeake Bay. Diatom (a taxonomic group of phytoplankton) abundance was positively correlated to growth of a zooplankton, *A. tonsa* (Roman, 1984). Park and Marshall (2000) found that during times of higher temperature (17.58 ºC vs. 13.99 ºC), the maximum difference in primary production was 16.37 $\mu g\ C\ l^{-1}h^{-1}$. More recently, Adolf et al (2006) found that in the fall, chlorophyll *a*, a measure of primary productive biomass, is higher than in the summer, so it follows that zooplankton growth should be higher in the fall. Variations in primary production will influence the amount of food available for zooplankton, which in turn will affect zooplankton production.

PREVIOUS RESEARCH

Previous research on the distribution of zooplankton has addressed survival rates, seasonal and temporal migrations, and feeding rates. However, no studies have been identified that have directly analyzed the effect of salinity and temperature on zooplankton distribution in estuarine ecosystems. A general expected distribution of zooplankton can be formulated based on previous data on zooplankton abundance and current knowledge of circulation dynamics. For instance, Kimmel et al. (2006) found an abundance of zooplankton biomass for the fall with a range from 2.7 kg x 10^6 C to 5.3 kg x 10^6 C during October of 1996-2000. The zooplankton biomass during this period was dominated by the copepod, *A. tonsa* (Kimmel et al., 2006).

The abundance and biomass of mesozooplankton species, such as copepods, will depend on the changes in salinity that, in turn, depend on the degree of freshwater input from the tributaries. If salinity should decrease in the Chesapeake Bay due to an increased flow from the Susquehanna River, higher population concentrations of *E. affinis* would be expected (Kimmel et al., 2006). The freshwater input, due to a variety of physiological and physical processes, will also result in higher concentrations of larva and other mesozooplankton in sampling sites as compared with other areas in the estuary (Epifanio & Garvine, 2001). If the reverse is true, with low freshwater input, higher amounts of *A. tonsa* would be expected to be observed due to the higher salinity of the water, and lower densities of larva (Kimmel et al., 2006). However, other studies have shown that *A. tonsa* propagates better in lower salinities (Jeffries, 1962), so a large variability in *A. tonsa* distribution would be expected.

In the case of decapods, Roman and Boicourt (1999) found that in September 1985, zoea of *C. sapidus* dominated the decapod population in the Chesapeake Bay. They also reported that at lower salinities, there was a significant decrease in *C. sapidus* megalopa. There is less information on the class of Chaetognatha. Of what little is known, *Sagitta serratodentata*, a chaetognath, is most abundant in the Delaware Bay at high salinities and low temperatures (Grant, 1963).

Overall, research studies have indicated that salinity has more of an influence on the distribution of zooplankton than temperature. Further understanding of this subject has potential applications in fisheries science and coastal resource management. This will contribute to this field of knowledge.

METHODOLOGY

SAMPLE COLLECTION

Samples of zooplankton were collected by Dr. Elizabeth North in the fall of 2005 over an on-shore/off-shore transect at the mouths of the Chesapeake Bay and Delaware Bay (Figure 1) using the MOCNESS (Figure 2) which traps samples at different depths. The MOCNESS also records temperature and salinity at each sampling depth. Individual concentrated samples were stored in 1-quart mason jars and preserved with formalin.

SAMPLE SELECTION

Because of time constraints, the number of zooplankton in each sample could not be enumerated. Thus, a number of other considerations were taken to determine which samples would be analyzed in order to investigate zooplankton distribution patterns. The other factors were salinity, tidal flow, and temporal migration patterns. Since salinity was one of the major factors examined in this study, samples from each depth at each end of one transect from each Bay were chosen to compare differences in salinity. These select samples were then enumerated. After enumeration, depth profiles of zooplankton were compared to salinity and temperature measurements at the same sites.

SAMPLE PROCESSING

The samples were first cleaned off with copious amounts of water and poured into a Folson splitter, where the sample was then split into half, resulting in two subsamples. The process was repeated until a subsample was yielded with a manageable ratio of 1:128.

SPECIES SELECTION AND IDENTIFICATION

Zooplankton species chosen were modeled after species used by McGehee (2004) and modified as necessary. Two particular zooplankton species, *Acartia tonsa* and *Labidocera aestiva*, from the subclass Copepoda were distinguishable and abundant enough to warrant individual recognition. Various larval stages of the order Decapoda were identified, specifically crab zoea and megalopa, shrimp zoea and postlarva, and *Callinectes sapidus* zoea and megalopa. Chaetognaths and fish were also identified.

During the process of identifying species, there were distinguishable species in each class/order whose presence was recorded, but their numbers were not counted. These organisms were noted as "identifiable species" and recorded (Table 2). The same was true for large fish larva (>2 cm). The fish larva were observed during the splitting process, but put back in the sample jar. After enumeration of the split sample, the sample was poured into a new vial and preserved.

Statistical Analyses

Statistical analyses were done using SigmaPlot 10 (Systat Software, Inc.). Data points (salinity vs zooplankton, temperature vs zooplankton) from both the Chesapeake and Delaware Bays were plotted on graphs. In graphs with visible linear trends between either salinity or temperature and zooplankton, linear regression fits were performed. r^2 and p values were recorded.

Results

Salinity and Temperature

Temperatures for the Chesapeake Bay for September 2005 varied from 24 °C to 24.5 °C. In the Delaware Bay, during the same month, the variation in temperature was from 21.5 °C to 22.9 °C (Figure 3, Table 1). The range of salinity in the Chesapeake Bay transect was from 24.5 to 29.59 while in the Delaware Bay transect, the range was narrower, from 29.52 to 30.52 (Figure 4, Table 1). In Delaware Bay, salinity levels were generally uniform across the transect, but in the Chesapeake Bay, there was a visible salt wedge (Figure 4).

Zooplankton Distribution

The overall distribution of zooplankton had no significant linear trends with salinity or temperature (Figure 5). However, significant linear trends were observed for some individual species of zooplankton. Salinity was not a factor in copepod distribution, but, in the Delaware Bay, temperature was negatively correlated with *Labidocera aestiva* (r^2=0.43, p=0.06). As temperatures changed from 23 °C to 21 °C, *L. aestiva* abundance increased (Figure 6F).

Temperature appeared not to be correlated to decapod distribution, while salinity was positively correlated. The abundance of decapods increased as salinity increased in the Chesapeake Bay (Figures 7A (r^2=0.33, p=0.08) and 7B (r^2=0.24, p=0.15)). For chaetognaths, no significant linear trends were observed (Figure 8).

DISCUSSION

Temperature and salinity both may play a role in the distribution of zooplankton in estuaries such as the Chesapeake and Delaware Bays. This study, however, focused on the zooplankton distribution during a short window, early fall of one year, when water was well-mixed, and temperature was generally uniform across the transect. There was a very small range of temperature as opposed to salinity. However, because of more variation in salinity, zooplankton distribution was expected to be more likely to be impacted by changes in salinity.

SALINITY

During this study, salinity levels in the Chesapeake Bay were below measured averages in other years (Roman, 1999; Maryland Department of Natural Resources). The main reason may be because of an increased flow of water from the Susquehanna River. However, according to the US Geological Survey, the water inflow between October 2004 and September 2005 was within normal range (United States Geological Survey).

This means that there may have been other forces regulating salinity levels. In the Delaware Bay, salinity levels matched measured averages (Cronin, 1962).

The presence of a salt wedge in the Chesapeake Bay may have affected overall catches of zooplankton. Zooplankton have been found to converge at zones at the salt wedge (Epifanio & Garvine, 2001). In these zones, zooplankton are often channeled into locally high dense (LHD) zones by water, affecting population counts. In the Chesapeake, however, the samples with the highest counts were located away from the salt wedge (Table 2, Figure 4), showing that LHD zones were not necessarily occurring.

Since the range of salinity was greater than for temperature in the Chesapeake Bay, it was possible to see how salinity may have an impact on decapod distribution, particularly in *Callinectes sapidus* zoea. As salinity increased, zoea abundance also increased. This may be linked to physiological and metabolic requirements. *C. sapidus* requires a particular level of salinity for its larva to progress through stages of development. Salinity in the water acts on the larva to induce morphological changes, which in turn lead to molting stages (Forward et al., 2004).

TEMPERATURE

During the study, temperature levels in the Chesapeake Bay were slightly above measured averages in other years by 1 °C (Maryland Department of Natural Resources). In the Delaware Bay, temperatures were 3 °C below measured averages (National Oceanic and Atmospheric Administration).

There was 0.5 °C temperature variance in the Chesapeake Bay, showing a well-mixed water column, which is normal for September (Nybakken 2003). The Delaware Bay showed a similarly uniform distribution of temperature, but temperatures ranged a bit more widely in the Delaware Bay than in the Chesapeake Bay. The difference in distribution of temperature may have had an impact on zooplankton distribution. With more variance in temperature, it is more likely a linear trend will be seen, and this was true for the copepod, *L. aestiva*. Also, because temperature impacts phytoplankton biomass, feeding and growth rates are impacted which in turn influences copepod distribution.

A. tonsa may be the most extensively studied copepod in the Chesapeake and Delaware Bays, so it was interesting to notice that temperature, in this study, only affected *L. aestiva*. *A. tonsa* populations appeared not to be correlated to temperature, so it is necessary to evaluate other factors that may regulate zooplankton distribution.

OTHER INFLUENCES

Temperature and salinity were not the only factors influencing zooplankton distribution. There may have been a lack of linear trends associated with chaetognaths, but there was a visible disparity between chaetognath abundance in the Chesapeake and Delaware Bays, regardless of temperature or salinity. The higher abundance of chaetognaths and the lower abundance of *A. tonsa* in the Chesapeake Bay compared to levels of each in the Delaware Bay may be because chaetognaths are predators of *A. tonsa* (Mallin, 1991). Lower levels of chaetognaths have previously been observed in the Delaware than the Chesapeake Bay (Grant, 1963; Cronin, 1962). This evolutionary history, combined with predation pressures, is a plausible explanation for the lower *A. tonsa* populations in the Chesapeake Bay. At the sample with the highest chaetognath count (sample 335, with 156 individuals), there was a low *A. tonsa* population (19 individuals). However, sometimes at the highest concentration of *A. tonsa*, chaetognath populations are also relatively high, suggesting that there may not be a perfect predator-prey model at work. Chaetognaths are also capable of feeding on other organisms (Mallin, 1991), and this variety in chaetognath diet may explain why at times there is not a direct relationship between chaetognaths and *A. tonsa*. However, there is sufficient evidence to show that there is possibly more top-down biological control by way of chaetognaths in the Chesapeake Bay than the Delaware Bay.

Chaetognath predation is not the only biological factor that may regulate zooplankton distribution. Trophic structure of each estuary needs to be considered when trying to understand zooplankton distribution. Trophic structure differs between locations and times of the year in each estuary, so other top-down controls (i.e. other nekton) may have been at work regulating populations. There is a large variety of fish living in the Chesapeake Bay (menhaden, shad, perch, and etc.), and other predators include *C. sapidus* and other decapods (Maryland Department of Natural Resources). These organisms were not all enumerated or collected, so it is difficult to estimate how much of a top-down control other predators may have on zooplankton distribution. These conclusions are purely theoretical, because the study parameters were not designed to incorporate this information.

CONCLUSION

Temperature was negatively correlated with the distribution of the copepod, *L. aestiva* in the Chesapeake Bay, while salinity was positively correlated with the distribution of the decapod, *C. sapidus* zoea in Delaware Bay. Each estuary will experience a larger range of temperature and salinity throughout the year than during the period observed in this study. From our limited data set, we observed possible linear relationships between zooplankton and temperature and salinity that need to be further explored.

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TABLES

FIGURES

Figure 1: Sampling transects (surfer figure compiled by Dr. Elizabeth North)

Figure 2: Picture of the MOCNESS (taken by Ginger Jahn)

Figure 3: Temperature Distributions in both the Chesapeake and Delaware Bays

Figure 4: Salinity Distributions in both the Chesapeake and Delaware Bays

Figure 5: Total Individuals collected in both the Chesapeake and Delaware Bays vs. salinity and temperature

Figure 6: Abundance of all copepods, *A. tonsa*, and *L. aestiva* vs. salinity and temperature

Figure 7: Abundance of all decapods, *C. sapidus* zoea and megalopa vs. salinity and temperature

Figure 8: Abundance of chaetognaths vs. salinity and temperature

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