

Abstract

Parkins, Grant Morrow. Connecting High School Students to Research: Testing Blue Crab (*Callinectes sapidus*) Settlement and Educational Outcome Hypotheses. (Under the direction of David B. Eggleston)

Blue crab megalopal settlement within Pamlico Sound has shown a precipitous decline since 1999, most likely due to a 74% decline in spawning stock over that period, and a strong stock-recruit relationship (Eggleston et al. 2004). There is a critical need to continue to monitor blue crab postlarval settlement in North Carolina to identify whether or not settlement, which appears to reflect relative spawning stock biomass that same year, is improving or remaining low. There is also considerable variation in the relative abundance of postlarvae within a recruitment season, most likely due to the interaction of physical forcing mechanisms that facilitate onshore transport and the available pool of postlarvae offshore. In this study, we tested the following blue crab settlement hypothesis: H1) Mean blue crab megalopal settlement at inlet stations will be positively correlated with the number of hours of dark flood tide, maximum height of a dark flood tide event the night before sampling, and with northeasterly wind speeds. Megalopal samples were collected in Pamlico Sound, NC at four sites (Oregon Inlet, Hatteras Inlet, Manns Harbor, and Engelhard) on a daily basis from August 1 to October 31, 2003 by high school students and other paid assistants. Time series analyses identified the relationship between megalopal settlement at Oregon and Hatteras Inlets, and wind and tidal variables. No time series analyses could be conducted for settlement at Manns Harbor or Engelhard because settlement at those sites was characterized by a majority of days with no settlement and episodic peaks on a few days. At Hatteras Inlet, megalopal settlement was positively correlated with wind speeds from the northeast and southeast at lags of 0 days. At Oregon Inlet, megalopal settlement was positively correlated with wind speeds from the northeast at lags of 4 and 5 days. Tidal

forcing was also important to settlement at Oregon Inlet. Blue crab megalopal settlement at Oregon Inlet was inversely related to maximum tidal height at a lag of four days. Other studies on megalopal settlement in North Carolina identified a similar relationship and suggested that this phenomena was due settlement peaks occurring around neap tides, when the number of hours of dark flood tide is high, there was; however, no relationship between the number of hours of dark flood tide and megalopal settlement at any of the sampling sites used in this study.

This study also examined the effectiveness of web-based and classroom blue crab activities on increasing student content knowledge and understanding of the nature of science. In conjunction high school students' involvement in the field portion of blue crab megalopal research, two activities were developed to illustrate some basic concepts in biology using blue crab and estuarine ecology: 1) A hands-on laboratory activity examining the morphology and behavioral characteristics of blue crabs at all life stages; and 2) A lesson incorporating a web-based simulation showing the relationship between wind direction, current flow in Pamlico Sound, and blue crab megalopal settlement at our four sampling sites. One group of high school students participated in the life cycle activity, and another group of students participated in the web-based activity. Students were given a modified version of the *Views of the Nature of Science* (VNOS) test both before and after participating in the activity. This test consisted of questions about the nature of science, and questions about blue crab and estuarine ecology. Scores on the blue crab ecology and nature of science portions were calculated, along with the total scores (the sum of the blue crab ecology and nature of science scores). Scores from pre- versus post-activity tests were compared to test the following hypothesis: H2) Students who participate in our blue crab educational modules

will show positive educational outcomes as evidenced by significant increases in scores on the VNOS test from pre- to post-activity testing. Both groups of high school students significantly increased their test scores from pre- to post-activities on both the total scores and the blue crab ecology scores, but no increases were seen in scores on the nature of science portion of the test. This study highlights how integration of high school students and teachers into university-based research can not only provide high quality data to test research hypotheses and provide hands on research experiences for high school students, but when combined with educational activities, can increase student knowledge of the broader concepts that typically frame the research.

**Connecting High School Students to Research:
Testing Blue Crab (*Callinectes sapidus*) Settlement and Educational
Outcome Hypotheses**

by

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Dedication

To my mother and father who taught me the value of hard work and a good education, and to my wife for her endless support. This is as much your accomplishment as it is mine.

Thank you.

Biography

Grant Morrow Parkins was born on April 28, 1979, in Pittsburgh Pennsylvania, the youngest of three siblings. Two years later, his family moved to rural DeGraff, Ohio where he would be raised. Grant became interested in the natural world early in life as he spent much of his childhood in the surrounding fields, lakes, woods, and creeks. After graduating from Riverside High School in 1997, he attended Bowling Green State University, in northwest Ohio, majoring in Biology. While at Bowling Green, Grant discovered his interest in Marine Science. Bowling Green State University is home to the largest marine laboratory housed on a college campus in the Midwest, with more than 60 aquaria ranging in size from 10-1000 gallons. During his Junior year, Grant became heavily involved in the marine lab, and began studying the physical, chemical, and biological processes of the ocean independently. The summer after his Junior year, Grant found his interest in education when he co-instructed marine and aquatic biology camps with the director of the marine lab and one of his close friends. He would go on to teach those camps the following summer as well. During his fourth year of college Grant began to consider going to graduate school, and decided to delay graduation by one semester to allow him the opportunity to conduct research on soft coral growth in the marine lab. Grant graduated with his Bachelor of Science degree in Biology in December of 2001, and entered the graduate program at North Carolina State University's Department of Marine, Earth and Atmospheric Science.

Grant moved to Raleigh, NC in August, 2002 with his eventual wife, who was to begin a job at University of North Carolina at Chapel Hill. Grant quickly felt at home in his new surroundings, enjoying NCSU football games, happy hour with fellow graduate students, and southern comfort food. Upon entering his graduate program, Grant met a

professor named Dave Eggleston whose interests included blue crab ecology and educational outreach. Grant became involved in one of Dr. Eggleston's projects that used high school students to collect blue crab postlarval samples around Pamlico Sound, NC.

Grant currently works as a Science Education Specialist for the DESTINY traveling science laboratory, traveling to all corners of North Carolina teaching cutting edge science lessons to high school students in economically depressed areas.

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Introduction

The Blue Crab in North Carolina

The blue crab (*Callinectes sapidus*) supports large fisheries on the Atlantic and Gulf Coasts of the United States, including North Carolina's largest commercial fishery in terms of dockside value (Annual Fisheries Bulletin 2005). Adult and recruit stocks have declined significantly in Chesapeake Bay (Lipcius and Stockhausen 2002), Delaware Bay (Kahn et al. 1998), and Pamlico Sound, NC during the past 3-10 years (Eggleston et al. 2004), with concomitant detrimental economic effects on those areas. In North Carolina, relative abundance of the blue crab population is monitored by the Division of Marine Fisheries (DMF) through two fishery-independent trawl surveys: (1) Program 120, which is a survey of juveniles in relatively shallow (< 2 m) habitats throughout North Carolina and has been conducted since 1987, and (2) Program 195, which is an adult survey primarily in the deeper (> 2 m) portions of Pamlico Sound and has been conducted since 1987 (Eggleston et al. 2004). These fishery-independent trawl surveys provide key indices for identifying long-term trends in blue crab abundance for stock assessment purposes. For example, trawl survey catch per unit effort (CPUE) is significantly related to commercial landings during the same year, but is largely ineffective in predicting commercial landings in subsequent years (Eggleston et al. 2004). Similarly, there is a strong relationship between blue crab spawning stock biomass and recruitment of blue crab postlarvae (megalopae) into North Carolina's estuaries (Eggleston et al. 2004). Therefore, monitoring of megalopal estuarine settlement can be used to augment other age specific data gathered by studies such as Programs 120 and 195, and provides another measure of the response of the blue crab spawning stock to

management actions such as an upper size limit restriction on mature females (NC Fisheries Management Plan: Blue Crab, 2004).

Megalopal recruitment into North Carolina's estuaries has been measured every Fall, the main period for postlarval ingress to Pamlico Sound, since 1996 (Eggleston et al. 2004). This project has also provided high school students, many from economically depressed coastal areas, with a unique, hands-on experience in scientific research, by allowing them to collect megalopal settlement samples. This study was designed to test hypotheses regarding the importance of various physical forcing events on megalopal settlement, as well as the importance of educational activities on learning success.

Blue Crab Life History and Patterns of Abundance

The blue crab has a complex life cycle, with juvenile and adult benthic phases, and a larval pelagic phase. Ovigerous female blue crabs with late-stage embryos use ebb-tides to disperse down-estuary towards inlets after mating (Tankersley et al. 1998). Once there, the crabs spawn their larvae and then use flood-tide to disperse back up-estuary (Tankersley et al. 1998). The larvae, also called zoeae, are carried by ebb-tides seaward, where they undergo 7-8 stages over roughly 30 days (Costlow and Bookhout, 1959). At the end of this time, zoeae metamorphose into the megalopal stage, which migrates into the estuary from offshore (Van Engel, 1958; Forward and Tankersley, 2001).

Blue crab postlarvae (megalopae) are known to migrate vertically in the water column in response to wind stress (Goodrich et al. 1989; Blanton et al. 1995; Johnson 1995), light (Forward and Rittschof 1994), turbulence (Welch et al. 1999), and salinity (Tankersley et al. 1995; Welch and Forward 2001) in a manner that would favor their transport into estuaries

during dark flood tide and storm events. Once there, megalopae distinguish among settlement sites using chemical cues, taking into account predation risk and food supply (Welch et al. 1997), and typically settle in seagrass and shallow detrital habitats (Heck and Thomas, 1984; Orth and Van Montfrans 1987; Etherington and Eggleston, 2000).

Blue crab megalopal settlement within Pamlico Sound has shown a precipitous decline since 1999, most likely due to a 74% decline in spawning stock over that period, coupled with a strong stock-recruit relationship (Eggleston et al. 2004). There is a critical need to continue to monitor blue crab postlarval settlement in North Carolina to identify whether or not settlement, which appears to reflect relative spawning stock biomass that same year, is improving or remaining low. There is also considerable variation in the relative abundance of postlarvae within a recruitment season, most likely due to the interaction of physical forcing mechanisms that facilitate onshore transport and the available pool of postlarvae offshore. For example, wind events drive surface currents that enhance both early juvenile blue crab recruitment (Etherington and Eggleston 2003) and megalopal ingress into estuaries (Epifanio 1995, Mense et al. 1995), though wind may not play a role in megalopal settlement in Beaufort Inlet, NC (Forward et al. 2004). In addition, temporal variation in megalopal settlement to the Newport River estuary, NC was positively related to neap tides. One possible mechanism cited for this relationship is that neap tides generally have a higher number of hours of dark flood tide, thereby providing a greater period of time over which megalopae could successfully migrate into the estuary, as compared to spring tides (Forward et al. 2004). In addition, megalopal settlement was positively correlated with maximum tidal height in the Cape Fear River estuary, NC (Mense et al. 1995). This positive correlation was most likely due to the larger volume of oceanic water being forced into the estuary during

maximum tidal height and the delivery of more megalopae. Another study, however, found that megalopal settlement was negatively correlated to maximum tidal height during dark flood tide in the Newport River estuary, NC (Forward et al. 2004). The relative importance of hours of dark flood tide, maximum tidal height, and wind forcing on megalopal settlement in Pamlico Sound, NC, remains unclear.

Educational Outreach

The majority of the nation's teachers primarily use textbooks without hands-on instruction (Helgeson et al. 1978, Bybee et al. 1989). The absence of hands-on science instruction is potentially a problem because activity-based science can substantially improve students' understanding of the process of scientific research, while moderately improving performance on tests of logic, perception, and science content (Bredderman 1982). It is important that activity-based science also be inquiry-based. Inquiry-based learning involves students in generating questions based on previous knowledge and in finding the answers to those questions. Inquiry-based learning is important because it can have a positive impact on students' critical thinking test scores (Magnussen 2000). High school curricula in North Carolina's public schools attempt to give students a solid foundation of knowledge about science. These curricula fall short, however, in the area of inquiry-based learning (in the form of the scientific method), and the link of science to its application (hands-on research).

A recent study found that low-achieving high school students who participated in question generation, experimental design, and argument construction were able to respond to open-ended problems in a way consistent with scientific arguments (Yerrick 2000). Unfortunately, even when students are involved in activity-based science, they are not

necessarily participating in inquiry-based learning. An examination of high school biology laboratory manuals showed that students are seldom encouraged to use their knowledge to pose questions, solve problems, or construct generalizations (Germann et al. 1996). Without these capabilities, students were less successful in matching theory with evidence, and were less likely to search for necessary underlying principles in science (Zachos et al. 2000). The need to incorporate inquiry-based learning and hands-on science activities into public school curriculum is evident. High school teachers, however, often lack the resources and connections with active researchers to provide their students with hands-on research experiences. This lack of resources is often compounded by perceived barriers between teachers and scientists, preventing many teachers from taking the first step towards getting involved with scientific research. This study addresses this lack of resources and perceived barriers by involving high school teachers and students in research on the blue crab in North Carolina.

The overall purpose of this study was twofold: (1) Quantify spatiotemporal patterns in blue crab megalopal settlement in Pamlico Sound, and assess the physical forcing mechanisms that explain the greatest temporal variation in settlement, and (2) involve high school students in the collection of blue crab megalopal settlement data, and to increase students' science content knowledge and understanding of the nature of science by developing and implementing blue crab-based laboratory modules. Specifically, the following hypotheses were tested: H1) Mean blue crab megalopal settlement at inlet stations will be positively correlated with the number of hours of dark flood tide, maximum height of a dark flood tide event the night before sampling and with northeasterly wind speeds; and H2) Students who participate in our blue crab educational modules will show positive

educational outcomes as evidenced by significant increases in scores on a given test from pre- to post-activity testing.

Methods

Blue Crab Megalopal Settlement

Blue crab postlarval settlement in Pamlico Sound, NC was quantified daily using artificial settlement substrates (Van Montfrans et al. 1995) from August 1 through October 31, 2003, the primary time of megalopal ingress into Pamlico Sound (Eggleston et al. 2004). Postlarval samples were collected at two sites on the western shore of Pamlico Sound (Manns Harbor and Engelhard), and two inlet stations (Hatteras Inlet and Oregon Inlet) (Figure 1). High School students from Manteo, Hatteras, and Mattamuskeet High Schools in coastal North Carolina collected megalopal settlement data at Manns Harbor, Hatteras Inlet, and Engelhard, NC, respectively. Oregon Inlet samples were collected daily by employees of the North Carolina Aquarium in Manteo, NC.

At each of the four sites, three replicate artificial settlement substrates were suspended from a dock or seawall. These substrates were constructed of 16.3 cm diameter X 37.5 cm length polyvinyl chloride (PVC) pipes covered by sleeves of air conditioning filter material known as “hogs-hair” (Metcalf et al. 1995). The hogs-hair covered PVC-pipe contained a float at the top, and a weight at the bottom, allowing the substrate to float upright just below the surface of the water. This type of settlement substrate has been used extensively along the Atlantic and Gulf coasts of the United States to measure the relative magnitude of blue crab megalopal settlement (e.g., Van Montfrans et al. 1995 and references therein). Each day, participants removed collectors from the water and placed each “hogs-hair” sleeve in a separate bucket and rinsed. After each sleeve was thoroughly rinsed, the

bucket's contents were sieved through a 500 μm sieve. The organisms collected from each bucket were then placed in separate jars containing 70% ethanol. New sleeves were then placed on the PVC-pipes and the substrates were returned to the water. Blue crab megalopae were subsequently identified and counted using a dissecting microscope in the laboratory.

Data reduction and statistical analyses of blue crab settlement data

The response variable was calculated as the average number of postlarvae per collector per site per 24 hour period at each of the four sampling sites: Oregon Inlet, Hatteras Inlet, Manns Harbor and Engelhard. During our study, gaps in sampling during which the substrates remained in the water without being sampled did not exceed 4 days. Blue crabs remain in the postlarval stage for about 5 days once exposed to estuarine cues (Wolcott and DeVries 1994); therefore, to account for the accumulation of postlarvae on days not sampled, daily postlarval abundance was estimated by averaging the number of postlarvae collected on the day sampling resumed, over the total number of sampling days missed. Gaps in sampling occurred at all stations during the days immediately preceding and following landfall of Hurricane Isabel on September 18, 2003. During this time period, however, the substrates were removed from the water and no settlement data was gathered. Although sampling of megalopal settlement at Oregon Inlet, Engelhard and Manns Harbor resumed after the passage of Hurricane Isabel, Hatteras Island was severely damaged and sampling did not resume at Hatteras Inlet after September 16, 2003.

The relationship between megalopal settlement at the inlet stations and physical forcing variables (maximum tidal height during dark flood tide, hours of dark flood tide, and wind speed from a given direction) was tested with time series analysis. To calculate the

hours of dark flood tide, observed tidal heights and times for Oregon Inlet and Hatteras Inlet were obtained from NOAA's "Tides Online" website (www.noaa.gov). Those times were used in conjunction with sunset and sunrise times to determine the total hours of dark flood tide in a night. NOAA's "Tides Online" website (www.noaa.gov) was also used to determine the maximum tidal height during dark flood tide.

Hourly wind speeds and direction were obtained for Billy Mitchell Airport, near Cape Hatteras, as well as the Manteo Airport, near Oregon Inlet, from NOAA's National Climatic Data Center (www.noaa.gov/ncdc/). Hourly wind speed and direction were used to determine the U (North/South) and V (East /West) vectors for each hour in a given day. The average vectors for a sampling day were obtained by taking the mean of each vector from 7 am on one day to 6 am on the next. These times were chosen because 7 am would be just after dawn and 6 am would be just before dawn for all sampling days. By averaging the vectors from 7 am on day 1 to 6 am on day 2, the dark flood tide events are completely accounted for, and would be a good approximation of the winds most likely affecting megalopal settlement on day 2. There was a strong correlation between wind speed and direction at Manteo and wind speed and direction at Hatteras, NC, for both the north/south vector ($r^2 = 0.95$, $n = 103$) and the east/west vector ($r^2 = 0.89$, $n = 103$). Therefore, only wind data from Billy Mitchell airport near Cape Hatteras were used in further data analyses. Wind data from this station were missing for 4 days, and the values from those days were substituted with data from the Manteo airport. The wind vectors were then rotated to reflect the wind's principal axes (Figure 2). The rotation of the wind revealed a main axis, running approximately Northeast (+) to Southwest (-), and a minor axis, running approximately

Southeast (+) to Northwest (-). The wind will hence be described in terms of main and minor axes.

All settlement and physical variables were examined and fit with the best model (when needed) using auto-regressive integrated moving average (ARIMA) procedures. The response variables were the log-transformed mean daily settlement at Oregon and Hatteras Inlets (LOGORG and LOGHAT, respectively). Mean daily settlement at Manns Harbor and Engelhard could not be analyzed with time series analysis because settlement at these sites was characterized by a majority of days with no settlement and a few episodic peaks (see Results below). Independent variables describing the tidal characteristics of interest were hours of dark flood tide at Oregon and Hatteras Inlets (ODFT and HDFT, respectively), and maximum dark flood tidal height at Oregon or Hatteras Inlets (OHIGH and HHIGH, respectively). Wind direction and speed at Cape Hatteras are herein referred to by their main and minor axes (MAIN, MIN, respectively). Once the best model was fit to each variable (see below), cross correlations were run with 6 day lags and leads to determine the relationship between megalopal settlement and independent variables over time. Lags of more than 6 days, and leads (where the response variable occurs first) were not considered because of the inability to explain the physical mechanisms underlying them. Although the sampling period at Hatteras Inlet was cut short by Hurricane Isabel, cross correlations were run for Hatteras Inlet to identify any connections between physical forcing events and mean daily settlement that may have been apparent from August 1 to September 16, 2003.

All variables were fit to ARIMA models where needed (Table 1). Applying a combination of autoregressive and moving average models sufficiently reduced the data to white noise (removed the cycles) for the following variables: OHIGH, HDFT, HHIGH, and

MAIN (Table 1). The log-transformed mean daily megalopal settlement at Hatteras Inlet (LOGHAT) and wind along the minor axis (MIN) showed no signs of cycles in the data, so no autoregressive or moving average time series models were applied to those variables. With ODFT, the models removed cycles on the 12, 18, and 24 day lags, but were insufficient to remove the cycle seen in a 6 day lag (Table 1). Despite the use of various orders of ARIMA models, significant autocorrelations remained for the Oregon Inlet settlement (LOGORG) at lags of 6, 12, 18, and 24 days (Table 1). Thus, all significant correlations between settlement at Oregon Inlet and physical variables at lags of 6, 12, 18, and 24 days were deemed spurious.

Educational Outreach

In addition to participation by high school students in the field collections of settled megalopae, classroom and web-based activities were also developed and implemented in association with this project. These activities were designed to further students' understanding of estuarine ecology, blue crabs, and the scientific method. The materials were based on the North Carolina Science Standard Course of Study, so that they could be used in classrooms in North Carolina. Curriculum were developed and made available online for teachers to implement in their classrooms during the spring of 2004 (see below).

Classroom Activity

Students in two Biology classes at Cape Hatteras Secondary School (n=27) participated in an inquiry based, hands-on classroom activity in April, 2004. The lesson examined the complex life cycle of blue crabs, by comparing and contrasting the morphology, habitat, and behavior of blue crabs during their different life stages (Appendix

A). Students used preserved samples of blue crabs at each life stage, and materials outlining the characteristics (feeding habits, motility, etc.) of each life stage were reviewed. This lesson was an inquiry-based, question-driven exploration of complex life cycles (see Appendix A). As students examined each life stage, they generated questions about blue crabs at that stage, and then outlined an experimental design to answer the question. The question generation was designed to illustrate the creative nature of science, and to encourage independent thinking. In general, the lesson was designed to use blue crabs and estuarine systems as a framework for teaching some basics of science (i.e. the scientific method, the interaction of organisms with their environment, and the continuity and diversity of life).

Web-Based Activity

As a complement to field research and classroom activities, a web page was created to give students background information on blue crab ecology in North Carolina. The web page, located at <http://www4.ncsu.edu/~gmparkin>, contains information on blue crabs and estuarine environments, including life cycles and ongoing research. In addition, the website contains the aforementioned lesson plans for high school science teachers who want to incorporate blue crab ecology, biology, and marine science into their regular curriculum.

The website also contains a lesson for students to examine how meteorology influences biology, through a simulation of wind-induced changes in water currents in Pamlico Sound, and the effects of these currents on postlarval blue crab settlement (Appendix B). By observing how wind influences water currents, students are able to pose hypotheses on postlarval blue crab settlement patterns in different locations in Pamlico Sound, and test these hypotheses with data generated by former student participants in this

research program. Students attending a marine biology camp in Bowling Green, Ohio participated in the web-based activity (n=15) in July, 2004.

Educational Testing and Statistical Analyses

Identical tests were given to the participants the day prior to as well as the day after the classroom and web-based activities (Appendix C). The test was not administered to students who participated in the field portion of the project because all student participants were returning for their second sampling season, and no true pretest could be given. The test was a modified form of the *Views of the Nature of Science Questionnaire*, version B (VNOS-B) with one question from VNOS-C, both developed by Abd-El-Khalick et al. (1998). These questionnaires are useful tools in gauging student views of the nature of science by identifying their understanding of the empirical nature of scientific knowledge, the nature of scientific theory, the creative and imaginative nature of science, and social and cultural influences on scientific knowledge (Lederman et al. 2002). In addition, the activity test (Appendix C) included questions about the scientific method, estuarine ecology, and blue crabs. The difference in scores from pre- to post-activity (H2) was determined for three response variables: (1) Total test scores; (2) scores on the nature of science questions (Questions 1-8, Appendix C); and (3) scores on the blue crab ecology questions (Questions 9-11, Appendix C). Each of these response variables was tested with a paired t-test to determine if there were any statistically significant increases in scores within a given student class.

Adherence to North Carolina Science Standard Course of Study

All three components of this project: field, classroom, and web-based activities, adhered to the North Carolina Science Standard Course of Study (NCSSCS). Specifically, this project addressed the four strands for teaching science in grades 9-12: 1) Nature of science; 2) Science as inquiry; 3) Science and technology; and 4) Science in personal and social perspectives. The activities also aligned with some of the five competency goals for NCSSCS Biology curriculum: 1) Developing an understanding of the physiological, chemical and cellular basis of life; 2) Developing an understanding of the continuity of life and the changes of organisms over time; 3) Developing an understanding of the unity and diversity of life; 4) Developing an understanding of ecological relationships among organisms; and 5) Developing an understanding of the behavior of organisms, resulting from a combination of heredity and the environment. For example, the combination of classroom and web-based activities addressed technology and science as inquiry, as well as three NCSSCS objectives for Biology curriculum (goals 2 and 5 as listed above). The activity examining complex life cycles was designed to help students understand the changes of organisms over time by comparing the morphology, habitat and behavior of different life stages of blue crabs (goal 2).

The importance of science in a social or personal context (Strand 4) was stressed in a presentation given by graduate student Grant Parkins that preceded classroom and web-based activities. For example, this presentation illustrated the importance of blue crabs to the economic development of coastal states, and showed how science is working to achieve sustainable crabbing practices, maximizing catches for many years to come. The introductory presentation also addressed the nature of science (Strand 1) by demonstrating

that research is an ongoing human endeavor to gain knowledge, as is the case with research programs on the blue crab and estuarine ecology. Science as inquiry (Strand 2) was addressed through the question-driven style of the activities, and through student question generation. The relationship between science and technology (Strand 3) was best illustrated through the web-based simulation, which allowed students to visualize something they could not normally see (wind/water currents in and around Pamlico Sound). The web module relating wind, currents, and blue crab settlement was designed to help students gain an understanding of how dispersal and distribution of postlarval and early juvenile stages of blue crabs is driven by environmental conditions such as wind, current direction and speed (goal 5).

The field component of the project addressed the idea that science is inquiry based (Strand 2) by showing how experimentation is a method of answering one or more questions. The specific NCSSCS goals achieved through participating in the field component included: developing an understanding of: 1) the physical basis of life; 2) the ecological relationships of organisms; and 3) the behavior of organisms as influenced by the environment (goals 1, 4, and 5, respectively). The compliance with NCSSCS guidelines makes the field activities and outreach materials a valuable supplement to high school Biology curriculum.

Results

Blue Crab Megalopal Settlement

Megalopal settlement at Oregon and Hatteras Inlets occurred much more regularly than settlement at Engelhard and Manns Harbor, where settlement was characterized by long periods of no settlement with a few episodic peaks (Figures 3-6). Mean daily settlement was highest at Engelhard, and lowest at Manns Harbor. Settlement at Oregon Inlet averaged 1.28

megalopae/collector/day and was greatest from approximately August 27, 2003 until the collection was stopped temporarily prior to Hurricane Isabel on September 16, 2003 (Figure 3). Very little settlement occurred at Oregon Inlet from August 1 to August 26, and after September 27 when sampling resumed after Hurricane Isabel (Figure 3). Settlement at Hatteras Inlet averaged 0.88 megalopae/collector/day and was relatively consistent from August 1 to September 16 (Figure 4). Sampling did not resume at Hatteras Inlet after September 16 due to the extensive damage caused by Hurricane Isabel. Settlement at Manns Harbor, located on the western shore of Pamlico Sound, was extremely low, averaging just 0.02 megalopae/collector/day over the sampling period and occurred on just three days prior to the passage of Hurricane Isabel (Figure 5). Similarly, megalopal settlement at Engelhard, which is also located on the western shore of Pamlico Sound, occurred on the 10 days prior to the passage of Hurricane Isabel (Figure 6). In contrast to Manns Harbor, however, settlement at Engelhard was extremely high with an average of 228 megalopae/collector on September 13, 2003, and the highest daily average during this study with 4.57 megalopae/collector/day (Figure 6). At all stations, more megalopae settled prior to landfall of Hurricane Isabel than afterwards (Figures 3-6).

Megalopal settlement at Oregon Inlet increases with increasing wind speed from the Northeast at lags of 4 and 5 days. Blue crab megalopal settlement at Oregon Inlet was positively correlated with wind speed along the main axis (Northeast wind speeds) at lags of 4 and 5 days (Figures 7 and 8), which explained roughly 20% and 37% of the variation in megalopal settlement at Oregon Inlet in 2003, respectively (Table 2). Megalopal settlement at Oregon Inlet was also negatively correlated with wind speed on the minor directional axis

at a lag of 6 days; however, this relationship may be spurious given that we were unable to pre-whiten the settlement time series at Oregon Inlet at lags of 6, 12, 18, and 24 days.

Similar to settlement patterns at Oregon Inlet, megalopal settlement at Hatteras Inlet increased with increasing wind speed from the Northeast. Settlement at Hatteras Inlet, however, also increased with increasing wind speed from the Southeast. Mean blue crab megalopal settlement at Hatteras Inlet was positively correlated with wind speed along the main directional axis (Northeast wind speeds) at a lag of 0 days, explaining approximately 32% of the variation in settlement over the abbreviated field season at Hatteras Inlet (Table 2). There was also a significant positive correlation between megalopal settlement at Hatteras Inlet and wind speed on the minor directional axis (Southeast wind speeds) at a lag of 0 days, which explained approximately 30% of the variation in settlement (Table 2). Thus, variation in megalopal settlement at Oregon and Hatteras Inlets appears to be driven in a similar manner by wind speed from the Northeast. Settlement at Hatteras Inlet, however, also appears to be driven at least partially by winds from the Southeast.

Megalopal settlement at Oregon Inlet decreased with increasing maximum tidal height, but was not correlated with the number of hours of dark flood tide. Settlement at Hatteras Inlet, however, was not correlated with either of the tidal variables. Megalopal settlement at Oregon Inlet was negatively correlated with maximum tidal height during dark flood tides at a lag of 4 days, explaining roughly 26% of the variability in megalopal settlement (Table 2). There was no statistically significant relationship between megalopal settlement at Oregon or Hatteras Inlets, and the number of hours of dark flood tide (all $p > 0.10$).

Educational Outreach

High school students that participated in the classroom and web-based activities showed an improved understanding of Blue Crab Ecology, but not in the Nature of Science from pre- to post-activity test. Students who participated in the classroom activity showed a significant increase from pre- to post-activity in total score, which is the sum of scores from the Blue Crab Ecology portion of the test and the Nature of Science portion of the test. The total score increased by more than 23% from pre- to post-activity tests for students who participated in the classroom activity, which was a statistically significant increase (t-test; $p < 0.01$; Figure 7). Students who participated in the classroom activity increased their Blue Crab Ecology scores by more than 82%, which was also statistically significant (t-test; $p < 0.0001$; Figure 7). Students who participated in the classroom activity did not, however, increase their scores on the Nature of Science portion of the test (t-test; $p = 0.33$; Figure 7).

Students who participated in the web-based activity significantly increased their Blue Crab Ecology scores by more than 125% ($p < 0.0001$) from pre- to post-activity tests (Table 3, Figure7). Those students did not, however, show a significant increase in their scores on the Nature of Science portion of the test (t-test; $p\text{-value} = 0.08$; Figure 7).

Discussion

Blue Crab Megalopal Settlement

This study identified hurricane and wind forcing, as well as tidal forcing as contributing to megalopal settlement in Pamlico Sound. Settlement at Oregon Inlet was negatively correlated with maximum tidal height during dark flood tide at a lag of four days. Similarly, megalopal settlement in the Newport River estuary, NC was lowest when tidal

height was greatest (Forward et al. 2004). The negative relationship between maximum tidal height and blue crab settlement is likely due to the minimal number of dark flood tide hours during spring tides (Forward et al. 2004).

Wind forcing during 2003 was a key determinant of temporal variation in megalopal settlement at Oregon and Hatteras Inlets. In contrast, Forward et al. (2004) found that blue crab settlement in the Newport River estuary was not related to either along- or across-shore wind stress. One possible reason is that during the fall and winter, winds commonly come from the north and northeast. The orientation of the Newport River and Beaufort Inlet is southward facing, and winds from the north or northeast would force water out of the Newport River estuary, inhibiting megalopal ingress into the Newport River. Moreover, the Newport River is a strongly tidal system (Seim 2002), whereas the tidal signal near Oregon Inlet is greatly diminished within 2.5 km of the inlet (Nichols and Pietrafesa 1997).

The positive correlation between wind speed from the northeast and megalopal settlement at Oregon and Hatteras Inlets in this study partially corroborates model predictions from Xie and Eggleston (1999). For example, Xie and Eggleston's (1999) models predicted that winds from the northeast would promote water flowing into Pamlico Sound through both Oregon and Hatteras Inlets, creating favorable conditions for megalopal ingress at those sites. The current study also showed a positive correlation between megalopal settlement at Hatteras Inlet and wind speeds from the southeast. Xie and Eggleston (1999), however, predicted that winds from the southeast would facilitate outflow of water from Pamlico Sound through Hatteras Inlet, inhibiting megalopal ingress. Other studies have illustrated the importance of wind forcing on megalopal settlement. For example, studies have found that megalopal settlement is dependent on exchange driven by southward winds in both Delaware

(Little and Epifanio, 1991) and Chesapeake Bays (Goodrich et al. 1989). Additionally, winds from the northeast facilitated transport of megalopae into estuaries near Wilmington, NC (Mense et al. 1995). Wind forcing mechanisms are important to the postlarval recruitment of other marine crustaceans as well. Among these are the fiddler crab *Uca spp.* (Little and Epifanio, 1991), the American lobster *Homarus americanus* (Hudson and Fradette 1993, Wahle and Incze 1996), and the Caribbean spiny lobster *Panulirus argus* (Eggleston et al. 1998).

Educational Outreach

The classroom and web-based modules that were created were each useful in increasing knowledge about Blue Crab Ecology, but not for increasing an understanding of the Nature of Science for the student participants. For groups that participated in either the classroom or web-based activities, significant increases were seen in total test scores as well as scores on the blue crab ecology portion of the test, but no increase was seen on the nature of science portion of the test. The significant increase in the total score was most likely due to the increase seen in the blue crab ecology portion of the test, as the nature of science portion did not show any significant increase. It is not unexpected that student scores on the nature of science portion of the test did not increase, as numerous studies call for a high level of involvement in authentic research experience to increase understanding of scientific inquiry, scientific processes, and the nature of science (Cooley and Bassett, 1961; Bleicher, 1996; Ritchie and Rigano, 1996; Krasney, 1999; Richmond and Kurth, 1999; Barab and Hay, 2001), compared to the brief involvement the students had in this study. The classroom and web-based blue crab lessons were taught in a single, 90-minute period, therefore a high level

of involvement was not achieved. The single blue crab activity presented to the students, however, was adequate to increase student knowledge of the basics of blue crab and estuarine ecology. Thus, the lessons seemed to be a useful tool to impart content knowledge, but inadequate to change students' views on the nature of science. These results are similar to those found in a study of an 8-week apprenticeship program for high school students. Bell et al. (2003) used the VNOS-B questionnaire and found that an apprenticeship program, where high school students worked alongside university science and engineering faculty on research projects for eight weeks, had no positive effect on changing students' misconceptions about the nature of science. In addition, our conclusion that the hands-on classroom and web-based activities significantly increased students' content knowledge is similar to those of Freedman (1997) who found that students who participated in hands-on laboratory instruction scored significantly higher on content-based tests than students who did not participate in laboratory experiments.

With regards to the effectiveness of the instrument used to measure student gains in learning in this study, it should also be noted that the pre- and post-activity tests given to students who participated in web-based and classroom activities did not seem to be a good tool for measuring high school students' understanding of the nature of science. The difficulty and abstract nature of the original *VNOS* questions (Questions 1-8, Appendix C) seemed too complicated for the average high school student. Many of the participants indicated that the test was extremely difficult, and many test questions were incompletely answered or answered in a way that indicated the student did not understand the question. Conversely, the *VNOS* test adequately showed the weaknesses of secondary science education, as evidenced by extremely poor scores on the NOS portion of the test. This

argument certainly has some validity, as the test helped to clearly identify misconceptions about science across all groups. In particular, in response to Question #3 (Difference between a Law and Theory), a common misconception was that a scientific law was once a theory, but now has been “proven”. This misconception resurfaced in student responses to Question #8, “What is the Scientific Method?”. Many students who participated in the classroom-based “Life Cycle” activity indicated that after enough experimentation, a theory can become a law. It should be noted, though, that all of the students who participated in the “Life Cycle” activity were from the same high school, and were taught by the same science teacher. It is very likely that the misconceptions seen in their answers were actually misconceptions of the students’ science teachers. As a result, one must consider the possibility that this group was not a representative sample of the population. The individuals that participated in the wind/water/settlement activity, however, were each from different high schools, though they too showed some of the same misconceptions about science as the students who participated in the “Life Cycle” activities.

Conclusion

The data on blue crab postlarval settlement generated from this project has provided a direct measure of recruitment to the blue crab population in NC, which is currently at historically low levels (Eggleston et al. 2004). Moreover, this project has identified key physical forcing factors that facilitate blue crab megalopal recruitment into Pamlico Sound, NC. Lastly, the data gathered can be used with data from other life stages of the blue crab as a potential measure of the blue crab spawning stock’s response to management, and may serve as a predictor of future adult populations (Forward et al. 2004).

The involvement of high school students in our classroom activities has strengthened their understanding of blue crab and estuarine ecology. Though the students who participated in the megalopal settlement data collection portion of this project could not be tested for increases in content knowledge or understanding of the nature of science because of their previous experience with blue crab megalopal sampling, they were provided a unique opportunity to participate in an authentic scientific research experiment. The value of this participation to the students involved is perhaps best reflected in a statement by Hodson (1993, pg. 120): “The only effective way to learn to do science is by *doing* science...”. In addition, this unique partnership between North Carolina State University (Dr. David Eggleston), public school students, and teachers provides an important and unique resource, as financial and geographic restrictions would prevent the research without it. In some cases, the participants have come from economically depressed areas of North Carolina, giving these students an opportunity that they might not have otherwise. The model for involving high school students and teachers in scientific research has a wide range of applicability. Scientists in many fields whose research requires a large number of people to collect data can utilize local educational institutions to accomplish their research goals. For example, a scientist studying bird migration may recruit numerous high schools along the migration route to identify and quantify birds at certain times of the year. For these collaborations, our project can serve as an illustration of the successful integration of high school science into applied research.

The combination of classroom activities, field research, and web-based learning has enabled students to get involved with pertinent research in their communities. In addition, the blue crab settlement data they collected is a valuable tool in gaining an understanding of

the status of North Carolina's blue crab population. Thus, this project has valuable contributions to both the scientific and education communities.

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Table 1.

Results of using ARIMA time series models to eliminate periodicity (“pre-whitening”) in blue crab megalopal settlement and abiotic time series data prior to cross correlation analyses. Values of $Pr > Chi^2$ greater than 0.05 indicate that the model applied to the variable eliminated periodicity at the stated lag. Values of $Pr > Chi^2$ less than 0.05 indicate that the model applied could not eliminate the periodicity in the variable at the stated lag.

<i>Variable</i>	<i>Model</i>	$Pr > Chi^2$			
		<i>6 day</i>	<i>12 day</i>	<i>18 day</i>	<i>24 day</i>
LOGORG	AR1	0.0565	0.0380	0.0106	0.0094
LOGHAT	N/A*	0.0054	0.1112	0.4184	0.7338
ODFT	AR1 MA1	0.0245	0.2796	0.1952	0.2008
OHIGH	AR1 MA1	0.6023	0.9325	0.9930	0.9981
HDFT	AR1 MA2	0.5721	0.4276	0.4185	0.2450
HHIGH	AR1	0.4671	0.7871	0.2591	0.4798
MAIN	AR1	0.2477	0.7095	0.6845	0.5656
MIN	N/A*				

AR1 refers to a 1st order autoregressive model, MA1 refers to a 1st order moving average model. LOGORG is the log-transformed mean daily blue crab megalopal settlement at Oregon Inlet; LOGHAT is the log-transformed mean daily blue crab megalopal settlement at Hatteras Inlet; ODFT is the hours of dark flood tide at Oregon Inlet; OHIGH is the maximum dark flood tidal height at Oregon Inlet; HDFT is the hours of dark flood tide at Hatteras Inlet; HHIGH is the maximum dark flood tidal height at Hatteras Inlet; MAIN is the wind vector along the main axis at Cape Hatteras; MIN is the wind vector along the minor axis at Cape Hatteras.

*Variables marked N/A showed no cycles in the data and did not need to be transformed by a model.

Table 2.

Results of statistically significant cross correlation analyses examining the relationship between mean megalopal settlement, and tidal and wind forcing mechanisms at various lags. The value for the correlation coefficient is the proportion of variability in the first variable listed that is explained by the second variable listed at the given lag.

<i>Cross Correlation</i>	<i>Lag*</i>	<i>Correlation Coefficient</i>
LOGORG vs. MAIN	5	0.20144
	4	0.36895
LOGORG vs. OHIGH	4	-0.25911
LOGHAT vs. MAIN	0	0.31653
LOGHAT vs. MIN	0	0.30478

* Values in the lag column indicate the number of days by which the second variable listed leads the first variable listed.

Figure 1
Map of Pamlico Sound, NC with blue crab megalopal settlement study sites identified

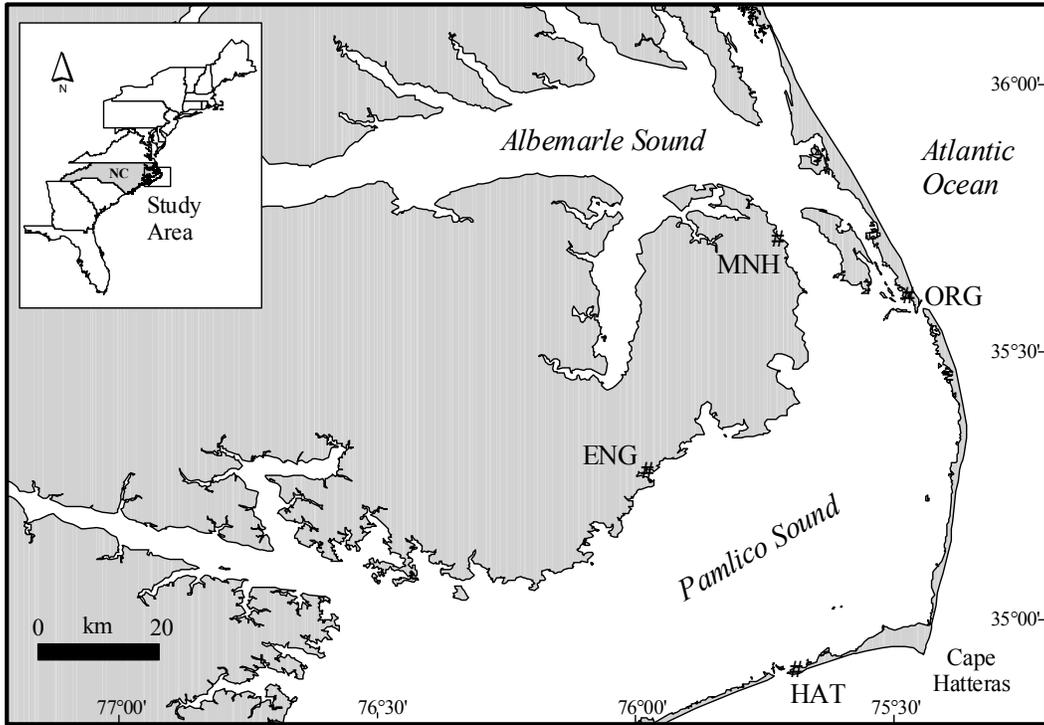


Figure 2.

Principal axis of variance of daily-averaged wind velocity during the blue crab megalopal recruitment season (August through October, 2003). Points represent U (east-west) and V (north-south) components of wind velocities. The main axis is denoted by a line extending along the length of the ellipse, while the minor axis is denoted by a line extending the width of the ellipse. Positive values on the main axis denote north and east directions while positive values on the minor axis denote south and east directions.

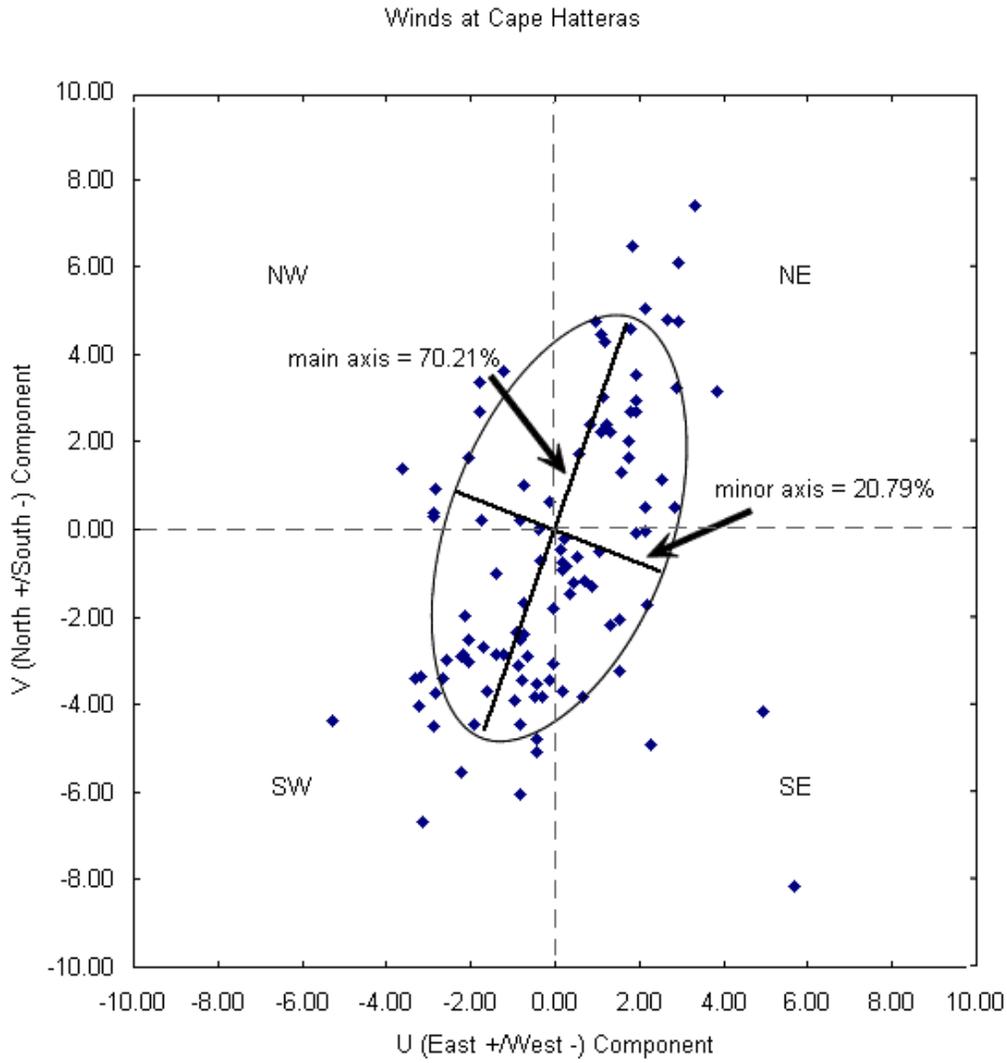


Figure 3.

Daily mean blue crab postlarval settlement (n = 3 settlement substrates) at Oregon Inlet with moon phases indicated. Open circles represent full moons, and solid circles full moons.

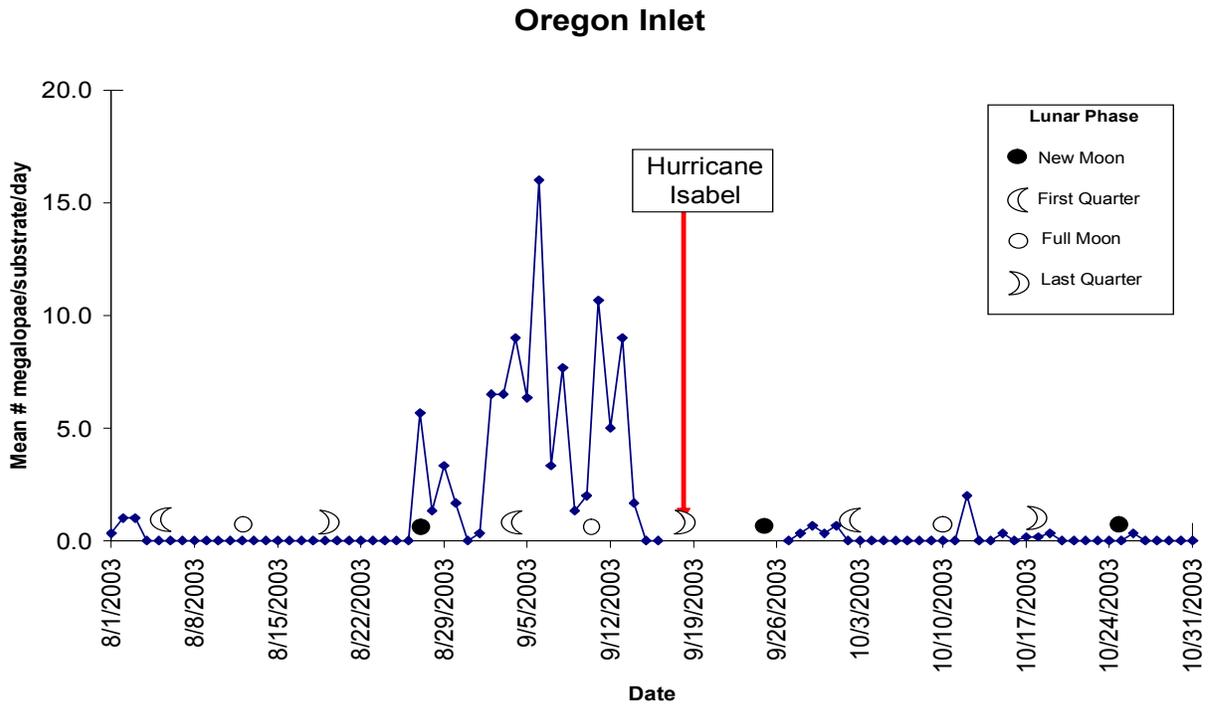


Figure 4.

Daily mean blue crab postlarval settlement (n = 3 settlement substrates) at Hatteras Inlet with moon phases indicated. Sampling ceases after 9/16/03 as a result of damage following Hurricane Isabel. Open circles represent full moons, and solid circles full moons.

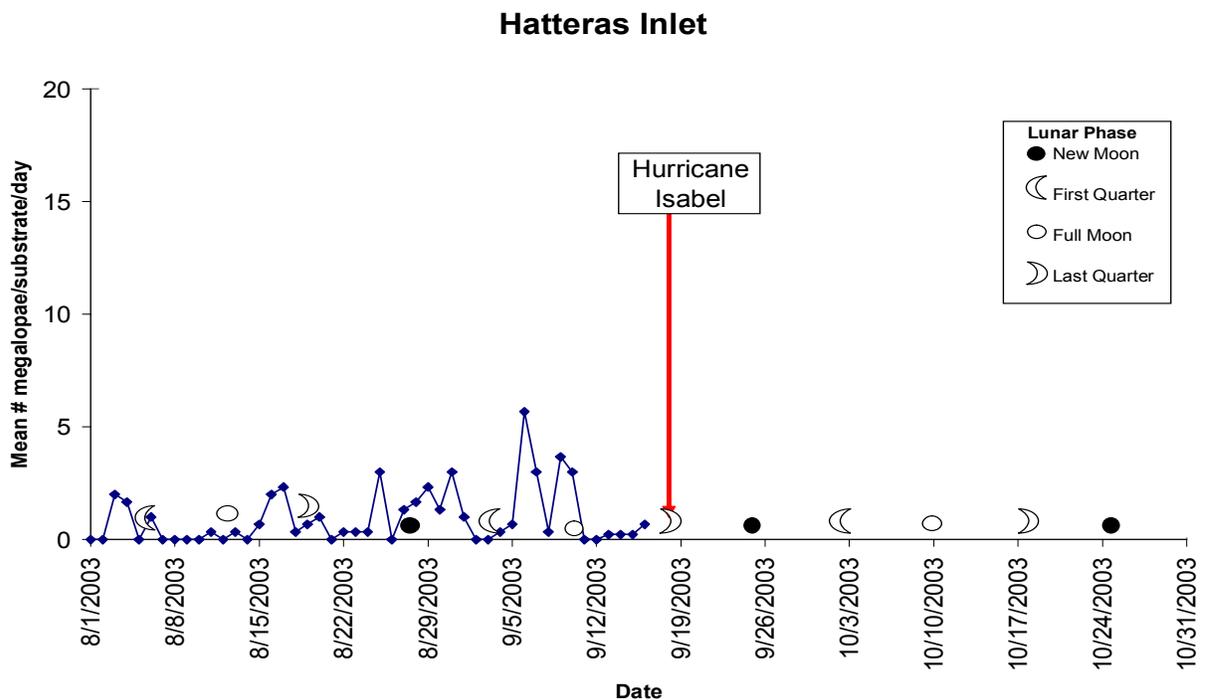


Figure 5.

Daily mean blue crab postlarval settlement (n = 3 settlement substrates) at Manns Harbor, NC with moon phases indicated. Open circles represent full moons, and solid circles full moons.

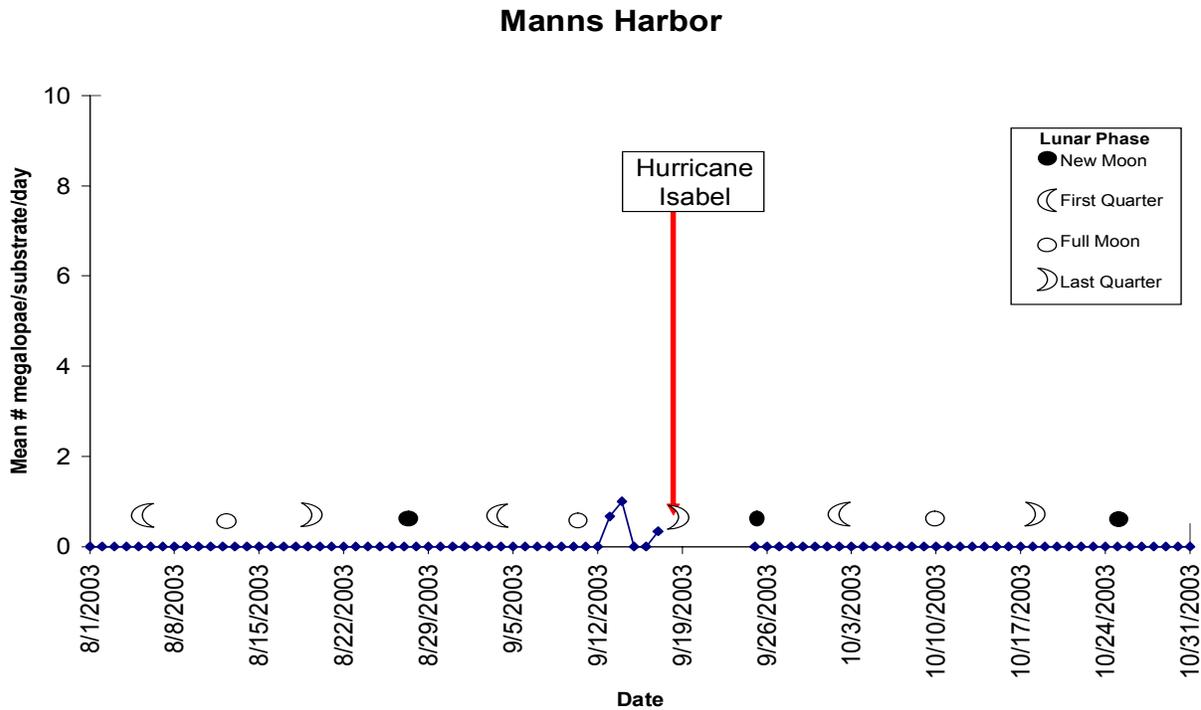


Figure 6.

Daily mean blue crab postlarval settlement (n = 3 settlement substrates) at Engelhard, NC with moon phases indicated. Open circles represent full moons, and solid circles full moons.

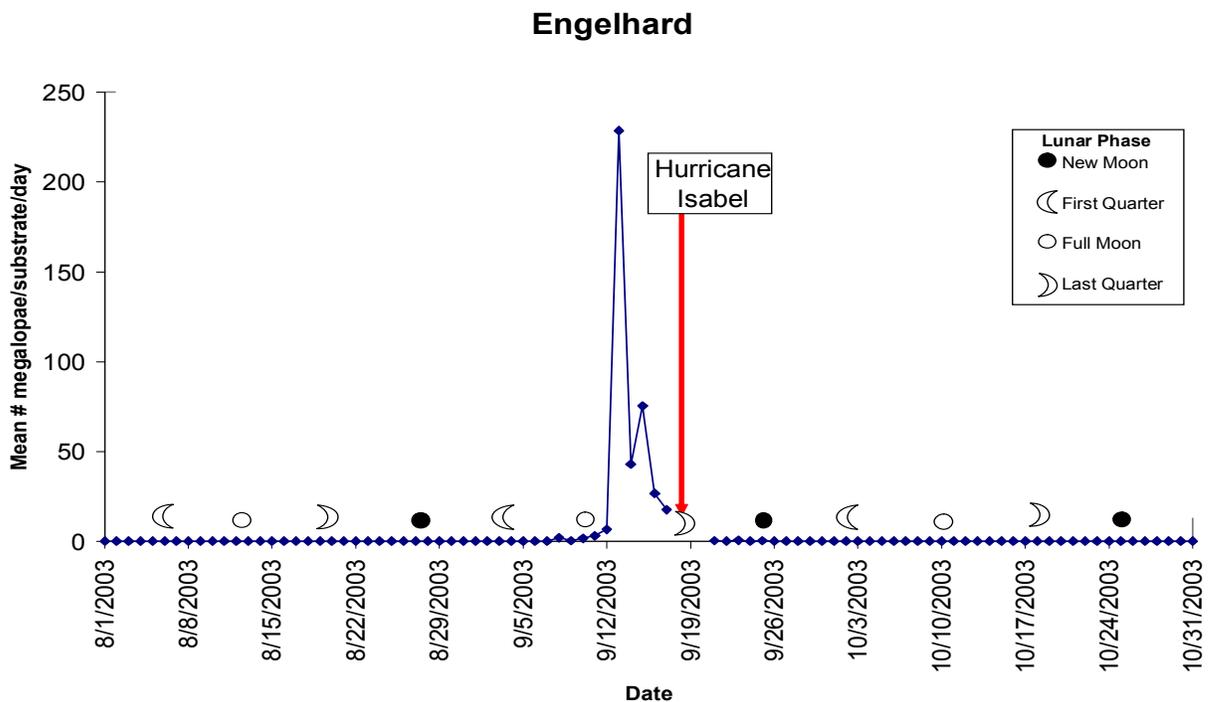
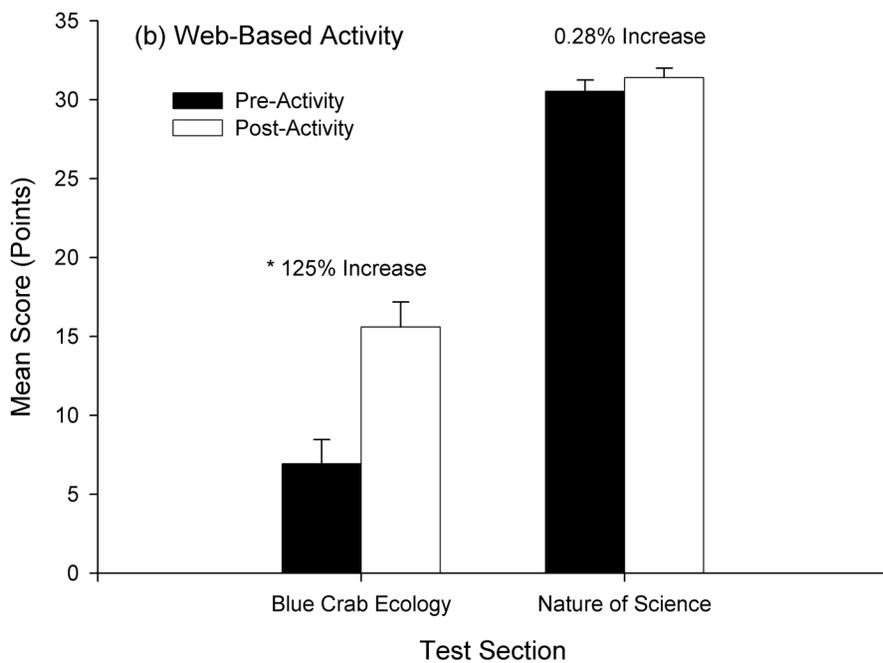
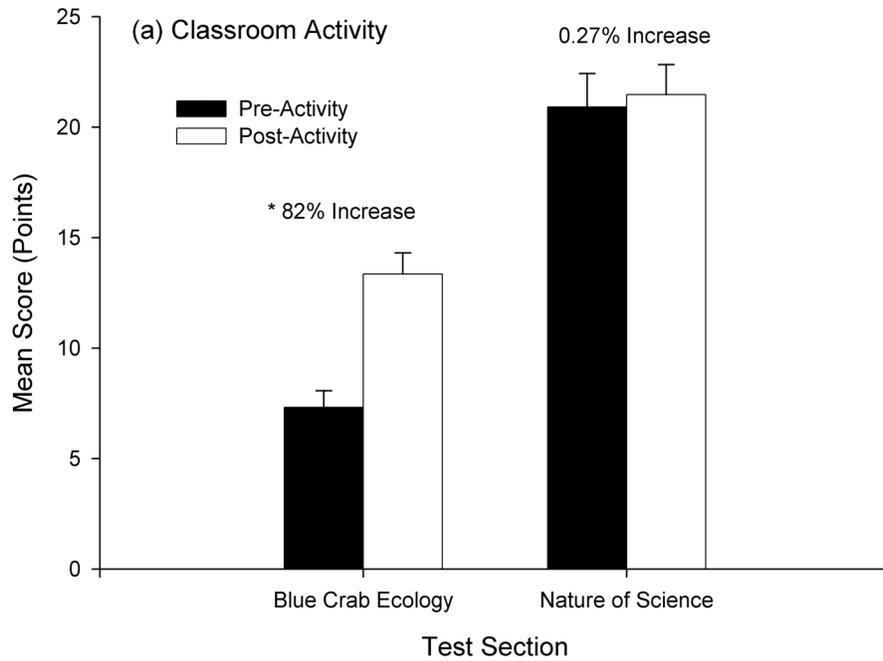


Figure 7.

Scores on the Blue Crab Ecology and Nature of Science portion of pre- and post-activity tests for students who participated in the classroom activity (a) and the web-based (b) activity with percent increase in score indicated. An * denotes a significant increase in mean score from pre- to post-activity test. N = 27 for the classroom activity and N = 15 for the web-based activity.



Appendix A

The Blue Crab Life Cycle

Objectives:

- 1) Students will learn the life cycle of Blue Crabs.
- 2) Students will learn about the habitats, predators, and prey of blue crabs at each life stage.
- 3) Students will compare the blue crab life cycle to the life cycle in mammals and identify the costs/benefits of each type of life cycle.
- 4) Students will generate questions regarding blue crabs and their life history.

Materials needed:

Each group will need a dissecting microscope and preserved specimens of blue crabs in the zoeal, megalopal, and juvenile and/or adult life stage (If one or more life stages cannot be obtained, a photograph of that life stage can be substituted).

Introduction:

The blue crab, *Callinectes sapidus*, is a marine crustacean (other crustaceans include lobsters). That is both economically and ecologically important. The blue crab fishery represents the largest in North Carolina in terms of total weight and dockside value. The blue crab is also commercially important to other states on the East Coast and Gulf Coast of the United States. With so many states relying on the blue crab to provide food and jobs to its citizens, scientists have done much research to further understand blue crabs. The blue crab is ecologically important as one of the top predators in estuaries, and can determine distribution and abundance patterns of its prey.

The blue crab, like many other marine invertebrates, have what is called a **complex life cycle**. Animals with complex life cycles have multiple stages throughout their lifetime, each with its own characteristics. Many times organisms in one life stage will live, behave, and feed in ways that are different from their other life stages. Blue crabs have 4 life stages. This activity will introduce you to each life stage, allowing you to see crabs in each stage and explore the unique characteristics of each stage.

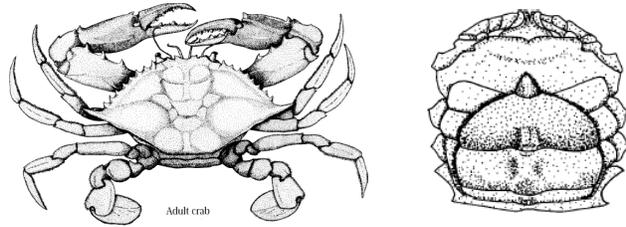
Procedure:

- 1) Read the introduction to each life stage;
- 2) View and draw the blue crab in that life stage;
- 3) Answer the questions that follow;

Life Stage 1: Zoea (Larvae)

Adult blue crabs live in **estuaries**, areas such as Pamlico Sound where salt water and freshwater mix. After mating, a female carries a brood of 800,000-8,000,000 eggs under her apron on the underside of her body (see Fig 1.)

Fig. 1 The adult female blue crab from the top (left) and the underside (right). The apron of the adult female blue crab is the shape that looks rounded with a point on the top (it looks like the capitol dome).



When the eggs are ready to hatch, the female migrates to mouth of the estuary (Oregon Inlet or Hatteras Inlet in NC). The eggs hatch and become **zoea**, or larvae. Upon hatching, zoea are less than 1 mm, and carried by currents out to sea, where they will spend the next 30-45 days in this life stage.

1. Draw a blue crab zoea in the space to the right.

2. Where does a blue crab at this life stage live (open ocean, seafloor, seagrass, etc.), and how is it adapted to live there (hard shell for protection, large eyes to see, etc.)?



Zoea

3. At this stage, what do you think a blue crab eats, how does it move, and what eats it?

4. Generate one question you have about the blue crab at this life stage. (Ex. How close to shore do zoea live?)

5. How would you answer that question? (Ex. Use a boat to drag nets through the water at different distances from the coast, and see where most are caught)

Life Stage 2: Megalopa (Post-Larvae)

After 7-8 zoeal stages and 30-45 days, a zoea **metamorphoses** (changes) into a **megalopa**, which is about 1-3 mm in size. At the megalopal stage blue crabs use light, turbulence, and salinity to tell them when to swim upward in the water, so they can be carried by tidal and wind currents at night into the estuary. In North Carolina, most megalopae enter the Pamlico Sound region through Oregon, Hatteras, and Ocracoke Inlets. Megalopae settle to the seafloor in habitats such as seagrass with high amounts of food and places to hide. When they settle in seagrass, they can molt to their next life stage.

1. Draw a blue crab megalopa in the space to the right and explain how it looks compared to earlier life stages



Megalopa

2. Where does a blue crab at this life stage live (open ocean, seafloor, seagrass, etc.), and how is it adapted to live there (hard shell for protection, large eyes to see, etc.)?

3. At this stage, what do you think a blue crab eats, how does it move, and what eats it?

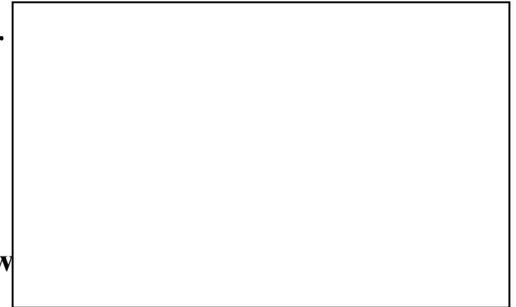
4. Generate one question you have about the blue crab at this life stage. (Ex. What time of year do megalopae primarily migrate into estuaries in North Carolina?)

5. How would you answer that question? (Ex. Sample seagrass beds near inlets for blue crab megalopae every day for a year.)

Life Stages 3 & 4: Juvenile and Adult

Once the megalopa finds a suitable habitat to settle (usually seagrass), they metamorphose into juveniles which are 3mm and larger. Juveniles will shed their outer shell (called molting) numerous times to grow into adults, which reach 120 mm or more (5-6 inches) carapace width when they are sexually mature.

1. Draw a blue crab juvenile in the space to the right and explain how it (and adults) look compared to earlier life stages



Juvenile

2. Where does a blue crab at this life stage live, and how is it adapted to live there?

3. At these stages, what do you think a blue crab eats, how does it move, and what eats it?

4. Generate one question you have about the blue crab at these life stages. (Ex. How often does a juvenile molt?)

5. How would you answer that question? (Obtain a blue crab megalopa, and count the number and timing of molts as it matures to a juvenile and eventually an adult).

6. How does the life cycle of the blue crab compare to the life cycle in mammals (such as humans)? How are they similar? How are they different?

7. What do you think are the advantages/disadvantages of having a complex life cycle, like the blue crab?

Appendix B

Blowing In the Wind: Biophysical Interactions in Estuaries

Objectives:

- 1) To gain an understanding of the concept of biophysical interactions
- 2) To examine the relationship of postlarval blue crab settlement, wind direction, and current flow.
- 3) To generate questions about the biophysical interactions of blue crabs

Materials Needed:

Students will need this lab report, and a computer with internet access. This activity uses a computer simulation found at the URL <http://www4.ncsu.edu/~gmparkin/>. The introduction portion of this lab should be accompanied by students browsing that web page, particularly the blue crab life history section.

Introduction:

The blue crab, *Callinectes sapidus*, is a very important species to states of the Atlantic and Gulf coasts. It supports very large fisheries in many states, including Maryland, Virginia, Louisiana, and North Carolina. With so many states relying on blue crabs to provide food and jobs to their citizens, much research has been done to gain a better understanding of blue crab biology.

The blue crab, like many other invertebrates, has a **complex life cycle**. Animals with complex life cycles have multiple stages throughout their lives, each with its own set of characteristics and behaviors. Adults live in an estuary, where fresh water and salt water meet. When a female's eggs are ready to hatch, she migrates to the mouth of the estuary, where the larvae are hatched and carried by ocean currents out to sea. The larval stage of blue crab, known as zoea, is less than 1 mm in size and cannot swim against ocean currents. After 30-45 days, zoea metamorphose, or change, into the next stage of blue crab, megalopa (postlarvae). Megalopae use salinity, light, and water turbulence cues to ride tidal and wind-driven currents back into the estuary where they search for seagrass or shallow detrital habitats to settle. Once the megalopae settle to the bottom, they metamorphose into juveniles, which will grow at discrete molting steps into adults.

Procedure:

- 1) Open a web browser and go to the URL <http://www4.ncsu.edu/~gmparkin/>
- 2) Read the information contained in the “General Information” and “Life History” pages.
- 3) Open the “Simulation” page, read it, and click on the wind/water current simulation link.
- 4) Run the simulation of water currents from each wind direction, the numbers that appear at the end of the simulation are the average numbers of megalopae that settled for all the days with that wind direction.
- 5) For each wind direction, record the mean megalopal settlement at each of the four sites in the table below.
- 6) For each wind direction, draw a picture of how water flows in the area. HINT* When the simulation stops for each direction, a still frame of the water currents appears, you can just draw this.
- 7) Answer the questions that follow

Table 1. Record megalopal settlement at each site in Pamlico Sound for each wind direction.

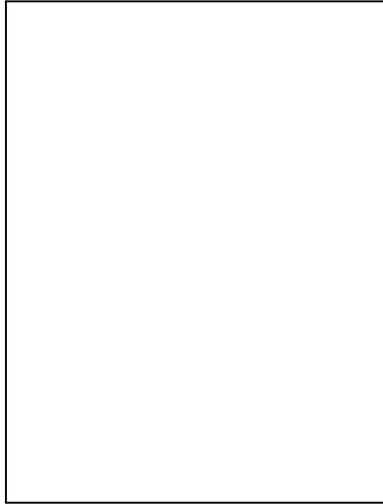
	N	NE	E	SE	S	SW	W	NW
Oregon Inlet								
Manns Harbor								
Engelhard								
Hatteras Inlet								

Draw a picture showing the current flow for each wind direction.

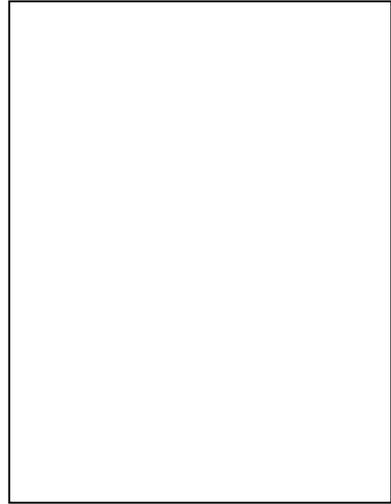
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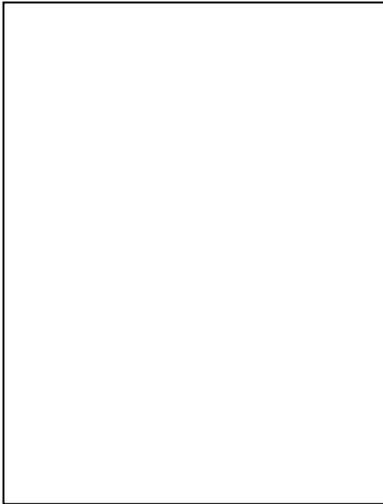
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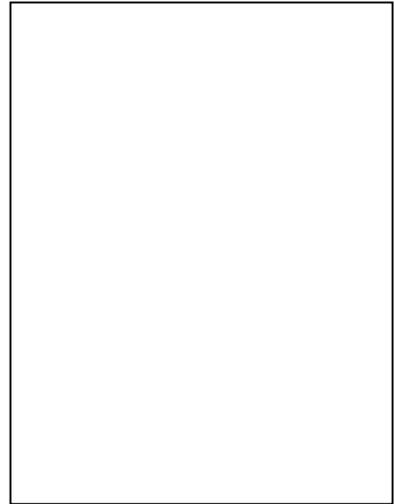
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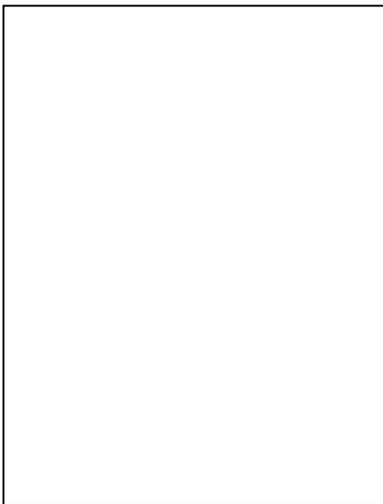
S



SW



W



NW



- 1) Which wind directions caused water to flow into Pamlico Sound through Oregon Inlet? Hatteras Inlets?

- 2) Which wind directions caused water to flow from the east side of Pamlico Sound to the west side?

- 3) Which wind directions would you expect to see the most blue crab megalopal settlement at Oregon Inlet? Hatteras Inlet? Why would you expect this?

- 4) Which wind directions actually produced the highest settlement at Oregon Inlet? Hatteras Inlet? Are these the same wind directions you used to answer question #3? If not, Why?

- 5) Which wind directions would you expect to see the most blue crab megalopal settlement at Engelhard? Manns Harbor? Why would you expect this?

- 6) Which wind directions actually produced the highest settlement at Engelhard? Manns Harbor? Are these the same directions you used to answer question #5? If not, Why?
- 7) For each site, which wind direction produced the highest settlement? Are they the wind directions you would expect to produce high settlement at each site?
- Oregon Inlet
Hatteras Inlet
Manns Harbor
Engelhard
- 8) Look again at the current flow with SW wind direction. Would you expect this wind direction to produce high settlement at Engelhard? Settlement at Engelhard for this direction is higher than settlement at any site for any wind direction, how might this be explained?
- 9) What factors, other than wind direction, might influence megalopal settlement?
- 10) Pretend you're a scientist who gets paid a lot of money to study blue crab megalopal settlement. Generate one question that you have about this process. (Ex. What time of year do megalopa primarily migrate into estuaries?). Explain how you would answer that question. (Ex. Sample seagrass beds near inlets for blue crab megalopae every day for a year).

Appendix C

Test given to students before and after classroom based blue crab life cycle activity and web-based wind/ water current computer simulation activity: Includes modified questions from VNOS-B (1, 3-7), a question from VNOS-C (2), and additional questions (8-11). Questions 1-8 represent the Nature of Science (NOS) portion of the test; Questions 9-11 represent the Blue Crab Ecology (BCE) portion of the test.

Answer every question to the best of your ability. Please do not look for the answers, this is designed to determine your current understanding of these things.

1. After scientists have developed a theory, does the theory ever change? If you believe that theories do change, explain why we teach scientific theories. Defend your answer with examples.
2. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain do you think scientists are about their characterization of what a species is? What evidence do you think they used to determine what a species is?
3. Is there a difference between a scientific theory and a scientific law? Please give an example to illustrate your answer.
4. How are science and art similar? How are they different?
5. Scientists perform experiments/investigations when trying to solve problems. Other than planning and designing these experiments/investigations, do scientists use their creativity and imagination during and after data collection? Please explain your answer and provide examples if appropriate.
6. Is there a difference between scientific knowledge and opinion? Give an example to illustrate your answer.
7. Some astronomers believe that the universe is expanding while others believe that it is shrinking, still others believe that it is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?
8. What is the Scientific Method? How often do you think scientists rigidly follow the scientific method?
9. What is a complex life cycle? What do you think are the costs and benefits to an organism with a complex life cycle?
10. Do the physical, chemical, and geological processes of an environment interact with its biological processes? Give examples to support your answer.
11. What factors (human or environmental) can affect the blue crab population in Pamlico Sound?