JELLYFISH-HUMAN INTERACTIONS IN NORTH CAROLINA

by

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ABSTRACT OF DISSERTATION

This dissertation investigated potential drivers of jellyfish-human interactions in North Carolina. Jellyfish populations and human use of coasts are increasing; therefore, jellyfish-human interactions are poised to become more frequent. This research investigated how abiotic variables (i.e. temperature and salinity) and wind-driven circulation in the Neuse River Estuary influenced the distribution and abundance of the sea nettle, *Chrysaora quinquecirrha*, at six recreational sites. Life history traits were also investigated to determine if jellyfish aggregations at the recreation sites could be linked to sexual reproduction. Finally, the human perspective on jellyfish was investigated. One hundred eighteen people were surveyed at 25 coastal locations prone to jellyfish occurrences. This survey used cultural consensus theory to gather perspectives of jellyfish ecology and how jellyfish influence society from four cultural groups: fishers (commercial and recreational), recreationists (surfers, swimmers, etc.), North Carolina coastal researchers, and jellyfish researchers in the United States. Results show: 1) southwest winds 3 to 8 meters per second that occurred 1 and 5 days prior to

observations resulted in more sea nettles observed at the Neuse River Estuary recreation sites; 2) aggregations of sea nettles resulting from wind events could not be definitively linked to sexual reproduction based on jellyfish gonad analysis; 3) cultural perspectives of jellyfish ecology were different among groups; this was most obvious when the role of jellyfish in food webs was evaluated. All groups shared similar societal perspectives, including tolerance to specific numbers of jellyfish. Overall, this research has identified physical, ecological and societal factors that influence jellyfish-human interactions in North Carolina and these interactions appear to be mediated by several different factors. Understanding these factors will allow for management of jellyfish-human interactions. Recreational areas subjected to high sea nettle occurrences based on local oceanographic conditions may employ barrier nets to decrease the frequency of encounters. Further studies into the dominant mode of reproduction for sea nettles may indicate which life history stage, polyp or medusa, might be the best target for management to reduce jellyfish-human interactions. Finally, outreach education about common misconceptions concerning jellyfish may remove some confusion surrounding the role of these organisms in the environment.

JELLYFISH-HUMAN INTERACTIONS IN NORTH CAROLINA

A Dissertation

Presented To the Faculty of the Institute for Coastal Science and Policy

East Carolina University

In Partial Fulfillment of the Requirements for the Degree

Coastal Resources Management

Primary Concentration in Coastal and Estuarine Ecology

Secondary Concentrations in Coastal Geosciences and Social Science & Coastal Policy

by

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May, 2013

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ACKNOWLEDGEMENTS

I have profound gratitude to many people who have contributed to this effort. First, I thank my adviser, Dr. David Kimmel, for providing me with the opportunity to gain this tremendous education. His patience, assistance, and mentoring throughout my time at East Carolina University has been invaluable to me. I also thank my dissertation committee, Tom Allen, Mary Beth Decker, Trip Lamb, David Mallinson, and Tracy Van Holt. I have learned a great deal from each of them, and will always appreciate their guidance throughout my studies. I could not have completed this work without the support of the Institute for Coastal Science and Policy's staff and faculty; especially, Hans Vogelsong, John Rummel, Kay Evans, and Cindy Harper. I had the pleasure of working with many students, Meghan Barbee, David Buckley, Allyn Hollingsworth, Ben Nelson, Barryn McLaughlin, Amanda Cornelsen, Jarrod Howe, Hampton Farmer, Robert Melvin, Amy Shore, and Thomas Steelman. Our time "jelly-fishing" will always be dear to me and I am in deep gratitude for your help with my field work. I thank Mike Askew, Ross Pease, Ray Bullock, Dennis Foster, Will Flannery, Ryan Ellis, and Brian Blanton for granting me on-site access to their facilities for my field research and data acquisition from the National Weather Service and RENCI NC-CERA, respectively. I also appreciate the support of my lab mates and fellow colleagues in Coastal Resources Management. I am particularly grateful for the scholarly advice, comforting spirits, and unwavering encouragement from Andrea Dell'Apa, Chad Smith, Wendy Klein, Cecilia Krahforst, and Devon Eulie. Thank you for being there for me and for anything. Finally, I have the upmost gratitude for my husband, Eric Pineiro; my mother, Lucy Kaneshiro; brother, Kamuela Kaneshiro; and the rest of my family. I simply could not have done this without your love and thank you for always believing in me.

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CHAPTER 1

Introduction to dissertation

Jellyfish-human interactions

I assigned the term “jellyfish-human interactions” to describe circumstances where jellyfish are present in coastal or oceanic environments that experience significant human use, resulting in frequent contact between jellyfish and humans. Understanding that the type of jellyfish-human interaction is dependent on the jellyfish species, and if the species is favorable or unfavorable to humans, it is likely that jellyfish-human interactions vary globally. For example, many jellyfish species are edible (Hsieh et al. 2001) and jellyfish fisheries worldwide harvest more than 500,000 tons of jellyfish annually (Pitt 2010). In Palau, tourists will travel to “Jellyfish Lake” to swim with large numbers of *Mastigias* sp. jellyfish as this species stings are not harmful to humans (Dawson and Hamner 2005; Fautin and Fitt 1991). In contrast, the synergy of large numbers of jellyfish and human usage of coastal environments has created several problems, including power plant closures, challenges to fishery and aquaculture operations (Purcell et al. 2007), and beach closures due to the pain and/or death of beach-goers from jellyfish stings (Fenner and Williamson 1996).

Current data on jellyfish populations indicate that in certain regions of the world, populations have increased (Condon et al. 2012), and two trends have been identified. A weak trend since 1970 suggests that jellyfish have increased in relation to human activities. Most notably are the increase in global temperature due to anthropogenic production of carbon dioxide and overfishing. A strong trend over the last century indicates that an oscillation in jellyfish populations may be a function of environmental oscillations in ocean-atmosphere cycles and variations in insolation on food webs (Condon et al. 2013). A recent study has documented the presence of jellyfish populations along the majority of US coastlines, including Alaska and Hawai‘i, with notable increases in the Northeast (Brotz et al. 2012). Thorough investigations into jellyfish population dynamics require long term data sets, and these data are not uniformly distributed worldwide (Condon et al. 2013; Hay 2006; Purcell et al. 2001). This is especially true in estuaries, where jellyfish can be intermediate-top level predators (Baird and Ulanowicz 1989; Condon and Steinberg 2008). As a consequence, the role of jellyfish in food webs is often overgeneralized or misconstrued (Condon et al. 2012; Purcell et al. 2007). Furthermore, because outreach education and associated social media about scientific explorations stems from research (McKenna and Main 2013), it is quite possible that the roles that jellyfish play in the environment are ambiguous at the public interface. Jellyfish will continue to affect coastal communities as human usage of coasts continues (Hinrichsen 1995) and jellyfish-human interactions are likely to become more frequent. Thus, this research aims to provide perspective on the interaction between jellyfish and at recreational areas.

North Carolina’s Albermarle-Pamlico estuarine system (APES) is the nation’s second largest estuarine complex (Figure 1). APES provides important ecosystem services, including essential habitat and nursery areas for a variety of east coast fisheries and supports a substantial assortment of ecological, economic, recreational, and aesthetic functions. APES was designated “an estuary of national significance” in 1987 (N.C. Department of Environmental and Natural Resources 2011).

Jellyfish are top predators in estuaries; however, studies on the distribution and abundance of jellyfish within estuaries in general and APES in particular are limited. The two most common jellyfish species are the scyphomedusan sea nettle, *Chrysaora* *quinquecirrha* [Desor, 1848], and the ctenophore, *Mnemiopsis leidyi* [A. Agassiz, 1865], (Miller 1974; Williams and Deubler 1968). The best record of these two jellyfish species was noted in the Pamlico River Estuary (PRE) (Figure 1), where *M. leidyi* distribution and abundance was documented by Williams and Deubler (1968), and spring/summer abundance of the *C. quinquecirrha* (2 m^{-3}) was calculated in 1967-68 by Miller (1974). A study by Mallin (1991) on zooplankton distributions in the Neuse River Estuary (NRE) reported the presence of jellyfish, but did not record species or abundance. Current observations of the presence of other species of jellyfish, such as the cannonball jellyfish *Stomolophus meleagris* [L. Agassiz, 1860], along the Outer Banks and Oak Island (Figure 1) has been documented on-line by Appalachian State University (http://www.jellyfish.appstate.edu/) and the Monterey Bay Aquarium (http://jellywatch.org/) (Appalachian State University 2011; Elliott and Haddock 2010). It should be noted that although the term "jellyfish" has been used to describe species belonging to Phylum Cnidaria, Phylum Ctenophora and Phylum Chordata, Subphylum Urochordata, Class Tunicata (Purcell 2012), unless otherwise indicated, I will use the term "jellyfish" to describe species belonging to Phylum Cnidaria, Class Scyphozoa (Figure 2).

I chose to investigate the potential drivers of jellyfish-human interactions in North Carolina. My approach is described in three chapters: chapter 2 investigated physical drivers of jellyfish-human interactions in the Neuse River Estuary (NRE) (Figure 1). The NRE was selected as a study location for this chapter due to the annual presence of the sea nettle, *C. quinquecirrha*, and because the NRE is a highly used recreational area. A vital concern to NRE residents and stakeholders is recreation and tourism revenue, and since sting of *C. quinquecirrha* are harmful to humans (Schultz and Cargo 1969), the annual presence of *C. quinquecirrha* may have negative effects on NRE recreation and, by association, tourism revenue. The Albermarle-Pamlico estuarine system (APES) (Figure 1) and the NRE are greatly influenced by wind-driven circulation (Luettich et al. 2000; Reynolds-Fleming and Luettich 2004), and since *C. quinquecirrha* cannot swim against water currents (Costello et al. 1998; Matanoski et al. 2001), I investigated how wind affected the distribution and abundance of *C. quinquecirrha* in 2011 and 2012 at six recreation sites located on the central north and south NRE shorelines. I used a null hypothesis to test that the distribution and abundance of sea nettles would not differ at all six recreation sites regardless of the wind dynamics, speed and direction. In addition to analyzing wind, I also investigated other potential factors known to influence the life history of the sea nettle and distribution, most notably salinity and temperature (Decker et al. 2007; Calder 1974; Cargo and Schultz 1966).

The frequency of occurrence of jellyfish populations can also be directly correlated to reproduction and growth (Hamner and Dawson 2008), and aggregations of large numbers jellyfish or medusae may indicate sexual reproduction (Arai 1997). Thus, the annual occurrences of *C. quinquecirrha* in the NRE may be undergoing sexual reproduction. To evaluate the potential of sexual reproduction of *C. quinquecirrha*, I used histology to determine gonad maturity, the presence of brooded larvae or planulae, and the sex ratio of *C. quinquecirrha* collected throughout the 2011 field season. The basis of my histological analysis stemmed from research done with *C. quinquecirrha* in Chesapeake Bay where Littleford (1939) documented egg maturity, the onset of fertilization, and development of planulae within female stomachs or gastric cavities was documented. The size of jellyfish, which is typically measured by bell diameter, may also influence spawning (Arai 1997) and in some jellyfish species bell diameter may (Saucedo et al. 2012) or may not (Toyokawa et al. 2010) be linearly related to egg diameter. I proposed several hypotheses: 1) the proportion of female and male sea nettles would not differ, 2) measured egg diameters would be greater than 0.07 mm, indicating sexual maturity, 3) sexually mature males would have ruptured sperm follicles or evidence of spent sperm follicles, 4) brooded planulae would be observed in female gastric cavities indicating that sexual reproduction had occurred, and 5) there would be no correlation between female *C. quinquecirrha* bell and egg diameters. I also took the opportunity to compare visual observations of the sex of *C. quinquecirrha* with my histology results since the color of mature gonads has been used to classify sex (Littleford 1939).

The risk of receiving a sting by a jellyfish, like the sea nettle, is often a choice that a coastal recreationist faces. The choice to recreate in water where jellyfish are clearly visible is influenced by culture and human belief about jellyfish ecology. I chose to evaluate cultural perspectives of jellyfish ecology and how jellyfish influence society among four groups of people; fishers (recreation and commercial), recreationists (surfers, swimmers, etc.), coastal researchers, and jellyfish researchers with a jellyfish survey based on cultural consensus theory (CCT). CCT is a method used in anthropology that allows researchers to quantify qualitative data, estimate cultural beliefs, and to report an individual's knowledge of those beliefs (Weller 2007). CCT is based on culture or the set of learned beliefs, shared beliefs, and behaviors (Weller 2007). Cultural beliefs are affected by social norms or normative beliefs that are associated with a group (Heywood 1996; Vaske and Whittaker 2004), and group culture is the most frequently held items of knowledge and belief (D'Andrade 1987).

The cultural perspectives of jellyfish ecology among each group were assumed to be different because knowledge of jellyfish in ecosystems is often misinterpreted (Condon et al. 2012) and jellyfish are typically understudied despite being intermediate to top level predators (Condon and Steinberg 2008). Therefore, it is likely that misinterpretation of the ecological role of jellyfish would extend to the public interface because most outreach education and associated social media about scientific explorations stems from research (McKenna and Main 2013). To test ecological literacy concerning jellyfish, I hypothesized that the cultural perspectives of jellyfish ecology would not differ among fishers, recreationists, coastal researchers, and jellyfish researchers. Jellyfish-human interactions may depend on jellyfish species and specifically if the jellyfish stings are harmful to humans. Often jellyfish are viewed as “nuisance” species (Richardson et al. 2009) and media reports about jellyfish can be negative (Condon et al. 2012). I tested the null hypothesis that all groups would share similar cultural perspectives of jellyfish.

The goal of my dissertation research was to add to the growing knowledge of jellyfish research by studying jellyfish-human interactions in North Carolina. Specifically, my results will indicate: 1) if jellyfish interactions at recreational sites can be related to abiotic conditions. Such an outcome would indicate that periods of high jellyfish encounter rate at recreational sites may be predictable; 2) if sexual reproduction is occurring at different recreational sites during jellyfish aggregation events. If sexual reproduction is occurring it would indicate that management of jellyfish in the APES system should be focused on the medusa stage; and 3) if there are particular areas of human perception of jellyfish ecology that may be the focus of educational outreach and if particular characteristics of jellyfish perception that may be targets of regulation. To date, multifaceted research approaches similar to that which I have adopted have helped manage encounters with jellyfish species in Australia (Gershwin et al. 2010) and Germany (Baumann and Schernewski 2012). To understand the global extent of jellyfish ecological and socio-economic implications, the National Center for Ecological Analysis and Synthesis (NCEAS) developed the “Global expansion of jellyfish blooms” working group, to analyze and synthesize existing jellyfish data. With more data available on jellyfish in coastal environments, the management and sustainability of coastal resources by local, state, and federal agencies will improve in areas prone to jellyfish-human interactions.

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LIST OF FIGURES

Figure 1.

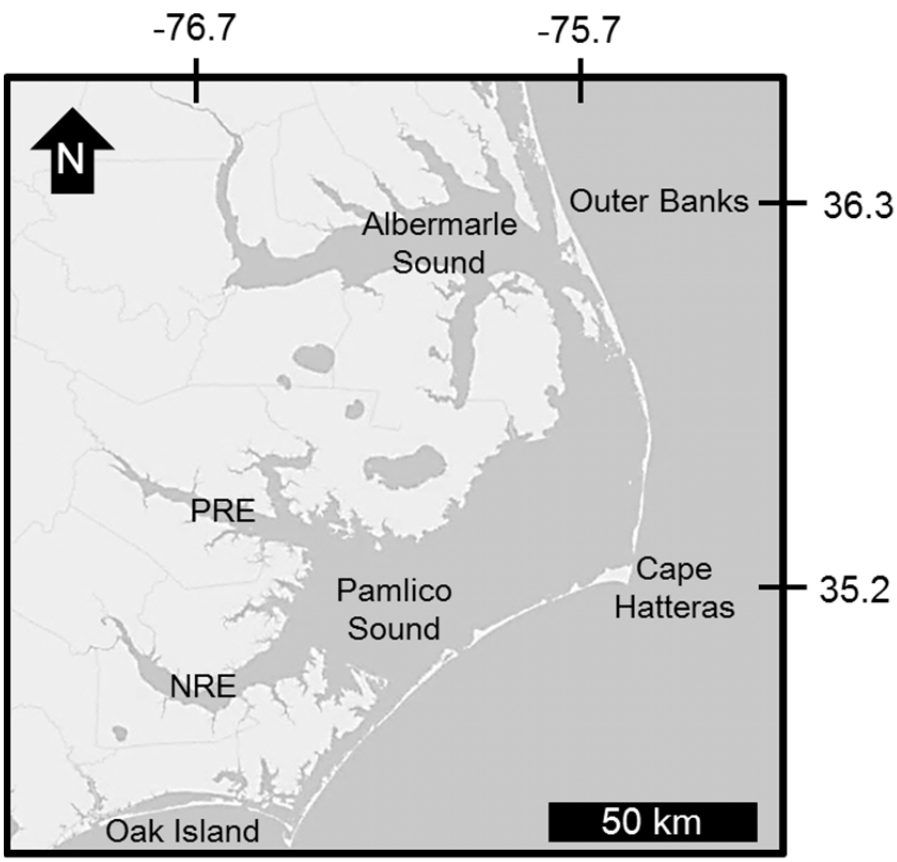
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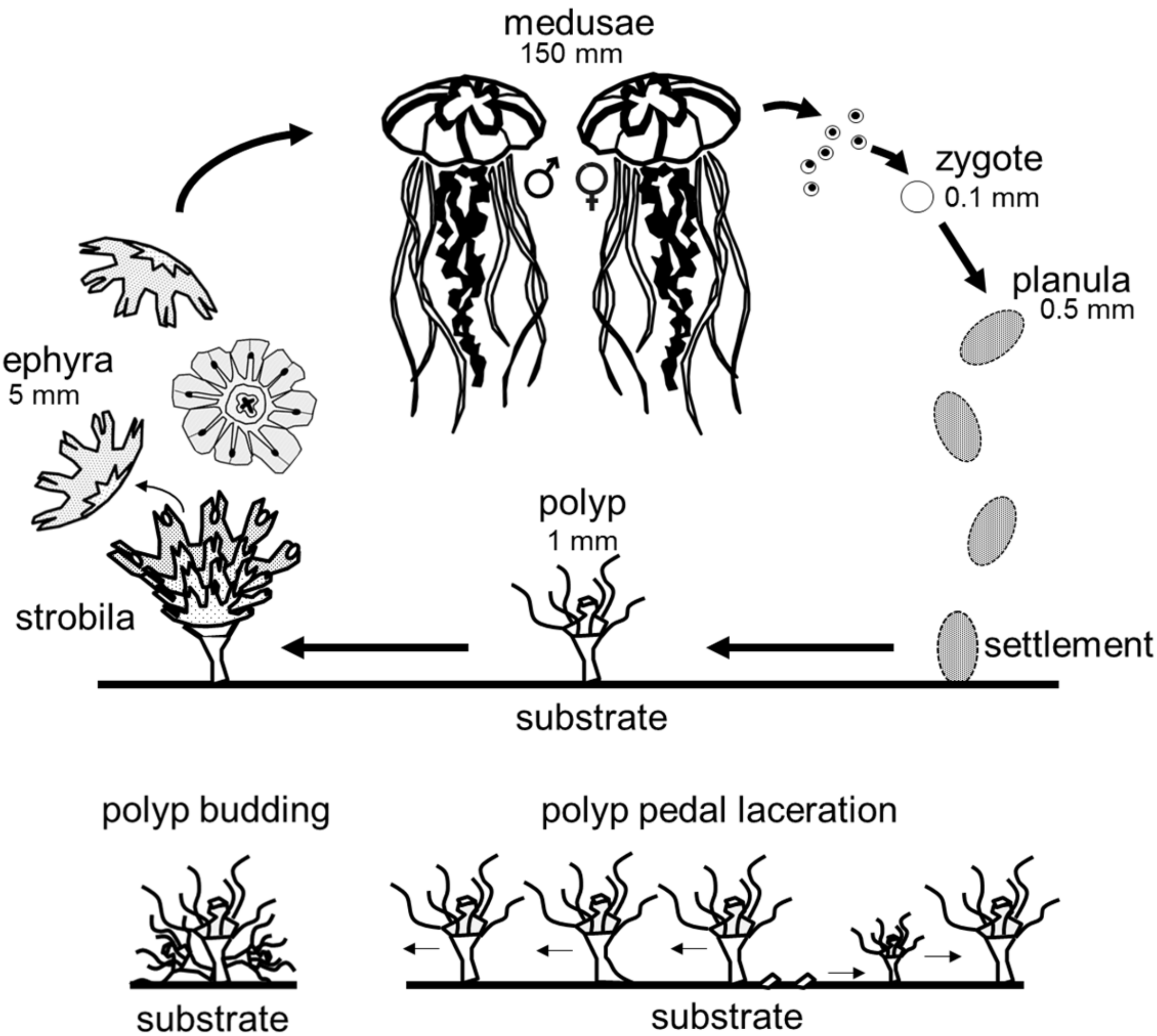
Figure 2.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CHAPTER 2

Local wind dynamics influences the distribution and abundance of the sea nettle, *Chrysaora quinquecirrha*, at six estuarine recreation sites in the Neuse River Estuary

ABSTRACT

The “stinging” sea nettle, *Chrysaora quinquecirrha*, has been observed annually in the Neuse River Estuary (NRE), a site of intense human recreation in North Carolina. The purpose of this chapter was to evaluate what physical drivers influence jellyfish-human interactions. Jellyfish were counted and abiotic variables were measured bi-weekly at six recreation sites from May to August, 2011 and 2012. In particular, the influence of wind on jellyfish abundance was investigated as circulation within the NRE is primarily a function of wind. The two years differed in stream flow, salinity, and temperature, due to drought conditions in 2011. Wind speed and direction did not differ between the two years; however, the number of high-speed wind events did differ across years at the Cherry Point Marine Weather Station. A total of 3,241 jellyfish were observed, with peak counts in July and minimum counts in August. There were significant differences in mean sea nettle counts between sites, specifically between north and south shorelines. Northeast-east and southeast-southwest wind events (3 – 8 m s^{-1}) measured from Cherry Point and SW wind events (2 – 7 m s^{-1}) measured from Cape Hatteras were correlated to sea nettle abundance (m^2) when a lag period was included. I conclude that NRE wind dynamics are one of the factors influencing jellyfish-human interactions at the six recreational sites in the NRE. The relatively strong influence of wind, compared to the abiotic variables temperature and salinity, suggests that prediction of sea nettle abundances at these sites subsequent to wind events is possible.

INTRODUCTION

Large numbers of cnidarian scyphomedusae (jellyfish) have created problems in coastal environments (Brotz et al. 2012; Condon et al. 2011; Mills 2001; Purcell 2012; Purcell et al. 2007). These deleterious effects include power outages due to clogged cooling intake-valves of power plants (Matsueda 1969; Matsumura et al. 2005; Rajagopal et al. 1989; Yasuda 1988), severe damage to commercial fishing and aquaculture operations due to net bursting (Graham et al. 2003; Nagata et al. 2009), tainted catches and predation of farmed fish (Purcell et al. 2007), and beach closures and injury (including death) to coastal recreationists (Fenner and Williamson 1996; Pages 2001). Coastal and estuarine environments are conducive for jellyfish blooms in that they are characterized by seasonal pulses of nutrients, ample habitat for benthic/juvenile phases of jellyfish, and an environment to aggregate for reproduction (Lo et al. 2008; Omori and Nakano 2001; Pitt and Kingsford 2000; Purcell 2005; Purcell 2012). Therefore, when compared to the open ocean, coastal and estuarine jellyfish species are observed in higher densities and may have seasonal mass occurrences (Decker et al. 2007; Doyle et al. 2007; Hamner and Dawson 2009).

High abundances of the sea nettle *Chrysaora quinquecirrha* [Desor, 1848] have been reported in the Neuse River Estuary, North Carolina, during the spring and summer (Mallin 1991) (Figure 1A). *Chrysaora quinquecirrha* is a brackish water (salinity 5 – 18) jellyfish species (Cargo and Schultz 1966) that is highly abundant during the spring and summer months in mid-Atlantic estuaries, e.g. Chesapeake Bay (Virginia and Maryland) (Calder 1974; Calder 1972; Cargo and Rabenold 1980; Cargo and King 1990; Decker et al. 2007; Mansueti 1963), the Albermarle-Pamlico Estuarine System

(North Carolina) (Mallin 1991; Miller 1974; Williams and Deubler 1968), and Barnegat Bay (New Jersey), USA. The most common negative interaction between jellyfish and humans is a sting (Purcell et al. 2007), and although all species belonging to Phylum Cnidaria have stinging cells or nematocysts, the extent to which a jellyfish sting will affect humans is variable from “feeling nothing” to life threatening (Arai 1997; Gershwin et al. 2010; Mills 2001). The pain associated with sea nettle stings have been described as “bothersome” to “extremely painful” (Cargo and Schultz 1966; Decker et al. 2007). To circumvent harm to humans, barrier nets have been utilized in swimming areas due to the presence of *C. quinquecirrha* in Chesapeake Bay (Schultz and Cargo 1969) and Barnegat Bay, New Jersey. It is unknown how sea nettles affect coastal tourism and/or recreation within the NRE (Figure 1B) and the greater APES, but an assessment of NRE stakeholder interests revealed that recreation and maintaining tourism income were important public interests (Maloney et al. 2000). Coastal recreationists in the NRE desired to be safe in the water when engaging in prolonged-body contact activities (i.e. swimming and water skiing) and ‘getting rid of “slime” on fishing nets (Maloney et al. 2000). Although “slime” was not properly defined by Maloney et al. (2000), jellyfish are known to clog fishing nets and in consequence the gelatinous bodies of jellyfish are often torn apart (Nagata et al. 2009; Purcell 2009) and could resemble “slime.”

Similar to other reports of jellyfish occurrences, the presence or absence of *C. quinquecirrha* along NRE shorelines has been considered ephemeral and unpredictable. It is plausible that the combination of jellyfish swimming behavior, wind velocity and local hydrology, topography, and bathymetry contribute to the advection of jellyfish within coastal areas and in some cases an increase in abundance (Cargo and

King 1990). *Chrysaora quinquecirrha* have been described as “cruising predators,” that will constantly swim in order to maximize prey capture via water vortices generated by bell contractions or pulsation (Ford et al. 1997). Although pulsation rate and swimming velocities will increase when prey is present, most of the swimming directions are vertical rather than horizontal in the water column and maximum swimming velocities are approximately 1.8 cm s^{-1} (Costello et al. 1998; Matanoski et al. 2001). Furthermore, *in situ* observations of *C. quinquecirrha* swimming toward or into tidal currents did not achieve overall forward direction (Costello et al. 1998). On average, water current velocities measured along and across the NRE are approximately 5-10 cm s^{-1} (Luettich et al. 2000).

Pamlico Sound (Figure 1A) and NRE estuarine circulation is dominated by wind and density currents due to the large volume of shallow water that encompasses this system and negligible tidal ranges (0.15 m near the mouth and 0.3 m in the upper estuary) (Luettich et al. 2000; Pietrafesa et al. 1986; Roelofs and Bumpus 1953; Stanley and Nixon 1992). Wind blows across Pamlico Sound and the NRE from the south (S) to southwest (SW) between April and August and from the northwest (NW) to northeast (NE) between September and February (Wells and Kim 1989). The presence of a wind-tide (13.2 hr period) has been documented in the NRE due to a wind-induced seiche within Pamlico Sound (Luettich et al. 2002). Depending on wind magnitude, it takes roughly one to two weeks for water to move in and out of the NRE to Pamlico Sound. Water is pushed into the NRE from Pamlico Sound with winds originating from the NE and conversely, water is driven out of the NRE with SW winds (Luettich et al. 2002; Luettich et al. 2000). Water currents move across the channel of the NRE with SW winds moving water toward the north shoreline and NE winds moving water toward the south shoreline. These across-channel circulation dynamics also influence salinity and water level (Reynolds-Fleming and Luettich 2004). Observations of along and across-channel circulation in the NRE may vary from within a day to about two weeks (Luettich et al. 2002; Luettich et al. 2000; Reynolds-Fleming and Luettich 2004) and this results in a delayed observed response in the presence or absence and abundance of sea nettles along the NRE coast. A geomorphologic characteristic of the NRE is its distinct “V” shape (Figure 1) with the upstream section oriented NW-SE and the downstream section oriented SW-NE. This orientation, coupled with shallow water and dominant wind directions from the NE and SW creates a significant vector for longitudinal wind forcing in the NRE (Reynolds-Fleming and Luettich 2004). The sharp bend in the middle of the NRE has been used as a midway marker in many North Carolina estuarine studies (Buzzelli et al. 2002; Luettich et al. 2000; Reynolds-Fleming and Luettich 2004). This midway area is also the narrow section of the river estuary, which crosses the Minnesott sand ridge; a feature associated with the regional Suffolk Shoreline, a stranded Pleistocene paleo-shoreline feature (Mallinson et al. 2008; Parham et al. 2013). Since water is moved along and across this narrow NRE bend (Luettich et al. 2000), this area could serve as an accumulation area for *C. quinquecirrha*, especially if wind-generated water currents exceed the threshold of *C. quinquecirrha* swimming capabilities.

The life history of *C. quinquecirrha* and how abiotic variables influence the biology of this species has been thoroughly studied in Chesapeake Bay. Preliminary work done by Cargo and Schultz (1966), Calder (1972, 1974), and Cargo and Rabenold

(1980) documented the development and behavior of the polyp, strobila, and ephyrae in both laboratory and field observations. An ecological forecasting system has been developed to predict the distribution of medusae within Chesapeake Bay based on temperature (26-30°C) and salinity (10-14) (Decker et al. 2007). Within large bays and estuaries, including Chesapeake Bay, *C. quinquecirrha* are dominant carnivores that are adapted to estuarine salinities (Decker et al. 2007; Hamner and Dawson 2009; Purcell and Decker 2005).

The purpose of this chapter was to investigate if physical factors could be correlated to the distribution and abundance of NRE *C. quinquecirrha* at six recreation sites (Figure 1B). Since the NRE is heavily influenced by wind-driven circulation, has a geomorphology conducive for the possibility of jellyfish accumulation, and *C. quinquecirrha* are weak swimmers, I tested the null hypothesis that the distribution and abundance of *C. quinquecirrha* would not differ at NRE six recreation sites. I also investigated whether other abiotic variables could be correlated with the distribution and abundance of this species at these six sites (Figure 1B). The overall objective of this chapter was to determine if jellyfish-human interactions at the six recreational sites may be influenced by local estuarine conditions. If this is the case, it may be possible to predict when jellyfish abundance may increase at these sites.

MATERIALS AND METHODS

Study area and recreation sites

The Neuse River Estuary (NRE) is a shallow estuary located SW of Pamlico Sound, North Carolina (Luettich et al. 2000) (Figure 1). It occupies a drowned river valley that flooded and filled during the last post-glacial sea-level rise, beginning approximately 18,000 years ago (Wells and Kim 1989). The length of the NRE is approximately 70 km, with a mean width of 6.5 km and mean depth of 3.6 m (Luettich et al. 2000). For the purposes of this chapter, the estuarine shorelines of the NRE will be referred to as “north” and “south” shorelines (Figure 1B), with the horizontal axis located at the center of the NRE bend. Each shoreline had three recreation sites that spanned a horizontal distance of 15 km. These research sites were selected due to the high number of sea nettles observed annually by coastal recreationists and all sites are highly used for recreation each spring and summer.

The north shoreline sites included the Town of Oriental’s marina and two YMCA camps called Camp Sea Gull and Camp Seafarer. Oriental (OM) is located along the north bank of the NRE (Figure 1B). It is a town that has more registered boats (~1,200) than residents (~825) and offers a range of coastal activities, including sailing, fishing, kayaking, wind surfing, etc. for residents and tourists. Camp Sea Gull (CSG) and Camp Seafarer (CSF) (Figure 1B) provide activities/programs for children, teens, and adults through spring, summer, and fall. Each camp spans 8 km (5 mi) along the NRE, with approximately 0.9 km (3000 ft) of estuarine shoreline for seamanship and other water activities. During the summer camp session, each camp hosts approximately 800 campers (age 6-16).

The south shoreline sites surveyed belong to the “Neuse River Recreation Area” of the USDA Croatan National Forest; a federal national forest that encompasses 651.54 km^2 (161,000 acres) of land and offers a vast array of recreational activities for the general public. I chose three sites within this area: Flanners Beach (FB), Pine Cliff

(PC), and Siddie Fields (SF) (Figure 1B). All three sites were used as research sites because each site has an extensive beach area for recreation and frequent observations of sea nettles and therefore, a greater potential for jellyfish-human interactions.

Sea nettle abundance and in situ abiotic data collection

The abundance of *C. quinquecirrha* was surveyed using visual counts at each site within a 12-hr diurnal period, twice a week, from spring (Mid-May) to summer (Mid-August), for two consecutive years (2011-2012). On each observation day, two to four researchers counted *C. quinquecirrha* and all observations were conducted in unison. In 2011, observations did not begin until 1 June, but *C. quinquecirrha* were noted in Mid-May. In 2012, observations started in Mid-May. On each observation day, there were at least two researchers that conducted visual counts and *C. quinquecirrha* were surveyed at two types of coastal-recreation interfaces, a coastline and/or pier. At the coastline research sites (FB, PC, and SF) a 100 m transect was followed along the water's edge and jellyfish in the water or washed ashore were counted along the transect line, in adjacent coastal waters 2 m from the transect line, and in water depth less than 1 m. At CSG and CSF, coastline and pier counts were conducted. Coastline counts at each camp site were performed in the same manner as the Neuse River recreation area. A pier count was also performed at the Town of Oriental's marina (OM). All pier counts included *C. quinquecirrha* within a 2 m distance from the pier.

To standardize researcher effort and extent of observations, a 1-sec footstep pace was employed at the start and end of the transect line and/or pier. It should be noted that unlike the coastline surveys, each pier length was variable among research sites; Camp Seafarer (~200 m), Camp Sea Gull (~280 m), and Oriental Town Marina (~215 m). However, since all observations were conducted at a 1-sec footstep pace, the time spent observing jellyfish was relative to pier length. It should be noted that for all statistical analyses, *C. quinquecirrha* counts were standardized to 100 m length observations to assure that the amount of observation time was consistent among research sites. At each site, a Conductivity Temperature Depth meter (YSI CastAway) was used to measure temperature (ºC), salinity, and depth (m). Secchi disk (m) was used to approximate water turbidity. These measurements were collected from midway markers at each coastline site and in the middle and end of all pier sites. Daily stream flow (m^3 s^{-1}) data were collected from the USGS Fort Barnwell location. These abiotic variables were selected for this study because *C. quinquecirrha* medusae are greatly influenced by these variables in Chesapeake Bay (see Cargo and Schultz 1966, Cargo and King 1990, and Decker et al. 2007).

Statistical analyses and data acquisition

Sea nettle abundance (m^2) was tabulated for each site and observation day to investigate how abundance differed by month and site, and the standard deviations of all counts were calculated to account for variability in researcher observations. If the site had coastline and pier interfaces, the interface with the greatest number of *C. quinquecirrha* was used. Since *C. quinquecirrha* abundance did not fit a normal distribution, the data were transformed (Log+1) in order to fulfill the requirements of the parametric tests. Variation in mean sea nettle count was then assessed between sites, months and year using a three-way ANOVA. For this analysis, since no data were collected in May 2011, only the months June, July, and August were used for both years. To compare annual mean *C. quinquecirrha* counts (Log+1) in 2011 and 2012, a *t*-test was performed. Comparisons were also made for abiotic variables between years using *t*-tests.

Pearson correlations were used to compare *C. quinquecirrha* abundance and all abiotic variables by year and by shoreline. Wind data were acquired from the National Weather Service, NOAA weather station at Cherry Point Marine Base and Cape Hatteras Weather Station, North Carolina. These weather stations were the same used by Luettich et al. (2000, 2002) and Reynolds-Fleming and Luettich (2004) to generate models of wind-driven circulation in APES, the NRE and the Renaissance Computing Institute (RENCI), Coastal Emergency Risks Assessment (NC-CERA), ADCIRC Coastal Circulation and Storm Surge Model + SWAN Wave Model. Wind variables included daily wind speeds (m s^{-1}) and directions (North = 0°) that were calculated from hourly data. To observe wind dynamics, wind diagrams were created to observe daily changes in wind speed (m s^{-1}) and direction (North = 0°). Pearson correlations were used to determine if wind events (when wind speed increased by at least 4 m s^{-1} over the course of 6 hours) were correlated to *C. quinquecirrha* abundance and distribution. The time frame of a week prior to observations was used for wind speed, wind direction, and wind event analyses because variable wind speeds and directions affect surface current vectors in the NRE within this time frame (Luettich et al. 2000; Luettich et al. 2002). To help create conceptual diagrams of *C. quinquecirrha* and wind dynamics, NRE water velocity and direction data were acquired from model runs generated by the RENCI NC-

CERA ADCIRC model from nodes within 100 – 300 m of FB in 2011 and all research sites in 2012.

RESULTS

Abiotic variables compared by year

Mean temperature, salinity, stream flow, and wind speed measured at Cherry Point were all significantly different in 2011 and 2012 (Table 1). The range in stream flow and salinity was considerably smaller in 2011 than 2012 (Table 1, Figure 2). There was also a larger range in wind speed in 2011 (Figure 3). Mean wind directions measured at Cherry Point as well as mean wind speed and direction measured from the Hatteras weather station were not significantly different (Figure 3).

Variation in C. quinquecirrha abundance

A total of 3,241 ± 800 (standard deviation) *C. quinquecirrha* were counted at all research sites in 2011 and 2012 (Figure 4). The *t*-test showed that mean *C. quinquecirrha* counts for 2011 and 2012 were not significantly different (t = -0.47, DF = 729.3, p-value = 0.64). Overall, the majority of *C. quinquecirrha* were counted in July and the least in August (Figure 4). The three-way ANOVA revealed significant differences in mean *C. quinquecirrha* count by sites and months and significant interactions among all three factors (Table 2).

Abiotic parameter and wind correlations

Most of the *C. quinquecirrha* abundance correlations with *in situ* abiotic variables were not significant on the north (Table 3) and south (Table 4) shorelines. Weak but statistically significant correlations were noted with stream flow on the north shoreline ($R = -0.20$, p-value = 0.01) and depth ($R = -0.19$, p-value = 0.02), secchi ($R = -0.19$, p-value = 0.02), and salinity ($R = 0.18$, p-value = 0.04) on the south shoreline. Wind speeds measured from Cherry Point one and two days prior to observations and wind data measured from Hatteras also had weak correlations with wind direction two days prior and wind speeds one and two days prior to north shoreline observations (Table 3). On the south shoreline, wind speed measured from Cherry Point one day prior to observations was correlated with *C. quinquecirrha* abundance. Significant correlations were also noted with wind direction and speeds measured from Hatteras one and two days prior to observations (Table 4).

Wind events and C. quinquecirrha abundance

Wind event correlations were higher than the correlations with daily averaged wind speeds and directions (Table 3 and Table 4). During this study, wind events of 3 to 8 ms^{-1} ($N = 7$) measured at Cherry Point occurred in July 2011, May 2012, and June 2012 (Figure 6) and correlations were observed with wind direction five days prior to observations on the north shoreline (Table 5) and one day prior to observations on the south shoreline (Table 6). Wind events from 2 to 7 ms^{-1} ($N = 8$) measured at Hatteras occurred in May, June 2011 and May, June and July 2012 (Figure 7) and there were no significant correlations made with abundance on the north shoreline. A negative correlation ($R = -0.54$, *p-value* = 0.02, Table 6) with *C. quinquecirrha* abundance on the south shoreline and wind direction two days prior to observations was observed. It should be noted that wind events up to 6 ms^{-1} were observed with the greatest frequency (Figure 6 and Figure 7). When wind events of 3 to 8 ms^{-1} were measured from Cherry Point, *C. quinquecirrha* abundance ranged from 50 to 280 m^2 on the north and south shorelines with wind directions SE, S, and SW (Figure 8A). A smaller range of abundance measuring 25 to 75 m^2 was associated with NE and E wind directions and in general, larger abundances were recorded on the south shoreline (Figure 8B). The distribution of *C. quinquecirrha* along the south shoreline was not uniform, instead, higher abundances were observed at PC and SF when wind events occurred from a SSE to a SSW direction (Figure 8B). Wind events in August were not included in these analyses because no jellyfish were observed in August 2011 and < 10 jellyfish were observed in August 2012.

DISCUSSION

Wind dynamics and C. quinquecirrha in the NRE

My data showed that wind speed and direction are correlated to the distribution and abundance of *C. quinquecirrha* in the NRE; therefore, I rejected my null hypothesis that there is no difference in sea nettle abundance among the six recreational sites. It was interesting that wind dynamics appear to be more influential to NRE jellyfish-human interactions than other abiotic variables, including temperature and salinity. When wind events occurred, I found that SSE to SSW wind directions one day prior to observations could be correlated with increased numbers of *C. quinquecirrha* along the south shoreline, particularly at stations PC and SF (Figure 1, Figure 8B). The highest abundances of 300 m^2 observed at PC and SF were correlated to S to SW winds (Figure 8B) and because *C. quinquecirrha* are weak swimmers with maximum swimming velocities of 1.8 cm s^{-1} (Costello et al. 1998; Matanoski et al. 2001) it is likely that these abundances are a function of the water currents, shallow waters, and geomorphology of the NRE.

Wind dynamics and stream flow are two major factors that influence how water moves in the NRE (Luettich et al. 2000) and in 2011 there was significantly less stream flow than in 2012 (Table 1, Figure 2). Weak stream flow and averaged water velocities obtained from ADCIRC data near Flanners Beach (Figure 1B) showed along-channel water movement (currents toward the NW and SE) instead of across-channel water movement (currents toward NE and SW) as observed in 2012 (RENCI 2012). However, with no data available for the other sites in 2011, I cannot conclude that water velocities and direction were similar or an anomaly of the 2012 data. Therefore, although water directions observed near Flanners Beach may have been different in 2011 and 2012, I do not attribute this variation to an increase or decrease in *C. quinquecirrha* abundance (Figure 4). Instead, understanding that during June and July, wind speed and direction are the primary drivers of water currents that move either along or across the channel of the NRE (Luettich et al. 2000; Reynolds-Fleming and Luettich 2004); I suggest that variation in *C. quinquecirrha* abundance is a function of wind-driven circulation more so than stream flow dynamics. Surface currents of 5 to 13 cm s^{-1} will move water downstream (east of the bend) when SW winds were measured at 8 m s^{-1} (Luettich et al. 2000; RENCI 2012). Movement of jellyfish is likely to follow the downstream direction of the surface current and accumulation occurs at the bend of the NRE, which coincides with the PC and SF locations (Figure 9A) and water current directions obtained from the RENCI ADCIRC model.

Downstream surface currents generated from SW winds will also decrease in speed when winds shift to opposing directions and this can occur in short periods of time from hours to within a week (Luettich et al. 2000). These downstream surface current dynamics could explain why large numbers of *C. quinquecirrha* were not uniformly observed throughout the field seasons at PC and SF. All south shoreline sites were coastline interfaces with beaches and large expanses of shallow water, therefore, it is plausible that *C. quinquecirrha* were washed ashore by surface currents and confined to these areas with shallow water depths. Water is also moved into NRE from Pamlico Sound via a NE wind; and when wind events were measured from Cherry Point, the movement of water toward the south shoreline could also favor the accumulation of *C. quinquecirrha* at the bend of the NRE (Figure 9B). A SW wind could also move *C. quinquecirrha* away from this accumulation area, which is near PC and SF, depending on water currents near the bend of the NRE and this may explain why I noted a negative correlation (R = -0.54, p-value = 0.02) with wind events measured from Hatteras two days prior to observations (Figure 9C). These observations may reflect the 13.2 hr wind tide, or seiche of water that moves in and out the NRE with NE and SW winds (Luettich et al. 2000).

Water depth is also influenced by water currents that move across the NRE channel; SW winds 2 to 8 m s^{-1} will lower water depths on the south shoreline (Reynolds-Fleming and Luettich 2004) and this contributed to an increase in south shoreline *C. quinquecirrha* abundance (Figure 9D). South shoreline *C. quinquecirrha* abundance was also correlated with NE wind events and because NE winds 2 to 5 m s^{-1} generate currents 5 to 10 cm s^{-1} that move toward the south shoreline (Luettich et al. 2000), cross channel water circulation may also explain accumulations of jellyfish on the south shoreline via wind (Figure 9E). Although the wind events correlation (R = 0.53, p-value = 0.00) was weaker on the north shoreline versus the south shoreline, NE winds can upwell bottom water along the north shoreline, which could bring *C. quinquecirrha* to the surface and explain why jellyfish abundance also corresponded to NE wind events five days prior to observations (Figure 9E). A five day lag in *C. quinquecirrha* observations reflected the delayed response of water movement with wind dynamics as described by Luettich et al. 2000 and Reynolds-Fleming and Luettich 2004 in the NRE. Additionally, SW winds 7 m s^{-1} can generate water currents up to 5 cm s^{-1}, which move water toward the north shoreline (Luettich et al. 2000), increasing the likelihood of more *C. quinquecirrha* being pushed toward the north shoreline (Figure 9D). It should be noted that lower abundance was consistently observed at the north shoreline recreations sites (Figure 8A). A possible explanation for this is all north shoreline sites were pier interfaces, which made accumulation and confinement of jellyfish less likely to occur at these recreation sites. Therefore, future abundance studies should use beach seines and trawl nets to compare if there are significant differences in sea nettle abundance on the south and north shorelines, respectively.

C. quinquecirrha life history stages and inference to North Carolina

I did not find significant correlations with *C. quinquecirrha* medusa abundance and temperature and/or salinity at the six NRE recreation sites. This was surprising as these variables correlate strongly with medusa presence in Chesapeake Bay (Decker et al. 2007). It is possible that the shallow nature of the NRE yields different relationships with the abiotic variables commonly associated with life history stages of *C. quinquecirrha*. The NRE can be a strongly stratified estuary or a well-mixed estuary depending on wind direction (Luettich et al. 2000), therefore temperature and salinity correlations with *C. quinquecirrha* may be similar to Chesapeake Bay observations but at shorter time intervals. Field research in Chesapeake Bay noted that ephyrae production started in April and continued to early July; however, the highest number of ephyrae produced was during the spring (Calder 1974; Cargo and Rabenold 1980). Ephyrae of *C. quinquecirrha* have not been documented in North Carolina; however, the movement of ephyrae in the NRE can be inferred using Chesapeake Bay life history and APES estuarine circulation literature. In the NRE, Wells and Kim (1989) reported that the highest freshwater input occurred in February (high precipitation, low evaporation) and the lowest freshwater input occurred in June (low precipitation, high evaporation). Therefore it is likely that the dominant circulation type, estuarine circulation, is prominent during February and extends into spring. Calder (1974) noted that ephyrae production is highest in the spring in Chesapeake Bay and when dispersed ephyrae will swim toward bottom waters (Calder 1974). This behavior coupled with the estuarine circulation noted during spring months, would favor the movement of ephyrae into the NRE from Pamlico Sound via estuarine circulation and these ephyrae would be isolated therein.

Ephyrae production occurs at a bi-monthly rate (Calder 1974); therefore aggregations of *C. quinquecirrha* medusae in APES and the NRE should be similar to

Chesapeake Bay where jellyfish are observed in variable frequencies and abundances. With adequate nutrition, ephyrae can grow into medusae within a month (Calder 1972; Olesen et al. 1996). Therefore, based on Chesapeake Bay literature and NRE estuarine circulation dynamics, the *C. quinquecirrha* medusa stage should be present toward the end of spring, with highest numbers in the summer (Calder 1972; Decker et al. 2007). In our two year study, *C. quinquecirrha* presence began in Mid-May and decline began in late July at the six recreation sites in the NRE (Figure 1B). These observations coincide with Miller's (1974) *C. quinquecirrha* observations conducted in the PRE (Figure 1A). Miller (1974) attributed the spring presence of *C. quinquecirrha* in the PRE to dramatic decreases in *M. leidy*i abundance and noted that *M. leidyi* abundance steadily declined until the end of July or as long as *C. quinquecirrha* were present. It is well known that *C. quinquecirrha* feed on *M. leidyi* and this relationship has been thoroughly documented in many Chesapeake Bay food web studies and experiments (Baird and Ulanowicz 1989; Cargo and Schultz 1967; Feigenbaum and Kelly 1984; Purcell 1992; Purcell et al. 1994a; Purcell et al. 1994b). I observed *M. leidyi* in the early spring of each field season and made note that by the end of June none were present at the study sites. Other than these observations, no surface counts and/or abundance surveys were taken of *M. leidyi*. To date, *C. quinquecirrha* abundances in the PRE have been reported to be 2 m^{-3} via net sampling (Miller 1974).

It is also possible that *C. quinquecirrha* polyps have an established habitat within the NRE and ephyrae are moved around the NRE by wind-induced water circulation. Possible NRE polyp habitat sources include docks or oyster sanctuaries (Figure 1A) and *C. quinquecirrha* polyps appear to preferentially settle on oyster shells (Breitburg and Fulford 2006; Calder 1974). Since 1996, the North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries (DMF) has launched an oyster sanctuary program where ten oyster sanctuaries have been established within Pamlico Sound (Figure 1A), with a sanctuary located in the NRE (Figure 9), to develop and protect native oyster brood stock and increase biodiversity. If these oyster sanctuaries provide habitat for *C. quinquecirrha* polyps, then they are a likely source population for medusae to enter the NRE. In contrast, it is also quite possible that the oyster sanctuaries may not be suitable habitat for *C. quinquecirrha* polyp populations. To date, no *in situ* experiments have evaluated this potential nor the contribution and possible preference of human supplied substrate for *C. quinquecirrha* polyps in North Carolina Estuaries, including the NRE.

In this study, *C. quinquecirrha* abundance was calculated from surface counts divided by the area of observation (100m length of coastline or pier * the field of view per observer 2m) multiplied by the depth of observations (1m). From this calculation, we concluded that *C. quinquecirrha* abundance varied from 0 to ~2 per m^3, with greater *C. quinquecirrha* abundances noted at the NRE south shoreline sites in July (Figure 9). Although different methods were employed in this study and Miller's study in 1974, the 2 m^{-3} *C. quinquecirrha* abundance observations and the seasonal presence/absence of *C. quinquecirrha* noted raises two interesting points about the *C. quinquecirrha* populations in North Carolina. First, the abundance of *C. quinquecirrha* populations in North Carolina seems to be much less than those sampled in Chesapeake Bay, where the highest abundance of ~16 m^{-3} occurs in July and August (Purcell 1992). Second, the sea nettle season in North Carolina reduces to a few sighted jellyfish in August whereas sea nettles in Chesapeake Bay are present in low abundances through the fall until October (Purcell et al. 1994b). Longer term studies on the biology of *C. quinquecirrha* are needed to confirm these abundance observations and accurately report sea nettle population dynamics in North Carolina.

CONCLUSIONS

My study has shown that jellyfish-human interactions in the NRE are influenced by wind speed, wind direction, and subsequently water current direction. Prevalent SE to SW wind events cause large numbers of *C. quinquecirrha* to accumulate at recreation sites on the south shoreline one day after a wind event and significant increases or decreases may be noted on the north shoreline five days after a wind event, depending on direction. Rosa et al. (2012), also correlated wind speed and SE direction to an increase in the abundance of *Pelagia noctiluca* [Fosskaal, 1775] (R = 0.2, p-value = 0.01) at a sheltered research site (S. Agata) in the Straits of Messina, Italy. However, unlike my study where wind was a very influential factor in *C. quinquecirrha* abundance, stronger correlations were made with temperature and the abundance of *P. noctiluca* (Rosa et al. 2012). In addition to wind direction, it is known that Langmuir circulation is associated with patch formations of jellyfish species (Hamner and Schneider 1986; Larson 1992). In Belize, Larson (1992) observed *Linuche unguiculata* [Roberts, 1827] in slicks and windrows with flotsam that are oriented parallel to wind, which are indications of Langmuir circulation. The *L. unguiculata* are aggregated at the convergence zones between adjacent Langmuir cells and remain there by the jellyfish’s upward swimming behavior. Circular swimming behavior also reduces the rate of patch dispersion and may explain why jellyfish patches were observed when Langmuir circulation was not prominent in March and April (Larson 1992). In the Bering Sea, species of hydromedusae and scyphomedusae are also aggregated at surface waters between Langmuir convergence cells (Hamner and Schneider 1986). These aggregations form rows between the areas of convergence and divergence that may be evenly dispersed by 100 m. This linear pattern may be advantageous for jellyfish predation, especially at night when planktonic prey will migrate vertically to surface waters where the jellyfish are gathered. However, confinement of jellyfish to the surface waters also increases the likelihood of predation, especially from seabirds (Hamner and Schneider 1986).

Wind dynamics may be used to potentially predict the distribution and abundance of *C. quinquecirrha* in the NRE; therefore, these data may be used to reduce harmful jellyfish-human interactions and thereby reducing the possibility of loss in tourism/recreation revenue. Jellyfish stings in tourism and/or recreations areas have been an on-going coastal management problem globally and coastal communities have responded by attempting to minimize these jellyfish-human interactions. For example, in Australia, public awareness, mitigation devices, and on-site first-aid stations have been made available to tourists (Gershwin et al. 2010). Public education and awareness, including information posted on signs and pamphlets about jellyfish given to beach-goers, has also helped people cope with large numbers of jellyfish on German beaches (Baumann and Schernewski 2012). In Chesapeake Bay, large numbers of the *C. quinquecirrha* have affected coastal recreationists since the 1960's (Cargo and Schultz 1966). Fortunately, over 50 years of research on this stinging jellyfish species in Chesapeake Bay has provided the foundation for a monitoring system, which has continued to accurately predict the probability of encountering a sea nettle (Decker et al. 2007). In areas where extensive jellyfish research is limited, public monitoring of high numbers of stinging species has been conducted to reduce harmful jellyfish-human interactions. Examples of these observations include the high likelihood of occurrence of the harmful box jellyfish species historically referred to as *Carybdea alata* [Reynaud, 1830] but currently regarded as *Alatina moseri* [Mayer, 1906] (Bentlage et al. 2010; Gershwin 2005) on Waikīkī Beach, Hawaiʻi, 8 to 12 days after a full moon (Thomas et al. 2001), and more recently *C. quinquecirrha* abundances are frequently reported to the public by the Barnegat Bay Partnership in Barnegat Bay, New Jersey. The use of data gathered from research and public interfaces will increase the likelihood of successful management of jellyfish-human interactions.

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LIST OF TABLES AND FIGURES

Table 6. South shoreline, Pearson correlations with sea nettle count (log+1) and wind events 3 to 8 ms^{-1} (N = 7) measured from Cherry Point Marine Base Weather Station (CP)

Table 7. South shoreline, Pearson correlations with sea nettle count (log+1) and wind events 2 to 7 ms^{-1} (N = 8) measured from Cape Hatteras Weather Station (HT)

Figure 1. (A) The Albermarle-Pamlico estuarine system (APES), which includes Albermarle Sound, Pamlico River Estuary (PRE) and Neuse River Estuary (NRE). The circles indicate the location of the North Carolina Division of Marine Fisheries oyster sanctuaries. The Cape Hatteras Weather Station (HT) and Cherry Point Marine Base Weather Station (CP) were the weather stations used to collect wind data for this study. (B) Research was conducted in the Neuse River Estuary (NRE) at the 6 starred locations: Camp Seafarer (CSF), Camp Sea Gull (CSG), Oriental Town (OM), Flanners Beach (FB), Pine Cliff (PC), and Siddie Fields (SF). The squares within the NRE are the approximate locations of the current nodes of the RENCI ADCIRC forecast model data for 2011 (site nearest FB only) and 2012 (all gauges). The circles on this Figure indicate the oyster sanctuaries in closest proximity to the NRE.

Figure 2. Box plots of stream flow and salinity in 2011 and 2012. *T-test p*-values are displayed to compare differences in 2011 and 2012 mean stream flow (N = 231) and salinity (N = 196), accordingly. Open circles indicate outliers > 1.5 times of upper and lower quartile and horizontal bars within the box plots indicate the count median. The

upper box above the median extends to the third quartile and the lower box extends to the first quartile. The bars extend to the largest and smallest values, respectively.

Figure 3. Box plots of wind speed and direction measured from Cherry Point Marine Base (N = 170) and Cape Hatteras (N = 177) weather stations for 2011 and 2012. *T-test* *p*-values are displayed to compare differences in 2011 and 2012 mean wind speed and direction, accordingly. Horizontal bars within boxplots indicate sample median. The upper box above the median extends to the third quartile and the lower box extends to the first quartile. The bars extend to the largest and smallest values, respectively.

Figure 4. The total amount of *C. quinquecirrha* counted with standard deviation error bars for field seasons 2011 (N = 150) and 2012 (N = 149).

Figure 5. Box plots showing the range of sea nettle counts (Log +1) at the research sites Camp Seafarer (CSF), Camp Sea Gull (CSG), Oriental Town (OM), Flanners Beach (FB), Pine Cliff (PC) and Siddie Fields (SF) in 2011 and 2012. Open circles indicate outliers > 1.5 times of upper quartile and horizontal bars within the box plots indicate the count median. The upper box above the median extends to the third quartile and the lower box extends to the first quartile. The bars extend to the largest and smallest values, respectively. Data was standardized to ~100m observation length per site.

Figure 6. Daily wind speeds and directions in the 2011 and 2012 field seasons at Cherry Point Marine Base Weather Station. Inverted triangles indicate wind events, where winds increased in speed from 3 to 8 ms^{-1}.

Figure 7. Daily wind speeds and directions in the 2011 and 2012 field seasons at Cape Hatteras Weather Station. Inverted triangles indicate wind events, where winds increased in speed from 2 to 7 ms^{-1}.

Figure 8. (A) Sea nettle abundance (m^2) with standard deviation error bars compared to wind directions observed at North shoreline sites Camp Seafarer (CSF), Camp Sea Gull (CSG) and Oriental Town (OM) with wind events changed from 3 to 8 ms^{-1} occurring five days prior to observations in July 2011, May 2012 and June 2012. (B) Sea nettle abundance (m^2) with standard deviation error bars compared to wind directions observed at South shoreline sites Flanners Beach (FB), Pine Cliff (PC) and Siddie Fields (SF) with wind events from 3 to 8 ms^{-1} occurring one day prior to observations in July 2011, May 2012 and June 2012.

Figure 9. Conceptual diagram of wind-driven circulation circulation and NRE sea nettle observations. Wide arrows indicate wind direction from the SW (A, C, D) and NE (B, E) measured from Cherry Point Marine Base Weather Station (CP) or Cape Hatteras (HT) and narrow arrows show water current direction based on work done by Luettich et al. (2000), Reynolds-Fleming and Luettich (2004), the RENCI NC-CERA ADCIRC forecast model data from 2012, and water depth observed in this study. Water depth (the

solid/curved line) at the coastline sites on the South shoreline (S), Flanners Beach (FB), Pine Cliff (PC) and Siddie Fields (SF) and pier sites Camp seafarer (CSF), Camp Sea Gull (CSG) and Oriental Town (OM) on the North shoreline (N) is influenced by wind-driven circulation circulation in the NRE and may also affect sea nettle distribution and abundance. Circles on each NRE map indicate the location of the two nearest oyster sanctuaries. Shorelines, Pearson correlation coefficients and *p*-values are displayed on the top of each figure and for figures D and E, above each abundance graph for reference. The value and bar in the center of each abundance bar plot are the averages of sea nettles counted at each site for both study years.

Table 1.

***T-test* comparison of abiotic variables by year**							
variables	*year*	*min*	*max*	*mean*	*median*	*t stat*	*p-value*
Depth (m)	2011	0.3	2.7	1.3	1.0	-1.5	0.1
	2012	0.3	3.1	1.4	1.2		
Secchi (m)	2011	0.3	1.4	0.7	0.7	-1.6	0.1
	2012	0.3	1.6	0.8	0.8		
Temperature (ºC)	2011	22.2	38.0	29.5	19.2	7.0	< 0.001*
	2012	21.3	33.9	27.5	28.9		
Salinity	2011	8.8	30.7	18.9	19.2	13.7	< 0.001*
	2012	1.0	23.7	13.1	13.6		
Stream flow (m^3s^{-1})	2011	425	2130	850	722	-12.1	< 0.001*
	2012	559	6300	2469	2100		
CP Wind speed (ms^{-1})	2011	1.0	8.0	3.9	4.0	3.6	0.0*
	2012	1.0	7.0	3.2	3.0		
CP Wind direction (North = 0°)	2011	48.0	246.0	161.9	180.0	1.7	0.1
	2012	29.0	285.0	147.3	148.0		
HT Wind speed (ms^{-1})	2011	1.7	6.4	3.8	3.6	-0.3	0.7
	2012	2.0	7.0	3.8	4.0		
HT Wind direction (North = 0°)	2011	46.3	258.3	176.6	194.2	0.8	0.5
	2012	25	267.0	169.8	194.0		

Table 2.

Comparison of sea nettle count by site, month and year					
ANOVA	*DF*	*Sum Sq*	*Mean Sq*	*F-value*	*p-value*
Site	5	21.6	4.3	23.1	< 0.001*
Month	2	46.0	23.0	122.9	< 0.001*
Year	1	0.34	0.3	1.8	0.18
Site * Month	10	19.8	2.0	10.6	< 0.001*
Site * Year	5	3.7	0.7	4.0	0.00*
Month * Year	2	7.8	0.9	4.8	0.00*
Site * Month * Year	10	5.89	0.6	3.1	0.00*

Table 3.

North shoreline, Pearson correlations with *in situ* and wind variables		
variables (log)	*R*	*p-value*
stream flow (m^3s^{-1})	-0.20	0.01
CP 1 day prior wind speed (ms^{-1})	0.35	< 0.001
CP 2 day prior wind speed (ms^{-1})	0.28	0.00
HT 1 day prior wind speed (ms^{-1})	0.18	0.03
HT 2 day prior wind speed (ms^{-1})	0.25	0.00
HT 2 day prior wind direction (North = 0°)	0.19	0.02

Table 4.

South shoreline, Pearson correlations with *in situ* and wind variables		
variables (log)	*R*	*p-value*
depth (m)	-0.19	0.02
secchi (m)	-0.19	0.02
Salinity	0.18	0.04
CP 1 day prior wind speed (ms^{-1})	0.21	0.01
CP 1 day prior wind direction (North = 0°)	0.24	0.00
HT 1 day prior wind direction (North = 0°)	0.28	0.00
HT 2 day prior wind speed (ms^{-1})	0.22	0.00
HT 2 day prior wind direction (North = 0°)	0.20	0.02

Table 5.

North shoreline, Pearson correlations with wind events 3 to 8 ms^{-1} (*N* = 7)		
variables (log)	*R*	*p-value*
CP 5 days prior wind speed ($m\ s^{-1}$)	0.41	0.03
CP 5 days prior wind direction (North = 0°)	0.53	0.00

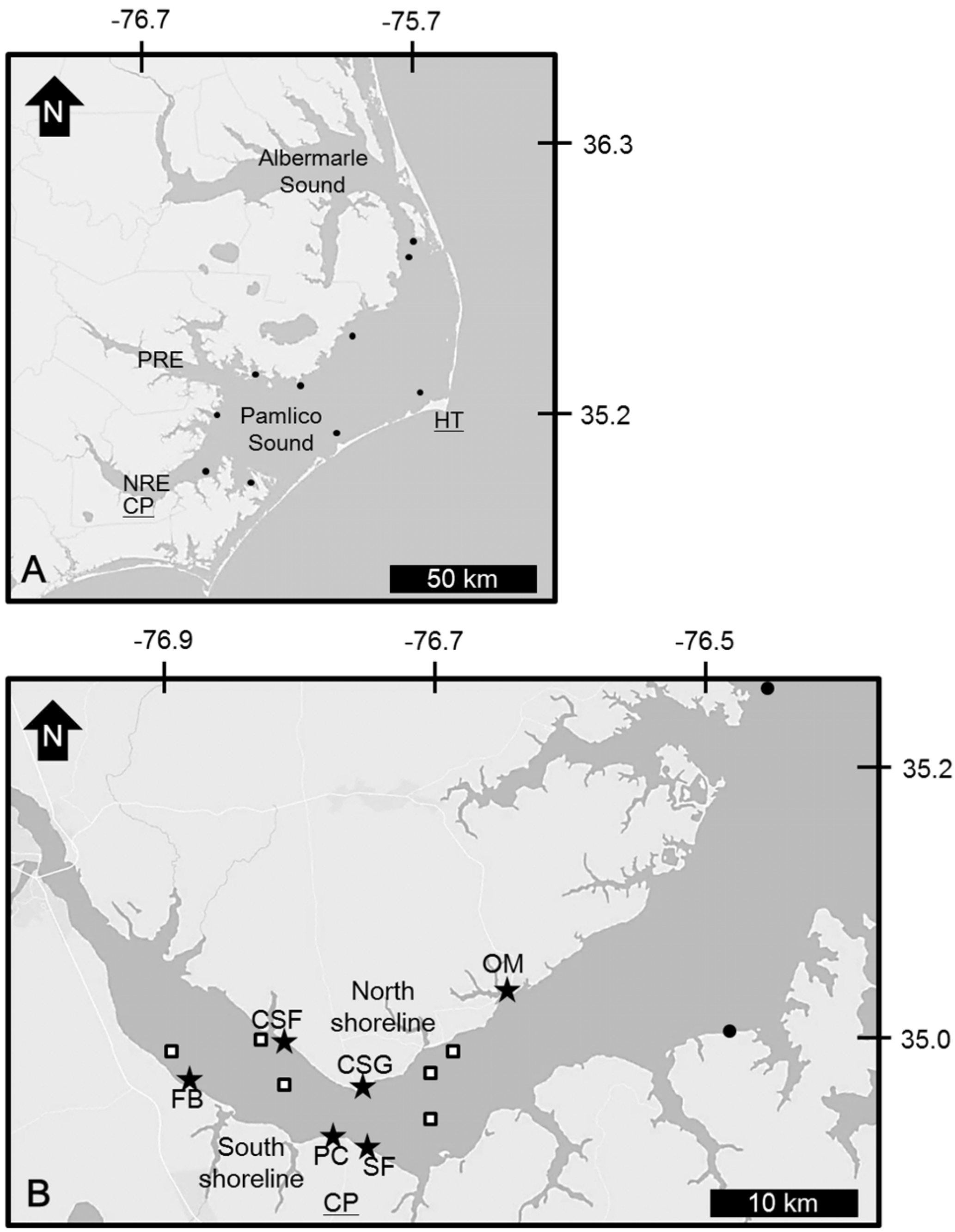
Table 6.

South shoreline, Pearson correlations with wind events 3 to 8 ms^{-1} (*N* = 7)		
variables (log)	*R*	*p-value*
CP 1 day prior wind direction (North = 0°)	0.70	4.07 e-05
CP 3 days prior wind speed ($m\ s^{-1}$)	0.57	0.00
CP 4 days prior wind speed ($m\ s^{-1}$)	0.46	0.01
CP 6 days prior wind speed ($m\ s^{-1}$)	0.53	0.00

Table 7.

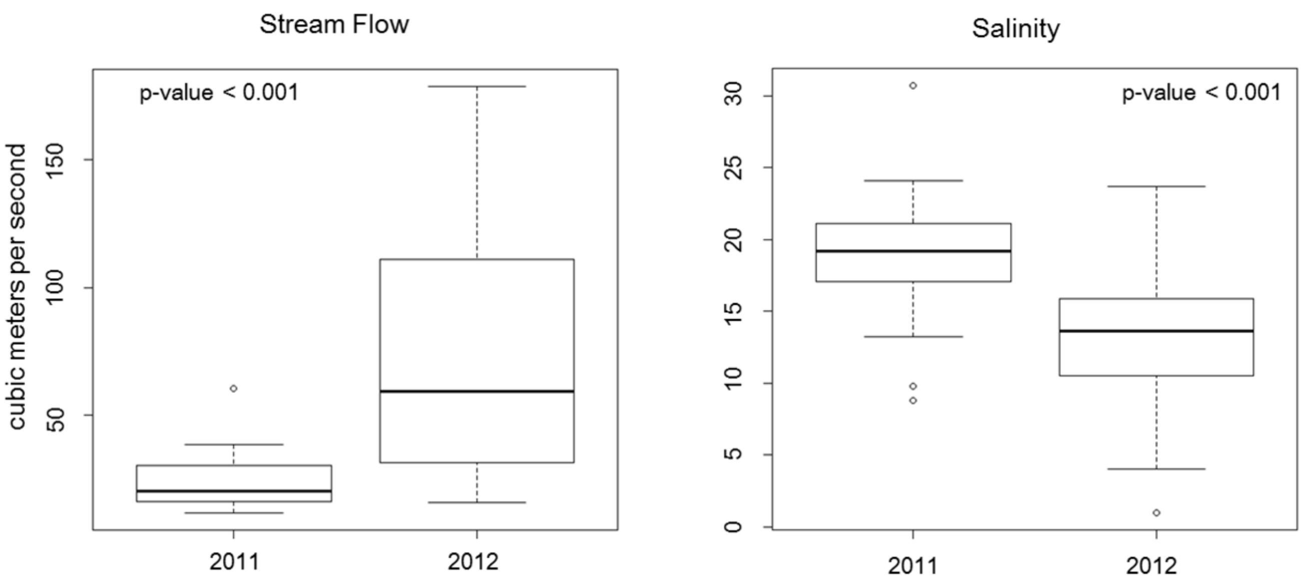
South shoreline, Pearson correlations with wind events 3 to 8 ms^{-1} (*N* = 8)		
variables (log)	*R*	*p-value*
HT 2 days prior wind direction (North = 0°)	-0.54	0.01
HT 7 days prior wind speed (m s^{-1})	0.49	0.02

Figure 1.



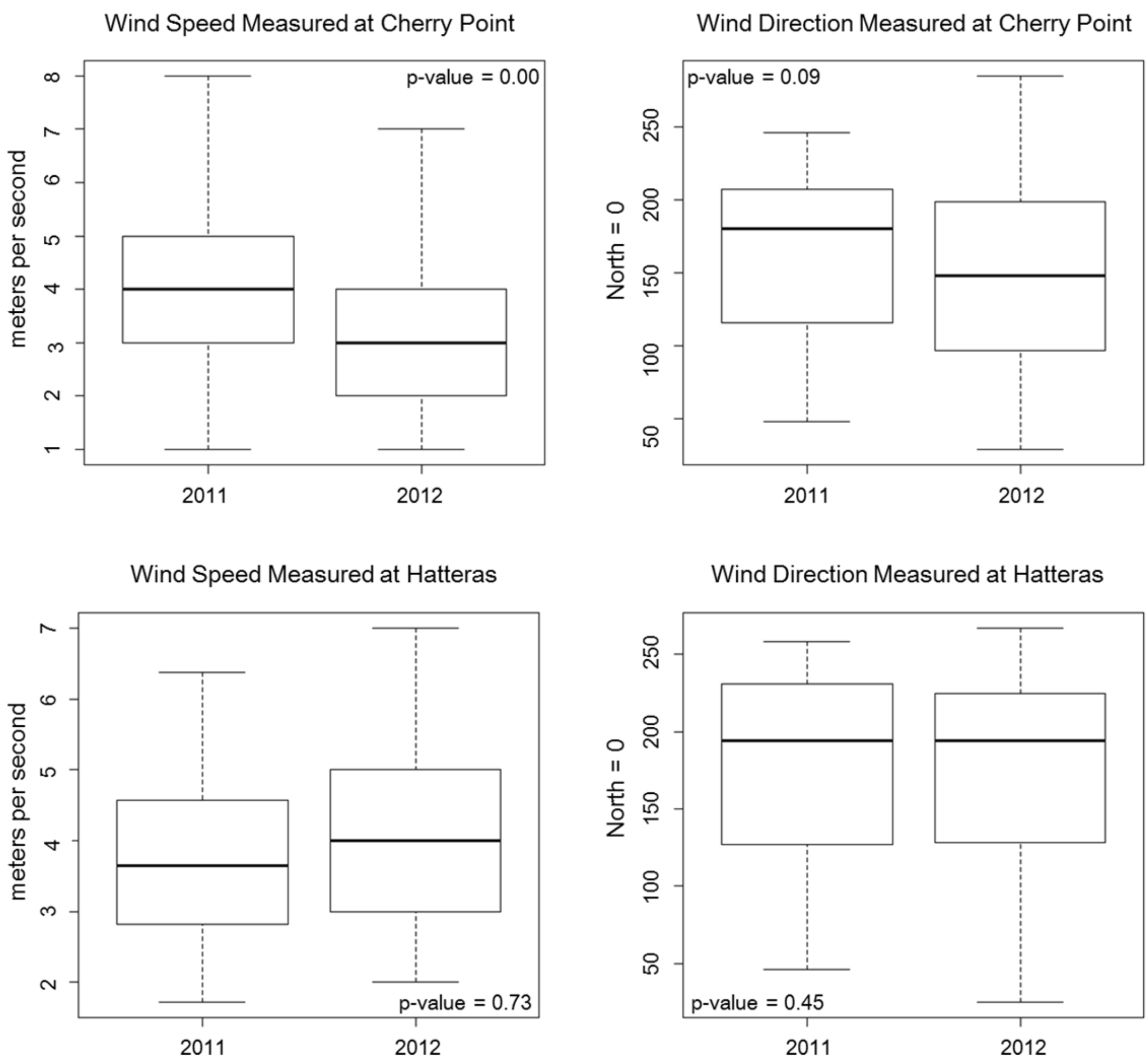
-76.7
-75.7
N
36.3
Albermarle Sound
PRE
Pamlico Sound
35.2
HT
NRE
CP
A
50 km
-76.9
-76.7
-76.5
N
35.2
OM
North shoreline
CSF
35.0
CSG
FB
South shoreline
PC
SF
CP
B
10 km

Figure 2.



Stream Flow
p-value < 0.001
cubic meters per second
50
100
150
2011
2012
Salinity
p-value < 0.001
0
5
10
15
20
25
30
2011
2012

Figure 3.



Wind Speed Measured at Cherry Point
p-value = 0.00
meters per second
1
2
3
4
5
6
7
8
2011
2012
Wind Direction Measured at Cherry Point
p-value = 0.09
North = 0
50
100
150
200
250
2011
2012
Wind Speed Measured at Hatteras
p-value = 0.73
meters per second
2
3
4
5
6
7
2011
2012
Wind Direction Measured at Hatteras
p-value = 0.45
North = 0
50
100
150
200
250
2011
2012

Figure 4.

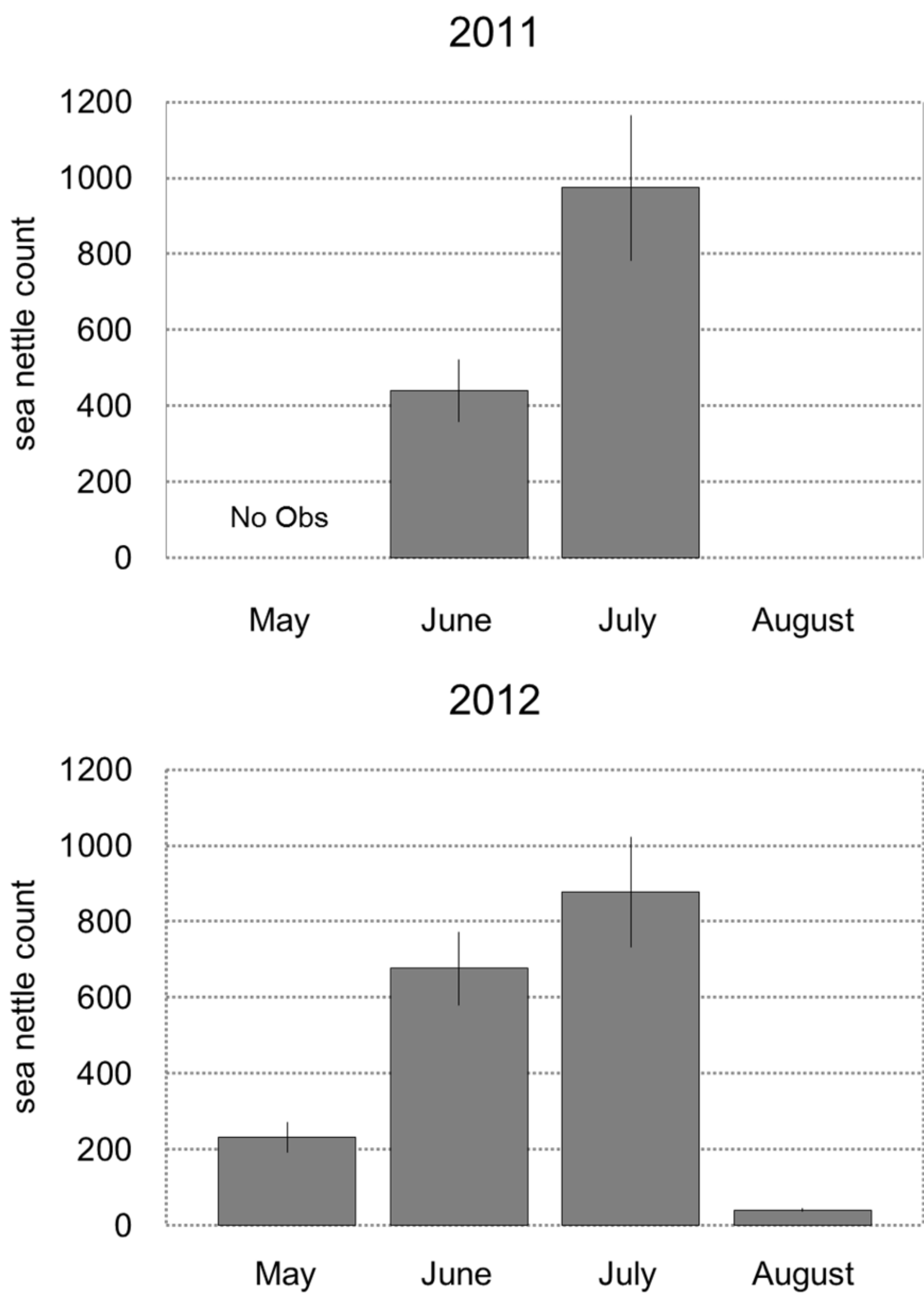
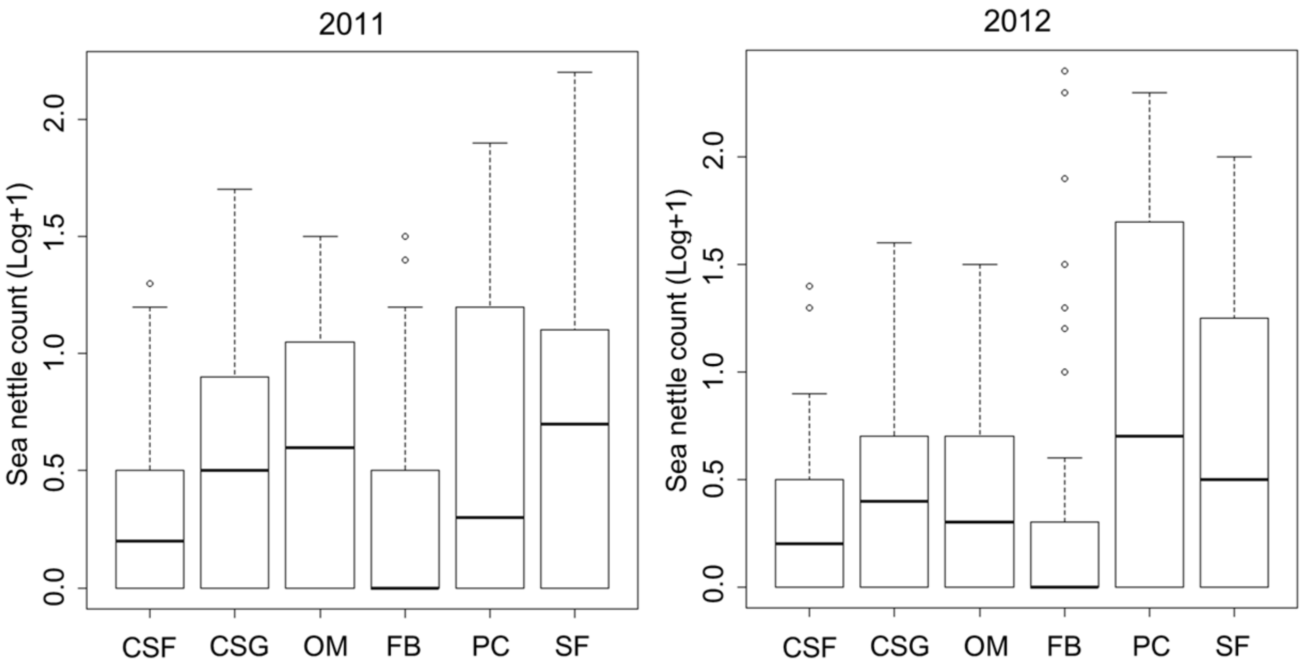
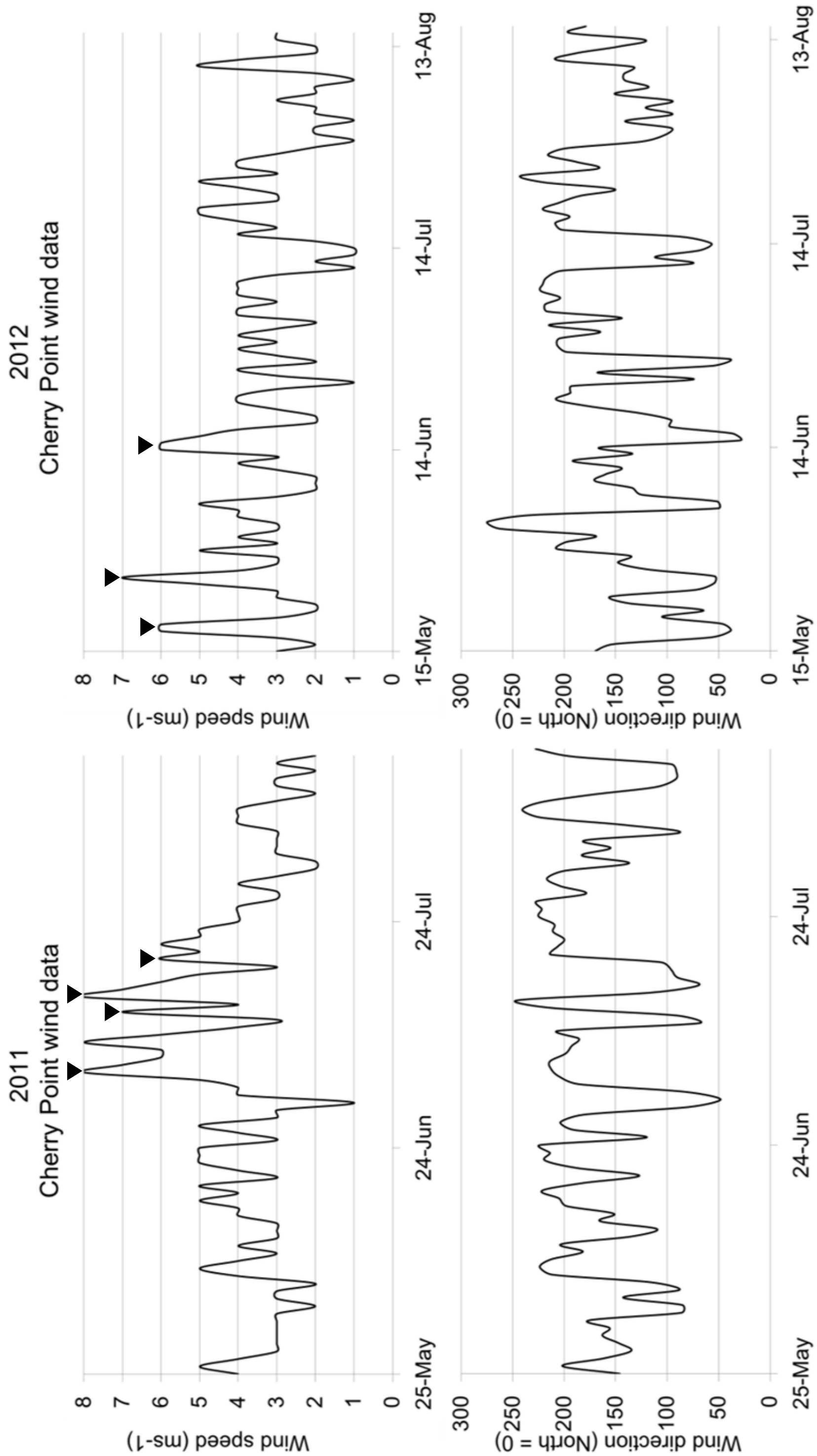

2011
1200
1000
800
600
400
200
0
sea nettle count
No Obs
May
June
July
August
2012
1200
1000
800
600
400
200
0
sea nettle count
May
June
July
August

Figure 5.



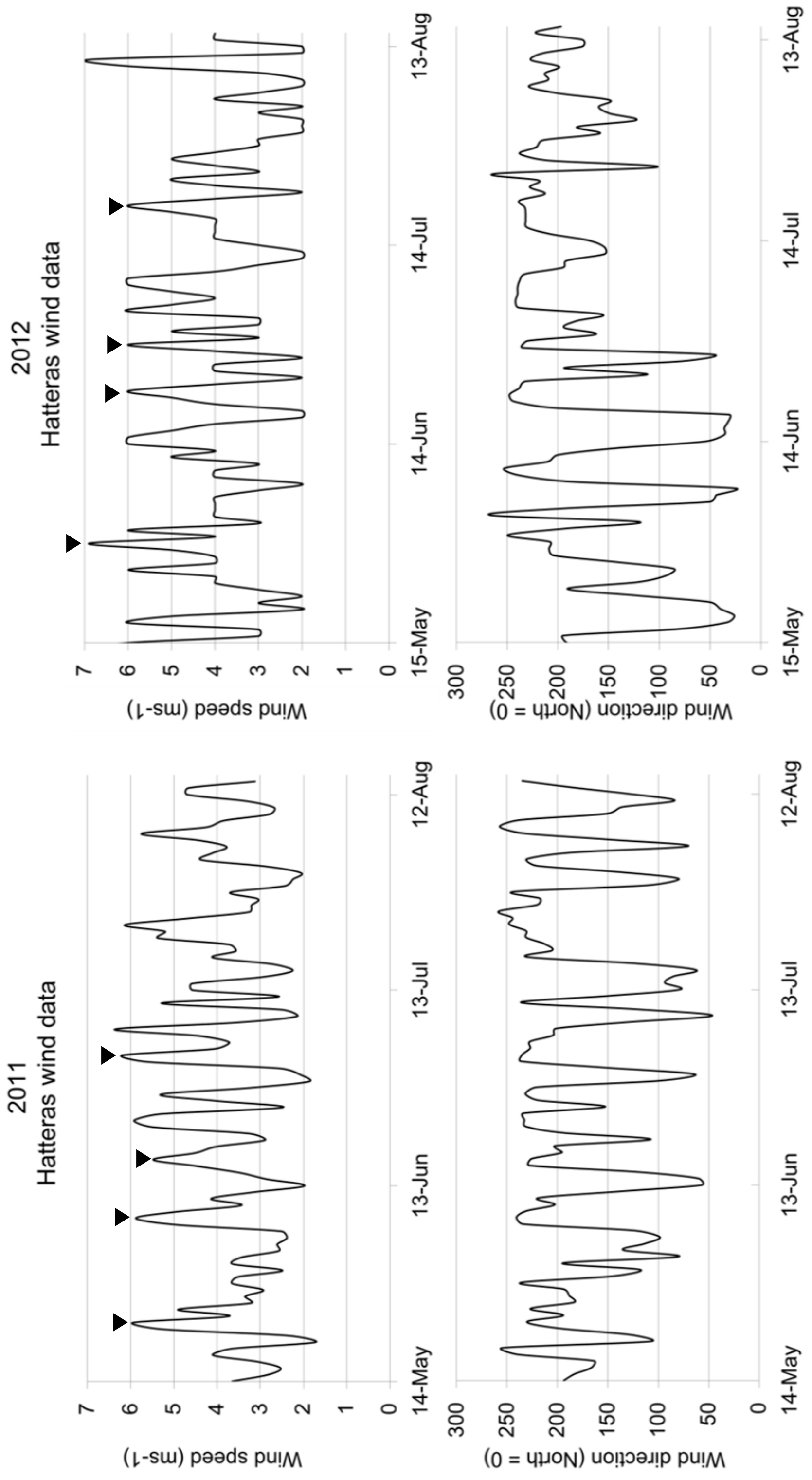
2011
Sea nettle count (Log+1)
0.0
0.5
1.0
1.5
2.0
CSF
CSG
OM
FB
PC
SF
2012
Sea nettle count (Log+1)
0.0
0.5
1.0
1.5
2.0
CSF
CSG
OM
FB
PC
SF

Figure 6.



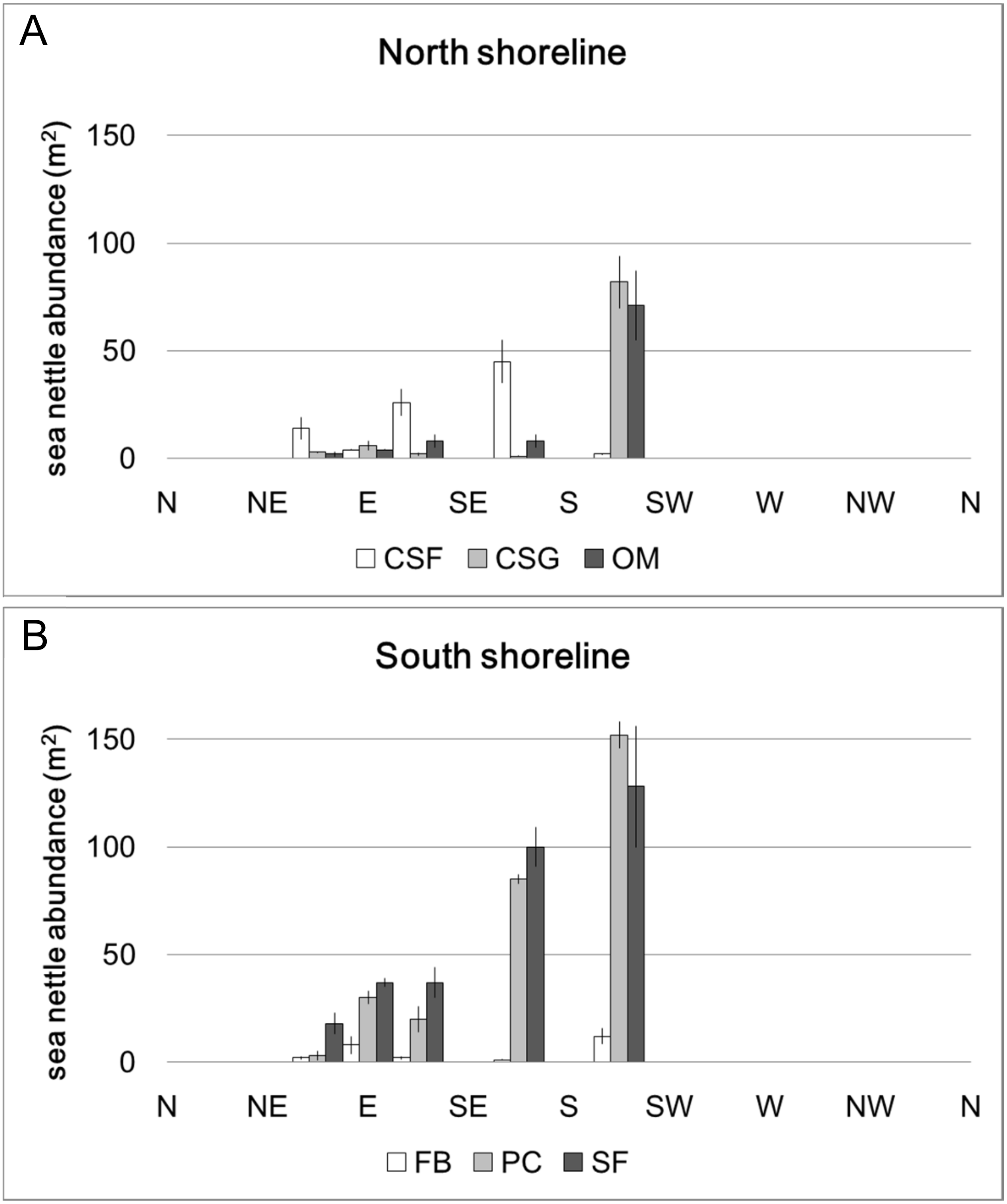
2011
Cherry Point wind data
2012
Cherry Point wind data
Wind speed (ms-1)
Wind direction (North = 0)
25-May
24-Jun
24-Jul
15-May
14-Jun
14-Jul
13-Aug

Figure 7.



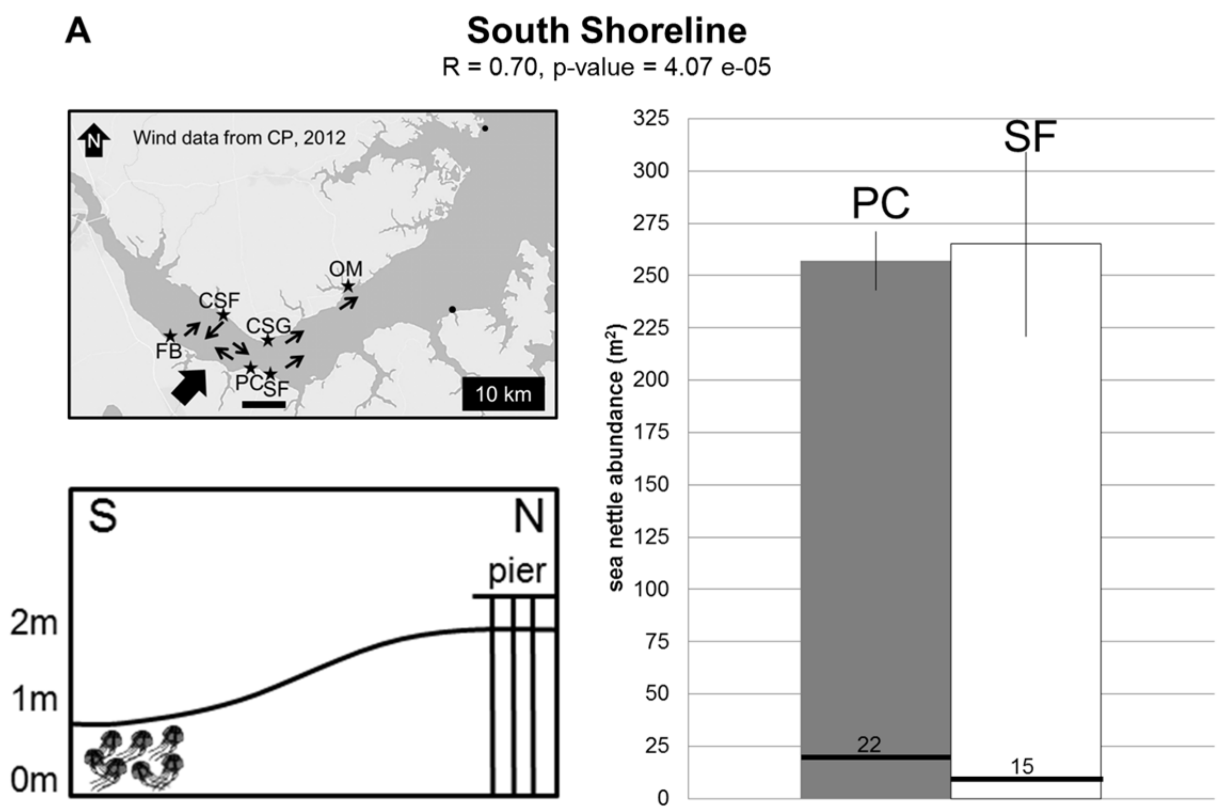
2011
Hatteras wind data
2012
Hatteras wind data
Wind speed (ms-1)
Wind direction (North = 0)
14-May
13-Jun
13-Jul
12-Aug
15-May
14-Jun
14-Jul
13-Aug

Figure 8.



A
North shoreline
sea nettle abundance (m2)
150
100
50
0
N
NE
E
SE
S
SW
W
NW
N
CSF
CSG
OM
B
South shoreline
sea nettle abundance (m2)
150
100
50
0
N
NE
E
SE
S
SW
W
NW
N
FB
PC
SF

Figure 9.

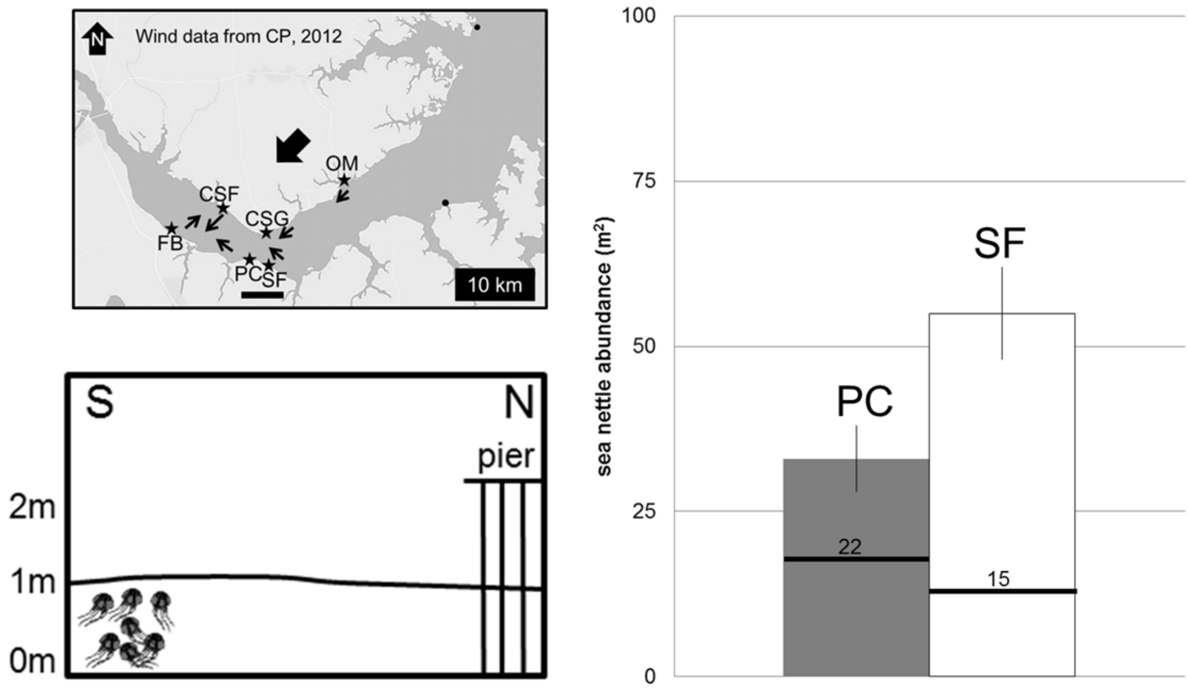


A
South Shoreline
R = 0.70, p-value = 4.07 e-05
Wind data from CP, 2012
N
CSF
FB
CSG
OM
PC
SF
10 km
S
N
pier
2m
1m
0m
sea nettle abundance (m²)
325
300
275
250
225
200
175
150
125
100
75
50
25
0
PC
SF
22
15

B

South Shoreline

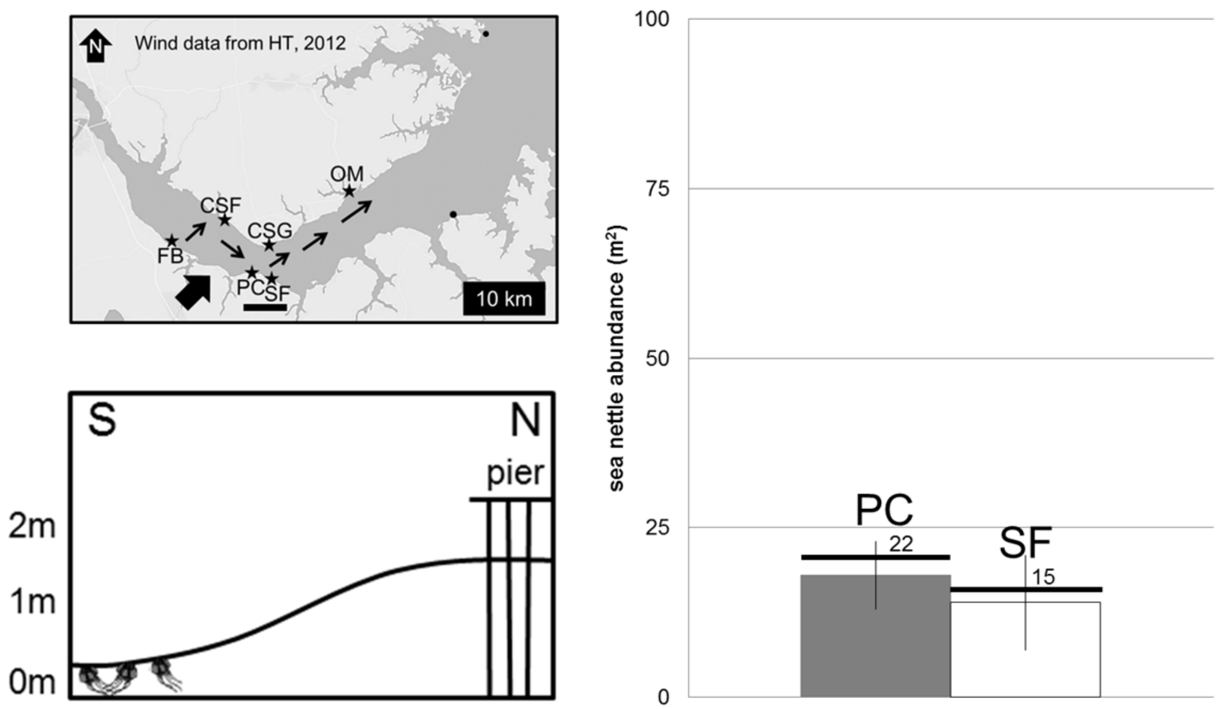
R = 0.70, p-value = 4.07 e-05



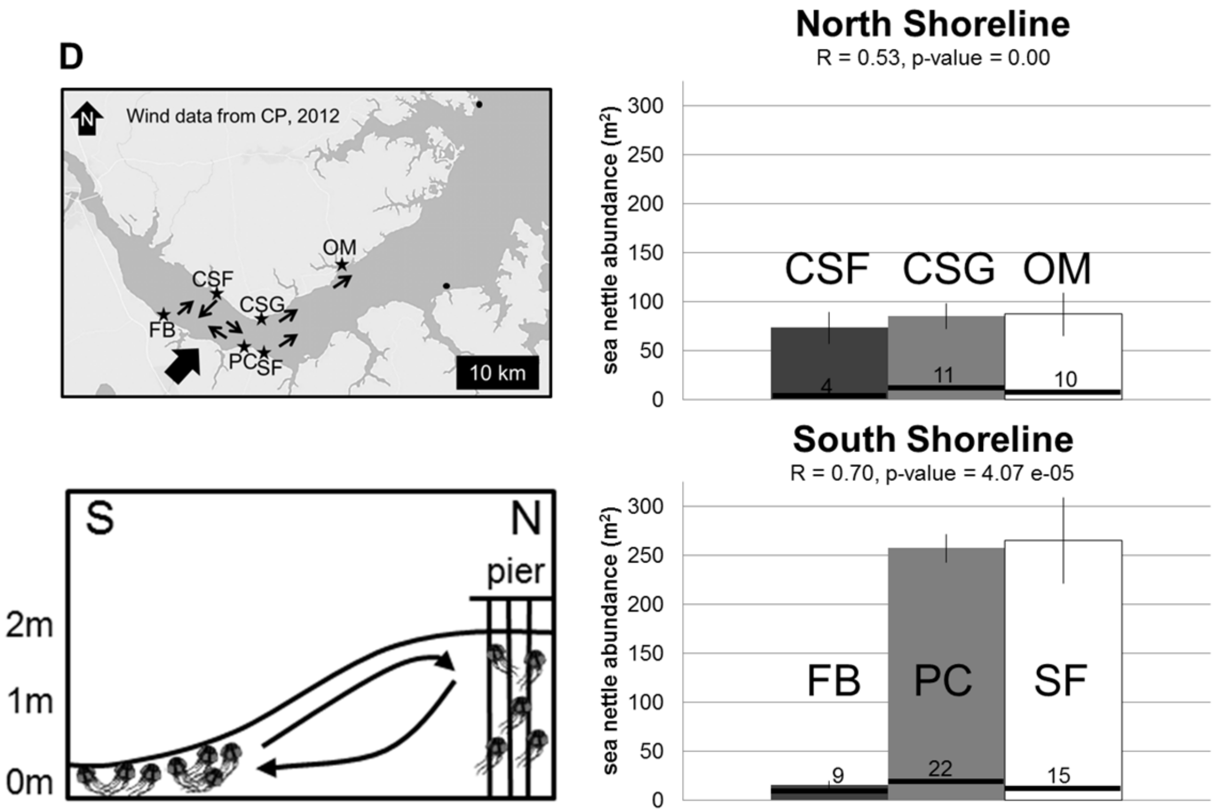
C

South Shoreline

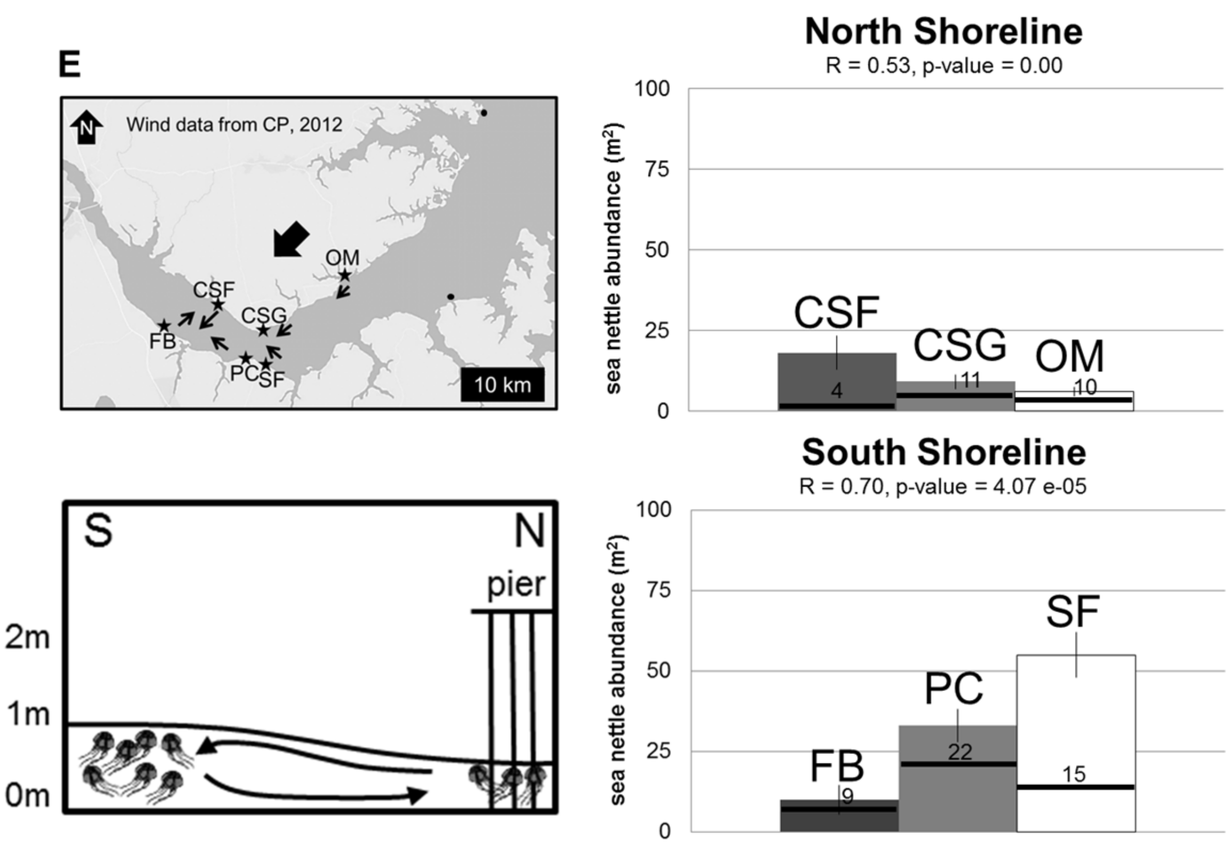
R = -0.54, p-value = 0.01



D


Wind data from CP, 2012
N
OM
CSF
CSG
FB
PC
SF
10 km
S
N
pier
2m
1m
0m
North Shoreline
R = 0.53, p-value = 0.00
sea nettle abundance (m²)
300
250
200
150
100
50
0
CSF
CSG
OM
4
11
10
South Shoreline
R = 0.70, p-value = 4.07 e-05
FB
PC
SF
9
22
15

E


Wind data from CP, 2012
N
OM
CSF
CSG
FB
PC
SF
10 km
S
N
pier
2m
1m
0m
North Shoreline
R = 0.53, p-value = 0.00
sea nettle abundance (m²)
100
75
50
25
0
CSF
CSG
OM
4
11
10
South Shoreline
R = 0.70, p-value = 4.07 e-05
FB
PC
SF
9
22
15

CHAPTER 3

An assessment of the potential of sea nettle, *Chrysaora quinquecirrha*, sexual reproduction in the Neuse River Estuary

ABSTRACT

This chapter focused on determining if sexual reproduction of the sea nettle, *Chrysaora quinquecirrha*, was occuring the Neuse River Estuary (NRE). Many species of jellyfish aggregate for sexual reproduction thereby potentially increasing the encounter rates with humans. One-hundred jellyfish were randomly sampled from May-July 2011 at six recreation sites. Histology was used to determine the sex ratio, the presence/absence of mature gonads, and the presence/absence of brood planulae. The jellyfish sex ratio was found to not be significantly different from 1:1. Based on egg diameter, no females were sexually mature and no females had planulae present in their gastric cavities. Of the 48 males, five showed rupture sperm follicles and all of these males were sampled early in the season. There was no relationship between bell and egg diameter, suggesting that female size was not related to egg maturity. However, a negative linear relationship between bell diameter and time indicated a gradual decrease in organism size over time. These results suggest 1) sexual reproduction may occur very early in the season and sampling did not capture this event or 2) sexual reproduction is not occurring and the primary source of medusae during the year comes from the strobilation of polyps. These findings suggest that NRE *C. quinquecirrha* egg maturity should be further investigated as these jellyfish may possess smaller sized, mature eggs. Research on other life history stages (polyp, ephyrae, etc.) should be conducted to gather more information on the longevity of *C. quinquecirrha* in the NRE and greater APES. Further life history research will indicate which stage of jellyfish, sexual or asexual, is more important to manage.

INTRODUCTION

This chapter evaluated the potential of sexual reproduction of *Chrysaora quinquecirrha* as a potential factor related to jellyfish-human interactions in the Neuse River Estuary (NRE). The annual occurrences of *C. quinquecirrha* may have negative effects on NRE recreation and subsequently tourism revenue (Figure 1), which is economically important to residents and NRE stakeholders. Estuaries can be highly conducive to jellyfish populations by providing placid areas for adult jellyfish or medusae to aggregate for spawning (Omori and Nakano 2001). The NRE is primarily influenced by wind-driven circulation (see Chapter 2) and because *C. quinquecirrha* are weak swimmers with maximum swimming rates of 1.8 cm s^{-1} (Costello et al. 1998; Matanoski et al. 2001) and on average ~ 5 - 10 cm s^{-1} currents velocities are generated by wind (Luettich et al. 2000; Reynolds-Fleming and Luettich 2004), aggregation of large numbers of *C. quinquecirrha* by wind-driven circulation may or may not indicate specific areas where sexual reproduction occurs in the NRE. Moreover, since the NRE is a highly used recreation area, awareness that wind-driven circulation may influence where sexual reproduction is likely to occur could help with managing this nuisance species

The life history of Chesapeake Bay *C. quinquecirrha* populations has been thoroughly studied (Figure 1). Pioneer research by Littleford (1939), Truitt (1939), Cargo and Schultz (1966), Calder (1972, 1974), and Cargo and Rabenold (1980) have documented the development and behavior of the *C. quinquecirrha* polyp, strobila, and ephyrae in both laboratory and field conditions. In these studies, the asexual reproduction phase of the life cycle is well described, including the perennial nature of the polyp phase (Cargo and Schultz 1966; Truitt 1939) and how the polyp can reproduce asexually through transverse fission (strobilation), pedal laceration, and/or budding (Cargo and Rabenold 1980; Littleford 1939). In contrast, sexual reproduction of the ephemeral medusa phase of the *C. quinquecirrha* life cycle has seldom been described due to the difficult nature of documenting a spawning/fertilization event *in situ*, which has been problematic with most jellyfish species (Arai 1997). Therefore a traditional method to assess if *C. quinquecirrha* populations are reproducing sexually is polyp-substrate studies whereby planulae settle on a substratum and undergo metamorphosis into polyps (Breitburg and Fulford 2006; Cargo and Schultz 1966).

The best attempt to assess sexual reproduction in *C. quinquecirrha* was performed by Littleford (1939). His research established a visual means of identifying mature female and male *C. quinquecirrha* based on gonad color, how to determine gonad maturity in female *C. quinquecirrha*, and presented a time frame from egg fertilization to planula development within female *C. quinquecirrha* gastric cavities. Spawning/fertilization occurred in the evening, from 2000-2100, and planula stages were found from 1000 onward the next morning. Upon fertilization, development into planula occurred instantly or started six or seven hours later. Planulae remained in the gastric cavities no more than 24 hours after fertilization (Littleford 1939). Littleford (1939) also suggested that fertilization and the development of planulae is more likely to occur in the gastric cavities of female *C. quinquecirrha* than the water column (Figure 1B). However, a study on planulae behavior revealed that fertilization and development outside female also occurs (Cargo 1979) (Figure 1A). To date, Littleford's egg fertilization and diameter maturity experiments have not been revisited and *C.*

quinquecirrha literature from the past ~ 35 years seldom report sex ratios of medusae, gonad maturity, and if planulae are present in gastric cavities.

The primary objective of this chapter was to assess the potential of NRE *C. quinquecirrha* sexual reproduction by using Littleford's (1939) observations and sexual reproduction characteristics reported from other jellyfish species. *Chrysaora quinquecirrha* are gonochoristic and 1:1 sex ratios have been reported in other jellyfish species known to sexually reproduce (Arai 1997; Pitt and Kingsford 2000; Rosa et al. 2012); therefore, I hypothesized that the proportion of female and male sea nettles would not differ. Littleford's (1939) experiments and observations showed that egg diameters of 0.07 to 0.19 mm, with an average of 0.15 mm, could be successfully fertilized and were classified as sexually mature (Littleford 1939). Based on these observations, I evaluated gonad maturity in female NRE *C. quinquecirrha* and tested the hypothesis that the majority of eggs found would be greater than 0.07 mm and therefore sexually mature.

Jellyfish spermatogenesis occurs in follicles and spawning occurs when sperm follicles rupture allowing mature sperm to enter the gastric cavity and dispensed orally (Arai 1997). In addition to ruptured sperm follicles, an indication that sperm was released into the water column can be determined by observations of "spent gonads," where instead of sperm the presence of amoeboid cells and free spaces in the lumen are observed (Schiariti et al. 2012). To evaluate gonad maturity in male *C. quinquecirrha*, I hypothesized that sexually mature males would have ruptured sperm follicles or show signs of spent sperm follicles. It should be noted that spent gonad observations have also been attempted on female jellyfish but due problems with histology procedures, artifacts from staining slides make it difficult to discern spent female gonads (Schiariti et al. 2012). Thus, I did not attempt to observe spent gonads in female *C. quinquecirrha*. Internal fertilization of planulae occurs when sperm is taken up from the water column into the gastric cavity by the female's oral arms similar to feeding (Arai 1997). If mature eggs are released from the female gonad at this time, development of planulae occurs in the gastric cavity and the planulae will swim out of the mouth of the females when fully developed (Littleford 1939). I hypothesized that brooded planulae would be observed in the gastric cavity of females indicating that sexual reproduction had occurred.

The size of jellyfish, which is typically measured by bell diameter, may influence sexual reproduction and spawning commencement (Arai 1997) because jellyfish maturation may be stopped and started as the medusa starves or eats and this change in size is reflected in bell and egg diameter (Arai 1997). Experiments with the moon jellyfish *Aurelia* sp. documented that when the jellyfish shrink or "degrow" the female gonad regresses along with egg maturity. Spermatogenesis, however, continues to proceed regardless of gonad regression (Hamner and Jenssen 1974). In recent studies where jellyfish were surveyed *in situ*, female egg diameter, fecundity, and bell diameter were positively linear (Saucedo et al. 2012) or unrelated to the size of jellyfish (Toyokawa et al. 2010). To date, no comparisons with bell and egg diameter have been made with *C. quinquecirrha*. I hypothesized that bell diameter would not be correlated to egg diameter in female *C. quinquecirrha.* If bell diameter and egg diameter are correlated, it would be possible to determine sexual maturity of females from size alone, to the exclusion of histology. In addition, since Littleford (1939) observed mature females to have grayish-yellow brown gonads and males with bright pink colored gonads, I also explored the possibility of identifying sex of *C. quinquecirrha in situ* by taking observations of gonad color.

The populations of *C. quinquecirrha* in the NRE are influenced by wind dynamics (see Chapter 2). In this chapter, I evaluated if these wind-driven aggregations may be related to the potential of sexual reproduction of NRE *C. quinquecirrha* thereby contributing to the annual occurrences of jellyfish-human interactions in the NRE. In response to the ecological and societal implications of large numbers of jellyfish in coastal environments worldwide, sexual reproduction capabilities in jellyfish species have steadily gained attention (Saucedo et al. 2012; Schiariti et al. 2012; Toyokawa et al. 2010). Research from this chapter was the first to assess sexual reproductive characteristics in NRE *C. quinquecirrha*. I anticipate that these results will contribute to jellyfish reproduction studies and on-going jellyfish research in North Carolina.

MATERIALS AND METHODS

Gonad collection and histology

A total of 100 *C. quinquecirrha* were randomly collected in 2011 on 19 May, 3 June, 10 June, 18 June, 8 June, 5 July, 12 July, and 19 July by dip netting (Figure 2B). Basic morphological data including bell diameter, bell color, oral arm color and visual observations of the sex of medusa were recorded for each collected *C. quinquecirrha*. Bell and oral arm colors were also documented because there are different color varieties of *C. quinquecirrha* in the NRE, similarly to Chesapeake Bay *C. quinquecirrha* (Littleford 1939). The entire gastric cavity (the mouth, stomach, and four gastric pouches) excluding oral arms was dissected out of each jellyfish and preserved in 5% formalin in filtered estuarine water. All gonad samples were collected twice a week from the hours of 0800 and 1700; therefore, I presumed all female gonad observations would have an assortment of eggs, mature eggs, and/or planulae based on Littleford's (1939) fertilization and planulae development timeline. Since each gastric pouch contains a gonad with the potential of harvesting mature eggs, planulae or sperm, all four gonads were placed in a single histology cassette and a single slide was created per jellyfish. Additionally, *C. quinquecirrha* sperm is located in one of the four gastric pouches (Littleford 1939) so analyzing all four gonad pouches assured that I could properly identify if the jellyfish was male or female. Tissue samples of fixed gonads were washed in an ethanol series, embedded in paraffin and 5 μm slices were placed on each histology slide. Histology slides where stained with a Harris Hematoxylin and Eosin stain (Edna and Prophet 1992) and all histological procedures were performed at the East Carolina University Histology Core Facility at the Brody Medical School, Greenville, North Carolina.

Microscopy and CellSens image analysis

All slides were analyzed with an Olympus BX41 light microscope at 10x to 40x magnification. Gonad pictures were taken and analyzed with *CellSens* image analysis software. To determine how many egg diameters were needed to account for sample variation, the diameters of all eggs were measured for six jellyfish. The number of eggs per jellyfish ranged from 106 to 4,137, and a standard deviation analysis of the measured egg diameters showed that fluctuations in measurements plateaued when

100 egg diameters per slide were measured. Therefore, for the remaining slides with eggs, approximately 100 randomly selected egg diameters were measured. Eggs were identified by a well-defined nucleus, circular shape and egg diameters were measured at the widest part of each egg (Figure 3A). Fertilized eggs were identified by multicellular composition and larger diameters. If planulae were present, the number of planulae was recorded within each of the four gastric pouches. Identification of planulae was based on the oval shaped characteristic of the larvae and multicellular composition. If sperm follicles were present (Figure 3B), I searched the entire gonad for ruptures in cell membranes or spent sperm follicles as described by Schiariti et al. (2012) (Figure 4). If ruptured sperm follicles or spent sperm follicles were present, these individuals were classified as mature males.

Statistical analysis

To meet the requirements for parametric tests, all measured egg diameters belonging to each female jellyfish were Log transformed. To evaluate sex ratio, a chi-square test was performed on all jellyfish collected and distributed by site and throughout the field season. I used a one-way *t*-test to evaluate if the egg diameters were > 0.07 mm. Bell diameters were also logged transformed and an ANOVA was used to compare egg diameters by site, bell diameters by site, and bell diameters by maturity. Bartlett tests of variance were performed to evaluate the validity of each ANOVA and if significant, Tukey post hoc tests were used to compare means. Linear regression analyses were used to compare female bell and egg diameters and bell diameters of females and males throughout the field season. All statistical analyses were performed with R version 2.14.2 (2012-02-29).

RESULTS

Sex ratios and microscopy observations

I found a sex ratio of 13:12 with 52% females and 48% males, which is not significantly different that a 50:50 ratio (χ^2 = 0.16, *DF* = 1, *p*-value = 0.69). The frequency of females and males found at each site was relatively uniform except for FB (Figure 1B) where there were ~65% females and ~35% males (χ^2 = 9, *DF* = 1, *p*-value = 0.00) (Figure 5). The frequency of females and males found throughout the field season also had a somewhat uniform distribution, however more males were observed on 19 May (χ^2 = 36, *DF* = 1, *p*-value = 2.0 e-09), and 17 July (χ^2 = 16, *DF* = 1, *p*-value = 6.3 e-05) and more females were observed on 1 June (χ^2 = 16, *DF* = 1, *p*-value = 6.3 e-05) and 12 July (χ^2 = 8.6, *DF* = 1, *p*-value = 0.00) (Figure 6).

Based on the egg diameter maturity of > 0.07 mm (Littleford 1939), none of the females sampled in our study were sexually mature (Figure 7). The ANOVA of mean egg diameters by site was not significant (Table 1), but the range of egg diameters was higher at the South sites (FB, PC and SF) and at CSG (Figure 1B, Figure 8). Sites CSF and FB had the largest range in egg diameter (Figure 8). No planulae were observed in the gastric cavities. Of the males, five showed ruptured sperm follicles and sperm entering the gastric cavity of the male jellyfish (Figure 4). Males with ruptured sperm follicles were found early in the field season and at sites OM and PC (Figure 1B) and I did not observe spent sperm follicles any of the male samples. Unlike Littleford's (1939) observations, I found sperm follicles in all four gonads for each male *C. quinquecirrha*.

Bell diameter comparisons

The range of bell diameters and mean bell diameter for females, immature males and mature males varied at each site (Figure 9A, Figure 9B and Figure 9D, Table 1). Immature females and males had a similar range in bell diameters (cm) and medians, which seem to be smaller than the mature males (Figure 9C). The range of mature males was between 7 - 12 cm at OM and ~ 8 - 10 cm at PC (Figure 9D), but the ANOVA of maturities was insignificant. Therefore, it is difficult to compare if the mean bell diameters of immature and mature males are similar or dissimilar (Table 1). The ANOVAs and Bartlett tests of variance were significant for the female and immature male bell diameters by site comparisons (Table 1). The Tukey post hoc test of mean bell diameters of females were significantly different between OM, north, and most of the south sites (CSF, *p*-value = 0.01; CSG, *p*-value = 0.00; FB, *p*-value = 0.00; SF, *p*-value = 0.00). Mean bell diameters of immature males were also significantly different between OM and CSG (*p*-value = 0.00), and all south sites (FB, *p*-value = 0.00; PC, *p*-value = 0.02; SF, *p*-value = 0.01) (Figure 9A, 9B).

Relationship between egg and bell diameters

There was no linear relationship between egg and bell diameter (r^2 = 0.01, *p*-value = 0.5, Figure 10); however, there was a negative linear relationship between female bell diameter and time throughout the field season and a positive linear relationship between egg diameter and time throughout the field season (Figure 11). There was also a negative linear relationship between male bell diameter and time throughout the field season (Figure 12).

Histology versus in situ gonad observations

Sex determined by histology was substantially different than *in situ* gonad observations to classify sex. Despite the differences in bell and oral arm color, females were more accurately identified than males. There was no bell and oral arm color combinations that were associated with the sex of jellyfish (Table 2).

DISCUSSION

I found a 1:1 sex ratio (Figure 5 and Figure 6) and of the male *C. quinquecirrha* surveyed ~10% showed ruptured sperm follicles, which indicated that these males were sexually mature. These individuals were collected on 19 May and 10 June, when egg diameters were measured at the 0.035 to 0.040 mm (Figure 11, Figure 12), which was the most frequently measured egg diameter in my study (Figure 7). Mature males were also collected on 3 June at OM and PC when egg diameters were smaller, 0.010 to 0.030 mm (Figure 11, Figure 12). The ANOVA of mean egg diameters by site was not significant (Table 1) but the range of egg diameters was higher at the South sites (FB, PC and SF) and at CSG (Figure 1B, Figure 8). Sites CSF and FB had the largest range in egg diameter (Figure 8). None of the females sampled were sexually mature based on Littleford's (1939) egg diameter index but it is possible that mature egg diameters may be smaller for NRE *C. quinquecirrha* populations. Recent histology studies evaluating reproductive capabilities in Rhizostomae jellyfish known as broadcast spawners have used egg yolk content and egg diameters to evaluate egg maturity in the giant jellyfish *Nemopilema nomurai* [Kinoshinouye, 1922] (Iguchi et al. 2010; Toyokawa et al. 2010) and *Lychnorhiza lucerna* [Hackel, 1880] (Schiariti et al. 2012). For *N. nomurai*, histology and fertilization experiments have indicated that smaller egg diameters could be successfully fertilized under favorable conditions with adequate yolk content (Kawahara et al. 2006; Ohtsu et al. 2007; Toyokawa et al. 2010). If this is the case with *C. quinquecirrha*, and mature eggs were present within the females surveyed, then the presence of mature males could indicate that commencement and the potential of spawning occurred early in the field season potentially at PC and OM where the mature males were collected.

Another way to directly document reoccurring reproduction events is the observation of fertilized eggs, embryos, and planulae inside female gastric cavities of brooder jellyfish species (Brewer 1989; Schiariti et al. 2012). Since I did not find brooded fertilized eggs and/or planulae, there was no evidence that egg fertilization had occurred in the gastric cavity among the females I sampled; however, it is also possible that fertilization and planulae development occurred in the water column, similar to other broadcast spawning jellyfish species (Figure 2A) and noted by Cargo (1979) for *C. quinquecirrha*. Furthermore, if egg production rates are similar to Chesapeake Bay *C. quinquecirrha* (up to 40,000 eggs daily (Purcell, unpublished data)), the overturn of immature to mature eggs could be on the order of hours and mature eggs may have been expelled prior to capture of the female. Internal planulae development (Figure 2B) and departure may have also been missed. On the other hand, since my sampling was conducted bi-weekly and at times that coincided with Littleford’s (1939) observations of fertilization and planulae development, the possibility that sexual reproduction did not occur is also possible, assuming NRE sea nettles adhere to similar fertilization and development time frames as documented in Chesapeake Bay.

I found that bell and egg diameters were not linearly related (Figure 10) but, similar to Toyokawa et al. (2010), I observed an increase in egg diameter as the season progressed (Figure 11). Although no egg diameters were measured, unpublished data have suggested that *C. quinquecirrha* in Chesapeake Bay are sexually mature at bell diameters approximately 2 cm (Purcell et al. 1999). Based on this finding, I could classify all *C. quinquecirrha* sampled in our study as sexually mature and this could explain why there was no relationship between bell and egg diameters (r^2 = 0.01, *p*-value = 0.5, Figure 10). Mean bell diameter of females and immature males was significantly different among sea nettles collected from OM when compared to the other sites (Figure 9A, 9B). Specifically, the mean bell diameters of these jellyfish appear to be smaller than those collected elsewhere. The negative linear relationship between bell diameters and time (Figure 11 and Figure 12) may reflect the seasonality of *C. quinquecirrha* where medusa numbers decline in late summer (Decker et al. 2007) and in conjunction with observed decreases in bell diameter (Purcell 1992).

My *in situ* observations of sex by gonad color proved to be misleading (Table 2); therefore, to determine sex in *C. quinquecirrha*, histology procedures should be used. These results also concur with other jellyfish reproduction histology observations where gonad color varied with sex in *N. nomurai* (Toyokawa et al. 2010) and *L. lucerna* (Schiariti et al. 2012). However, it is also possible that because most of the *C.*

quinquecirrha surveyed were classified as sexually immature, the coloration of mature gonads described by Littleford (1939) may have not been observed because the jellyfish were, in fact, not sexually mature. Lastly, the different color varieties of bell and oral arm color observed in my study showed no color combination associated with sex and these observations coincide with Littleford's (1939) conclusions of bell color, oral arm color, and sex.

CONCLUSIONS

The use of histology proved to be an informative way to assess the potential of sexual reproduction of *C. quinquecirrha* in the NRE. Although my results cannot definitively support that the annual occurrences of *C. quinquecirrha* are related to aggregation for the purposes of sexual reproduction, I can report that 1:1 sex ratios were observed at all recreation sites throughout the 2011 season and mature males were collected early in the field season at a North (OM) and South (PC) shoreline site (Figure 1B, Figure 9D). These observations support the argument that sexual reproduction could occur in the NRE and in areas that are used for recreation and/or tourism, but with equal evidence that sexual reproduction did not occur in 2011 (i.e., immature females based on egg diameter and no brooded planulae). I suggest that egg maturity be revisited before classifying what recreation sites or NRE shorelines are more prone to *C. quinquecirrha* aggregations for sexual reproduction. Future studies should include a variety of methodologies including histology, *in vitro* fertilization experiments, and the use of ecological techniques. For example, settlement plate studies similar to those conducted in Chesapeake Bay (Calder 1972; Cargo and Schultz

1967) and with other jellyfish species (Astorga et al. 2012; Holst and Jarms 2007; Hoover and Purcell 2009) should be conducted to investigate the potential of planulae settlement as a proxy for sexual reproduction events as well as substrate preference. Studies have suggested that *C. quinquecirrha* planulae prefer to settle on natural substrates, such as oyster shells (Breitburg and Fulford 2006; Purcell 2012) but other studies have shown that artificial substratum may also be selected by planulae of other species (Lo et al. 2008; Toyokawa et al. 2011). As discussed in chapter 2, if NRE *C. quinquecirrha* planulae prefer to settle on oyster shells like Chesapeake Bay *C. quinquecirrha*, the NC Division of Marine Fisheries oyster sanctuaries distributed throughout APES (Figure 1A) could serve as adequate habitats. In addition, if *C. quinquecirrha* planulae settled on artificial substrates, there are many docks and piers in the NRE that could also serve as suitable substrate.

Ample habitat for settlement would support the stability of the asexual life history stages (polyp and strobila) thereby increasing the likelihood of continued annual occurrences of *C. quinquecirrha* in the NRE driven by the asexual reproduction component of the bipartite lifecycle. For example, the polyp stage is highly resilient to changes in low dissolved oxygen (Condon et al. 2001), will cyst when unfavorable conditions are present, including changes in season and/or water temperature (Cargo and Schultz 1966), and may survive for several years (Cargo and Schultz 1967). Therefore, stable polyp populations that undergo metamorphosis into ephyrae each spring (Calder 1974; Cargo and Rabenold 1980) are not dependent on sexual reproduction making the possibility of NRE *C. quinquecirrha* annual medusae occurrences low in genetic diversity, but harmful to humans nonetheless. Genetic surveys of clonal generations and inference to reproductive mode of organisms belonging to Phylum Cnidaria have been conducted with the Hydrozoa (hydromedusae) (Meek et al. 2013) and Anthozoa (corals) (Jokiel et al. 2013) and similar techniques could be used to assess clonal diversity in the Scyphozoa or jellyfish similar to *C. quinquecirrha*.

The results reported in Chapter 2 and 3 seem to indicate that the physical driver of wind-driven circulation is more influential to determining the extent and frequency of jellyfish-human interactions in the NRE than sexual reproduction. Therefore, coastal management of sea nettles in the NRE should focus on mitigation strategies as outlined in Chapter 2 to minimize harmful jellyfish-human interactions with *C. quinquecirrha*, including barrier nets (Schultz and Cargo 1969), public outreach, awareness and first aid to treat stings as demonstrated in Australia (Gershwin et al. 2010) and Germany (Baumann and Schernewski 2012) instead of biological control methods such as removal of the medusae from the system.

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Figure 9. Box plots of immature female (*N* = 52, A), immature male (*N* = 43, B) and mature male (*N* = 5, D) bell diameters observed at each site; Camp Seafarer (CSF), Camp Sea Gull (CSG), Oriental Town (OM), Flanners Beach (FB), Pine Cliff (PC) and SF (Siddie Fields), throughout 2011. (D) Box plots of bell diameters of immature females, immature males and mature males. Open circles indicate outliers > 1.5 times of upper quartile and horizontal bars within the box plots indicate the bell diameter median. The upper box above the median extends to the third quartile and the lower box extends to the first quartile. The bars extend to the largest and smallest values, respectively

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Figure 11. Scatterplots of female bell (diamond) and egg (circle) diameters from May to July 2011. Linear regression lines show a decrease in bell diameter through season ($r^2 = 0.3$, p-value = 0.0, black dashed line) and an increase in egg diameter ($r^2 = 0.2$, p-value = 0.0, grey line).

Figure 12. Scatterplot of male bell diameters from May to July 2011. Arrows indicates the five mature males surveyed in this study. Similar to female bell diameter, male bell diameter decreased over the field season ($r^2 = 0.3$, p-value = 0.00, black regression line).

Table 1.

ANOVA Analyses by site, egg (mm), and bell diameters (cm)						
by site	*DF*	*Sum Sq*	*Mean Sq*	*F-value*	*p-value*	*Bartlett variance test*
Female egg diameters	5	0.00	0.00	1.3	0.3	none performed
Female bell diameters	5	121.8	24.4	8.1	< 0.001*	*p*-value = 0.6
Male bell diameters	5	76.6	15.3	4.8	0.00*	*p*-value = 0.8
ANOVA Analyses by bell diameters and maturities						
by maturities	*DF*	*Sum Sq*	*Mean Sq*	*F-value*	*p-value*	*Bartlett variance test*
All bell diameters	2	21.6	10.8	2.2	0.11	none performed

Table 2.

Histology versus *in situ* gonad observations							
bell color / oral arm color							
sex determination via histology							
clear / clear		clear / red		red / clear		red / red	
F	M	F	M	F	M	F	M
20	16	24	22	3	4	5	6
# of accurate *in situ* sex determination							
clear / clear		clear / red		red / clear		red / red	
20	1	23	0	3	0	4	0

Figure 1.

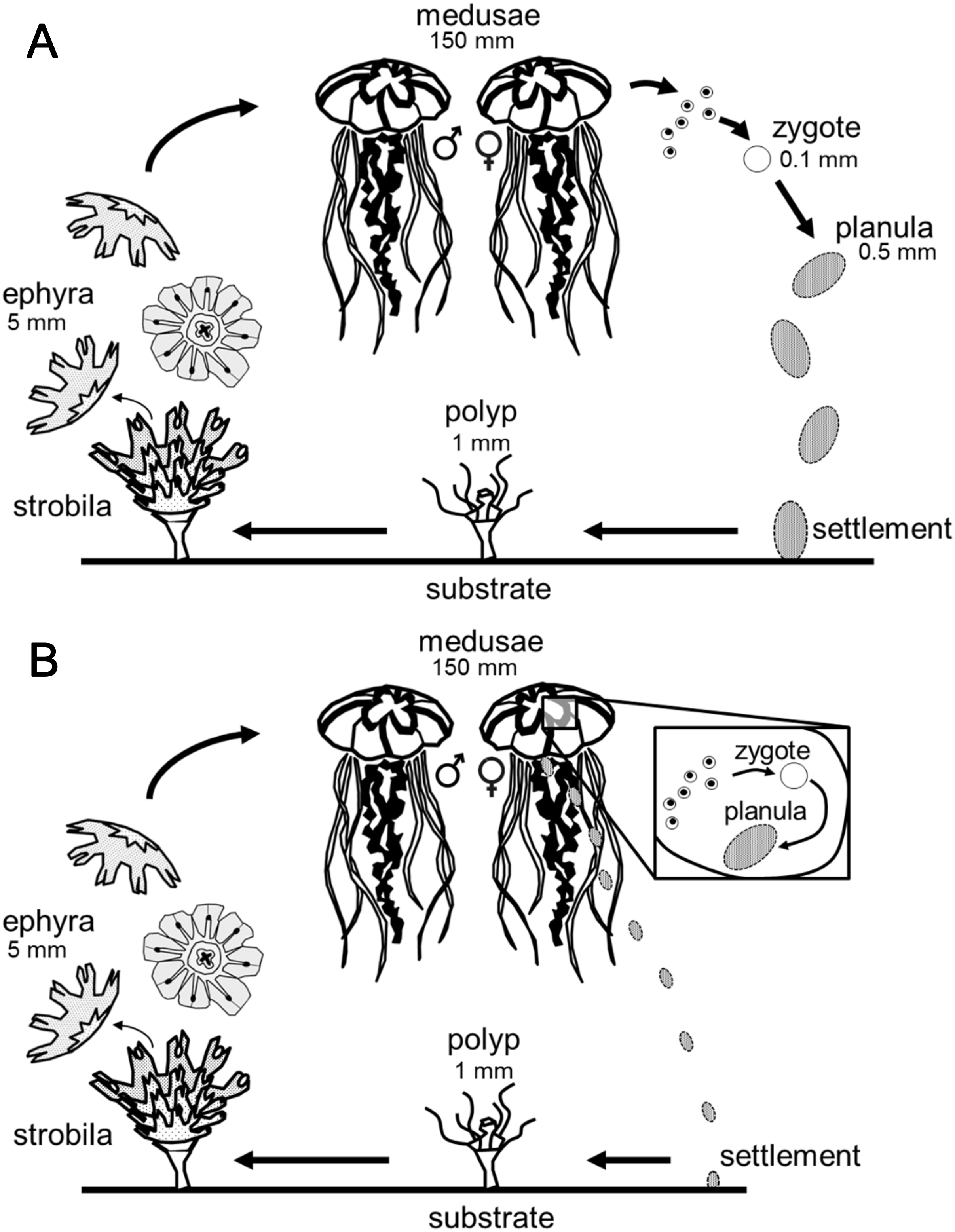
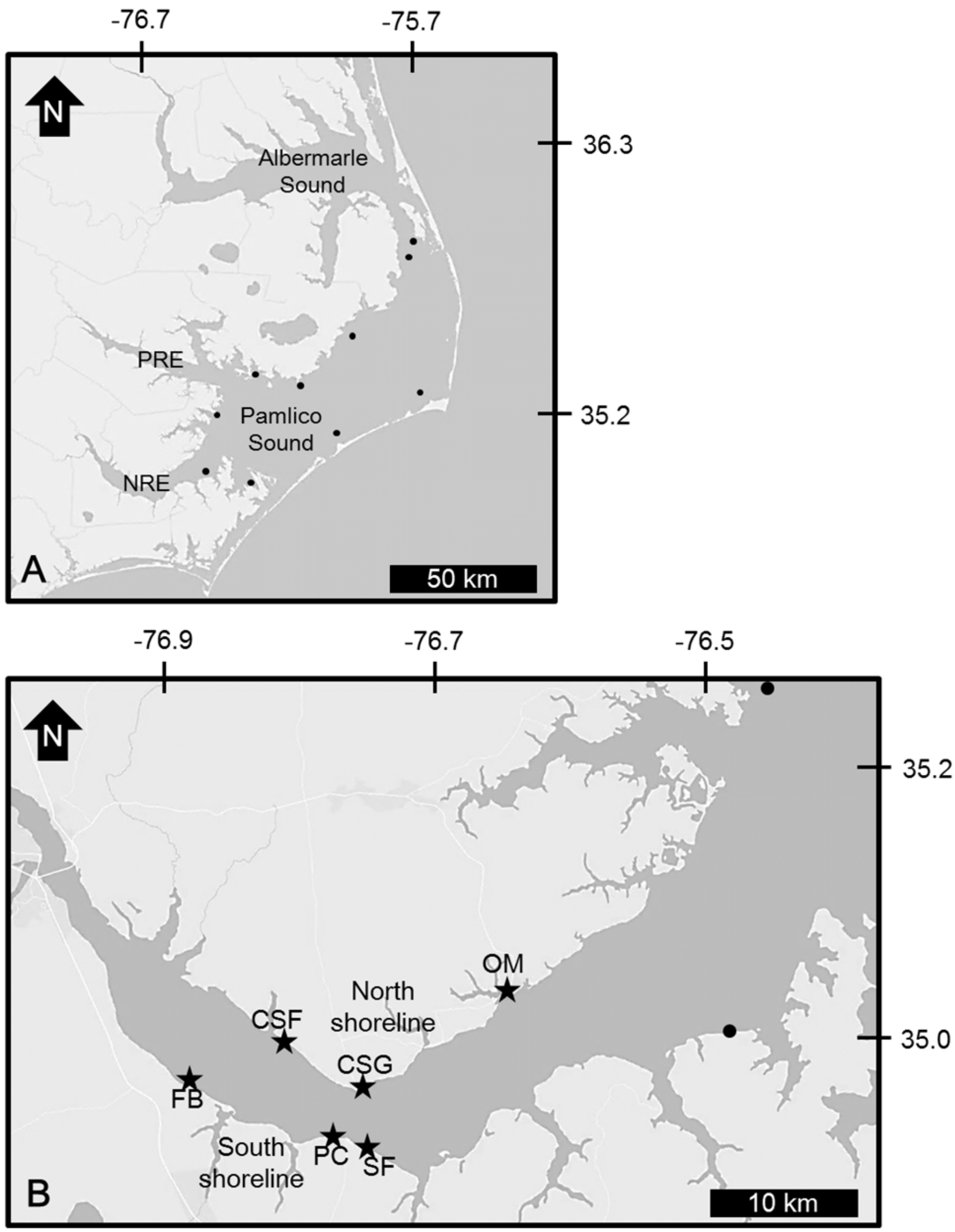
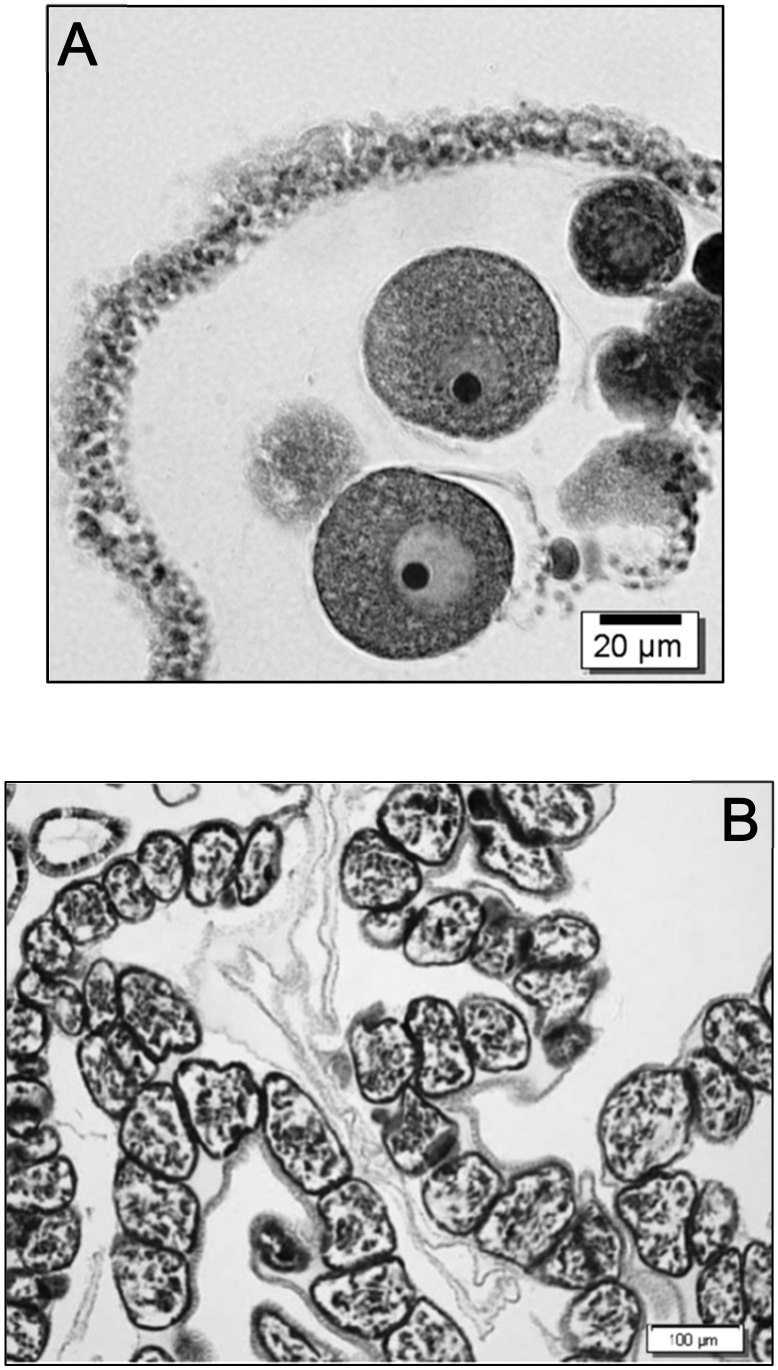

A
medusae
150 mm
♂
♀
zygote
0.1 mm
planula
0.5 mm
ephyra
5 mm
polyp
1 mm
strobila
settlement
substrate
B
medusae
150 mm
♂
♀
zygote
planula
ephyra
5 mm
polyp
1 mm
strobila
settlement
substrate

Figure 2.



-76.7
-75.7
N
36.3
Albermarle
Sound
PRE
Pamlico
Sound
35.2
NRE
A
50 km
-76.9
-76.7
-76.5
N
35.2
OM
North
shoreline
CSF
35.0
CSG
FB
South
shoreline
PC
SF
B
10 km

Figure 3.



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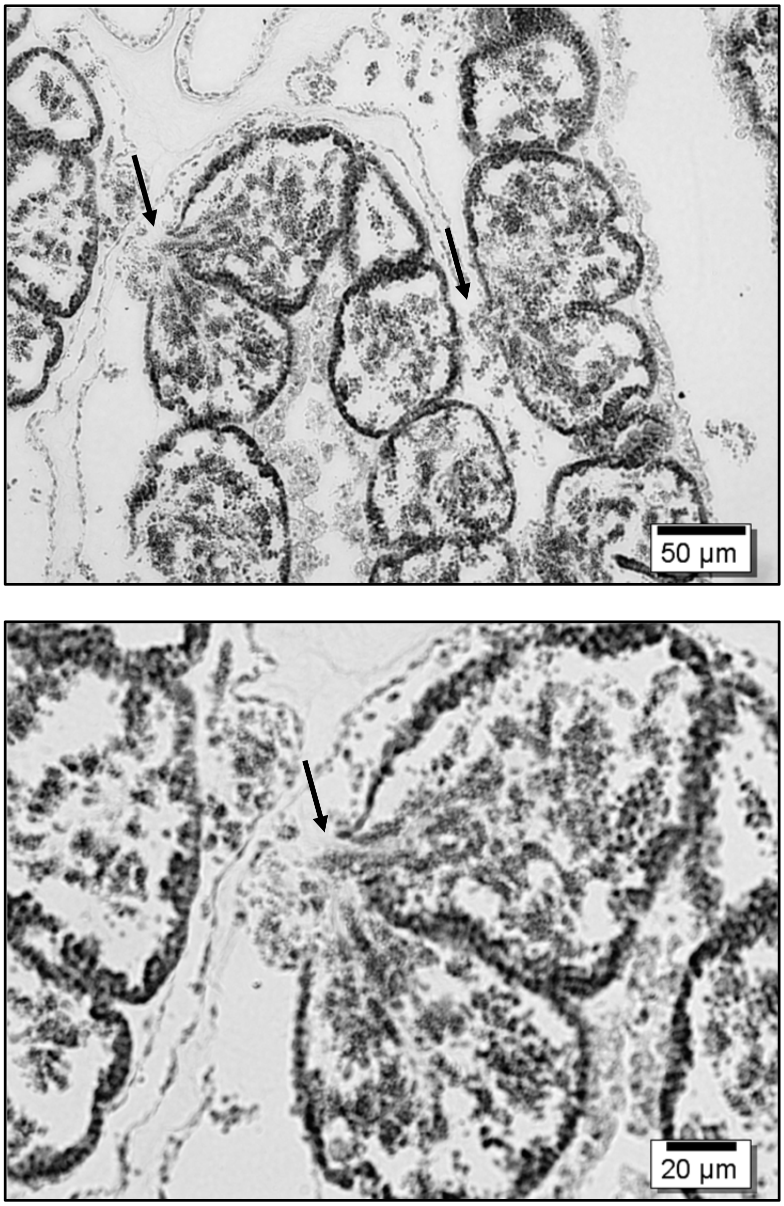

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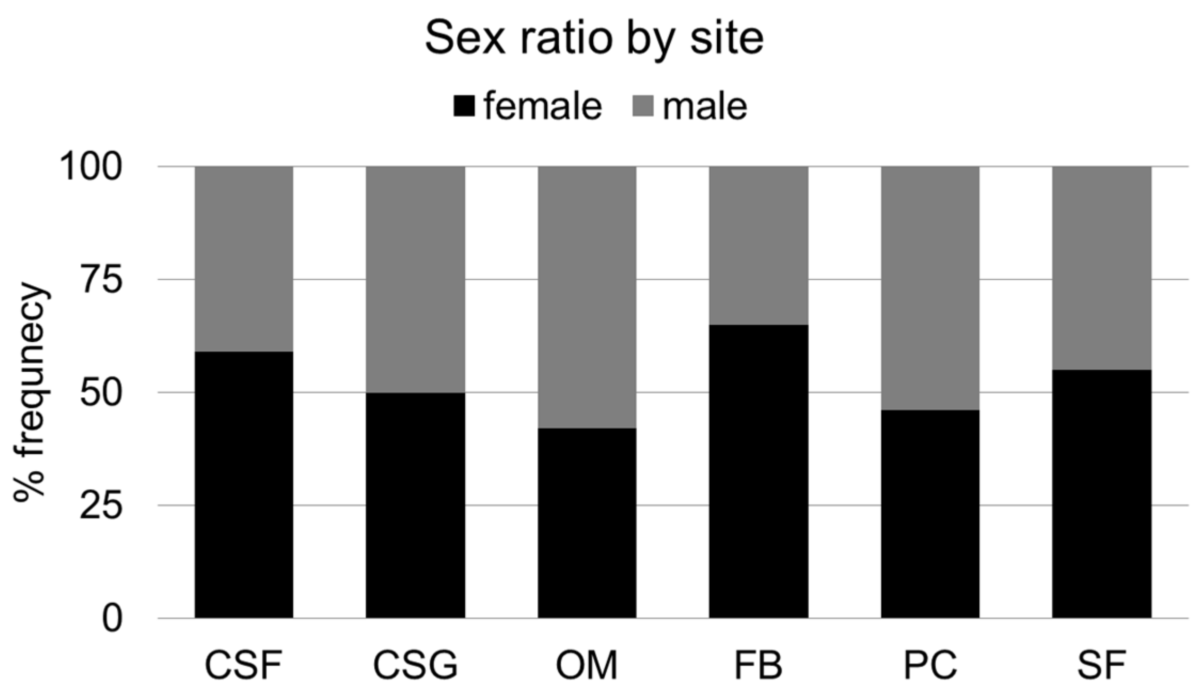

Sex ratio by site
female
male
100
75
50
25
0
% frequnecy
CSF
CSG
OM
FB
PC
SF

Figure 6.

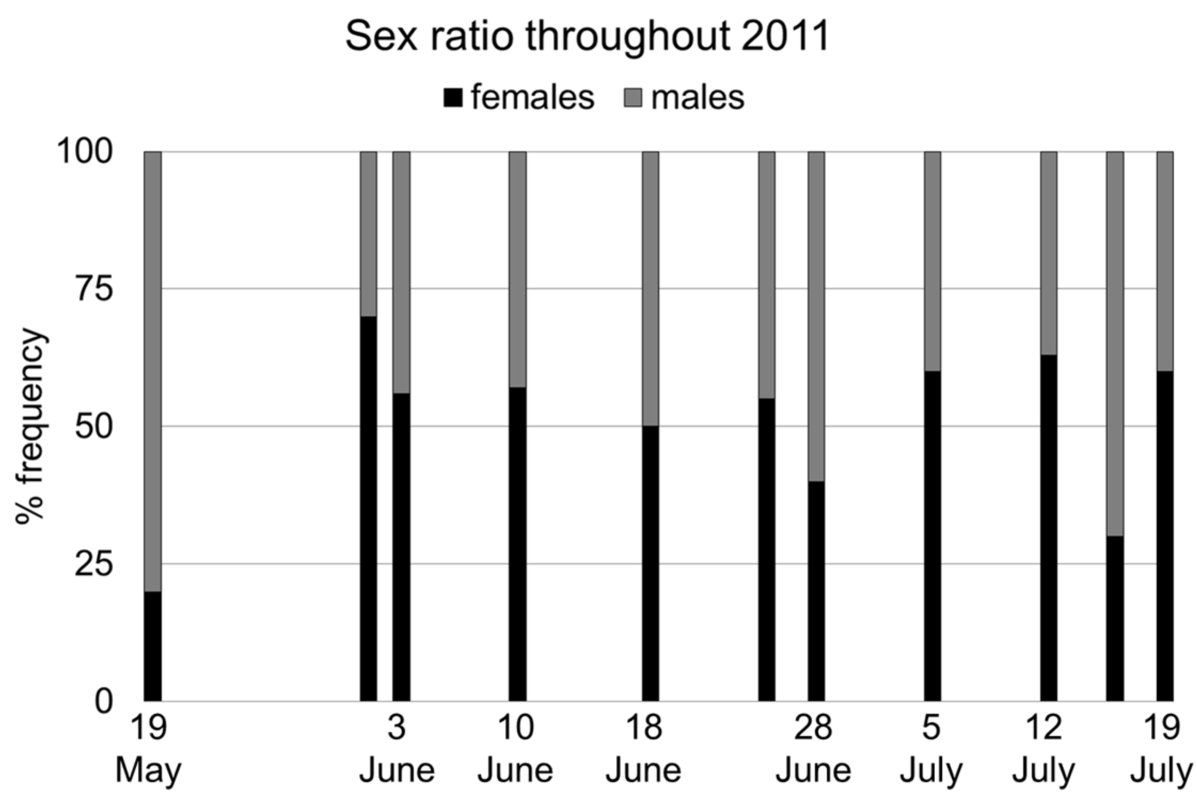

Sex ratio throughout 2011
females
males
% frequency
100
75
50
25
0
19 May
3 June
10 June
18 June
28 June
5 July
12 July
19 July

Figure 7.

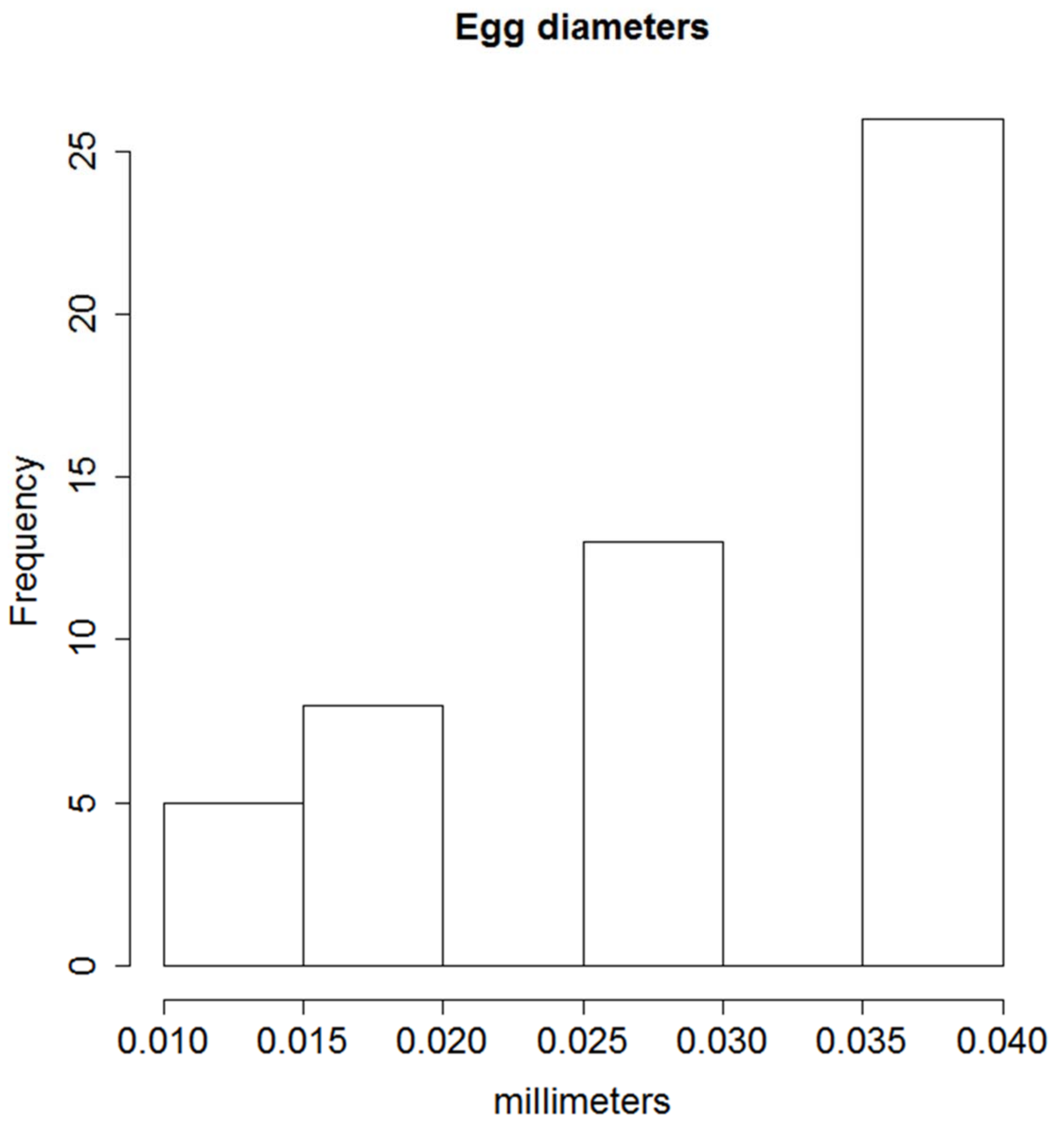
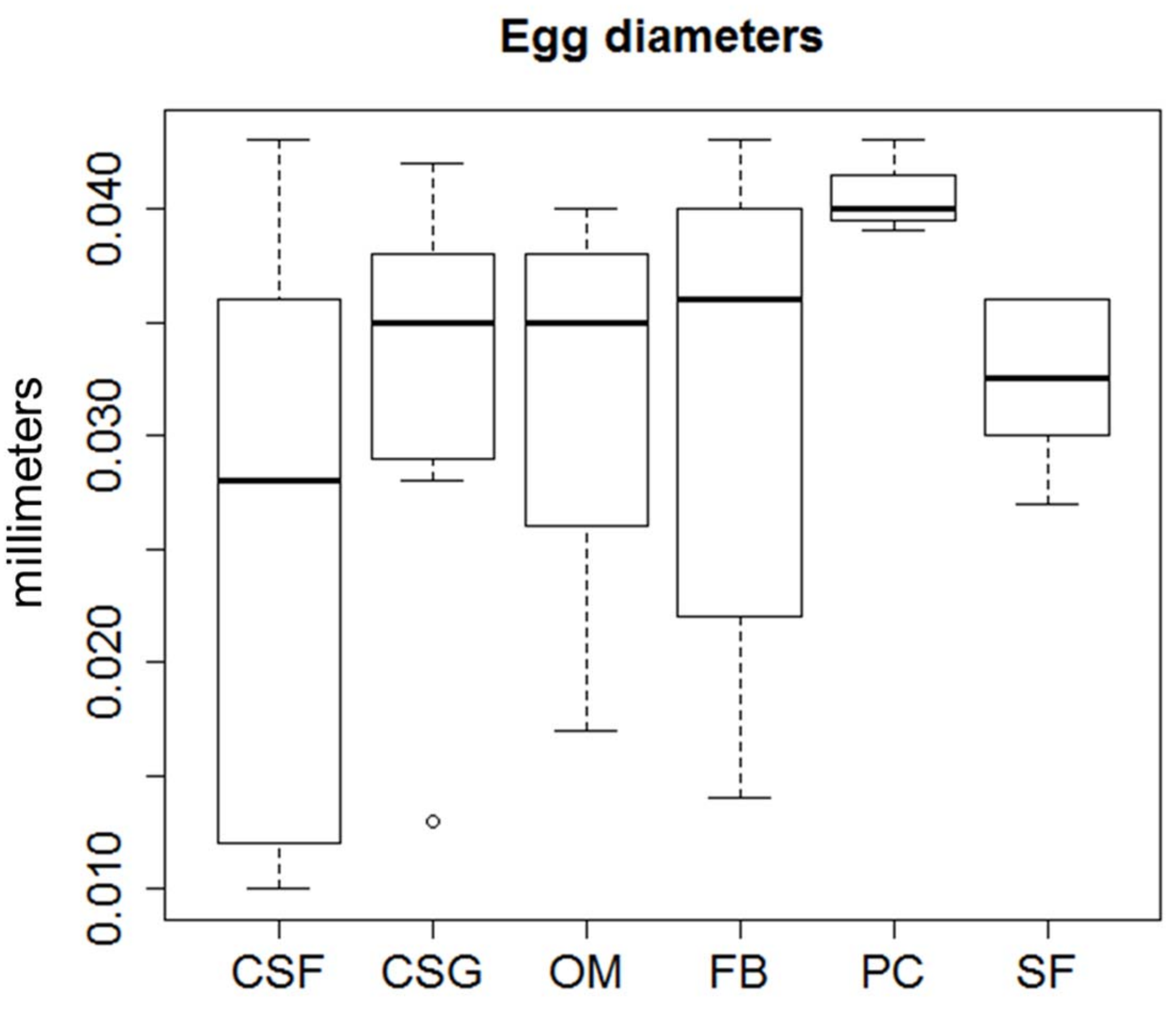
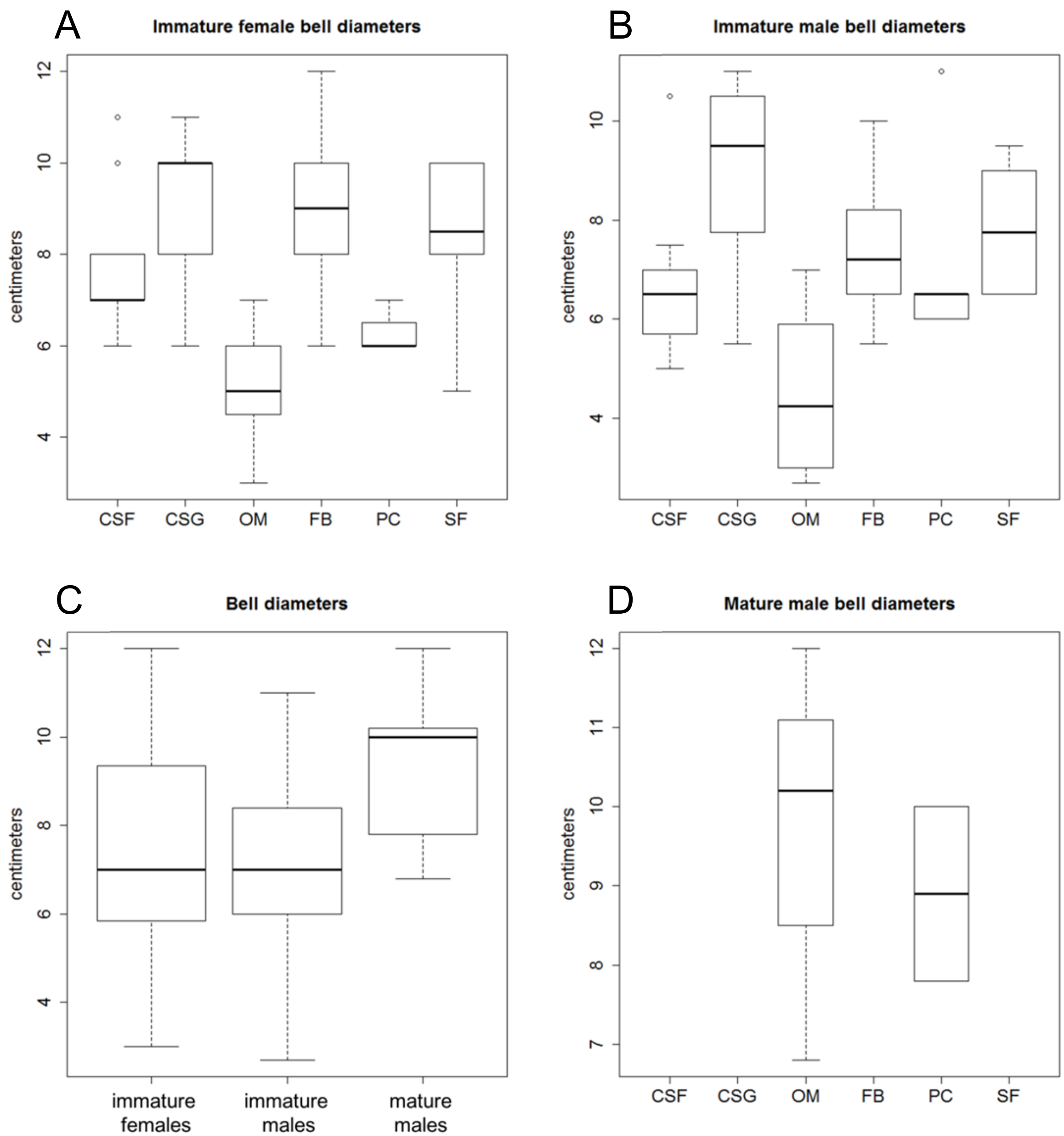

Egg diameters
Frequency
0
5
10
15
20
25
0.010
0.015
0.020
0.025
0.030
0.035
0.040
millimeters

Figure 8.



Egg diameters
millimeters
0.010
0.020
0.030
0.040
CSF
CSG
OM
FB
PC
SF

Figure 9.



A
Immature female bell diameters
centimeters
4
6
8
10
12
CSF
CSG
OM
FB
PC
SF
B
Immature male bell diameters
centimeters
4
6
8
10
CSF
CSG
OM
FB
PC
SF
C
Bell diameters
centimeters
4
6
8
10
12
immature females
immature males
mature males
D
Mature male bell diameters
centimeters
7
8
9
10
11
12
CSF
CSG
OM
FB
PC
SF

Figure 10.

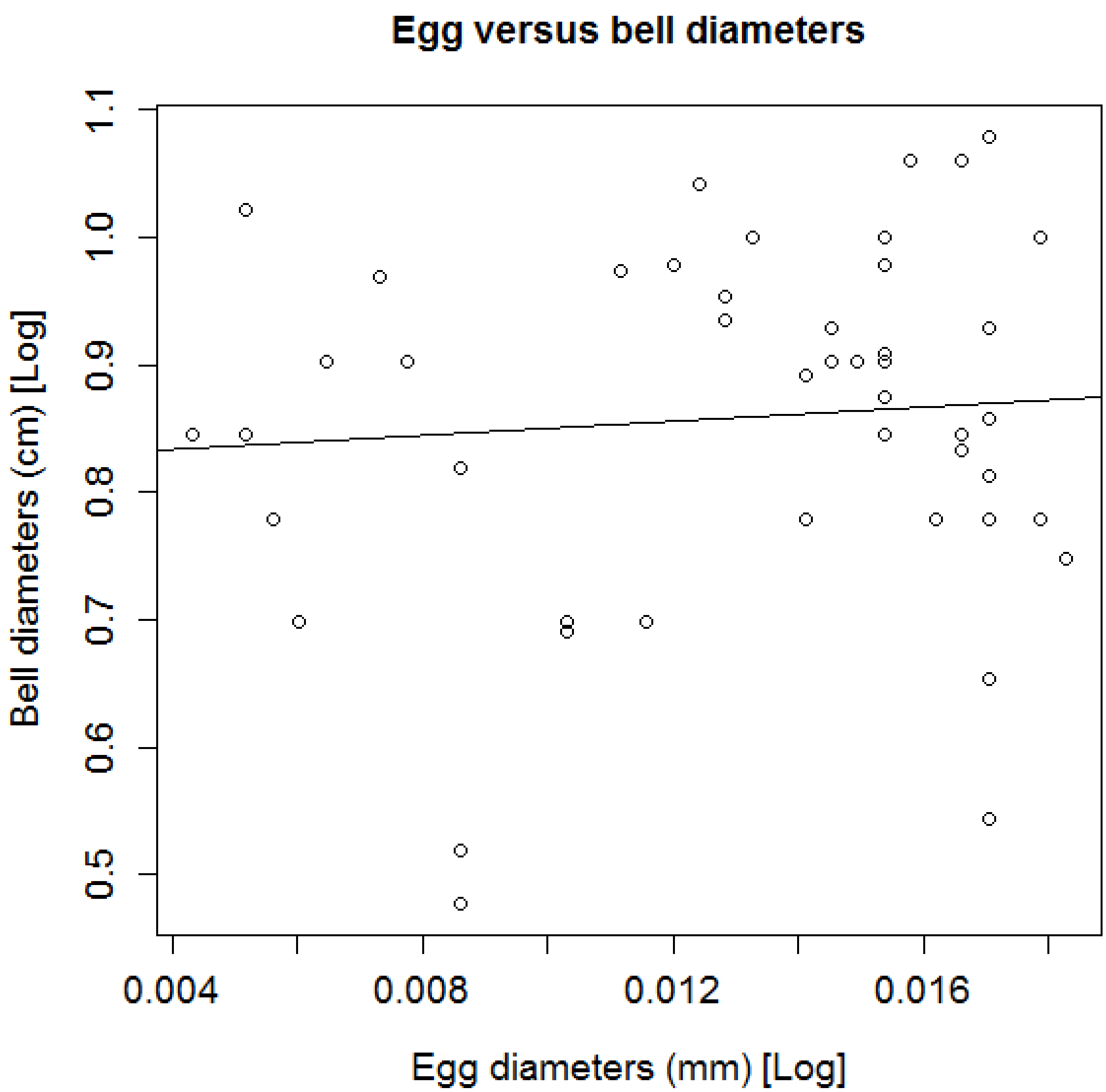
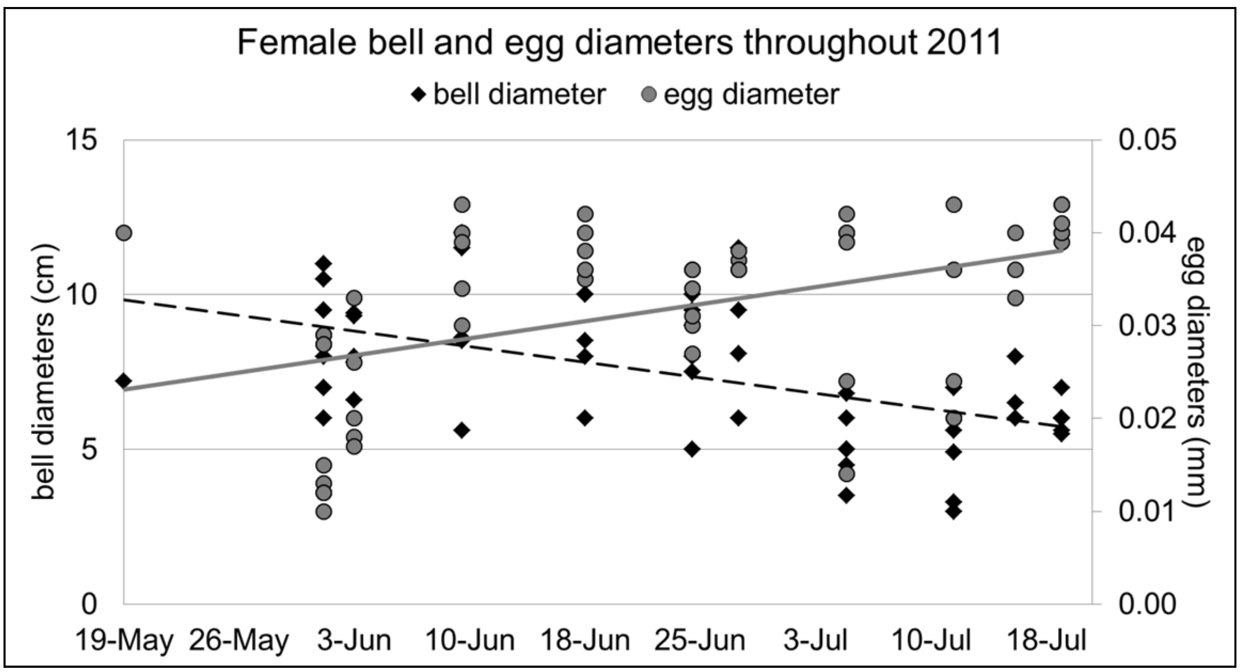
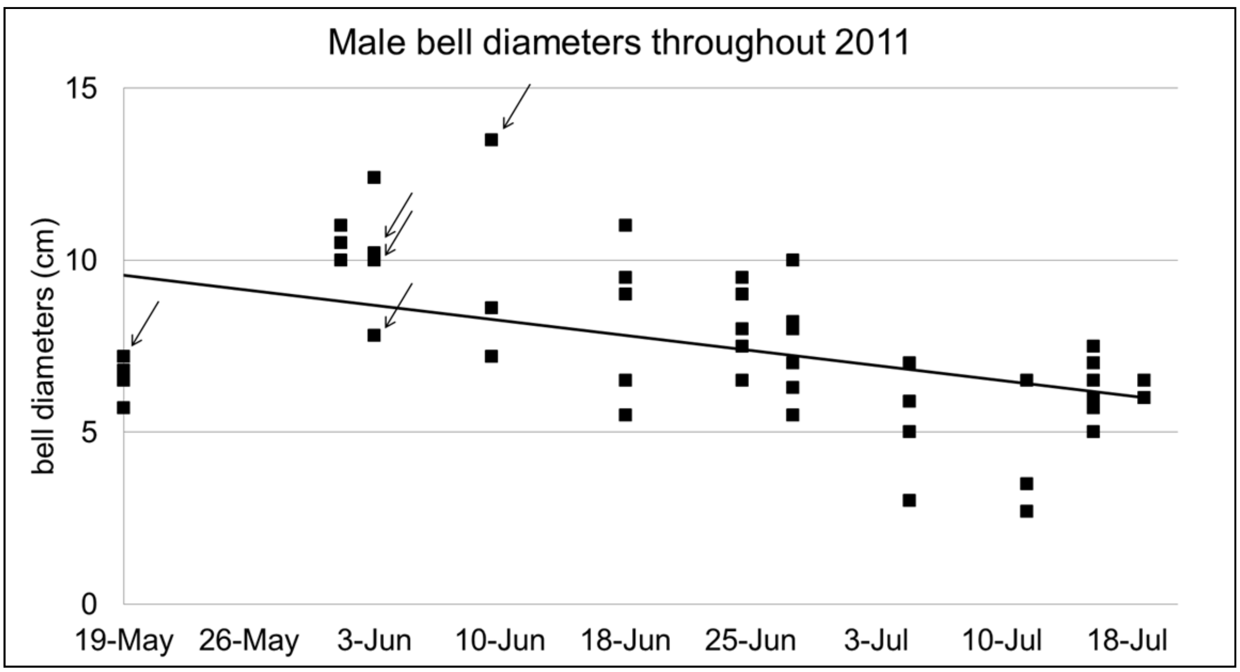

Egg versus bell diameters
Bell diameters (cm) [Log]
0.5
0.6
0.7
0.8
0.9
1.0
1.1
0.004
0.008
0.012
0.016
Egg diameters (mm) [Log]

Figure 11.



Female bell and egg diameters throughout 2011
bell diameter
egg diameter
15
10
5
0
0.05
0.04
0.03
0.02
0.01
0.00
bell diameters (cm)
egg diameters (mm)
19-May
26-May
3-Jun
10-Jun
18-Jun
25-Jun
3-Jul
10-Jul
18-Jul

Figure 12.



Male bell diameters throughout 2011
15
10
5
0
bell diameters (cm)
19-May
26-May
3-Jun
10-Jun
18-Jun
25-Jun
3-Jul
10-Jul
18-Jul

CHAPTER 4

Predators, stingers and economic influencers: a cultural consensus analysis of public perception and ecological knowledge of jellyfish

ABSTRACT

This chapter evaluated the social drivers of jellyfish-human interactions in Eastern North Carolina. Large numbers of jellyfish have created many ecological and societal problems worldwide. Specifically, adverse effects on fisheries and tourism have been observed when jellyfish-laden waters have interfered with fisheries operations or harmed people that encounter stinging species. Jellyfish populations exist on majority of U.S. coastlines and in some areas increases have been observed. Coupled with more coastal development, it is likely that U.S. coastal economies and communities will be affected by jellyfish. To successfully manage these jellyfish-human interactions, quantitative data on the public perspective of jellyfish ecology and how jellyfish influence society is needed. This chapter used “cultural consensus theory” (CCT) to compare public perspective of jellyfish across four culturally distinct groups of people: fishers (commercial and recreational), recreationists, coastal, and jellyfish researchers. When cultural knowledge of jellyfish ecology was compared, jellyfish researchers had the highest cultural competency but similar mean cultural competencies between coastal and jellyfish researchers were found. Mean cultural competencies among fishers, recreationists and coastal researchers were also similar. When shown food web illustrations, jellyfish researchers placed jellyfish in higher trophic levels in comparison to fishers, recreationists and coastal researchers who placed jellyfish at lower trophic levels. This could indicate that there is confusion as to the roles that jellyfish play in food webs. All groups agreed that fewer than five jellyfish will not affect people’s decisions to engage in water activities but the presence of jellyfish does affect people’s decisions to continue water activities, especially if stung by jellyfish. However, people will book

return vacations to areas known to experience jellyfish, even if they are stung. This chapter revealed that more education is needed about the role of jellyfish in food webs. Also, the knowledge that a threshold of tolerance (i.e., fewer than five) exits regarding jellyfish in coastal areas utilized for water activities could be used for tourism planning through coping and mitigation strategies such as on-site first aid, education and barrier nets for designated swimming areas.

INTRODUCTION

Jellyfish (Phyla Cnidaria and Ctenophora) are intermediate to top trophic level predators in coastal and estuarine food webs (Mills 1995; Purcell et al. 2007). In these environments, jellyfish prey heavily upon different species of zooplankton, including fish larvae and eggs (Arai 1988; Moller 1984; Purcell 1992; Purcell and Arai 2001; Purcell and Sturdevant 2001) and other jellyfish (Baird and Ulanowicz 1989; Purcell and Cowan 1995; Purcell and Decker 2005). Jellyfish predation affects fish populations as jellyfish are often in direction competition with zooplanktivorous fish for similar prey, also when large amounts of prey are present jellyfish feed without apparent satiation (Deason and Smayda 1982; Hay 2006; Kremer 1979). Therefore, increases in jellyfish abundance can result in the rapid depletion of prey resources to the detriment of fish. Jellyfish also feed upon fish eggs and larvae, directly impacting fish populations in their early life history (Purcell et al. 1994). Jellyfish are consumed by roughly 124 fish species and 34 other animal species (Arai 1988; Pauly et al. 2009; Purcell and Arai 2001), such as the endangered leatherback turtle *Dermochelys coriacea* (Eisenberg and Frazier 1983; Houghton et al. 2006), seabirds (Harrison 1984), crustaceans (Pauly et al. 2009) cephalopods (Heeger et al. 1992) and humans (Hsieh et al. 2001; Omori 1978; Omori and Nakano 2001; Pitt 2010). However, jellyfish are not consumed by predators as readily as fish. In consequence, carbon is accumulated in jellyfish biomass and trophic transfer to other, higher trophic level organisms is substantially reduced. The result is an altered food web with a larger fraction of biomass consisting of jellyfish (Brodeur et al. 2011; Condon et al. 2011).

The importance of jellyfish in ecosystems is frequently overgeneralized, misconstrued, and/or not well-known to the public (Condon et al. 2012; Purcell et al. 2007). When compared to other species, jellyfish are typically understudied (Hay 2006), especially in estuaries where jellyfish are intermediate-top level predators (Condon and Steinberg 2008). More research is needed to further understand how jellyfish affect pelagic and benthic food webs, how the degradation and utilization of jellyfish biomass influences large scale biogeochemical processes (Ducklow et al. 2009), and the positive benefits that jellyfish predation in food webs could have on biodiversity (Condon et al. 2011). Scientists often exclude jellyfish in ecological studies due to difficulties in sampling (Purcell 2009) and some researchers have labeled jellyfish as "nuisance species" (Richardson et al. 2009).

Occurrences of high jellyfish abundances (sometimes called blooms) have caused many socio-economic problems globally. For example, Japan and India have experienced power outages due to jellyfish clogging cooling intake-valves of coastal power plants (Matsueda 1969; Matsumura et al. 2005; Rajagopal et al. 1989; Yasuda 1988). Jellyfish have interfered with aquaculture operations by feeding on reared animals in Asia, Australia/Indo Pacific, Europe and North America (see Purcell et al. 2007 for review). In addition, fisheries in North America (Graham et al. 2003), the Black Sea (Darvishi et al. 2004; Daskalov 2002; Shiganova et al. 2003; Zaitsev 1992), Namibia (Lynam et al. 2006) Japan (Uye 2011), China (Dong et al. 2010), Brazil (Nagata et al. 2009), Argentina (Schiariti et al. 2008), and Peru (Quinones et al. 2012) have also suffered from excessive amounts of jellyfish that clog and burst nets. Overfishing also alters food webs that favor jellyfish abundance instead of commercial fish species (Boero et al. 2008; Pauly et al. 1998; Purcell 2012). Seasonal occurrences of jellyfish can also be problematic to fisheries. For example, *Chrysaora plocamia* [Lesson, 1832] abundances peak in the summer and can be caught as 30% by-catch in 5% of Peruvian anchovy *Engraulis ringens* [L. Jenyns, 1842] hauls. This equates to an economic loss of over US$ 200,000 in about a month's worth of time and fishery factories have refused to process hauls if catches include more than 40% jellyfish by-catch (Quinones et al. 2012). The weight of jellyfish by-catch has also increased the risk of capsizing trawling vessels (Graham et al. 2003). Processing hauls with jellyfish requires more labor (Kawahara et al. 2006b) and because jellyfish sting, fish catch mortality has increased (Bamstedt et al. 1998) and fish handlers who inevitably touch the jellyfish while working are stung (Kawahara et al. 2006a).

Jellyfish are also a great concern to coastal areas that rely on tourism for revenue (Purcell et al. 2007; Richardson et al. 2009). Periodic beach closures and injury (including death) to recreationists or people that spend a long time in the water swimming, wading, surfing, etc., have occurred globally in France, Spain, Thailand, and Australia (Fenner et al. 2010; Fenner and Williamson 1996; Gershwin et al. 2010; Pages 2001). Jellyfish stings in tourism areas have been an on-going coastal management problem in Australia; however, public awareness and mitigation strategies have been adopted to alleviate detrimental tourism effects (Gershwin et al. 2010). Public education and awareness, including information posted on signs and pamphlets about jellyfish given to beach-goers, have also helped people cope with large numbers of jellyfish on German beaches (Baumann and Schernewski 2012). In Chesapeake Bay, a monitoring system is in place that predicts the likelihood encountering a sea nettle

(Decker et al. 2007). In other areas without extensive jellyfish research, public monitoring of high numbers of stinging species has been conducted to reduce harmful jellyfish-human interactions. Examples of these observations include the harmful box jellyfish species in Hawai‘i (Thomas et al. 2001), historically referred to as *Carybdea alata* [Reynaud, 1830] but currently regarded as *Alatina moseri* [Mayer, 1906] (Bentlage et al. 2010; Gershwin 2005) and more recently the sea nettle *C. quinquecirrha* in Barnegat Bay, New Jersey (Vasslides, pers comm.). Although loss of tourism and/or recreation revenue due to jellyfish has not been recorded in these coastal areas or other areas with high jellyfish abundance, researchers have proposed that jellyfish-infested beaches will affect tourism (Purcell et al. 2007). Moreover, current media perspectives on jellyfish populations in the environment are often negative (Condon et al. 2012) and it has been suggested that as human populations and coastal recreation increase, jellyfish stings will continue to be problematic (Macrokanis et al. 2004).

To date, jellyfish populations have increased in certain regions of the world (Condon et al. 2012, Condon et al. 2013) and along the majority of U.S. coastlines, including Hawai‘i and Alaska, jellyfish populations have shown varying degrees of increase and certainty (Brotz et al. 2012). For example, an increase in jellyfish populations was documented with high certainty along the U.S. Northeast coast and Hawai‘i versus low certainty of increased jellyfish populations along the U.S. West coast and Gulf of Mexico (Brotz et al. 2012).There are many hypotheses associated with human activities as drivers for increasing jellyfish populations, including cultural eutrophication, habitat modification, transportation of ballast water, aquaculture practices and overfishing (See Purcell 2012 for review). Additionally, jellyfish undergo natural bloom and burst cycles of abundance, which can explain why large numbers of jellyfish are observed in periodic and seemingly aberrant fluctuations (Boero et al. 2008). Although these jellyfish 'blooms' have been described as ecological enigmas these occurrences are not ephemeral; instead, the 'blooming' nature of jellyfish species is a product of the bipartite lifecycle (Müller and Leitz 2001). Therefore, in order to accurately report jellyfish population dynamics instead of blooming events, more long term data sets of jellyfish abundance is needed (Purcell et al. 2007).

Excluding the Great Lakes, about 30% of the total U.S. population resides on the coast (Crowell et al. 2007). Moreover, the coastal population of the United States has increased from 275 to 400 people per square kilometer from 1960 to 1990; by 2025, it is predicted that nearly 75% of U.S. citizens will live in a coastal county or within 150km from the coast (Hinrichsen 1995). This increase in coastal communities and the existence of jellyfish populations along almost all U.S. coastlines equates to a considerable likelihood of jellyfish-human interactions. People-wildlife interactions and the rate of change in people's beliefs and attitudes about human-environment relations creates challenges in wildlife management (Decker and Enck 1996) and the efficient sustainability of environmental resources (Cater 1995). Therefore, to circumvent negative societal repercussions, such as loss of tourism revenue due to jellyfish encounters and/or not utilizing coastal areas due to jellyfish, determining the current state of jellyfish-human interactions in coastal communities affected by jellyfish is needed.

I chose to investigate jellyfish-human interactions in North Carolina by analyzing public perspective or cultural knowledge of jellyfish ecology and how jellyfish influenced people’s decisions to engage in water activities with cultural consensus theory (CCT). CCT is a theory that forms the foundation for cultural consensus analysis, which is a method used in anthropology that allows researchers to analyze qualitative data with quantitative data analyses to estimate cultural beliefs and to report an individual’s knowledge of those beliefs, known as cultural competency (Weller 2007). The overall objective of this chapter was to understand public perspectives of jellyfish. Specifically, I was interested in how cultural perspectives or knowledge of jellyfish would differ between four culturally distinct groups; fishers (recreational and commercial), recreationists, coastal researchers, and jellyfish researchers. These groups were selected for this study because of the high likelihood of interacting with jellyfish while engaging in water activities, including research. I evaluated jellyfish-human interactions of these groups by distributing a jellyfish survey that tested two hypotheses related to jellyfish ecology and how jellyfish influence society with an emphasis on people’s choice to engage in water activities. When compared to other ecosystem organisms, jellyfish are often understudied despite being intermediate to top level predators (Figure 1), therefore, it is likely that ecological literacy of jellyfish is misinterpreted by researchers other than jellyfish researchers. Moreover, since outreach education and associated social media about scientific explorations stems from research (McKenna and Main 2013), misinterpretation of jellyfish ecological literacy is possible and may reverberate to the public interface. To test this phenomenon, I hypothesized that the cultural perspectives of jellyfish ecology would not differ among fishers, recreationists, coastal researchers, and jellyfish researchers.

I wanted to gather insights on how people are influenced by jellyfish, including cultural perspectives of jellyfish stings, myths, and how jellyfish influence people's choices to engage in water activities. I chose to include common myths about jellyfish in North Carolina because residents reported to us that jellyfish of particular colors will "sting differently." I also included common myths about jellyfish such as urination as a treatment for jellyfish stings, where stings are felt on a person's body and how jellyfish will "appear" without warning. Jellyfish have influenced coastal economies that rely on tourism revenue; therefore, I also wanted to explore how jellyfish-human interactions affect water recreation, hobbies, and vacations to areas prone to jellyfish occurrences. Each group was presumed to have different experiences and beliefs of jellyfish, thus, perspectives of jellyfish-human interactions would also be variable among the groups. For example, jellyfish researchers may perceive that large amounts of jellyfish are tolerable in coastal waters because they study jellyfish versus recreationists may perceive that large amounts are not tolerable because jellyfish inhabit desirable surfing areas. Moreover, fishermen and coastal researchers may perceive jellyfish as problems because of gear interferences and/or damage. To account for this variation in perspectives, I hypothesized that the Cultural perspectives of jellyfish in society would be similar among the cultural groups.

Data on the public's perspective of unknown environmental-societal questions, problems and/or concerns has been used to help manage environmental problems. For example, to help forest management in the Amazon, cultural perspectives of the Guarayo indigenous people in Bolivia showed that ecological perspectives of sparse and plentiful species were similar to scientific perspectives of intrinsic growth rate (k or r-related species), determined what game species was considered valuable to the Guarayo community and that subsistence hunting and fishing would continue to be important. Since the landscape is changing, understanding the indigenous people’s cultural perspectives is important and fundamental to wildlife management and sustainability of the Bolivian Amazon natural resources (Van Holt et al. 2010). A study in Hawai‘i that used CCT revealed a high-yield of similar cultural perspectives among hand-line fishers and fishery scientists regarding yellowfin tuna stock structure, fish movements, resource abundance, stock conditions, and fishery interaction (Miller et al. 2004). This information was valuable to the management of Hawai‘i’s yellowfin tuna fishery because it provided data about the contemporary state of the fishery and revealed uniform cultural perspectives between hand-line fishers and fishery scientists (Miller et al. 2004). In North Carolina, cultural perspectives about coastal resource problems associated with fishing among recreational fishers, commercial fishers, and coastal resource managers were analyzed with CCT (Johnson and Griffith 2010). Unlike the yellowfin tuna study in Hawai‘i, this study revealed striking differences in cultural perspectives between the groups but recreational and commercial fishers did agree on several underline fishing issues, which may reflect shared values toward the philosophy and a willingness to support future fishery resource management actions in North Carolina. This chapter contributes to the building knowledge of jellyfish research by using CCT to determine cultural perspectives of jellyfish across four groups of people. By utilizing perspectives of jellyfish-human interactions, these data provides quantitative social science data that will benefit coastal communities prone to jellyfish occurrences.

METHODS

Cultural group classification and determination

The cultural groups were classified by the paradigm that cultures form around specific recreation and leisure activities (McDonough 2013). Under this definition, the "social world" of each group would have its own unique culture with behavioral norms, expectations, roles, language, and items such as clothing and gear (Ditton et al. 1992). The survey's participants self-identified themselves as fishers (people whose main career was commercial fishing or hobby was recreational fishing) or coastal recreationists (people whose main career or hobby entails long periods of time in the water, such as swimming, surfing, etc.). The coastal and jellyfish researchers did not self-identify themselves; instead, I identified them by their research interests and publications via scholarly searches. Although research is usually a career and not necessarily associated with recreation/leisure, coastal and jellyfish researchers were expected to have different social worlds and thus were classified as two distinct cultural groups just as fishers and recreationists.

Study design and sampling framework

I created the jellyfish survey under the guidelines presented by Weller (2007). The survey contained 64 statements; 32 statements on jellyfish ecology and 32 statements on how jellyfish influence society. The jellyfish survey (Appendix 1) was distributed in July 2012. All participants were adults (18+ years of age) and U.S. citizens. For the fishers and coastal recreationists, only NC residents were solicited with individual face-to-face interviews (N = 75, successful interview = 30 per group) were conducted at coastal areas in eastern North Carolina that are in proximity to areas known to experience jellyfish occurrences (Figure 2). All face-to-face interviews were conducted within two week period and the fishers and recreationists were found arbitrarily throughout the 25 areas (Figure 2). Mailed surveys (N = 82 total, returned = 38) were sent to coastal researchers in North Carolina, which consisted of researchers from academic institutions, federal and state agencies, and non-profit organizations. Mailed surveys (n= 47, returned = 20) were also sent to jellyfish researchers residing in the United States. The IRB for this study was obtained from the University & Medical Center Review Board at East Carolina University, number UMCIRB 12-000609.

Three jellyfish species that are frequently sighted in eastern North Carolina are the comb jellyfish *Mnemiopsis leidyi* [A. Agassiz, 1865] estuarine sea nettle *Chrysaora quinquecirrha* [Desor, 1848] (Williams and Deubler 1968) and the oceanic cannonball jellyfish *Stomolophus meleagris* [L. Agassiz, 1860] (Calder 1982). The sea nettle *C. quinquecirrha* is a jellyfish that is known to sting people (Schultz and Cargo 1969) but the encounters with the comb jellyfish *M. leidyi* and the cannonball jellyfish *S. meleagris* do not typically harm people. Since the severity of jellyfish-human interactions is dependent on if the jellyfish species' stings hurt people, I surveyed fishers and recreationists at estuarine and oceanic areas where potentially harmful and harmless species are found (Figure 2).

Statistical Analyses

The root of CCT is based the idea that culture is a set of learned and shared beliefs and behaviors (Weller 2007). Cultural beliefs are affected by the social norms (normative beliefs) associated with a group (Heywood 1996; Vaske and Whittaker 2004) and group culture is the most frequently held items of knowledge and belief (D'Andrade 1987). CCT generates 1) a culturally correct answer key derived from the average of participants' responses and 2) cultural competency scores or cultural competencies. Cultural competency, or cultural expertise of an individual, is calculated by comparing agreement between the study's participants and in general, higher values equate to greater cultural competencies (Weller 2007). To analyze cultural competencies within and across groups, a factor analysis of an informant by informant agreement matrix was performed (D'Andrade 1987; Vaske and Whittaker 2004) on all participant's responses and the participant responses separated by their group. The participants are considered to have a consensus about the domain analyzed if the 1st and 2nd factor loading (ratio) is greater than 3, there are no negative competency values, and there is a high amount of agreement in responses among participants (Romney et al. 1986; Weller 2007). Cultural competency of each participant was calculated by comparing agreement between all pairs of the survey's participants (Weller 2007) and represents the first factor loading of the factor analysis (Romney et al. 1986). The statistical program UCINET (version 6.322) from Analytic Technologies was used to perform all factor analyses and generate cultural competencies. Mean cultural competencies of all participants separated by their group were compared with a one-way ANOVA. Variance of the ANOVA was further tested for homogeneity or heterogeneity with a Levene test of variance. To determine how mean cultural competency differed between groups, a Tukey post-hoc test was performed. Comparison of the jellyfish survey's culturally correct answers for each statement derived from the each groups' consensus analysis were classified according to accordance and discordance, where “accordance” refers to the unanimous agreement of culturally correct answers among the four groups and “discordance” refers to at least one of the four groups disagreed. To visualize participant agreement within and across groups, UCINET was used to create metric multidimensional scaling diagrams based on the aggregate proximity matrix generated from the factor analysis.

RESULTS

Consensus analyses and cultural competencies of jellyfish perception

The consensus analyses performed on all of the statements within the jellyfish survey for all of the participants (N = 118) and each group had a first to second eigenvalue ratio greater than 3 and no negative values. Of the groups, fishers (ratio = 3.39, SD = 0.07) and recreationists (ratio = 4.55, SD = 0.06) showed more intragroup variation in jellyfish perception than the coastal researchers (ratio = 5.58, SD = 0.04) and jellyfish researchers (ratio = 5.63, SD = 0.06) (Table 1). The ANOVA revealed that mean cultural competencies across all groups were significantly different (F-value = 7.97, p-value = 7.21e-05) and the Levene test of variance confirmed that variance was homogeneous among the competency values (Test statistic = 1.43, p-value = 0.24). Therefore, mean cultural competencies were similar between fishers (0.23) and recreationists (0.24) (Tukey p-value = 1.00), fishers (0.23) and coastal researchers (0.27) (Tukey p-value = 0.05), recreationists (0.24) and coastal researchers (0.27) (Tukey p-value = 0.09), and coastal researchers (0.27) and jellyfish researchers (0.30) (Tukey p-value = 0.15). Significant differences in mean cultural competency were noted between the fishers (0.23) and jellyfish researchers (0.30) (Tukey *p*-value = 0.00) and recreationists (0.24) and jellyfish researchers (0.30) (Tukey *p*-value = 0.00) (Figure 3).

Accordance of jellyfish survey ecological statements

The culturally correct answers to the ecological statements of each group were often in accordance. The groups agreed that statements such as jellyfish are animals (#1), live longer than a year (#3), jellyfish eat fish and shrimp (#14, #15), jellyfish are able to eat more than it's body weight (#17) and all groups agreed that turtles and fish eat jellyfish (#20, #22). In addition, false statements, myths, and misunderstandings about jellyfish ecology were accurately identified by answer accordance regarding jellyfish ecology and stings. These statements included jellyfish use fins to swim (#7), jellyfish can swim against moving water (#9), jellyfish need to surface to breathe and eat (#12, #13), jellyfish do not need to eat to survive (#18), jellyfish are top trophic level organisms in food webs like sharks (#23, Figure 4A), jellyfish are low trophic level organisms in food webs like plants (#26, Figure 4D), and jellyfish do not sting to reproduce (#29), communicate (#30), and can sting more than once (#31) (Table 2).

Accordance of jellyfish survey societal statements

The culturally correct answers to the societal statements of each group were also in frequent accordance. Regarding jellyfish stings, answers from all groups accurately identified that jellyfish stings are felt on a person's body (#35) and 'vinegar is the best remedy for a jellyfish sting' (#38) was mutually agreed upon (Table 3). Several answers to the myths of jellyfish stings were also in accordance; for example, red-color jellyfish stings hurt more than other-colored jellyfish stings (#33), jellyfish cannot sting the palm of a person's hand (#34), and jellyfish do not need to touch a person to sting them (#37). Accordance of answers to the perception of jellyfish and society showed that all groups agreed that people would not benefit if there were no jellyfish (#47) and jellyfish have economic value (#48). However, all groups also agreed that the presence of jellyfish will deter people from water activities (#53). When asked 'how many jellyfish seen in water will make a person stop their water activities,' there was accordance that water activities will continue if there are fewer than five jellyfish seen in water (#41). Hearing that someone else was stung by jellyfish will not deter people from doing water activities (#57) but if people are stung by a jellyfish they will stop their water activities (#58). The presence of jellyfish affects vacationing (#52) but there was accordance that people will take a vacation to areas where jellyfish are sighted regularly (#49), and people will book a return vacation to a destination even if they are stung by jellyfish (#50). For recreation, group accordance revealed that if jellyfish are always present in an area, people will find another place for recreation (#56). When asked if jellyfish appear without warning and if people know where jellyfish come from, all groups agreed that people think jellyfish appear without warning (#59) and that people do not know where jellyfish come from (#60). Incidentally, all groups disagreed with the statement that jellyfish are taking over aquatic ecosystems worldwide (#62) (Table 3).

Discordance of jellyfish survey ecological statements

Answers to 14 ecological statements showed discordance among group responses, possibly reflecting expertise regarding jellyfish biology and ecology (Table

4). When specific questions were asked about jellyfish, the jellyfish researchers agreed with the statements jellyfish have eyes (#4), no brain (#5), no heart (#6), and do not use tentacles to swim (#8), which are also biologically correct. The fishers, recreationists, and coastal researchers varied in their answers to these statements but when compared to the jellyfish researchers, coastal researchers agreed that jellyfish do not have a brain (#5) and a heart (#6) and these answers are biologically correct. Jellyfish thrive in murky water (#10) and when asked, jellyfish researchers agreed and the other groups disagreed. Jellyfish also do not need a lot of air-in-water to survive (#11) and all groups except the coastal researchers agreed. Some of the false statements that inquired about what jellyfish consume and what eats jellyfish (#16, #19 and #21) varied in group response, specifically fishers agreed that jellyfish eat plants (#16) and dolphins eat jellyfish (#21), which is biologically incorrect. Jellyfish researchers answered that jellyfish are mid-trophic level organisms like fish (#24, Figure 4B) and the current research regarding jellyfish in food webs indicates that this is the correct answer (Brodeur et al. 2011; Purcell and Decker 2005; Suchman et al. 2008), whereas fishers and recreationist responses suggested that jellyfish are lower trophic level organisms like shrimp (#25, Figure 4C). As a group, the coastal researchers did not select any of the food web pictures but when individual participant answers were analyzed the response from coastal researchers varied. Forty-percent of coastal researchers selected the same food web picture as fishers and recreationists (#25, Figure 4C) and 29% of coastal researchers selected the same food web picture as the jellyfish researchers (#24, Figure 4B). The remaining 31% coastal researchers did not select any of the food webs pictures. For the sting questions, only jellyfish researchers agreed that all jellyfish sting (#27). Moreover, statements that reported myths about jellyfish stings were also highly variable in group response, where fishers and recreationists agreed that jellyfish sting to protect themselves (#28) but coastal and jellyfish researchers disagreed. Lastly, fishers were the only group that agreed to the statement “jellyfish cannot control their sting” (#32) (Table 4).

Discordance of jellyfish survey societal statements

There were nine societal statements that were in discordance across all groups. For example, the jellyfish researchers disagreed with the statement ‘jellyfish cannot sting a person through their clothes’ (#36) and fishers were the only group that agreed to the statement that urine as the best remedy for a jellyfish sting (#39). When asked ‘how many jellyfish seen in water will make a person stop their water activities,’ there were different answers among the groups. Coastal researchers and jellyfish researchers agreed that seeing five or more jellyfish in water will make people stop water activities (#44) but fishers and recreationists disagreed. Moreover, fishers were the only group that agreed with the statement ‘people will continue their regular water activities (hobbies) if jellyfish are in the water’ (#54). When asked if people would book a return vacation to an area if they were stung by jellyfish (#51), recreationists and jellyfish researchers agreed but fishers and coastal researchers disagreed. Only coastal researchers did not select the statement that people will leave a recreation area if jellyfish are present (#55). When asked if there is a way to predict when large numbers of jellyfish will appear (#61), fishers and coastal researchers disagreed whereas recreationists and jellyfish researchers agreed. Lastly, when asked if jellyfish are frequently reported in the media (newspapers, websites, etc.) (#63, #64), only jellyfish researchers agreed (Table 5).

MDS of ecological statements

For the ecological statements, the metric MDS showed higher agreement among the jellyfish researchers than other groups. The jellyfish researchers are close to the coastal researchers but the recreationists and fishers are quite dispersed from both coastal and jellyfish researchers. The most dispersed agreement was noted in the fishers. However, it should be noted that agreement among the fishers and recreationists is equally distant from the coastal and jellyfish researchers (Figure 4).

MDS of societal statements

For the societal statements, there was varying amounts of agreement across all groups with no cluster as in the ecological statements (Figure 4). This suggests that all participants of the jellyfish survey did not share the same agreement toward the cultural statements concerning jellyfish and society (Figure 5).

DISCUSSION

I found that perspectives of jellyfish ecology varied among the groups but societal perspectives of jellyfish were similar. The cultural perspectives of jellyfish researchers were closely aligned with what is biologically known about jellyfish, but perspectives on jellyfish ecology among fishers, recreationists and coastal researchers were less clear. All group perspectives on the influence of jellyfish on water activities showed that although jellyfish may be problematic to coastal communities, water activities and associated revenue may not be affected due to varying amounts of tolerance toward seeing jellyfish in water and stings.

Cultural consensus on jellyfish ecology

The results of the jellyfish survey's ecological statements support my first hypothesis that the cultural groups would share similar cultural perspectives of jellyfish ecology, with the obvious exception of jellyfish researchers. Mean cultural competencies of coastal and jellyfish researchers were similar but the range of cultural competency among the coastal researchers overlapped with fishers and recreationists more than jellyfish researchers (Figure 3). Most of the culturally correct answer keys for the ecological statements regarding jellyfish in food webs were in accordance across all groups (Table 2). Furthermore, all groups accurately selected what is scientifically known about jellyfish as predators and prey. However, the overlap in cultural competency and similar mean cultural competencies between fishers, recreationists, and coastal researchers (Figure 3) suggests that knowledge of jellyfish in ecosystems is less clear at both the public and research interfaces.

The statements regarding the feeding ecology of jellyfish had culturally correct answer keys in discordance (Table 4). Specifically, there seems to be confusion on the role jellyfish play in food webs (#23-26, Table 2 & 4). Fishers, recreationists, and most of the coastal researchers (41%) believed that jellyfish in nature are best described as an organism that shares a similar trophic level as shrimp (Figure 4C). Since the current data on jellyfish in food webs has shown that jellyfish are intermediate to top level trophic level predators (Figure 4B) (Brodeur et al. 2011; Mills 1995; Purcell et al. 2007) and jellyfish researchers selected this food web picture as the culturally correct answer, I can infer that fishers, recreationists, and 39% of coastal researchers all selected the incorrect food web picture that best describes jellyfish in food webs. It should be noted that 31% of coastal researchers did not select a food web picture and of the 31% only 1% wrote comments about the food web pictures being inaccurate due to the energy flow or arrow direction pointing downwards instead of upwards and the food web diagrams were too simplistic for them to make a choice. Although the simple food web pictures used in the jellyfish survey were created for the purposes of easy interpretation across all participation groups, I felt that the pictures were adequate enough to visualize where jellyfish belong in food webs. Moreover, 29% of coastal researchers did select the culturally and scientifically correct food web picture, which demonstrates that some of the coastal researchers surveyed were familiar with the role jellyfish play in foods webs.

It is plausible that selecting food web concepts by reading statements versus selecting a food web picture may have been easier for the survey participants to comprehend. This ideology may reflect what scientific educators refer to as an "ecological misconception" (Cherrett 1989). Research has shown that students (4^{th} grade to college level juniors and seniors) comprehend and internalize food chain concepts (what eats what), but have difficulties when food chain principles are applied to the complexities of food web dynamics (Adeniyi 1985; Griffiths and Grant 1985; Munson 1994). Ecological misconceptions are typically formed by students who utilize their prior knowledge and experience when asked about scientific phenomenon

(Hewson and Hewson 1988; Posner et al. 1982). Moreover, ecological misconceptions are created when students have an incorrect interpretation or hold an alternative understanding of the subject matter (Munson 1994). Since the ecological statements read in a systematic format (Table 2, #14, #15, #20 and #22), the information processed by the participant could have been ‘chain-like’ or ordinal, where the participant could internalize the information easier than applying this ecological knowledge to the food web pictures. Also, if the incorrect food web choice was indeed an ecological misconception, which stems from the participant’s prior knowledge and experience with jellyfish, it is conceivable that the lack of education and data about jellyfish in ecosystems may explain why fishers, recreationists, and coastal researchers placed jellyfish improperly in food webs.

Cultural consensus on the societal role of jellyfish

The results of the jellyfish survey’s societal statements supported my 2nd hypothesis that all groups would have similar cultural perspectives of how jellyfish influence society (Table 3). The MDS of the jellyfish survey’s societal statements did not show a clear distinction or cluster of a group’s agreement (Figure 5). Instead participants from all groups were randomly distributed throughout the matrix and varied spatially from each other. This showed that, unlike the jellyfish survey’s ecological statements, there was less agreement within each group in the statements regarding how jellyfish influence society.

I found that the cultural perspectives of how jellyfish influence water activities, recreation, and vacationing differed among all groups. Although all groups agreed that seeing fewer than five jellyfish would not stop people from engaging in water activities (Table 3, #41), there were different perspectives in the termination of water activities of seeing more than five jellyfish in water (Table 5, #44). Specifically, fishers and recreationists felt that seeing more than five jellyfish in the water would not stop water activities and coastal and jellyfish researchers thought water activities would cease. Since the survey was distributed in different coastal recreation areas in eastern North Carolina (Figure 1), it is possible that the jellyfish species that the fishers or recreationists were thinking about while taking the survey, have frequently observed, and/or had personal experiences with are not species that is harmful to humans. Of the three jellyfish species that are sighted frequently the comb jellyfish *Mnemiopsis leidyi* [A. Agassiz, 1865] and the oceanic cannonball jellyfish *Stomolophus meleagris* [L. Agassiz, 1860] are usually not harmful to humans but the sea nettle *C. quinquecirrha* is a jellyfish that is known to cause painful stings (Schultz and Cargo 1969). Twenty-three percent of fishers and 37% of recreationists felt that water activities would continue with more than five jellyfish conduct their water activities in oceanic areas where the relatively harmless cannonball jellyfish *Stomolophus meleagris* are observed. Continuing water activities with more than five jellyfish may also coincide with the type of protective equipment fishers and recreationists used when engaging in their water activities. Fishers in North Carolina are known to use waders and some of the recreationists wear wetsuits, which prevent contact with jellyfish. In fact, among the recreationists that enjoy water activities in estuarine areas where stinging sea nettles *C. quinquecirrha* are abundant were analyzed, only 2% felt that seeing more than five jellyfish would stop water activities. If the sea nettle *C. quinquecirrha* was the jellyfish that were frequently in contact with these recreationists, it could be that these individuals are more tolerant of sea nettle *C. quinquecirrha* stings. Conversely, although the consensus analysis showed that the fishers agreed with the recreationists, 46% of fishers who frequently fished in areas where sea nettles *C. quinquecirrha* are abundant felt that seeing more than five jellyfish would stop water activities. However, despite the negative repercussions of jellyfish stings, all groups agreed that people would take a vacation to areas where jellyfish are sighted regularly even if they are stung by jellyfish.

All groups felt that jellyfish have economic value. From a wildlife management standpoint, wildlife has either a positive or negative social value dependent on human perspective (Brown and Manfredo 1987). With this in mind, coastal communities may revisit their perspectives of jellyfish depending on changing environmental-social pressures. For example, the cannonball jellyfish *S. meleagris* is an abundant jellyfish species along the southeastern and Gulf coasts of the U.S. and large populations are observed off the Georgia coast from March to October (Calder 1982). According to a local newspaper, in 1998 the harvests of the cannonball jellyfish *S. meleagris* turned Georgia’s shrimping industry into the third-largest commercial fishery by jellyfish weight alone. Shrimpers can earn $0.06 per pound of jellyfish and the processing plant can process 60,000 pounds at a time. Due to high fuel costs, some shrimpers have completely switched from harvesting shrimp to jellyfish and all jellyfish harvests are exported directly to Asia (Landers 2011). It is unknown how this jellyfish fishery affects natural populations of jellyfish, but researchers have reported problems with the cannonball jellyfish *S. meleagris* preventing shrimping activities in Georgia and South Carolina for decades (Jenkins 2012; Kraeuter and Setzler 1975). Georgia’s cannonball fishery could be an example of how social value of jellyfish has changed overtime from negative to positive social value thereby altering public perception of jellyfish in the United States.

Implications for managing jellyfish-human interactions

These data, along with other research on perspectives of the jellyfish in society, will be useful for economic studies of tourism areas that are known to experience jellyfish occurrences and coastal managers to help mitigate deleterious jellyfish-human interactions. For example, the use of barrier nets to designate swimming areas in coastal areas prone to jellyfish occurrences may reduce the number of jellyfish to the "fewer than five" allowance of jellyfish sighted. Since seeing fewer than five jellyfish will not stop water activities, negative effects on coastal recreation could be minimized. Low jellyfish numbers in swimming areas will also reduce the potential of jellyfish stings. Thus understanding the cultural perspective of "fewer than five" could help with coastal recreation and subsequently tourism in North Carolina, and if the cultural perspectives are similar, other U.S. coastal states where jellyfish may be problematic. On the other hand, if cultural perspectives are different, there may be instances where more jellyfish sighted in recreation areas may not affect water activities. For example, in a recent study of jellyfish public perception on German beaches, beach users were reported to tolerate periodic and moderately increasing jellyfish numbers in the water (Baumann and Schernewski 2012). Additionally, Baumann and Schernewski's (2012) research investigated "willingness to pay" for a swimming area that is free from jellyfish and found that most beach users would not pay more for a netted swimming area devoid of jellyfish. However, the author's noted that the public is well-informed that there are no "life-threatening jellyfish species" in this area (Baumann and Schernewski 2012). Moreover, information (warning signs, information panels and pamphlets) on jellyfish that is readily available on-site proved to help beach users accept and feel better about jellyfish being on German beaches (Baumann and Schernewski 2012). Although our methodologies were different, this study and my cultural consensus analysis show how the utility of jellyfish public perspective can be used to evaluate the extent of jellyfish-human interactions.

CONCLUSIONS

Public perspective of marine predators, like jellyfish, has substantial effects on scientific explorations as well as the utilization of coastal recreation areas, and subsequently, ecosystem services and economics. For example, like jellyfish, the presence of sharks has also influenced coastal recreation because humans have feared sharks for centuries and shark attacks have been detrimental to tourism (Cliff 1991). Early shark research in the 1960s and 1970s focused on shark physiology and behavior, including attack behavior, with the goal of human protection from sharks. Overtime, shark research changed focus when shark-control programs proved to be more effective in mitigating shark attacks, but during this investigation process a plethora of life history research on sharks was obtained (Simpfendorfer et al. 2011). More shark research equated to a further understanding of the role of sharks in ecosystems and over time public perception has shifted from "adventure-seeking hunters" to "nature-seeking observers" of sharks (Whatmough et al. 2011). Today, instead of exploring ways to protect humans from sharks, shark conservation and management are at the forefront of research endeavors (Dulvy et al. 2008; Simpfendorfer et al. 2011). Although conserving jellyfish is an unprecedented scientific proposition, it is possible that jellyfish research may follow similar scientific exploration paths as shark research, especially since jellyfish have significant effects on water activities, recreation and vacationing. Jellyfish researchers are hopeful that jellyfish research continues to gain more attention as the scientific community accepts ecosystem-based fishery management and trans-disciplinary science, which includes both ecological and societal research questions and approaches to promote environmental sustainability (Condon et al. 2012; Lang et al. 2012; Pikitch et al. 2004; Purcell 2012). In time, as more research is conducted on jellyfish and knowledge is iterated to the public through different media outlets, education, and accurate scientific reporting, public perspective of jellyfish will change and the cultural knowledge of jellyfish in ecosystems are likely to improve.

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LIST OF TABLES AND FIGURES

Figure 1. Results from an ISI Web of Science search for the terms estuary + phytoplankton + zooplankton + fish and + jellyfish. The term 'jellyfish' included jellyfish, gelatinous, ctenophore and sea nettle.

Figure 2. Face to face interviews were conducted at coastal areas known to experience jellyfish occurrences in eastern North Carolina (circles).

Figure 3. Boxplots of cultural competency derived from the consensus analysis of jellyfish survey. The same letter indicates similar mean cultural competencies across groups. Circles indicate outliers > 1.5 times of lower quartile and horizontal bars within the box plots indicate the cultural competency median. The upper box above the median extends to the third quartile and the lower box extends to the first quartile. The bars extend to the largest and smallest values, respectively.

Figure 4. All survey participants were asked to circle the food web picture(s) that best described jellyfish in food webs (survey questions #23 and #26, Table 2; #24 and #25, Table 4).

Figure 5. Metric multidimensional scaling of the ecological statements agreement derived from the aggregate proximity matrix of the consensus analysis (stress = 0.329), where circles = fishers (N = 30), triangles = recreationists (N = 30), squares = coastal researchers (N = 38) and diamonds = jellyfish researchers (N = 20).

Figure 6. Metric multidimensional scaling of the societal statements agreement derived from the aggregate proximity matrix of the consensus analysis (stress = 0.314), where circles = fishers (*N* = 30), triangles = recreationists (*N* = 30), squares = coastal researchers (*N* = 38) and diamonds = jellyfish researchers (*N* = 20).

Table 1.

	All Participants (N = 118)	Fishers (N = 30)	Recreationists (N = 30)	Coastal Researchers (N = 38)	Jellyfish Researchers (N = 20)
Mean	0.25	0.23	0.24	0.27	0.30
SD	0.06	0.07	0.06	0.04	0.06
Min	0.03	0.02	0.01	0.18	0.18
Max	0.35	0.37	0.34	0.35	0.40
Ratio	4.39	3.39	4.55	5.58	5.63

Table 2.

#	Ecological Statements	F	R	CR	JR
1	Jellyfish are animals	1	1	1	1
2	Jellyfish are plants	0	0	0	0
3	Jellyfish live longer than a year	1	1	1	1
7	Jellyfish use fins to swim	0	0	0	0
9	Jellyfish can swim against moving water	0	0	0	0
12	Jellyfish need to come up to the surface to breathe	0	0	0	0
13	Jellyfish need to come up to the surface to eat	0	0	0	0
14	Jellyfish eat fish	1	1	1	1
15	Jellyfish eat shrimp	1	1	1	1
17	Jellyfish can eat more than their body weight	1	1	1	1
18	Jellyfish do not need to eat to survive	0	0	0	0
20	Turtles eat jellyfish	1	1	1	1
22	Fish eat jellyfish	1	1	1	1
23	The food web picture that illustrates that jellyfish are at the same trophic level as sharks best describes jellyfish in nature	0	0	0	0
26	The food web picture that illustrates that jellyfish are at the same trophic level as plants best describes jellyfish in nature	0	0	0	0
29	Jellyfish sting to reproduce	0	0	0	0
30	Jellyfish sting to communicate	0	0	0	0
31	A jellyfish can sting only once	0	0	0	0

Table 3.

#	Societal Statements	F	R	CR	JR
33	Stings from red-colored jellyfish hurt more than other-colored jellyfish	0	0	0	0
34	Jellyfish cannot sting the palm of a person's hand	0	0	0	0
35	Jellyfish stings are felt on a person's body	1	1	1	1
37	Jellyfish do not need to touch a person to sting them	0	0	0	0
38	Vinegar is the best remedy for a jellyfish sting	1	1	1	1
40	There is no remedy for a jellyfish sting	0	0	0	0
41	Seeing fewer than five jellyfish in water will make people stop their water activities.	0	0	0	0
47	People would benefit if there were no jellyfish	0	0	0	0
48	Jellyfish have economic value	1	1	1	1
49	People will not take a vacation to areas where jellyfish are sighted regularly	0	0	0	0
50	People will not book a return vacation to an area if they were stung by jellyfish	0	0	0	0
52	The presence of jellyfish does not affect vacationing	0	0	0	0
53	The presence of jellyfish will deter people from doing water activities	1	1	1	1
56	If jellyfish are always present in an area, people will find another place for recreation	1	1	1	1
57	If people hear that someone was stung by jellyfish they will stop their water activities	0	0	0	0
58	If people are stung by jellyfish, they will stop their water activities	1	1	1	1
59	People think jellyfish will appear without warning	1	1	1	1
60	People know where jellyfish come from	0	0	0	0
62	Jellyfish are taking over aquatic ecosystems worldwide	0	0	0	0

Table 4.

#	Ecological Statements	F	R	CR	JR
4	Jellyfish have eyes	0	0	0	1
5	Jellyfish have a brain	1	1	0	0
6	Jellyfish have a heart	1	1	0	0
8	Jellyfish use tentacles to swim	1	1	0	0
10	Jellyfish thrive in murky water	0	0	0	1
11	Jellyfish do not need a lot of air-in-water to survive	1	1	0	1
16	Jellyfish eat plants	1	0	0	0
19	People eat jellyfish	0	0	1	1
21	Dolphins eat jellyfish	1	0	0	0
24	The food web picture that illustrates that jellyfish are at the same trophic level as fish best describes jellyfish in nature	0	0	0	1
25	The food web picture that illustrates that jellyfish are at the same trophic level as shrimp best describes jellyfish in nature	1	1	0	0
27	All jellyfish sting	0	0	0	1
28	Jellyfish sting to protect themselves	1	1	0	0
32	Jellyfish cannot control their sting	0	1	1	1

Table 5.

#	Societal Statements	F	R	CR	JR
36	Jellyfish cannot sting a person through their clothes	0	0	0	1
39	Urine is the best remedy for a jellyfish sting	1	0	0	0
44	Seeing more than five jellyfish in water will make people stop their water activities	0	0	1	1
51	People will not book a return vacation to an area if they were stung by jellyfish	0	1	0	1
54	People will continue their regular water activities (hobbies) if jellyfish are in the water	1	0	0	0
55	People will leave a recreation area if jellyfish are present	1	1	0	1
61	There is no way to predict when large numbers of jellyfish will appear	1	0	1	0
63	Jellyfish are frequently reported in the media (newspapers, websites, etc.)	0	0	0	1
64	Jellyfish are rarely reported in the media (newspapers, websites, etc.)	1	1	1	0

Figure 1.

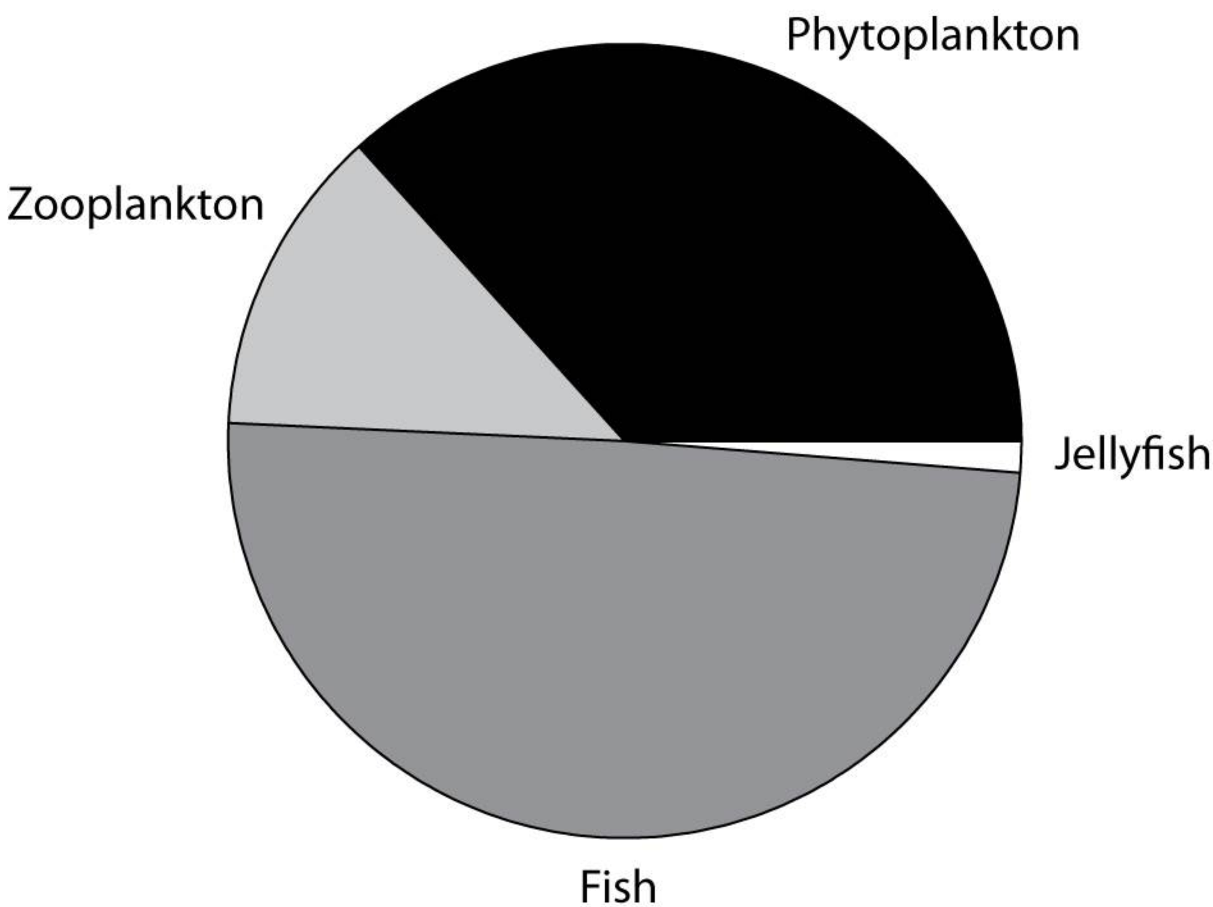


Figure 2.

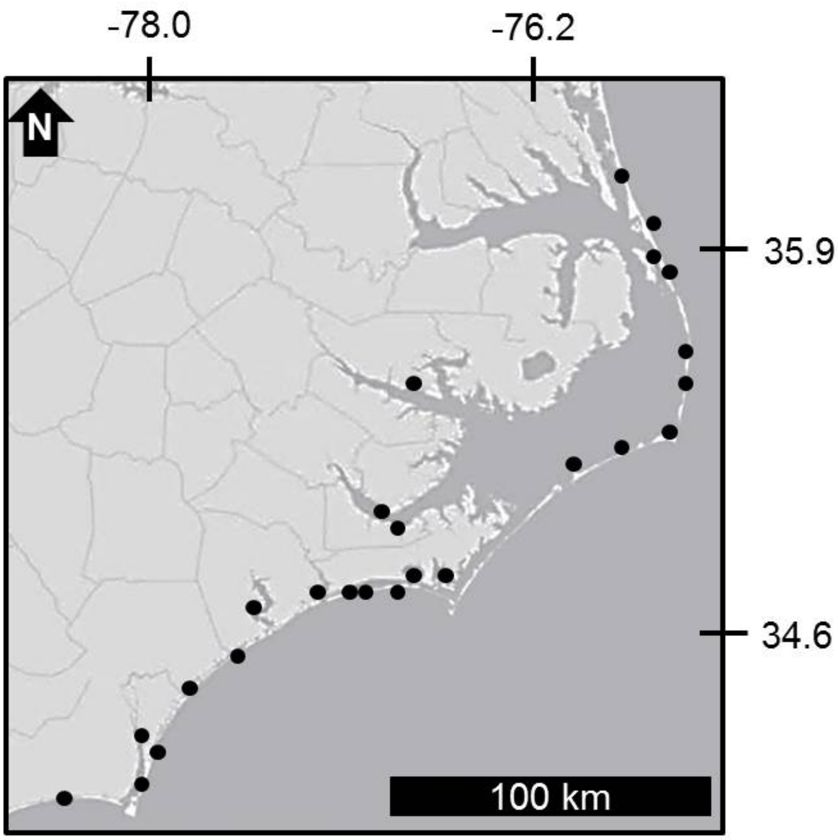
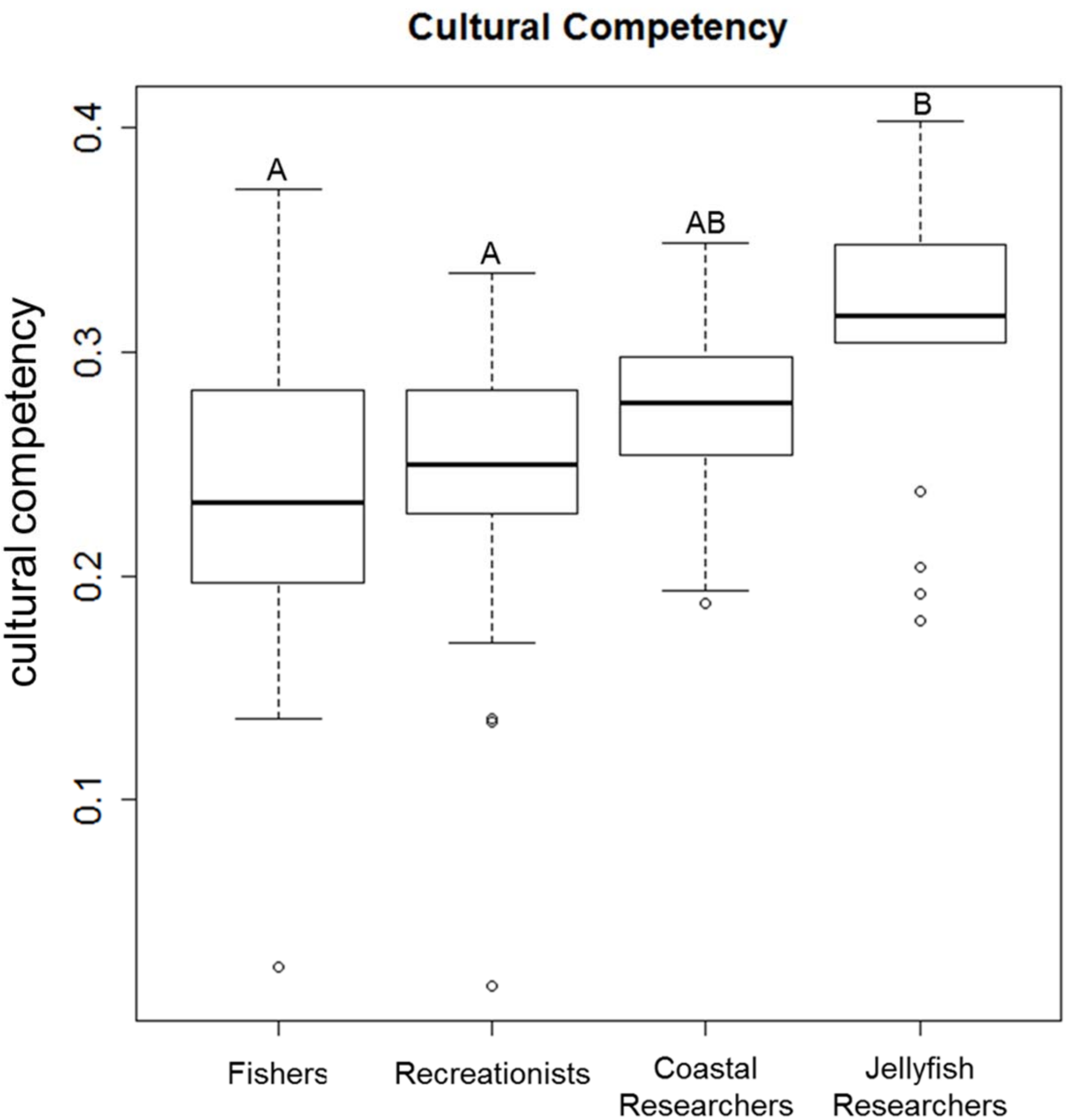
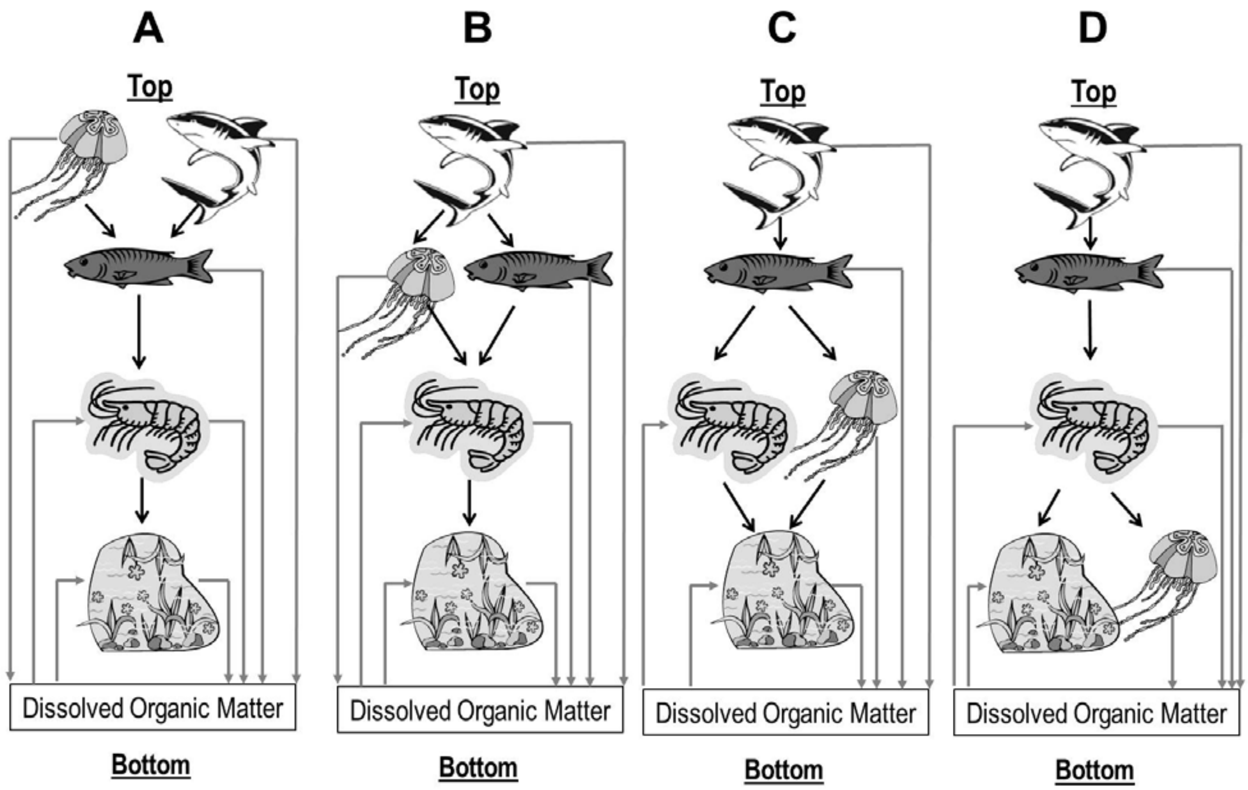


Figure 3.



Cultural Competency
cultural competency
0.1
0.2
0.3
0.4
A
A
AB
B
Fishers
Recreationists
Coastal Researchers
Jellyfish Researchers

Figure 4.



A
Top
Dissolved Organic Matter
Bottom
B
Top
Dissolved Organic Matter
Bottom
C
Top
Dissolved Organic Matter
Bottom
D
Top
Dissolved Organic Matter
Bottom

Figure 5.

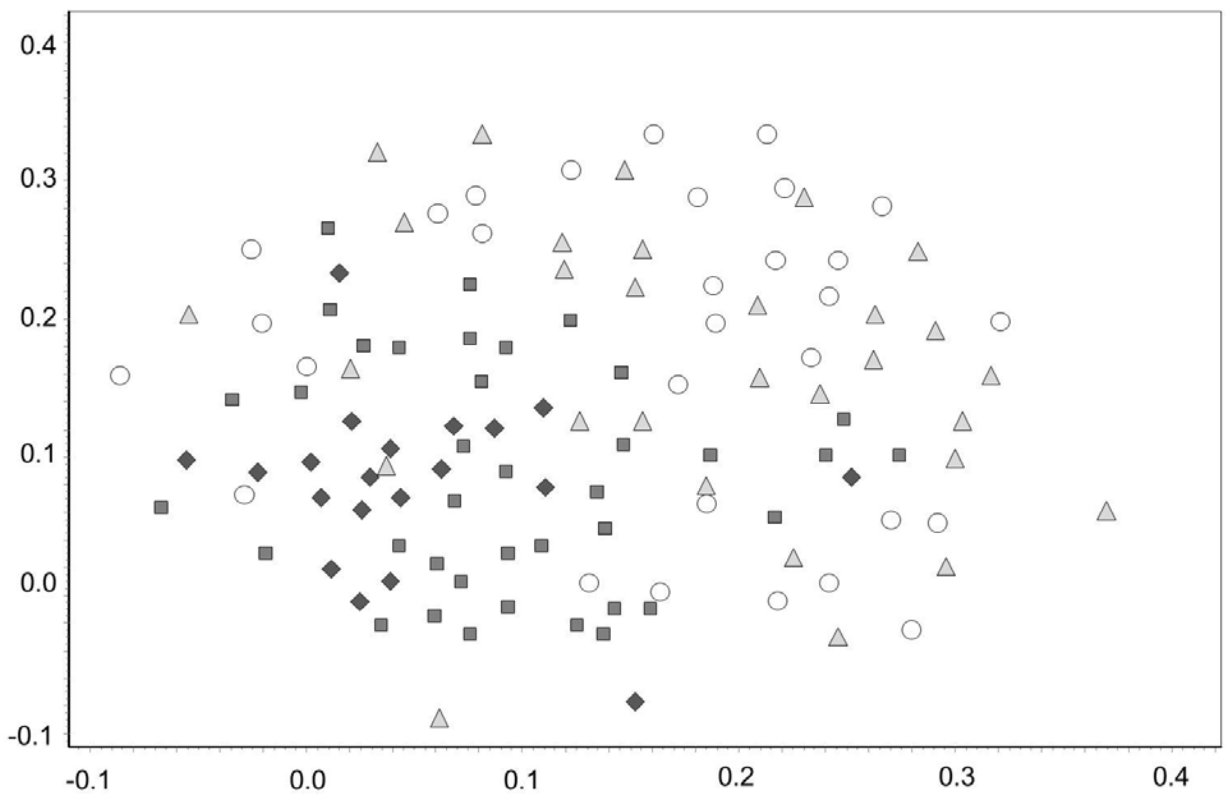
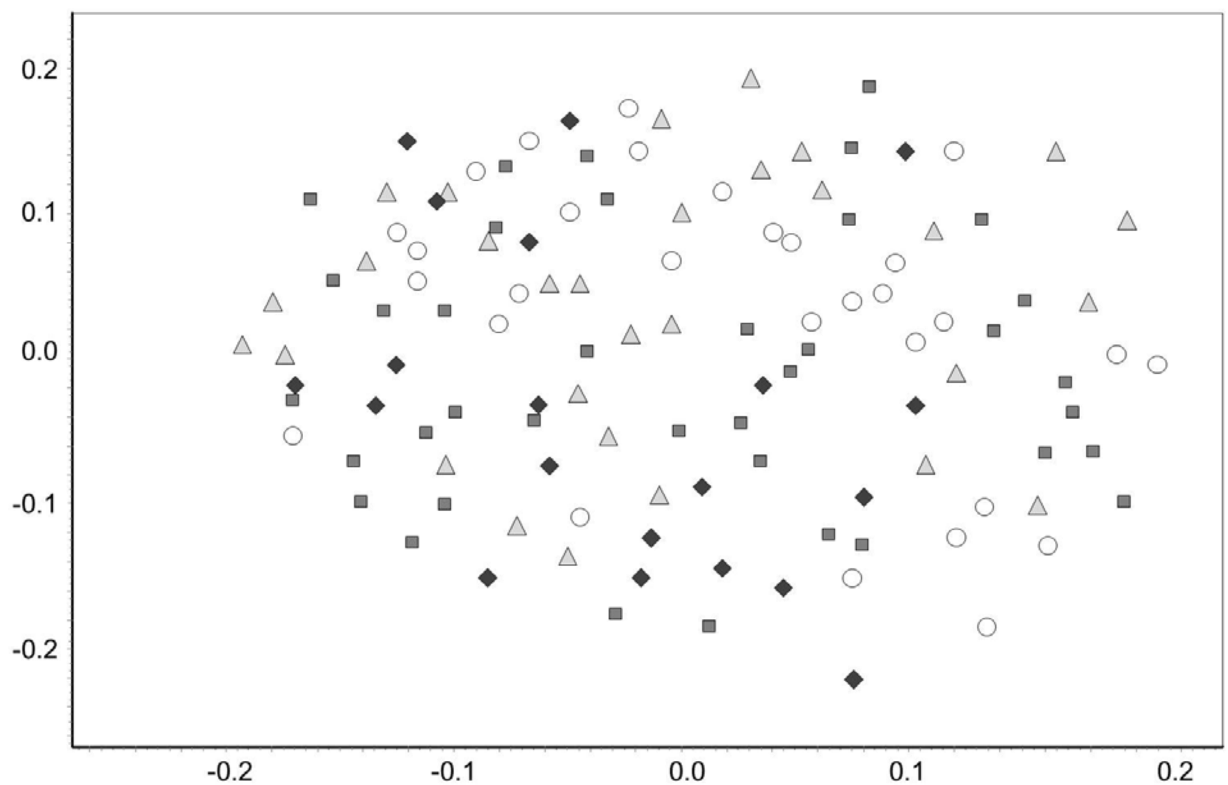


Figure 6.

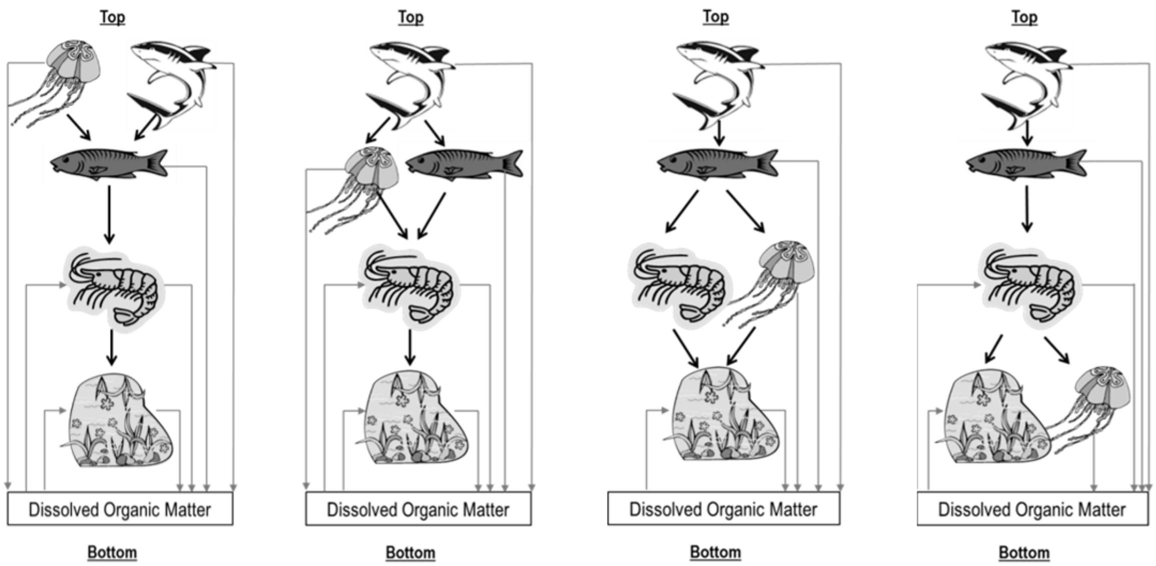


Appendix 1.

For these questions, please tell us if people agree or disagree with the following statements about jellyfish.

1. Jellyfish are animals	Agree	Disagree
2. Jellyfish are plants	Agree	Disagree
3. Jellyfish live longer than a year	Agree	Disagree
4. Jellyfish have eyes	Agree	Disagree
5. Jellyfish have a brain	Agree	Disagree
6. Jellyfish have a heart	Agree	Disagree
7. Jellyfish use fins to swim	Agree	Disagree
8. Jellyfish use tentacles to swim	Agree	Disagree
9. Jellyfish can swim against moving water	Agree	Disagree
10. Jellyfish thrive in murky water	Agree	Disagree
11. Jellyfish do not need a lot of air-in-water to survive	Agree	Disagree
12. Jellyfish need to come up to the surface to breathe	Agree	Disagree
13. Jellyfish come up to the surface to eat	Agree	Disagree
14. Jellyfish eat fish	Agree	Disagree
15. Jellyfish eat shrimp	Agree	Disagree
16. Jellyfish eat plants	Agree	Disagree
17. Jellyfish can eat more than their body weight	Agree	Disagree
18. Jellyfish do not need to eat to survive	Agree	Disagree
19. People eat jellyfish	Agree	Disagree
20. Turtles eat jellyfish	Agree	Disagree
21. Dolphins eat jellyfish	Agree	Disagree
22. Fish eat jellyfish	Agree	Disagree

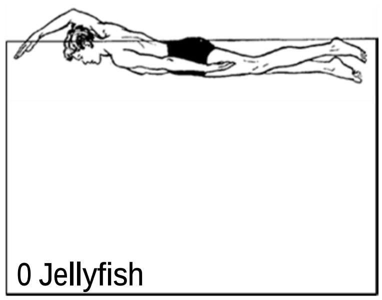
Which food web picture or pictures best describes jellyfish in nature?
Please circle your answer(s).

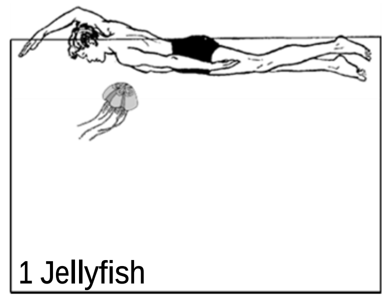


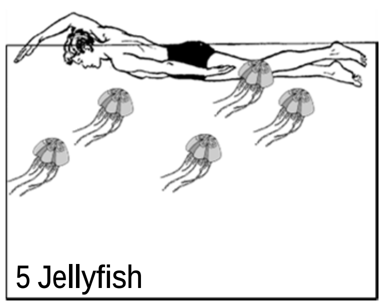
For these questions, please tell us if people agree or disagree with the following statements about jellyfish stings.

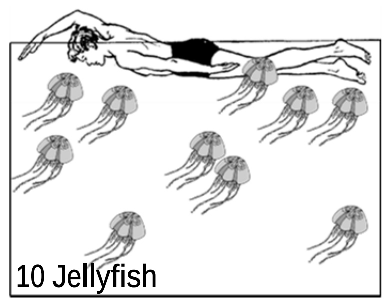
1. All jellyfish sting	Agree	Disagree
2. Jellyfish sting to protect themselves	Agree	Disagree
3. Jellyfish sting to reproduce	Agree	Disagree
4. Jellyfish sting to communicate	Agree	Disagree
5. A jellyfish can sting only once	Agree	Disagree
6. Jellyfish cannot control their sting	Agree	Disagree
7. Stings from red-colored jellyfish hurt more than other-colored jellyfish	Agree	Disagree
8. Jellyfish cannot sting the palm of a person's hand	Agree	Disagree
9. Jellyfish stings are felt on a person's body	Agree	Disagree
10. Jellyfish cannot sting a person through their clothes	Agree	Disagree
11. Jellyfish do not need to touch a person to sting them	Agree	Disagree
12. Vinegar is the best remedy for a jellyfish sting	Agree	Disagree
13. Urine is the best remedy for a jellyfish sting	Agree	Disagree
14. There is no remedy for a jellyfish sting	Agree	Disagree

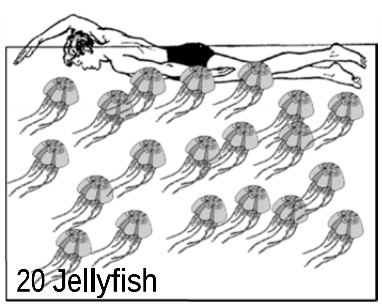
How many jellyfish seen in the water will make people stop their water activities?
Please circle your answer.

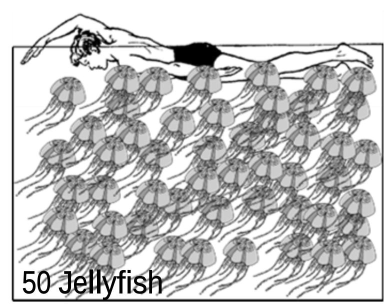












For these questions, think about jellyfish and society.
Please tell us if people agree or disagree with the following statements.

1. People would benefit if there were no jellyfish	Agree	Disagree
2. Jellyfish have economic value	Agree	Disagree
3. People will not take a vacation to areas were jellyfish are sighted regularly	Agree	Disagree
4. People will not book a return vacation to an area if they saw jellyfish in the water	Agree	Disagree
5. People will not book a return vacation to an area if they were stung by jellyfish	Agree	Disagree
6. The presence of jellyfish does not affect vacationing	Agree	Disagree
7. The presence of jellyfish will deter people from doing water activities	Agree	Disagree
8. People will continue their regular water activities (hobbies) if jellyfish are in the water	Agree	Disagree
9. People will leave a recreation area if jellyfish are present	Agree	Disagree
10. If jellyfish are always present at an area, people will find another place for recreation	Agree	Disagree
11. If people hear that someone was stung by jellyfish they will stop water activities	Agree	Disagree
12. If people are stung by jellyfish, they will stop water activities	Agree	Disagree
13. Jellyfish will appear in large numbers without warning	Agree	Disagree
14. People know where jellyfish come from	Agree	Disagree
15. There is no way to predict when large numbers of jellyfish will appear	Agree	Disagree
16. Jellyfish are taking over aquatic ecosystems worldwide	Agree	Disagree
17. Jellyfish are frequently reported in the media (newspapers, websites, etc.)	Agree	Disagree
18. Jellyfish are rarely reported in the media (newspapers, websites, etc.)	Agree	Disagree

CHAPTER 5

Dissertation conclusions and management implications

Jellyfish-human interactions in North Carolina

The overall objective of my dissertation was to identify physical, ecological and social drivers of jellyfish-human interactions in North Carolina. Since large numbers of jellyfish have created many ecological and societal effects on coastal communities, I chose a multifaceted research approach to gather physical and ecological data on what influences a harmful jellyfish species in a highly-used estuarine recreation area and to evaluate this interaction as well as other jellyfish-human interactions in North Carolina. By studying jellyfish-human interactions, my dissertation has provided data on jellyfish in North Carolina and this knowledge will help coastal management with future ecological and socio-economic issues caused by jellyfish.

I found that the distribution and abundance of *C. quinquecirrha* at six heavily used recreation sites was related to wind events (3-8 m s^{-1} at Cherry Point Marine Weather Station and 2-7 m s-1 at Cape Hatteras Weather Station). The dominant wind directions during the spring and summer in the months associated with *C. quinquecirrha* occurrences in 2011 and 2012 were SSE-SSW and these wind directions generate ~10 cm s^{-1} water currents that were likely to move *C. quinquecirrha* along and across the NRE estuarine shorelines. The highest abundance (m^2) was observed on the South shoreline, specifically at PC and SF, which are coastline sites located at NRE bend. It is possible that these sites experienced the highest *C. quinquecirrha* because of the shallow nature of the area and geomorphology of the NRE thereby making accumulation of jellyfish more likely than the North shoreline pier sites. When wind events occurred, I found that SSE to SSW wind directions one day prior to observations could be correlated with increased *C. quinquecirrha* abundance along the South shoreline and 5 days prior to observations could be correlated with increases on the North shoreline. Since no other abiotic variables could be correlated with *C. quinquecirrha* abundance, my results in chapter 2 indicated that one of the primary physical drivers of jellyfish-human interactions in the NRE are wind events.

The jellyfish-human interactions of *C. quinquecirrha* and NRE estuarine recreation enthusiasts may be manageable with the knowledge that wind speed and direction is correlated to higher abundances on the North and South shorelines. Future research should focus on creating a forecast system or adding potential *C. quinquecirrha* occurrence to the RENCI ADCIRC storm surge and coastal threats model. In the interim, readily available wind data via web-based and personal device social media from services such as the National Weather Service, NOAA, Weather bug ©, Earth Networks, and Wind Alert ©, Weather Flow, Inc. will allow NRE fishers and recreationists to plan their activities accordingly. This insight may help with mitigating the potential loss of recreation and tourism revenue as well as provide peace of mind to people that have trepidation towards jellyfish stings. For example, public announcements of the likelihood of encountering the stinging box jellyfish *A. moseri* at Waikīkī Beach eight to twelve days after a full moon has helped residents and tourists in Hawaiʻi plan their beach-going activities (Thomas et al. 2001). On-site first aid or outreach education has helped people cope with large amounts of stinging jellyfish in Australia (Gershwin et al. 2010) and Germany (Baumann and Schernewski 2012). While conducting field research in the NRE, I noticed that people were very receptive to learning about jellyfish and because we would have vinegar to treat ourselves if stung by the sea nettles *C. quinquecirrha*, we often shared vinegar with people who were also stung. After a vinegar treatment, even a most terrified child that experienced a jellyfish sting did not hesitate to jump back into the water. Since public education and information about jellyfish has helped mitigate unwanted jellyfish-human interactions, I recommend the use of signage to help the public know when jellyfish are likely to occur in large numbers used by the National Park Service within the Neuse River Recreation Area, Croatan National Forest and private vendors such as the YMCA camps. Information on jellyfish stings would also benefit the public.

Excluding my dissertation research, there have been three publications that mention jellyfish in North Carolina (Mallin 1991; Miller 1974; Williams and Deubler 1968) and of the three, only one investigated jellyfish abundance in the PRE (Miller 1974) (Figure 1). The use of citizen-science monitoring could determine the abundance and distribution of jellyfish species, as my visual observations of *C. quinquecirrha* ~ 2 m^2 were similar to Miller's (1974). Also, traditional net survey techniques (Tucker trawls, plankton tows, and beach seines) throughout APES could determine spatial and temporal jellyfish patterns over longer periods of time. *C. quinquecirrha* predation plays a critical role in Chesapeake Bay food webs but it is unknown how this estuarine predator influences the APES ecosystem. Therefore, food web studies in APES should include *C. quinquecirrha* and other jellyfish species to assure accurate conceptualization of trophic pathways.

Although my research in chapter 2 showed no significant correlations with abiotic variables known to influence *C. quinquecirrha*; temperature, salinity, and dissolved oxygen may influence some of the life history stages of the sea nettle, as documented in Chesapeake Bay (Calder 1974; Condon et al. 2001; Decker et al. 2007; Purcell and

Decker 2005). For example, it is well known that temperature and salinity affect the polyp and strobila stages of *C. quinquecirrha* (Calder 1974; Cargo and Rabenold 1980). In addition, jellyfish polyps and medusae are more resilient to hypoxia or low dissolved oxygen than other aquatic species (Condon et al. 2001; Purcell et al. 2001; Thuesen et al. 2005) and may benefit ecologically by consuming prey in hypoxic areas (Shoji et al. 2010). The tributaries in APES are prone to hypoxia (Paerl et al. 1998; Stanley and Nixon 1992) and could serve as an important study site for future hypoxia-jellyfish studies. Additionally, investigations of the abiotic drivers and substrate preferences of the early life history stages of *C. quinquecirrha* are essential to determining this species' vitality in APES and the annual occurrences observed in the NRE and other tributaries.

Although *C. quinquecirrha* abundances were correlated with wind events and associated wind-driven circulation, I cannot conclude that the annual occurrence of *C. quinquecirrha* is related to sexual reproduction. Instead, my results in chapter 3 indicated that there is potential for sexual reproduction to occur, but there was equal evidence that sexual reproduction may not be responsible for the annual occurrences. Moreover, the wind events, discussed in chapter 2, do not appear to aggregate jellyfish that are sexually reproducing based on my ANOVA analyses of egg diameters. Larger egg diameters were observed along the South shoreline; however, none of these eggs were considered mature based on the 0.07 mm threshold. The potential for sexual reproduction is reflected by the observations of a 1:1 sex ratio found at all recreation sites and throughout the field season. I also found that 10% of the males surveyed showed ruptured sperm follicles, which indicated that there was adequate nutrition for spermatogenesis and that sperm was released into the water column at the time these males were collected in mid-May to early June 2011. In contrast, all eggs were not sexually mature based on Littleford's (1939) egg diameter maturity index of greater than 0.07 mm and because no brooded planulae were observed in the female *C. quinquecirrha* sampled. Based on these results, I did not have sufficient evidence to prove that sexual reproduction had occurred. Mature gonad colors of female *C. quinquecirrha* in Chesapeake Bay were described to be grayish-yellow brown and males to be bright pink (Littleford 1939). Although my color comparison of female and male NRE *C. quinquecirrha* did not coincide with Littleford's observations, it could be that mature gonad colors were not observed because the majority of the jellyfish were indeed sexually immature. However, as documented in other jellyfish species (Schiariti et al. 2012; Toyokawa et al. 2010), it is also possible that gonad color is unrelated to mature gonads. Based on my results in chapter 3, I cannot attribute sexual reproduction of *C. quinquecirrha* as an ecological driver of jellyfish-human interactions in the NRE. However, it is clear that more research is required to fully support this conclusion. Planulae settlement studies within the oyster sanctuaries and on docks throughout APES would aid in determining to what extent sexual reproduction contributes to the annual occurrences. These observations coupled with histology, *in vitro* fertilization experiments, and genetic surveys would give us a better understanding of the reproduction cycle of *C. quinquecirrha* in APES, which would help with managing this species.

Cultural consensus analysis found that perspectives of jellyfish ecology varied among the four cultural groups, but societal perspectives were similar. The cultural perspectives of jellyfish researchers were closely aligned with what is biologically known about jellyfish, but perspectives on jellyfish ecology among the other groups were less clear. Specifically, there seems to confusion on the role jellyfish play in food webs, as jellyfish were placed in lower trophic levels by fishers, recreationists and 39% of the coastal researchers. Improper placement of jellyfish in food webs could be due to an "ecological misconception" (Cherrett 1989), which stems from the participant's prior knowledge and experience with jellyfish. This supports the argument that the lack of data and education about jellyfish in ecosystems has reverberated to the research and public interfaces. Therefore, one of the social drivers that influence jellyfish-human interactions is confusion in jellyfish ecological literacy.

Regarding the influence of jellyfish on society, all groups share similar perspectives that jellyfish may be problematic to coastal communities, but that socio-economics may not be affected due to varying amounts of tolerance toward seeing jellyfish in water and stings. For example, seeing fewer than five jellyfish in water was perceived to be tolerable because all groups agreed that this amount would not stop water activities. There was a notable difference in perspectives when the groups were asked if water activities would cease if more than five jellyfish were present and this could be a reflection of the jellyfish species encountered (i.e. the cannonball jellyfish *S. meleagris* versus the sea nettle *C. quinquecirrha*) and the type of water activity the people are engaged in (i.e. fishing, surfing, researching). Moreover, despite the negative repercussions of jellyfish stings, all groups agreed that people would take a vacation to areas where jellyfish are sighted regularly even if they are stung by jellyfish. Based on these data, I conclude that another social driver that influences jellyfish-human interactions is the acceptance of certain amounts of jellyfish in the water regardless of the severity of jellyfish stings.

Since the cultural perspectives of jellyfish in food webs were less clear among fishers, recreationists and coastal researchers, to improve jellyfish ecological literacy, outreach education that includes the role that jellyfish play in food webs should be conducted and coastal researchers should be encouraged to include jellyfish in their studies. In the NRE or other areas within APES that are prone to *C. quinquecirrha* occurrences, the use of barrier nets to protect swimming areas could prevent harmful encounters as demonstrated in Chesapeake Bay (Schultz and Cargo 1969) and Barnegat Bay, New Jersey (Vasslides and Sassano 2012). As well as preventing contact with *C. quinquecirrha*, the barrier nets could reduce the number of *C. quinquecirrha* to the fewer than five tolerances, which could prevent decreases in estuarine recreation and subsequently tourism revenue would not affected.

Residents reported that they enjoyed seeing and swimming with the cannonball jellyfish *S. meleagris* off the coasts of Oak Island and the Outer Banks (Figure 1). This type of interaction may be similar to swimming with *Mastigias* sp. in “Jellyfish Lake”, Palau. Moreover, jellyfish are aesthetically appealing in nature and also in aquariums worldwide. Fishers will use the cannonball jellyfish *S. meleagris* as bait for various types of fish, including spade fish and residents that frequently use the beaches of Oak Island (Figure 1) told me that they would be sad or “miss” seeing *S. meleagris* in the water if these jellyfish were to suddenly disappear. These interactions could render the classification of a positive jellyfish-human interaction. Furthermore, since *S. meleagris* is a commercial species that is heavily fished in Georgia, the potential utilization of *S.*

meleagris for North Carolina fishers could be beneficial. To assure the viability of a *S. meleagris* fishery in North Carolina, proper assessments of abundance and research on how the cannonball jellyfish affects the overall coastal ecosystem must be determine *a priori*.

Residents also have encounters with the "non-stinging" ctenophore comb jellyfish *M. leidyi*. Encounters with this species do not harm humans but residents observe *M. leidyi* quite often. North Carolina residents will refer to *M. leidyi* as the "moon jellyfish." I was surprised to hear that the common name of "moon jellyfish" is used to describe *M. leidyi* because this common name is usually associated with the cosmopolitan *Aurelia* sp. jellyfish. Future jellyfish research in North Carolina should be aware of the use of this common name, especially if discussing jellyfish with local residents. Lifeguards and beach-goers have observed the presence of the sea nettle on the Outer Banks beaches (Figure 1) each summer. Since the sea nettle is an estuarine jellyfish species (Cargo and Schultz 1966) it is possible that the sea nettles observed on the Outer Banks beaches were transported by an alongshore current that passes by the mouth of Chesapeake Bay. Although the gelatinous bodies of jellyfish poise problems for tagging experiments (Purcell 2009), set-nets and gonad maturity assessments were used to track the growth and movement of the giant jellyfish *N. nomurai* in the East China Sea and Sea of Japan (Toyokawa et al. 2010). Remote sensing or aerial photography could be used to observe if the sea nettles found on the Outer Banks originate from Chesapeake Bay. If these sea nettle occurrences are found to originate from Chesapeake Bay, the NOAA sea nettle "nowcasting" model (NOAA 2013) could be used by Outer Banks residents and tourists to prevent unwanted sea nettle encounters.

Evidence that jellyfish populations have increased in varying amounts of severity over the past century and the anticipated development of coasts worldwide suggests that jellyfish-human interactions are likely to continue. To manage these interactions, I have learned that multifaceted research practices provided substantial insight to what drives jellyfish-human interactions in North Carolina. I believe this approach would benefit other areas prone to jellyfish occurrences in lieu of the singularity of traditional jellyfish biology and/or ecology studies. To date, ecosystem-based management has encouraged researchers to expand their research scope from single species to studying the complexity of ecosystem dynamics (Rosenberg and McLeod 2005). Although this was a step in the right direction, incorporating human dimensions into ecosystem research has been difficult because of the extended amount of time between practice and policy implementation (Pikitch et al. 2004; Smith et al. 2007). It is hoped that current research endeavors using transdisciplinary science, where hypotheses are created with specific goals that benefit the sustainability of society (Lang et al. 2012), will curtail disparities between research, policy, and the general public. Under this auspice, scientists are encouraged to seek collaborations with colleagues from different academic backgrounds to investigate research problems that are important to the general public. By studying what drives the multifaceted interactions that surround jellyfish and humans, future studies will continue to benefit the sustainability, utilization, and management of coastal resources influenced by jellyfish-human interactions.

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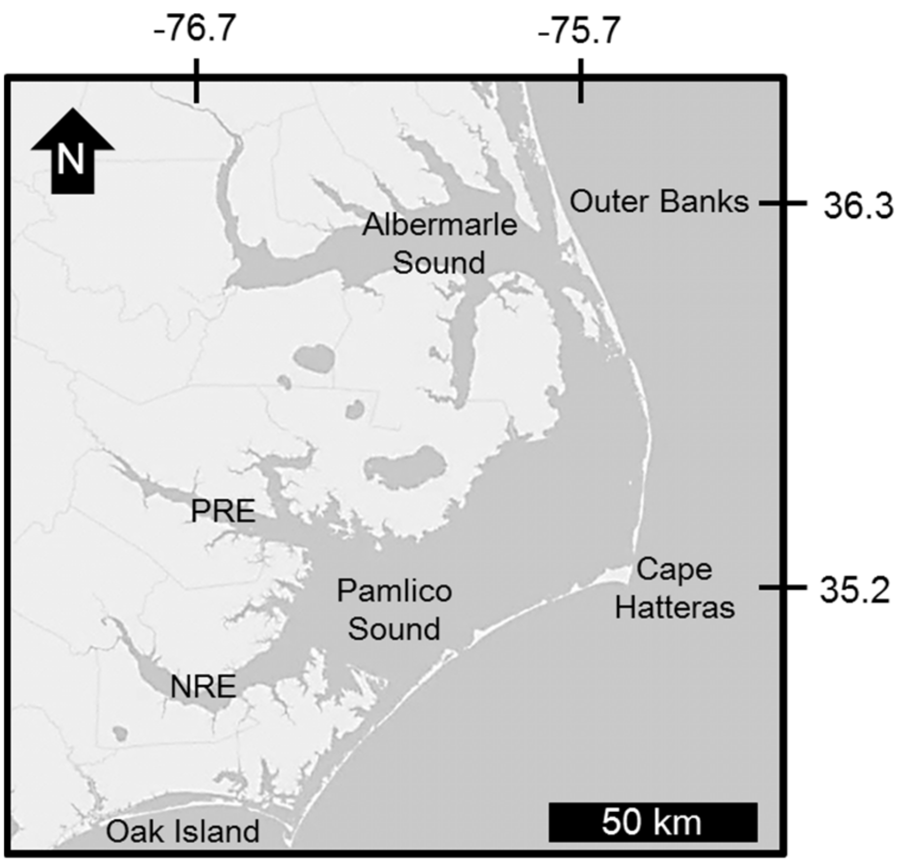
LIST OF FIGURES

Figure 1.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Appendix A: IRB letter/approval for Jellyfish Survey

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board Office
4N-70 Brody Medical Sciences Building· Mail Stop 682
600 Moye Boulevard · Greenville, NC 27834
Office **252-744-2914** · Fax **252-744-2284** · **www.ecu.edu/irb**

Notification of Exempt Certification

From: Biomedical IRB
To: Mahealani Kaneshiro-Pineiro
CC: Hans Vogelsong
Mahealani Kaneshiro-Pineiro
Date: 5/10/2012
Re: UMCIRB 12-000609
Jellyfish survey

I am pleased to inform you that your research submission has been certified as exempt on 5/10/2012. This study is eligible for Exempt Certification under category #2. It is your responsibility to ensure that this research is conducted in the manner reported in your application and/or protocol, as well as being consistent with the ethical principles of the Belmont Report and your profession.

This research study does not require any additional interaction with the UMCIRB unless there are proposed changes to this study. Any change, prior to implementing that change, must be submitted to the UMCIRB for review and approval. The UMCIRB will determine if the change impacts the eligibility of the research for exempt status. If more substantive review is required, you will be notified within five business days.

The UMCIRB office will hold your exemption application for a period of five years from the date of this letter. If you wish to continue this protocol beyond this period, you will need to submit an Exemption Certification request at least 30 days before the end of the five year period.
The Chairperson (or designee) does not have a potential for conflict of interest on this study.

IRB00000705 East Carolina U IRB #1 (Biomedical) IORG0000418

IRB00003781 East Carolina U IRB #2 (Behavioral/SS) IORG0000418 IRB00004973

East Carolina U IRB #4 (Behavioral/SS Summer) IORG0000418

Appendix B: Jellyfish survey consent form

Study ID:UMCIRB 12-000609 Date Approved: 5/10/2012 Does Not Expire.

Jellyfish Survey Participant Agreement

You are being invited to participate in a **research** study titled “Jellyfish-human interactions in North Carolina” being conducted by Mahealani Kaneshiro-Pineiro, a PhD candidate at East Carolina University in the Institute for Coastal Science and Policy, Coastal Resources Management PhD Program. The goal is to survey 150 individuals in/at beach, coastal and estuarine recreation areas and research institutions in North Carolina as well as jellyfish researchers located primarily throughout the United States. The survey will take approximately less than 30 minutes to complete. It is hoped that this information will assist us to better understand what people know about jellyfish and how jellyfish may influence a person’s choice to engage in water activities. The survey is anonymous, so please do not write your name. Your participation in the research is **voluntary**. You may choose not to answer any or all questions, and you may stop at any time. There is **no penalty for not taking part** in this research study. Please call Mahealani Kaneshiro-Pineiro at (252) 328-9375 for any research related questions or the Office for Human Research Integrity (OHRI) at 252-744-2914 for questions about your rights as a research participant.

Appendix C: Jellyfish survey

Jellyfish Survey

__Instructions:__

Please answer all questions by yourself and to the best of your ability
Do not look up any answers to the survey questions
If you do not know the answer to a question, guess
If you have any questions while taking this survey, please contact Mahealani for assistance

Contact: Mahealani Kaneshiro-Pineiro
Phone: 252-328-9375
kaneshiropineirom09@students.ecu.edu

Please tell us about your experiences with water activities and if you have seen jellyfish while doing your water activities.

1. When was the last time you went to the coast/water?

    ____

2. Did you see jellyfish?

    Yes No

3. Have you ever been stung by a jellyfish?

    Yes No

4. What months do you usually do your water activities?

    ____

5. On average, how many hours per week do you spend doing your water activities?

    ____________ hours per week

6. Where do you go for your water activities?

    ____

7. Are jellyfish usually in the water when you do your water activities?

    Yes No

    If you answered YES to the previous question, please answer these next questions:

    Are jellyfish new to your coastal waters, beaches and/or shorelines?

    Yes No

    Over the past 5 years, have you seen more jellyfish in the water and/or on shorelines?

    Yes No

    Over the past 10 years, have you seen more jellyfish in the water and/or on shorelines?

    Yes No

Look at each picture and please write down the name of each in the space below.

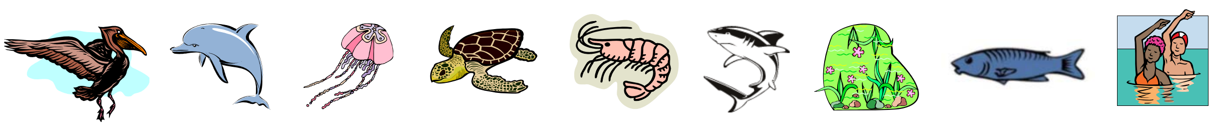
_______________ _______________ _______________ _______________ _______________

Please write any other names you know here: ____

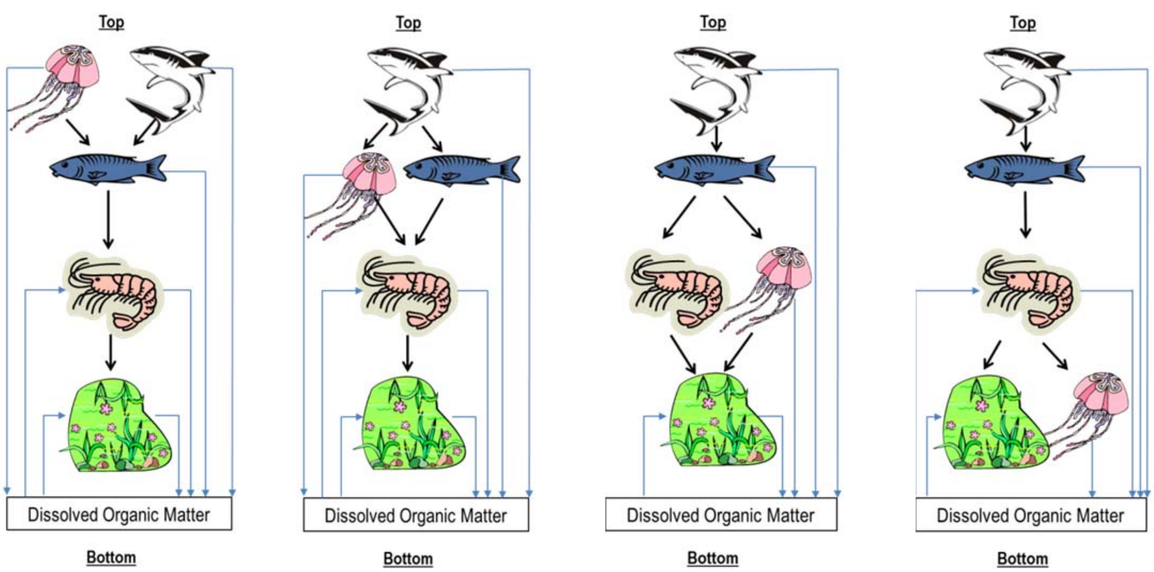
For these questions, please tell us if people agree or disagree with the following statements about jellyfish.

1. Jellyfish are animals	Agree	Disagree
2. Jellyfish are plants	Agree	Disagree
3. Jellyfish live longer than a year	Agree	Disagree
4. Jellyfish have eyes	Agree	Disagree
5. Jellyfish have a brain	Agree	Disagree
6. Jellyfish have a heart	Agree	Disagree
7. Jellyfish use fins to swim	Agree	Disagree
8. Jellyfish use tentacles to swim	Agree	Disagree
9. Jellyfish can swim against moving water	Agree	Disagree
10. Jellyfish thrive in murky water	Agree	Disagree
11. Jellyfish do not need a lot of air-in-water to survive	Agree	Disagree
12. Jellyfish need to come up to the surface to breathe	Agree	Disagree
13. Jellyfish come up to the surface to eat	Agree	Disagree
14. Jellyfish eat fish	Agree	Disagree
15. Jellyfish eat shrimp	Agree	Disagree
16. Jellyfish eat plants	Agree	Disagree
17. Jellyfish can eat more than their body weight	Agree	Disagree
18. Jellyfish do not need to eat to survive	Agree	Disagree
19. People eat jellyfish	Agree	Disagree
20. Turtles eat jellyfish	Agree	Disagree
21. Dolphins eat jellyfish	Agree	Disagree
22. Fish eat jellyfish	Agree	Disagree

For this question, think about jellyfish and their importance in nature.
Rank the following #1 to #9,
with #1 being the most important in nature and #9 being the least important in nature.

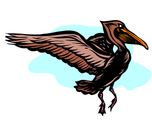
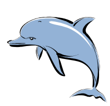
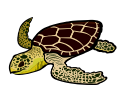
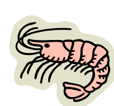


Which food web picture or pictures best describes jellyfish in nature?
Please circle your answer(s).



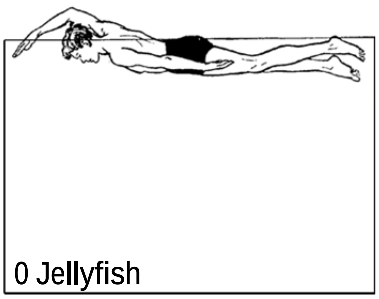
For these questions, please tell us if people agree or disagree with the following statements about jellyfish stings.

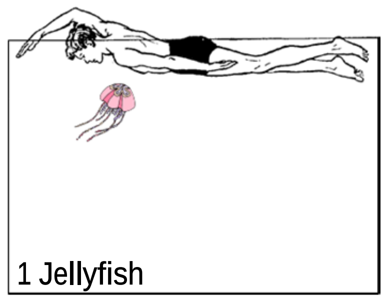
For this question, think about how people perceive jellyfish; specifically, think about the fear of jellyfish and how that would compare to other living creatures.
Rank the following #1 to #9, with #1 being the most feared and #9 being the least feared.

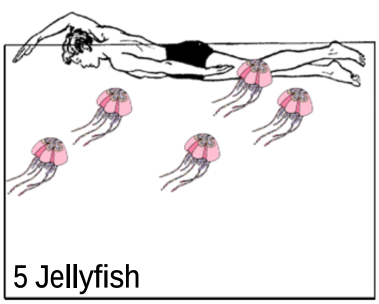
        

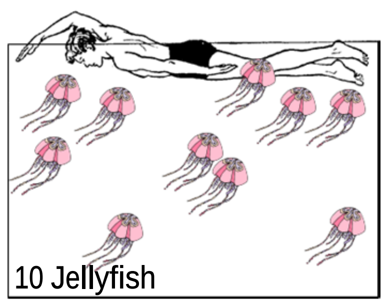
______ ______ ______ ______ ______ ______ ______ ______ ______

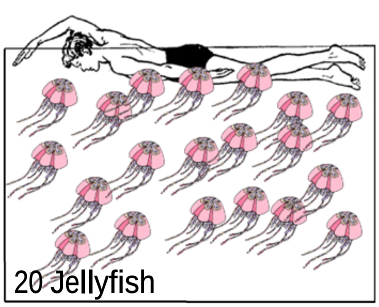
How many jellyfish seen in the water will make people stop their water activities?
Please circle your answer.

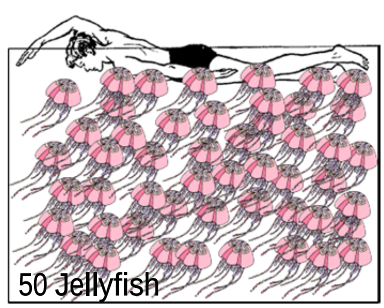






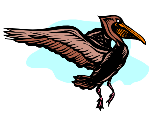
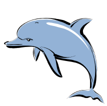
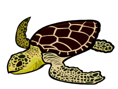
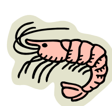






For these questions, think about jellyfish and society.
Please tell us if people agree or disagree with the following statements.

For this question, think about the aquatic ecosystem.
How do you think people should spend science money?
Rank the following #1 to #9, with #1 being the most money and #9 being the least money.

______ ______ ______ ______ ______ ______ ______ ______ ______

Please answer the following questions about yourself. The information you provide will remain strictly anonymous and your name will never be associated with your answers.

1. Are you (circle one)

(a) Female

(b) Male

2. What is your age?

__________ Years

3. Which state and country are you a resident of?

____________________, _______________

4. Which category best describes the highest level of education you have completed? (circle one)

(a) Some high school; grade completed _____

(b) High school/equivalency

(c) Associate's (2 year degree)

(d) Bachelor's (4 year degree)

(e) Graduate

5. Which group best describes you? (circle one)

(a) Fisher

(b) Coastal recreationist (swim, ski, surf, etc.)

In the space below, please share anything else you know about jellyfish. For example, when do you see jellyfish? Or use the space below to write any other comments about this survey. Thank you!

Survey ID#_____________

Please answer the following questions about yourself. The information you provide will remain strictly anonymous and your name will never be associated with your answers.

1. Are you (circle one)

    (a) Female

    (b) Male

2. What is your age?

    __________ Years

3. Which state and country are you a resident of?

    ____________________, _______________

4. Which category best describes the highest level of education you have completed? (circle one)

    (a) Some high school; grade completed _____

    (b) High school/equivalency

    (c) Associate's (2 year degree)

    (d) Bachelor's (4 year degree)

    (e) Graduate

In the space below, please share anything else you know about jellyfish. For example, when do you see jellyfish? Or use the space below to write any other comments about this survey. Thank you!

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Survey ID#_____________