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Rip Current Formation and Beach Safety Implications for Several U.S. Atlantic Coast Beach Areas

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FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

RIP CURRENT FORMATION AND BEACH SAFETY IMPLICATIONS FOR
SEVERAL U.S. ATLANTIC COAST BEACH AREAS

A dissertation submitted in partial fulfillment of

the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

GEOSCIENCES

by

Kathleen Michelle Fallon

2017

To: Dean Michael R. Heithaus
College of Arts, Sciences and Education

This dissertation, written by Kathleen Michelle Fallon, and entitled Rip Current Formation and Beach Safety Implications for Several U.S. Atlantic Coast Beach Areas, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this dissertation and recommend that it be approved.

Henry Bokuniewicz

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Date of Defense: May 15, 2017

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Dean Michael R. Heithaus
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Vice President for Research and Economic Development
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Florida International University, 2017

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DEDICATION

For my father, William Lawrence Fallon Jr.

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ABSTRACT OF THE DISSERTATION

RIP CURRENT FORMATION AND BEACH SAFETY IMPLICATIONS FOR
SEVERAL U.S. ATLANTIC COAST BEACH AREAS

by

Kathleen Michelle Fallon

Florida International University, 2017

Miami, Florida

Professor Stephen P. Leatherman, Major Professor

This dissertation combines seemingly different studies, which work together to describe the physical characteristics of rip current development and associated social implications at several locations. These fast-moving, concentrated flows of water travel offshore and can be found on any beach with sufficient wave action. Any event of increased wave steepness will erode a large quantity of sediment from the beach. The material deposited offshore eventually makes its way back; during this process, ocean water becomes trapped behind a shore-attached bar resulting in a ridge-and-runnel. These formations are seen at East Hampton, where rip-like currents form as concentrated water drains from the runnel through a breach in the ridge. Camera images from 2010-2016 captured ridge-and-runnel formations and the ensuing currents. These newly described rips behave similarly to bar-gaps; however, they are not directly related to wave action. Coastal scientists consider rip currents to be the number one hazard at most beaches. In Palm Beach County, two traditional rip types were studied: bar-gap and structurally-controlled. Lifeguard incident reports from 2011-2016 were used to correlate wind speeds and wave heights to rip related rescues at three beaches. This research was undertaken in

an effort to determine under what conditions most beachgoers become caught in this hazard. Rip currents were seen to be the most dangerous to bathers on days with moderate wind and wave activity. The same beach states that lead to the strongest rips also tend to keep beachgoers from entering the ocean. A social survey at Miami Beach, from 2011 to 2012, quantified beachgoer's rip knowledge and their recognition of hazards. A significant portion of the respondents showed insufficient knowledge, which indicated they are at-risk of being caught or drowning in a rip current. Frequent exposure to the beach, maturation, and residency were identified as the main contributors to one's literacy whereas education was the only variable that influenced a beachgoer's visual recognition of hazard. The information gathered by these surveys can aid in creating better rip current awareness campaigns targeted to demographics that were determined as the most at-risk. An understanding of the physical and social science of rip currents can mitigate the impact of these beach hazards.

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I. INTRODUCTION

Any surf beach, with significant wave action, can potentially develop rip currents. These swift, offshore moving flows form as wave run-up returns to the ocean, often concentrated in depressions, and slowing once past the surf zone (Shepard et al., 1941; Aagaard et al., 1997; Castelle et al., 2016). There are five main rip currents as defined by Leatherman (2012): bar-gap, structurally-controlled, flash, cusped, and megarips. Each type is characterized by uniqueness in controlling factors (i.e., sand or hard structure placement), behavior, and strength.

Many studies have been conducted in regards to rip currents. Originally research had been in an attempt to understand their genesis, controlling factors, and behavior. Among the first to describe the processes and characteristics of rip currents were Shepard et al. (1941). Rip currents are narrow and concentrated flows that form as waves push water onto the beachface. The return current moving in an offshore direction (Aagaard et al., 1997) extends from close to the shoreline through the surf zone (Castelle et al., 2016). Bathymetric, meteorological, and/or oceanographic factors (i.e., wave height, wind velocity, tidal level, etc.) control the appearance and strength of rips, which varies depending on the studied beach.

Coastal scientists have been studying these cross-shore currents in an attempt to understand the conditions for their generation and behavior, with the intent of deriving predictive models to warn of these events. The goal of rip current forecasts is to anticipate the future risk based on expected conditions. Warning systems, like the Lushine Rip Current Scale, correlate the occurrence of rip currents with observations of winds, tide, and the incident waves. Furthermore, some researchers have utilized social

science techniques to predict rip current occurrences. Engle et al. (2002) used lifeguard rescue logs from Daytona Beach, Florida to correlate rip current-related saves with wind and wave measurements. Woodward et al. (2013) utilized Royal National Lifeboat Institution (RNLI) incident reports to discover key demographic characteristics of rip current victims in the U.K. Scott et al. (2014) compared RNLI incident data reports with their Lagrangian rip-current measurements.

Rip currents are a global problem and considered to be the major hazard for bathers at surf beaches (Brander et al., 2013). In the United States, rips account for more than 80% of lifeguard rescues and it is estimated that an average of 100 people drown because of rip currents each year (United States Lifesaving Association (USLA), 2011). In order to take steps towards abating these deaths, the social implications of these beach hazards must be studied in an attempted to learn what the public knows about rip currents and create better education policies. In recent years, researchers have utilized public surveys to gain information about beachgoers and rip currents. Some studies, such as McCoy et al. (2010), have found that the public was well informed, while others discovered more heterogeneity in beachgoer understanding. When surveying rip current survivors, Drozdowski et al. (2012) determined older respondents were more likely to signal for help yet despite their knowledge bathers still panicked when pulled offshore. Williamson et al. (2012) determined that international tourists and men showed poorer knowledge of beach safety in comparison to locals and women, respectively.

Some surveys have begun to incorporate images of rip currents. One study at Pensacola Beach, FL, found that only 15% of respondents could identify the rips in a series of photographs and only seven of the 97 participants who claimed they could

identify a rip current with high confidence actually identified the rip-current channels (Caldwell et al., 2013). Another study in Australia found that 48% of respondents were able to answer correctly; when asked if they “could tell what a rip current was”, 93% indicated they could however, one-third of those incorrectly identified the current on the photograph (Sherker et al., 2010). They also found that a person who was moderate to highly confident in their ability to identify a rip was significantly more likely to avoid swimming in a rip current and that people with knowledge of rip currents or at the beach with children are significantly more likely to avoid swimming in a rip current (Sherker et al., 2010). In Texas, a total of 57% respondents were able to correctly choose the most dangerous photograph however, correct selection could not be related to any one variable (Brannstrom et al., 2014). In England, 61% chose correctly the safest place to swim in a photograph (Gallop et al., 2016), and in Ghana, 63% of respondents chose correctly (Hammerton et al., 2013). Williamson et al. (2012) observed that 60% of respondents reported their ability to identify a rip current as moderate to high, even though 31% of them made an incorrect choice in rip location; however, participants who rated their swimming ability as high were more likely to make a correct choice (Williamson et al., 2012).

This dissertation is a collection of studies completed at several locations and combined, ultimately to learn more about rip current formation and beach-safety implications. Rip current types and the cause of their formation were explored at three U.S. East Coast beach areas. These include a newly described rip at East Hampton, New York that forms as a result of ridge-and-runnel breaching, as well as bar-gap and structurally-controlled currents at three beaches in Palm Beach County, Florida. Also at

the latter location, the conditions apparent during rip rescues as recorded by lifeguards were examined. Furthermore, public surveys were used at Miami Beach, Florida, one of the most popular tourist destinations in the U.S., to determine what beachgoers know about rip currents and if they can recognize the hazard in photographs.

Chapter 2 explores a variation on the traditional idea of a bar-gap rip current by observing their occurrence associated to ridge-and-runnel morphology at beaches in East Hampton, NY. Ridge-and-runnels form as sand stored in offshore bars makes its way back onto the beachface. As the shore-parallel bar attaches to the beach, water is trapped in a shallow trough. Drainage of this runnel through a breach in the ridge results in a concentrated return flow, like a bar-gap rip; however, the current is not a direct resultant of modulated wave patterns. Although this particular beach morphology is not considered a hazard, the subsequent release of water can present a danger to beachgoers. I observed the appearance and duration of ridge-and-runnel events over seven years in images captured by a beach camera. Once dates of events were obtained, historical wave data collected by an offshore National Oceanographic and Atmospheric Association (NOAA) buoy correlated wave steepness to the occurrence of ridge-and-runnels. A subset of data determined how often these features culminated in drainage events. This study attempts to determine the parameters for ridge-and-runnel formation and considers a better predictive model assessing potential risk to beachgoers.

Chapter 3 examines bar-gap and structurally-controlled rip currents on three distinct beaches in close proximity to each other in Palm Beach County, FL, the research explores the conditions most likely to result in rip-current rescues by using historical lifeguard data. While organizations other than Palm Beach County Ocean Rescue also

record incidents, a study utilizing such an extensive data set has not been analyzed before. This particular area of southeast Florida is well suited for established channels and permanent rips; furthermore, persistent onshore winds generate wind waves (Paxton, 2014), which in turn push ocean water onto the beach. The return flow, seeking an area of low resistance, creates rip currents. Incident reports, from the beaches with the most rip-related rescues between 2011 and 2016, that detail the conditions during rip rescues were utilized in this study to correlate wind and wave conditions with rescue days. Each of these three parks has unique characteristics for the creation of rip currents. Two are in the vicinity of a pier, which builds up sand establishing deep rip channels; however, one has a steeper slope resulting in different current behavior. The third beach has exposed rock along the shoreline leading to permanently located currents that always “rip” given the appropriate wind and/or wave conditions. The goal of the research presented in Chapter 3 is to understand the particular beach states (i.e., slope, wave height, wind velocity, etc.) that are most likely to result in rip rescues.

Chapters 4 and 5 present results of the first public survey at Miami Beach to compile information about beachgoer’s rip current literacy and their recognition of the hazard. Florida’s Miami Beach is world-renowned and attracts a wide demographic of visitors; additionally, year-round beach-going temperatures and deceptively calm waters create a “hot spot” for rip current incidents. In fact, Miami Beach is listed as the third deadliest beach in the U.S. based on the frequency of rip-current deaths by year (Paxton and Collins, 2014). My surveys were collected over a yearlong period, the first study of this nature to do so. All responses were obtained from people at the beach, who represent the population at risk of being caught in a rip current. The data collected by these surveys

were analyzed using statistical systematic tests and multiple regression models. The public survey described in Chapter 4 delineates the sociodemographic and behavioral characteristics that make beachgoers more likely, or less likely, to possess knowledge of rip currents. The respondents were asked to mark their level of agreement with four statements regarding rip-current definition, occurrence, risk, and fatality. The results were compiled into an overall score entitled “rip-current literacy.” Chapter 5 discusses the second survey, which utilized two photographs of rip currents of the type that commonly appear at Miami Beach. Participants were rated based on their ability to identify the safest place to enter the water on both images. In this way, I could differentiate between what the respondents know and what they visually recognize.

The findings in each study are summarized in Chapter 6. Overall, the goal of this research is to investigate rip-current formation, to determine beach states during most rip-current related rescues, and to better understand the factors that influence both a beachgoer’s rip-current literacy and their recognition. Ultimately, the conclusions of this research are intended to contribute to improving rip-current forecasts and directing local coastal managers to create better coastal policies, leading to a decrease in rip-current rescues and fatalities.

II. RIDGE-AND-RUNNEL BEACH MORPHOLOGY AS A PORTENT FOR RIP CURRENTS AT EAST HAMPTON, NEW YORK

ABSTRACT

Ridge-and-runnels are morphological features that occur parallel to the ocean shoreline. The ridge is a linear mound of sand in the swash zone; and the runnel is a shallow trough, often filled with water and located between the ridge and the dry beach berm. This beach topography forms after storms as eroded sand makes its way back onto the beach *en masse*. Two data-sets of daily images from a camera in East Hampton were examined: the first, to look for the occurrence and duration of ridge-and-runnel events from October 2010 to November 2012. Images from February 2014 to July 2016 were utilized to determine the number of events that resulted in rip-like currents. Thus, we were able to determine the favorable conditions for ridge-and-runnel formation and how often rips are likely to be associated with this particular beach morphology ultimately, strengthening the ability to predict when these coastal hazards will occur. In this study, ridge-and-runnels were observed about 16% of the time, and rip currents occur over 74% of the time that this beach morphology occurred. Ridge-and-runnels appeared several days after an event of high wave steepness, and rip currents would form when there is a break in the then shore-attached sand bar, allowing the drainage of the runnel.

INTRODUCTION

Ridge-and-runnels are dynamic morphological beach features that extend parallel to the shoreline. The ridge is a long, low linear mound of sand at the swash zone and the runnel is the associated shallow trough, often filled with water, between the ridge and the beach berm (Figure 2-1). Ridge-and-runnel morphology typically forms on ocean

beaches after impacted by high-energy storm waves. Ridge-and-runnels are not considered to be a hazard by beachgoers. In fact, children seem to enjoy playing in the shallow, often warmer water filling a runnel. However, the drainage of the runnel by a breach in the ridge results in a concentrated return flow, similar to a rip current but not a direct result of wave action that could present a danger. In order to keep beachgoers safe, the National Weather Service and coastal researchers alike have a vested interest in modeling and improving our ability to predict rip current occurrences. In this paper, I will examine the occurrence of ridge-and-runnels along East Hampton, which is located on the southern fork of Long Island, New York, and consider the implications of these features on assessing this potential hazard.

2-1. Beach profile from the dune to the shoreline showing a ridge-and-runnel.

Ridge-and-runnel formation

Sandy beaches function as natural wave buffers and experience periods of accretion and erosion alternating over time (Quartel et al., 2008). Although severe storms cause episodic beach recession, the subaerial beach generally rebounds during the

recovery period (Dissanayake et al., 2015). Sand removed from the subaerial berm-beach and displaced offshore in a submerged bar is returned onshore by waves of low steepness. Ridge-and-runnel formations represent the readjustment of the post-storm beach (Davis et al., 1972; Hayes and Boothroyd, 1969). Offshore sand migrates landward en masse over a period of one to two weeks eventually attaching to the beachface. When the migrating bar reaches the foreshore, waves overtop the crest, carrying and trapping water and sediment between the ridge of the bar crest and berm (Figlus et al., 2012). Eventually, the ridge of sand becomes part of the berm if it is not re-eroded by the next storm.

Long Island's south shore is frequently battered by large waves, and is continuously reshaped by hydrodynamic forces. Ridge-and-runnels are known to form along the south shore of Long Island, New York after severe erosion events. Most of these erosion events are associated with intense cyclonic systems that bring steep waves and storm tides to the ocean beaches. However, information is lacking concerning the frequency of occurrence of these features and concerning oceanographic conditions conducive to their formation. We examined the frequency of occurrence, the seasonality, and the duration of ridge-and-runnels over several years along a stretch of New York's ocean coast.

The ridge-and-runnels that will be discussed throughout this paper are slip-face bars (Masselink et al., 2006). These were first described along the U.S.'s northeast coast by Hayes and Boothyard (1969) as migratory inner bars. These ridge-and-runnels are typical on microtidal or mesotidal beaches that have mild nearshore slopes of about two degrees (Davis et al., 1972; Masselink et al., 2006) or as break-point bars (Davis et al., 1972; Hayes and Boothroyd, 1969; Masselink et al., 2006) that developed after severe

storms. They tend to appear a few days after persistent nor'easters or hurricanes (Davis et al., 1972), especially those occurring over multiple high tides. However, five or six weeks may be needed to complete the process from the erosion events to a fully recovered beach (Hayes and Boothroyd 1969). Storm events with steeper waves generally cause greater changes, but storm duration, direction, peak wave period, and water level contribute to the extent of beach erosion (Dissanayake et al., 2015).

Rip currents

Rip currents are strong, narrow currents that flow seaward from the surfzone (Komar, 1998) and are a hazard at surf beaches that pose a significant danger to beachgoers. The United States Lifesaving Association claims that about 100 drowning deaths occur each year and lifeguards attribute 80% of all rescues to rips. This facet establishes the danger to beachgoers of drowning; they are quickly swept offshore to depths over the head or try to fight against the fast current eventually tiring out.

The goal of rip current forecasts is to anticipate the future risk based on expected conditions that will make these currents more or less likely to be present. Rip current warning systems, like the Lushine Rip Current Scale, correlate the occurrence of rip currents with observations of winds, tide, and the incident waves. Rip currents, for example, tend to appear when shore-normal incident waves approach with a moderate to high significant wave height. Another mechanism for rips are thought to be crossing, superimposed wave trains. Using these techniques, forecasts of rip current risk for New York's ocean beaches are provided by the National Weather Service during the summer (<http://www.erh.noaa.gov/okx/srf/srfDisplay.php>, accessed 2015).

Rip forecasts do not account for offshore-flowing currents associated with ridge-and-runnels. As the ridge of sand continues to migrate landward, channels episodically intersect the ridges (Figlus et al., 2012). The water escaping the runnel at the break in the ridge then acts like a bar-gap rip current (Leatherman, 2012) by which ocean water makes its way back from the swash zone. As a result, when ridge-and-runnels are in place, there is a statistically higher risk of rip currents than when these morphological features are not present.

Coastal hazards

East Hampton is a popular tourist destination with millions of visitors flocking there in the summer months (i.e., Memorial Day to Labor Day) that transitions to a quiet beach village the remainder of the year. As previously pointed out, ridge-and-runnels are not considered to be a hazard. During the warmer months, runnels act as shallow pools that attract beachgoers avoiding waves and swash run-up; however, when ridges are cut to form localized strong currents by runnel drainage, unsuspecting bathers, especially children, could be swept offshore and find themselves in danger. If the parameters for ridge-and-runnel formation and subsequent rip current development can be identified, a better predictive model could be utilized to keep beachgoers safe.

Study area

East Hampton is located on the southern fork of eastern Long Island. It is considered to be one of the more popular ocean beaches in New York (Figure 2-2). The Atlantic Ocean has moderately high wave-energy here; average wave heights are about one meter but can reach heights over three meters during winter nor'easters. The tidal range at the ocean's shore is microtidal -- typically one meter; yet, it can reach much

greater heights when combined with storm surges (i.e., Superstorm Sandy's surge of two meters). Nearshore wave periods average seven seconds during calm conditions; however, it is common for the period to increase to 14 seconds and maximum wave heights to reach almost four meters during storms (Buonaiuto, 2003; Kana, 1995). The beaches in East Hampton are on average 65 m wide and composed of sand with a grain size of approximately 0.30 mm (Tsien, 1986). They tend to have nearshore slopes between two and eight degrees with an average of four degrees (Batten, 2003; Tsien, 1986).

2-2. Study area along the NY's eastern ocean shoreline in East Hampton, NY. Physiographic provinces of the coastline are designated as "EH" East Hampton Beach (from: Taney, 1961). The star also designates where East Hampton is located.

Long Island's south shore displays the characteristics of a swell-dominated beach with alternating erosion and accretion on a long temporal scale, commonly in phase with

the seasons (Quartel et al., 2008). A steep beach face and berm are created by swell waves in the summer, while a subtidal bar is built by storm-generated waves during the winter months. Coastal storms impacting Long Island can cause 60-90 m of beach retreat with a large volume of sand being moved offshore. The average losses to East Hampton beach are $120 \text{ m}^3\text{m}^{-1}$ and the average accretionary gains are $133 \text{ m}^3\text{m}^{-1}$ (Bokuniewicz, 1981). The swell waves that occur after the storm bring the sediments back onshore through time, establishing the migrating repair bar that exhibits the ridge-and-runnel morphology.

Aerial photographs of East Hampton and the surrounding beaches are available for public access on 33 dates over the 20 years between 1994 and 2014 (i.e., <http://dune.seagrant.sunysb.edu/nyshore/viewer.htm> and Google Earth accessed, 2016). It is possible to use these images to track the occurrence of ridge-and-runnels; however, the data set is small. Ridge-and-runnels are observed between 33% and 42% of the time during this period. In order to have a more accurate data set for this study, daily images at an East Hampton, New York beach were examined from a land-based camera to document the occurrence of ridge-and-runnel morphology. The intention of this study is to generate a statistical temporal distribution of beach morphology that would define the appearance and longevity of rip current hazards on Long Island ocean beaches.

METHODS

An Erdman Systems ® camera was installed in March 2007 to be utilized for monitoring the East Hampton shore. The camera is located 15 m above mean sea level and 120 m landward of the shoreline. Images are recorded every 15 seconds between 6:00 A.M (EST) and 9:00 P.M (EST). From 6:00 A.M through 3:00 P.M. the camera is

oriented 90 degrees to the ocean viewing a stretch of beach about 80 m long but due to sun glare, from 3:00 P.M. through 9:00 P.M. it is oriented to look eastward along the shore. An average of four images per day from the time period of October 2010 to November 2012 were reviewed in observance of ridge-and-runnel events; images from February 2014 to July 2016 were utilized to search for rip current related occurrences. Once a ridge-and-runnel (i.e., Figure 2-2) was identified, successive frames were examined in order to determine the duration of this change in morphology. Rip-like currents were identified when breaks in the ridge drained the runnel to the surf zone (Figure 2-3).

2-3. Ridge-and-runnel event as seen from the camera located in East Hampton, NY. The runnel is filled with water and separated from the shoreline by a ridge of sand. This event formed after Superstorm Sandy; 10 November 2012.

2-4. Rip current caused by drainage of a ridge-and runnel-event, East Hampton, New York; 25 April 2014.

Wave calculations

The nearest National Oceanic and Atmospheric Association (NOAA) buoy (Number 44017; 40.694N, 72.048) is located 56 km south of East Hampton and floats above 52 m of water. The calculations to determine wave steepness utilized this buoy's archived hourly data on wave height and period (<http://www.ndbc.noaa.gov/>, accessed July 2016). NOAA wave buoys do not collect wavelength information; therefore, the formula to calculate wave steepness was modified by substituting wave period for wavelength. The dominant wave period, T , replaced wavelength by applying the deep-water relationship:

$$L = \frac{gT^2}{2\pi}$$

where g is the acceleration due to gravity; therefore, the wave steepness becomes:

$$\frac{2\pi H}{gT^2}$$

Offshore wave steepness has long been used as a parameter to predict beach morphology with the understanding that higher wave steepness results in lower beach slopes (Komar, 1998). As first proposed by Johnson (1949), if the wave steepness is greater than 0.03, an offshore bar will form. A barless profile will occur when wave steepness drops below 0.016 (Rector, 1954; Watts, 1954 as cited in Komar, 1998). Ridge-and-runnel are expected to appear as the beach transitions between these endpoints.

RESULTS

From October 2010 to November 2012, 643 days of images were examined in which 35 ridge-and-runnel were identified; their appearance corresponded to about 5% of the time. Throughout the entire study period from October 2010 to July 2016, 1,062 days of images were examined in which 89 total ridge-and-runnel were identified (see inventory tabulated in Appendix 1). They were observed therefore about 8% of the study

timespan. The morphology persisted for a total of 165 days, or for about 16% of the study period. Individual features endured for anywhere between one and eight days (Table 2-1). The number of events decreased approximately exponentially as

2-1. Lifetime of observed ridge-and-runnel	
Duration (days)	Count
1	33
2	21
3	9
4	7
5	0
6	2
7	1
8	2

$54 * e^{-(0.5 * \text{duration in days})}$. Over 78% of the occurrences persisted for four days or less. The two most long-lived events, each persisting for eight days, began on January 20, 2011 and November 9, 2012. The occurrence of ridge-and-runnel morphology was most

prevalent in the fall and spring when water was cold (Figure 2-5) rather than in the months of high recreational beach usage.

2-5. Seasonal distribution of ridge-and runnel-events.

2-6. Wave steepness at NOAA Buoy 44017 during 2015.

Plots of wave-steepness display a “saw tooth” pattern with increases in steepness suddenly followed by a gradual “decay” to values below 0.012 (Figure 2-6). These cycles occurred about every five days, but they seem to occur more frequently late in the winter (about every four days) and less frequently in the spring and fall (about every six days). These are in the classic synoptic periods of between two and seven days for the passage

of mesoscale weather systems. The changes in frequency of wave steepness relate to the passage of frontal cyclones.

In East Hampton, the change in morphology appeared two to three days after an event of high wave steepness. One such event produced the ridge-and-runnel on January 20, 2011. Wave steepness was below 0.012 on January 17, 2011; drastically increasing to about 0.05 in only one-hour's time early on January 18. The wave steepness then gradually declined over the next few days, falling to below 0.012 on January 20 coincident with the appearance of a ridge-and-runnel (Figure 2-7). The same pattern is seen again before a four-day feature on April 14, 2011, which was preceded by a similar increase in wave steepness to values approaching 0.05 (Figure 2-8). In fact, the observed ridge-and-runnels all occurred in such a cycle, but not all cycles produced this morphological change to the beach (see remaining graphs in Appendix 2). Using the data from 2015, we estimated that ridge-and runnels had a 4% or 5% chance of being observed after a period of elevated wave steepness. An increase in wave steepness above 0.03 seemed to be necessary but not sufficient to result in the appearance of a ridge-and-runnel. This may be, in part, a consequence of the limited stretch of beach under observation (80 m), that is, ridge-and-runnels certainly occurred outside the camera's frame. Alternatively, in the interval between a particular storm event, a second erosion event may have occurred before the offshore bar from the first one had time to reach the shoreline to form a ridge-and-runnel. As a result, offshore wave data did not seem to provide a good predictive parameter.

2-7. Wave steepness in January 2011. A ridge-and-runnel lasting eight days appeared on 20 January as indicated by the red line at a wave steepness of 0.012.

2-8. Wave steepness in April 2011. A ridge-and-runnel lasting four days appeared on 14 April as indicated by the red line at a wave steepness of 0.012.

Four hundred and nineteen days of images from February 2014 to July 2016 were examined for the occurrence of rip currents. During this period, ridge-and-runnels persisted for over 65 days or nearly 16% of the time. Rip currents resulting from water flowing out of the runnel through the ridge into the surf zone appeared 48 times (e.g.,

Figure 2-9). Ridge-and-runnels and any subsequent rip currents occurred throughout the year, most prominently during late spring however, a distinct absence was seen during the summer months of July and August (Figure 2-10). Rip currents were captured therefore during 74% of the ridge-and-runnel events. It is possible that rip currents occurred on every event, but because our observation distance was limited, the rip current might not have been captured in the camera's frame. A linear correlation relates the number of rip currents (RC) to the number of ridge-and-runnel events (RR) as $RC = 0.9 \cdot RR - 1.1$ with an r^2 of 0.91 (Figure 2-11).

2-9. Water flowing out of the runnel through the surf zone as a rip current on April 6, 2016.

2-10. Occurrence of ridge-and runnels-and rip currents by month between February 2014 and July 2016. The darker colored bars show ridge-and-runnels, and the lighter show rip currents.

2-11. Linear correspondence between the occurrence of ridge-and runnels and co-occurring rip currents between February 2014 and July 2016.

DISCUSSION

Extratropical cyclones, or nor'easters, prevail along the U.S. Northeast coast (Davis and Dolan, 1993). Nor'easters can persist for several days ensuring that the storm

surge will be superimposed on high tides and can produce waves that exceed those produced by hurricanes. Some of the most destructive nor'easters in history include the "Great Appalachian Storm" of 1950, "Ash Wednesday Storm" of 1962, "Halloween Storm" or "The Perfect Storm" of 1991, and "Storm from Hell" in 1992. There have been at least 20 other memorable nor'easters in the 20-year period between 1991 and 2011, each potentially culminating in a ridge-and-runnel event; for example, a three-day feature that appeared on April 19, 2011 was preceded by a nor'easter on April 16, 2011. In the same time period, 14 hurricanes and six tropical storms also occurred. "Superstorm" Sandy impacted the Northeast U.S. on October 27, 2012; this study captured the sequence of ridge-and-runnels that subsequently appeared in East Hampton. The first appeared seven days after on November 3 and lasted for two days; a second feature was seen on November 6 for another two days, followed by another ridge-and-runnel that existed for eight-days starting on November 9, 2012 (Figure 2-2).

Other (unpublished) data on the occurrence of ridge-and runnels was tabulated by Liana Simpson (School of Marine and Atmospheric Science, Stony Brook University, 2016 personal communication), which extended observations along the entire ocean coast of New York. Thirteen different public beach cameras were monitored daily between Rockaway beach and Montauk Point on New York's ocean coast (Figure 2-1), and this limited data set provided results similar to the present study. During the ten-month study period (232 days between 8 July, 2015 to 7 May, 2016), ridge-and-runnels were seen on eleven times, or 5% of the time, with durations between one and four days. These all tended to be associated with periods of low wave steepness following a high (>0.03) wave-steepness event by three to seven days. Combining these data with the results of

the present study showed the same seasonality of ridge-and-runnel occurrence along New York's ocean coast as found at East Hampton. Ridge-and-runnel formation was observed to be substantially more common during winter months, which is in agreement with Shepard's (1950) finding of low-energy waves impacting the beach in the summer months and storm-generated waves in the winter. Storms are possible throughout the year, but the frequency and intensity of coastal storms is higher during winter months than during summer months (Quartel et al., 2008).

Anticipation of a ridge-and-runnel is likely to imply a greater risk of this special kind of rip current. Wave steepness above 0.03 seems to be a precursor of ridge-and-runnels and thus may provide an early warning. To ensure accurate rip current warnings, however, a forecast of how long ridge-and-runnels will persist would need to be developed.

It is reasonable to assume as intensity and duration of the storm increases that larger bars will be created further from shore. The lag time between the storm and the appearance of intertidal bars will also increase, prolonging the lifetime of ridge-and-runnel morphology. Although, we have been unable to document enough cases to estimate the severity of the storm with the time delay of the appearance of the ridge-and-runnel morphology, we propose the following speculation. Assume that the equilibrium profile follows (Dean, 1991):

$$h_e = Ax_e^{2/3} \quad \text{or} \quad x_e = \left(\frac{h_e}{A}\right)^{3/2} \quad [1]$$

where h_e is the water depth along the equilibrium profile, x_e is the distance from the equilibrium shoreline, and A is an empirical coefficient. Along the East Hampton

shoreline, closure depth, the limit of the zone of extreme bottom changes for beaches (Komar, 1998), is 9.1 m and is at a distance of 457 m from shore (Batten, 2003). These values used in [1] yield $A = -0.153$. Any storm surge, s , will raise the water depth to $h_s = h_e + s$ or $h_e = h_s - s$. We assume that the intertidal bars formed by storms are break-point bars and the break point is defined, for convenience, as (Komar, 1998 p.414):

$$\frac{H_{st}}{h_{st}} = 0.78 \quad \text{or} \quad h_{st} = \frac{H_{st}}{0.78} \quad [2]$$

where H_{st} is the storm-wave height. The position of the intertidal bar, x_r , from the equilibrium shoreline, as a function of the storm surge elevation and the storm wave height is then:

$$x_r = \left[\frac{\left(\frac{H_{st}}{0.78} \right) - s}{A} \right]^{3/2} \quad [3]$$

If the post-storm, on-shore migration rate is R (m/day) then the ridge-and-runnel systems, and increased rip current risk, would materialize T days after the storm where:

$$T(H_s, s, R) = \frac{x_r}{R} = \left\{ \frac{\left[\frac{\left(\frac{H_{st}}{0.78} \right) - s}{A} \right]^{3/2}}{R} \right\} \quad [4]$$

Quantitative data regarding ridge-and-runnel features and their migration rates in real time are scarce. The onshore migration rates from the field studies elsewhere range anywhere from between one and ten meters per day (Masselink et al., 2006) or 1 cm/min during high-energy wave conditions (Robin et al., 2009); laboratory flume experiments produced onshore migration rates of 1.4 m/day (Figlus et al., 2012). In this spectrum, time delays would range from four to ten days, in fair agreement with the available observations of persistence from one to eight days (Table 2-1).

CONCLUSIONS

Ridge-and-runnels appear on East Hampton beaches after an event of increased wave steepness, and rip currents were observed during three out of every four ridge-and-runnel events, most likely due to our limited study site. In particular, my data indicates that bar gap-like rip currents would be more likely to occur between four and ten days after a major storm and persist for up to eight days. A relationship between their duration and steepness is still to be determined; however, both longer lag-times and lifetimes should be expected after storms with higher wave heights and storm surges. Of course, more observations are needed both over longer time periods and at different locations in order to assemble better statistics on the occurrence of ridges-and-runnels and to define the relationship between the evolution of this beach morphology and the characteristics of particular storms. Beach morphology can be used to anticipate elevated rip-current hazard, but although storms can occur in any season, overall, ridge-and-runnel morphology appears to be less prevalent in the summer when rip currents would pose the greatest risk to swimmers.

III. CONDITIONS CONDUCTIVE FOR RIP CURRENT OCCURRENCE AND RESCUES AT THREE PALM BEACH COUNTY PARKS IN FLORIDA

ABSTRACT

There are bathymetrical, meteorological, and oceanographic controls on the formation and behavior of rip currents. Although the mechanics of these nearshore flows is a subject of ongoing research (e.g., Castelle et al., 2016; Kumar and Feddersen, 2017; Leatherman, 2012; Pitman et al., 2016; Scott et al., 2014), the hazard rip-currents pose to beachgoers cannot be ignored. These rivers of the sea move offshore at fast rates of speed, endangering bathers who happen to be caught. This study will explore the conditions that cause rip currents in Palm Beach County, FL and utilize historical lifeguard incident reports to correlate rescue days to wind speeds and wave conditions. The goal is to better understand the conditions conducive to rip-current formation and the ensuing influence these dangerous flows have on the beach-going public. Three study sites were chosen because of their higher numbers of rip-related rescues: Juno Beach Park, Ocean Reef Park, and R.G. Kreusler Park. They also each have unique physical characteristics that influence the behavior of rip currents. It was determined that bathers have the greatest chance of being caught in a rip when beach conditions (i.e., wave heights and wind speeds) appear moderate. Rip-current rescues tend to be on days when onshore winds average 13 kt and waves are 1 m in height or less. Rips are stronger on days when wind and waves are higher; however, beachgoers tend to stay out of the water during these conditions. Therefore, the most dangerous rip currents are those that occur during moderate (i.e., yellow flag) beach days.

INTRODUCTION

Rip currents are narrow, concentrated, seaward-moving flows that extend from close to the shoreline through the surf zone, to varying distances beyond (Castelle et al., 2016). There has been much discussion about bathymetric, meteorological, and/or oceanographic factors that control the appearance and strength of rips, which varies depending on the studied beach. Most rip-related fatalities occur when beachgoers who cannot swim are swept into deep water or those who can swim, try to fight the current eventually tiring. Regardless of a beachgoer's ability to swim, a major factor determined by Attard et al. (2015) is that the victim panics and, according to Drozdowski et al. (2012), most likely forgets to not swim against the current.

Statistics of average rip current-related fatalities per year in the United States range from 34 people per year (Gensini and Ashley, 2009) to 150 (Lushine, 1991). However, the most widely accepted value is 100 reported by the United States Lifesaving Association (USLA, 2016). Although a possibility, rip-current drownings are relatively rare on patrolled locations thanks to the men and women who work guarding the beaches. However, rip currents are fairly common, with guards sometimes needing to rescue multiple beachgoers. Most ocean-rescue organizations keep record of incidents; therefore, the data set of rescues can be utilized to provide better site-specific information about rip currents than to rely on nation-wide fatality statistics.

Coastal scientists, to learn various aspects about beach statistics and/or hazards, have used incident reports of lifeguard rescues. Engle et al. (2002) used rescue logs from Daytona Beach, Florida to correlate rip current-related saves with wind and wave measurements. Pitman et al. (2016) used video imagery to classify the type of rip-current

channel present and determine existing trends during each rescue made by the Royal National Lifeboat Institution (RNLI) in the U.K. Woodward et al. (2013) utilized RNLI incident reports to discover key demographic characteristics of rip current victims. Scott et al. (2014) compared RNLI incident data reports with their Lagrangian rip-current measurements.

The following studies did not intend to further rip current understanding but still collected information about conditions during lifeguard rescues. Morgan and Ozanne-Smith (2013) utilized Life Saving Victoria's reports to determine that rescues were more likely to correlate with days of higher beach attendance in Australia. Harada et al. (2011) analyzed reports taken by the City and County of Honolulu to determine visitor and environmental characteristics that contributed to ocean rescues at Hanauma Bay, Hawaii.

The goal of my study is to better understand the conditions conducive to rip-current formation and the ensuing hazard these dangerous flows present to the beach-going public. This was undertaken by the utilization of lifeguard reports, which included the wind and wave conditions, among other details regarding each rescue. As aforementioned, previous studies have utilized these types of data, but never to the extent of including multiple years or such a wide range of variables (i.e., rescue conditions, tidal stage, wind speed, wave height, etc.). Knowing the conditions for rip current generation is beneficial to both further the physical science understanding and to mitigate the risk to beachgoers.

In Florida from 1989-2008, rip currents caused 364 deaths, more than any other state in the U.S. (Finkl and Makowski, 2013), and more than the 269 deaths attributed to lightning, tornados, and hurricanes combined (Lushine, 2011). It is known that the level

of funding allocated to rip-current awareness programs and risk management is significantly lower than funding provided to other more prominent hazards that claim less lives on an average annual basis (Brander et al., 2013). Therefore, the present study could help local agencies in their plea to obtain more resources to create or support their existing management policies.

PALM BEACH COUNTY BEACHES

The sand at beaches in Palm Beach County, which is located in Southeast Florida (Figure 3-1), is mostly composed of quartz and includes a moderate amount of calcium carbonate material. Some beaches retain up to three meters of sediment that overlays lithified sand, beachrock, and coquina limestone belonging to the Anastasia Formation (Benedet et al., 2004). This formation anchors the Palm Beach barrier islands so that unlike most others, they cannot migrate landward in response to sea level rise (Davis, 1997). In some locations this rock is exposed on the beachface, enhancing rip current activity. Elsewhere, rocks are submerged and covered by sand (Finkl and Andrews, 2008). Therefore, the main rip-current types seen in Palm Beach are bar-gap rips and structurally-controlled rip currents. As defined by Leatherman (2012), the first form because of depressions in the bars creating well-established channels and the latter are dependent on hard structures that are naturally occurring or artificially constructed, such as groins and jetties. Bathymetrically-controlled rip currents are ones that occur at fixed alongshore locations (Kumar and Feddersen, 2017), making them permanent and therefore, more predictable. These rip currents will always occur at the same locations when suitable wind and wave conditions are present.

A wave buoy that has the capabilities to collect and record real-time data does not exist in the area; the closest is located off Cape Canaveral, approximately 200 km north of Palm Beach County (Robertson, 2007). Therefore, this study cannot verify the historical wave heights or differentiate between swells and locally generated wind waves. However, using data from the Wave Information Study (WIS), wave

3-1. Location of Palm Beach County, Florida; indicated by yellow coloration.

statistics for this area can be determined as averaging 0.98 m in height with a period of 8 s and approaching from the east to northeast (Benedet et al., 2004).

Rip currents are typically present in Palm Beach County during conditions of persistent onshore winds. As the Bermuda High, which typically sits in the Mid-Atlantic, strengthens it will tend to move over Florida, bringing stronger than average easterly winds that increased the generation of wind waves over the region. These in turn create rip currents in which beachgoers can become caught. Paxton (2014) observed that by the day of frequent rip currents, the area of enhanced wind extended through Southeast Florida, including the Palm Beach area. Rip currents are also more likely to be present after the passage of a cold frontal system as the wind veers from north-northwest to northeast. In addition to meteorological patterns, large storms (i.e., nor'easters or hurricanes) either offshore or at the coast can bring higher than normal wave energy to the shore, resulting in changes in the beach morphology. It is likely that this increased

wave action reshapes the sediment, creating well-established channels that localize water, and create bar-gap rip currents.

Palm Beach County has been ranked as the third deadliest area in Southeast Florida (Paxton, 2014). According to data compiled by the National Weather Service (NWS), from 2013-2016 there were five deaths attributed to rip currents in Palm Beach, this includes one death at Juno Beach in 2014 (NWS, 2016).

STUDY SITES

Palm Beach County manages over 14 beaches, of which three were chosen for this study. The beaches were selected because they have the largest quantity of rip-current rescues throughout the six years of data--each had over 100; whereas, the remaining 11 had less than 60. Juno Beach Park was the northern most; the second site, Ocean Reef Park was approximately 12 km to the south, and R.G. Kreusler Park is another 23 km further south (Figure 3-2).

3-2. Locations of Juno Beach, Ocean Reef, and Kreusler Parks in relation to each other.

In the northern part of the county, Florida's coastline trends slightly to the southeast, which includes Juno Beach. Just south, this orientation changes to a north-south orientation resulting in a relatively straight shoreline between Ocean Reef and Kreusler Parks. This geology creates a promontory of the coastline, coincidentally located about the location of Ocean Reef Park (Figure 3-2). It is likely this bulge has increased the erosion rate at this beach resulting in the exposure of the Anastasia Formation.

The rip currents at both Juno and Kreusler Beaches are bar-gap and mainly influenced by the copious amount of sand present because of the piers at both locations. These structures slow the longshore sediment transport resulting in an accumulation of sand. However, the rip currents at Ocean Reef's beach were controlled by the aforementioned exposed rock along the shoreline (Figure 3-3). At every beach maintained by the county, lifeguard towers display warning flags in accordance with NOAA's color scheme (Figure 3-4), additionally the guards update large information boards at designated beach entrances.

3-3. Google Earth image of Ocean Reef Park showing exposed Anastasia Formation; permanent rip currents are located to the north of each structure.

3-4. Meanings of beach warning flags used by Palm Beach County Ocean Rescue.

Juno Beach Park

Juno Beach Park, located within the Town of Juno Beach, was situated in northern Palm Beach County; it was composed of 2 ha that includes 91 m of guarded beachfront. There was a large adjacent lot where visitors can park for free and another draw is the 302 m long pier. Ocean Rescue designates an area strictly for surfers and works to ensure bathers stay out of this area and additionally away from the pier. The county maintains two towers, one on either side of the structure.

Ocean Reef Park

Ocean Reef Park was located in the City of Riviera Beach situated in central Palm Beach County. It was the largest of the three parks, being 5 ha with 213 m of guarded beachfront. There are two permanent lifeguard towers that display warning flags, as well as a satellite tower placed closer to the shore and manned on days with strong rip currents. Since this beach was notorious for dangerous conditions caused by the rocks on the beachface, guards take extra precautions and have placed warning signs in front of rip

locations (Figure 3-5) in addition to the common placement at designated beach entrances next to the information board.

3-5. Rip current warning sign placed on the beach directly in front of permanent rip at Ocean Reef Park.

R.G. Kreusler Park

R.G. Kreusler Park was located in the Town of Palm Beach situated in southern Palm Beach County; it was 1.7 ha in size and includes 137 m of guarded beach. The county maintains one lifeguard tower with colored warning flags at this beach and large information signs are placed at the designated entrances. The City of Lake Worth maintains the beach directly adjacent to Kreusler Park. Therefore, it was not uncommon for the county and city guards to work together. Within the city's beach limits is a pier that extends 293 m offshore.

METHODS

Data collected by Florida Department of Environmental Protection (DEP) was utilized in this study. The Florida Geological Survey collected sand samples at every beach in the late 2000's; the results of the analysis from sand grab sites PB-06, PB-13,

and PB-25 were used in this research. Additionally, the DEP surveys beaches each year; profiles were created using the lines at Monuments R-31 (26.8934, -80.0574), R-63 (26.8068, -80.0339), and R-128 (26.6143, -80.0369), which were collected in July and August of 2015. I calculated the slope of the shoreface for each site using the location closest to mean water level to the first measurement at or more than -2 m below sea level. The foreshore slope was calculated from the berm to the step at each beach.

Lifeguards record statistics daily that includes wind and wave height, beach attendance, preventative actions (i.e., making a patron aware of a risky behavior if a rescue seems imminent), and rescues among others. Their rescue statistics are provided to the USLA and data from 2011 to 2016 was utilized in this study. However, these statistics are monthly totals. Therefore, incident reports had to be obtained for more specific information. The data set used for this project had been preserved within the county's headquarters and was made available upon request. Any time a lifeguard responds to an incident on or near the beach, they are required to submit a report in anticipation of possible litigation. These reports contain much more detail about the rip current rescues such as day, time of occurrence, and number of victims.

Lifeguards also make daily observations of wind speed and wave height. They utilize local weather stations (i.e., 8 km to the south of Juno and 6 km north of Ocean Reef at 26.8446, -80.0521, and 6 km west of Kreusler at 26.6064, -80.0886) to obtain wind speeds and their wave observations tend to be within 0.15 m of accuracy. The warning flag that is raised is determined by sea state specific to that beach; green flags are posted when no white water is seen, yellow when some waves begin to break, and red when all waves are creating whitecaps. It is important to note that this historical record is

subject to human error in the possible forms of common mistakes and missing information.

RESULTS

Juno Beach Park

Juno Beach's sand had a mean grain size of 0.33 mm (Figure 3-6). This composition resulted in this park having the steepest beach profile (Figure 3-7) the slope of the shoreface was calculated as -0.043 degrees, and the foreshore's slope is -0.15 degrees.

3-6. Sand grain analysis for Juno Beach

Throughout the six years (2011 to 2016) of USLA data, lifeguards at Juno Beach executed a total of 185 rescues pertaining to rip currents (Table 3-1). Most rip-current rescues occurred during in the month of March (Figure 3-8) and 2011 had the largest amount of rip-current incidents (Table 3-1).

3-7. Profile of Juno Beach Park, July 2015.

3-1. Number of rip current rescues per beach

Year	Juno Beach	Ocean Reef	Kreusler
2011	37	8	26
2012	21	23	23
2013	34	36	28
2014	36	14	26
2015	26	23	30
2016	31	38	3
Total	185	142	136

Source: Palm Beach County USLA Data

3-8. Comparison of total rescues by month at each beach, 2011-2016.

At this beach most rescues occurred during mid-tidal stage (Table 3-2). Contrary to the conventional wisdom, fewer rip-current rescues occurred at low tide when it is thought that currents would be moving the fastest. Indeed, 15% of rescues were recorded at high tide. At Juno Beach, all rip-current related rescues happened on days when winds ranged from 4.3 kt to 16.5 kt, with most occurring when winds ranged between 8 and 17 kt. Rip-current rescues were only performed on days with winds 17.4 kt or greater on one occasion (Table 3-3). The highest frequency of rescues (30%) occurred when waves reached 0.8 m, followed by 0.5 m, and then 1.2 m (Table 3-4).

3-2. Tidal stage during rip current rescues

	Juno	Ocean Reef	Kreusler
Tide			
<i>Low</i>	27	25	33
<i>Mid</i>	41	26	16
<i>High</i>	12	13	2

Source: Palm Beach County Ocean Rescue
Incident Reports 2011-2016

3-3. Wind speed during rip current rescues

	Juno	Ocean Reef	Kreusler
Wind (knots)			
<i>0 - 4</i>	0	0	0
<i>4 - 8</i>	4	3	4
<i>8 - 12</i>	19	11	16
<i>12 - 17</i>	17	17	9
<i>> 17</i>	1	5	3

Source: Palm Beach County Ocean Rescue
Incident Reports 2011-2016

3-4. Wave heights during rip current rescues

	Juno	Ocean Reef	Kreusler
Surf (m)			
<i>0.2</i>	0	2	0
<i>0.3</i>	1	2	3
<i>0.5</i>	17	8	18
<i>0.6</i>	12	11	13
<i>0.8</i>	25	13	13
<i>0.9</i>	6	12	1
<i>1.1</i>	4	12	5
<i>1.2</i>	14	1	0
<i>1.4</i>	0	0	0
<i>1.5</i>	2	0	2
<i>1.7</i>	0	1	0
<i>1.8</i>	2	0	0

Source: Palm Beach County Ocean Rescue
Incident Reports 2011-2016

At Juno Beach most rip-current related rescues are conducted on the weekends, 19 (29%) followed by 12 (18%) on Sundays and Saturdays, respectively (Table 3-5). Most of the time, guards enter the water to retrieve one beachgoer from a rip (44, 52%); however, almost just as commonly (25, 29%) two victims needed assistance (Table 3-6). On more than one occasion five people or more were pulled from a rip current. At no point during the six years did a rip-current rescue occur on a green flag day; most rescues occur during a yellow flag and only 10 when displaying the red flag (Table 3-7).

3-5. Number of rip rescues by day of week (N=183)

	Juno	Ocean Reef	Kreusler
Weekday			
<i>Sun</i>	19	16	12
<i>Mon</i>	5	9	10
<i>Tue</i>	9	10	6
<i>Wed</i>	6	5	5
<i>Thu</i>	7	6	3
<i>Fri</i>	7	5	7
<i>Sat</i>	12	17	7

Source: Palm Beach County Ocean Rescue
Incident Reports 2011-2016

3-6. Number of victims per rip rescue (N=217)

	Juno	Ocean Reef	Kreusler
Victims			
<i>1</i>	44	38	34
<i>2</i>	25	23	17
<i>3</i>	12	9	4
<i>4</i>	0	1	5
<i>5</i>	1	0	1
<i>6</i>	0	0	0
<i>7</i>	3	0	0

Source: Palm Beach County Ocean Rescue
Incident Reports 2011-2016

3-7. Number of rescues by flag color

	Juno	Ocean Reef	Kreusler
Warning flag			
<i>Green</i>	0	3	1
<i>Yellow</i>	60	59	39
<i>Red</i>	10	9	6

Source: Palm Beach County Ocean Rescue
Incident Reports 2011-2016

Ocean Reef Park

At Ocean Reef Park's beach, the mean grain size was 0.42 mm (Figure 3-9). This beach had a gentler slope than Juno Beach (Figure 3-10), measured as -0.039 degrees at the shoreface and -0.15 degrees at the foreshore.

3-9. Sand analysis at Ocean Reef Park.

There were 142 rip-current rescues in the six years of this study (Table 3-1). At this location most rescues are made in July (Figure 3-8) and 2016 reported the most rip rescues during this timespan (Table 3-1).

3-10. Profile of the beach at Ocean Reef Park, July 2015.

Nearly equal numbers of beachgoers needed rescuing from rip currents at low and mid-tidal levels, but 20% did occur at high tide (Table 3-2). Rip-current rescues were

most prevalent during wind speeds of 13 kt to 16.5 kt and five rescues (14%) were reported during winds greater than 17.4 kt (Table 3-3). Wave heights of 0.5 m to 1.1 m tend to be the most dangerous to beachgoers and only two rescues were ever recorded when waves were greater than 1.2 m (Table 3-4).

As seen in Table 3-5, beachgoers were likely to struggle against rip currents on weekends; nearly 50% of the incident reports were recorded on Sundays and Saturdays. It was most common (54%) for only one person to need a lifeguard's assistance to escape from the current (Table 3-6). At Ocean Reef, no more than four people were ever pulled from the same rip, and in six years only 10 rescues (14%) involved three or more people at once. As was seen at Juno, by far most of the rip-current rescues were recorded on yellow flag days, only nine on occurred on red flag days, and three rescues were executed on green flag days (Table 3-7).

R.G. Kreusler Park

The sand at Kreusler Park's mean grain size was 0.33 mm (Figure 3-11) creating a gentle slope calculated as -0.03 degrees and -0.12 degrees at the foreshore (Figure 3-12). According to the six years of data, lifeguards at Kreusler Beach performed a total of 136 rescues specific to assisting a swimmer caught in a rip current (Table 3-1). Palm Beach County guards made the most rescues associated

3-11. Sand analysis at Kreusler Park.

with rip currents in the month of May (Figure 3-8) and the year with the greatest number of rip-related rescues was 2015 (Table 3-1).

3-12. Profile of R.G. Kreusler Park's beach, surveyed August 2015.

In regards to tidal stage, most rip-current rescues occurred during low tide (33, 65%), and nearly half that number when the tide is in between stages (16, 31%); only two rescues were performed during high tide (Table 3-2). The number of rescues increased, peaked, and then decreased with wind velocity. Most rip rescues happened between wind speeds of 8.7 kt and 12.2 kt (Table 3-3). At Kreusler Beach most rip current rescues occurred when the waves were only reported to be 0.5 m in height (Table 3-4). Beachgoers typically become caught in rips during days when waves are between 0.5 m and 0.8 m; only two were executed in 1.5 m waves.

Rip rescues at this beach were most likely to occur on Sundays and least likely on Thursdays (Table 3-5). Most often only one victim at a time needed rescuing; the most swimmers pulled from a rip current were five and this only happened once within the six years (Table 3-6). Rip rescues mostly occurred on days that yellow flags were displayed; only six rescues were made on red flag days and one rescue while the green flag was flying (Table 3-7).

Effect of beach attendance on rescue numbers

Logically beach attendance must play a crucial role in rip current rescue occurrences--the more beachgoers, the greater chance for a rescue. However, Figures 3-13, 3-14, and 3-15 show this is not always the case in Palm Beach County. Unlike other moderately high-energy beaches,

the warm climate and water temperatures make Southeast Florida a high demand tourist location, allowing for year-round visitation and swimming (Figure

3-16). In addition to short-term visits by tourists and year-round

3-13. Comparison of number of rescues and attendance by month 2011-2016 for Juno Beach Park; note: blue line expresses rescues and red line is attendance in thousands.

residents, Palm Beach is subjected to a large number of residents from northern states that come to Florida to escape frigid winter weather (a.k.a., “snowbirds). The phenomenon creates much larger beach visitation in the south in the winter than in the summer. The winter increase in visits was reflected in beach attendance. In Figure 3-17, a decrease can be seen between the months of April and August, although one would expect beach attendance to continue rising and peak in the summer. In Palm Beach, a decrease in beachgoers was seen directly after spring break, which typically occurs in March, and lasts until the fall, explaining any drops in attendance during the most active rip-current rescue months. A second peak seen in rip-current rescues (Figures 3-13, 3-14, and 3-15) correlates to the warmest month in Southeast Florida when both air and water temperatures reach upwards of 30°C (Figure 3-16).

3-14. Comparison of number of rescues and attendance by month 2011-2016 for Ocean Reef Park; note: blue line expresses rescues and red line is attendance in thousands.

3-15. Comparison of number of rescues and attendance by month 2011-2016 for Kreusler Park; note: blue line expresses rescues and red line is attendance in thousands.

3-16. Average water and air temperatures by month in Palm Beach County.

3-17. Comparison of mean beach attendance by month at each park, 2011-2016.

DISCUSSION

Paxton (2014) states that rip current incidents are most likely to occur at low tide in Southeast Florida, and Engle et al. (2002) observed the frequency of rip-rescues increased during mid-low tidal stages. Palm Beach County's Kreusler Beach fits this model; however, this relationship is not as clear at Juno Beach or Ocean Reef Park (Table 3-2).

Only twice over the six-year period did rip-current rescues occur on the same day at all parks: April 9, 2013 and May 27, 2013. At all three locations wind speeds were recorded around 13 kt and waves as 0.6 m in height for both of these days. Furthermore, May 27 was Memorial Day, which most likely meant there were more beachgoers. It was more common for rip rescues to be seen at two parks on one day—this happened 12 times throughout the six-year period. Most of these dates occur around holidays or school breaks--Thanksgiving, Spring Break, and Memorial Day, which are very busy beach times and days of high beach attendance. On these days wave heights range from 0.5 m to 1.2 m in height; however more importantly, all the days have winds around 13 kt from

the east or southeast. All rip-current rescues in Palm Beach County occurred when the winds were directed onshore or resulted from the influence of swell waves generated by offshore storms.

Lushine (1991) correlated fatalities in Southeast Florida to wind speed, direction, and tidal variation. He determined that onshore winds greater than 23 kt occurred during 90% of rip current deaths. However, in Palm Beach County, rip-current rescues were most common (42%) at an average of 13 kt and less than 10 rescues (8%) were made when winds exceeded 17 kt (Table 3-3). Lushine's calculation represents only the rare case of rip current fatality, not the more commonly occurring rescue, explaining the apparent wind speed discrepancy. Days with greater wind velocities would normally have higher waves, in turn keeping most beachgoers out of the water. This is a beneficial correlation because on days with the strongest rip currents, fewer beachgoers enter the ocean. It should also be noted that rescues on days with low wind speeds are probably attributed to swell waves coming from offshore Atlantic storms. However, as lifeguards do not collect breaker type and wave period data, this possibility cannot be confirmed. It is recommended that rescue organizations and future researchers collect this information. Alternatively, a wave buoy could be installed offshore for more accurate measurements.

Frequency of rip rescues increased during wave heights of 0.5 m to 1 m. The resultant correlation between wave height and rip-current rescues in Palm Beach County is consistent with what Engle et al. (2002) observed in Daytona Beach, Florida. The theory of large waves keeping beachgoers from entering the water is further strengthened by the relationship between surf height and rip-current rescues at both Ocean Reef and Kreusler Beach however; the same relationship is not seen in Juno Beach's statistics

(Table 3-4). This departure from the norm is likely a result of the difference in beach slopes, as aforementioned both Ocean Reef (Figure 3-10) and Kreusler Beach (Figure 3-12) are a gently sloped (dissipative) and Juno Beach (Figure 3-7) is steepest (intermediate beach state). Beach slope has a relationship with wave height; gentle beaches tend to have lower wave heights and steeper beaches create large breakers closer to shore. Wave height in turn is related to rip-current strength as described by McKenzie (1958) who noted that with large waves, strong rip currents were produced whereas when the waves are smaller the rip currents were weaker. The findings in Palm Beach County support the results of Woodward et al. (2013), who determined that incident numbers increased from dissipative to intermediate beach states.

Since Palm Beach County is underlain by the Anastasia Formation, which in many locations is close enough to the surface to be exposed, I propose that the underlying limestone might have more control over the shape of seemingly sandy-bottom beaches than is currently thought. Further consideration might find that the breaks in these ancient shore-parallel structures result in rip currents. Such a situation may define a new type of rip current, one that is a hybrid between bar-gap and structurally controlled. These “permanent” rips would be found in the same location whenever there was enough wave energy. However, this study was unable to prove this correlation, and future work must be undertaken to test the validity of this postulation.

CONCLUSIONS

This study has explored the three most dangerous beaches in Palm Beach County, according to rip-current rescue statistics; each beach also has distinct physical characteristics that influence rip current formation and behavior. Out of the two sandy

beaches, Juno is steeper resulting in higher wave heights, stronger rip currents, and ultimately more rescues than Kreusler beach. Unlike the previous two beaches, the Anastasia Formation is exposed along the beach at Ocean Reef Park. These rock structures create permanent rip currents that are present during the proper wind and wave conditions.

The chance of a beachgoer being caught in a rip current increases when conditions appear deceptively calm. The same wind and wave conditions that result in the strongest rips also aid in keeping beachgoers from entering the water. Therefore, the most life-threatening rip currents are ones that occur under moderate wind speeds and wave heights when beachgoers feel comfortable going into the ocean. County lifeguards take many necessary precautions to avoid rip-related incidents--without their efforts Palm Beach might be one of the most deadly coastal areas.

IV. RIP CURRENT LITERACY OF BEACHGOERS AT MIAMI BEACH, FLORIDA

ABSTRACT

Rip currents are fast moving, offshore flows that have the ability to move even the strongest swimmers into deep waters. Miami Beach, Florida is one of the most visited beaches in the U.S. and a sought after destination for citizens and international tourists alike. It is also known to be a rip-current “hot spot.” These factors greatly increase the risk of drowning; however, no previous research has focused on beachgoer perception of rip-related risks in South Florida. Over a 12-month period, 203 public surveys were collected to determine the rip current knowledge of beachgoers at Miami Beach including factors such as swimming ability and frequency of beach visits. The responses were analyzed by normalized component factors to determine the respondent’s comprehensive knowledge of rips. Multiple regression models were used to assess the net influences of sociodemographic and behavioral characteristics on the responses. A significant proportion (53%) of the survey respondents showed insufficient knowledge, indicating they are at risk of drowning in a rip current. Frequent beachgoer’s exposure to the beach environment, maturation, and residency are identified as the main contributors to knowledge net of other sociodemographic compositions. The most at-risk groups were determined to be young adults, foreign tourists, poor swimmers, and those who infrequently visited the beach. Miami Beach needs to initiate a rip current safety campaign to target these at-risk beachgoers, where interventions beyond familial and educational institutions should be introduced.

INTRODUCTION

Rip currents and related risk

Rip currents can occur in any body of water, fresh or salt, which has significant wave action. The risk of drowning at a beach greatly exceeds all other beach-related risks (Hanes, 2016) such as marine life and meteorological phenomenon. Rip currents are a global problem and considered to be the major hazard for bathers at surf beaches; they are a high-frequency, low-intensity hazard that is almost always present on swell-dominated beaches, but only occasionally result in more than one simultaneous fatality (Brander et al., 2013). The United States Lifesaving Association (USLA) reports that on average 100 people per year drown in rip currents on beaches in the U.S., and that these dangerous currents account for 80% of the surf rescues (USLA, 2011).

Coastal scientists have been studying these cross-shore currents in an attempt to understand the conditions for their generation and behavior, with the intent of deriving predictive models and better educating the public. Among the first to describe the processes and characteristics of rip currents were Shepard et al. (1941). Rip currents form as waves push water onto the beachface with the return flow concentrated as a current moving offshore, often through breaks or depressions in the shore-parallel sand bars or ridges. These fast-flowing rivers of the sea extend seaward through the surf zone where they eventually decelerate and dissipate as an expanding rip head (Castelle et al., 2016).

Study site: Miami Beach, Florida

This is the first public survey in South Florida to determine beachgoer's knowledge of rip currents. While most respondents have probably heard of the term "rip current" and associate it with a beach danger, it is less likely that they possess specific

knowledge of these dangerous offshore-flowing currents. A survey of beachgoers was used to measure their level of understanding about rip currents, depending on their sociodemographic factors, swimming ability, and the amount of beach visits.

Lushine (2011) compiled data of all weather-related deaths in Florida over the period of 1989-2008. Rip currents caused 364 deaths, 95 more than were attributed to lightning, tornados, and hurricanes combined over the same period. His study indicates that on average 19 beachgoers succumbed to a rip-current hazard each year in Florida, and every one of these deaths was preventable. Gensini and Ashley (2009) concluded that the east coast of Florida has the highest number of rip-current fatalities in the United States due to persistent onshore winds, favorable beach visiting conditions, and warm ocean temperatures.

Miami Beach is nearly 13 km long (Figure 4-1). In the 1980's the beach was re-nourished with calcium carbonate sand pumped up from submerged offshore reef tracts. This nourishment project created a wide beach with a gentle slope and two offshore bars. The Government Cut jetty that maintains the inlet to the Port of Miami has caused an accretion of sand so that there the beach

4-1. Google Earth image of study site, from Miami Beach Ocean Rescue's outer boundary lifeguard towers. Miami Beach is located on a barrier island to the state of Florida.

reaches a width of around 200 m. However, northern portions such as near 36th Street can become very narrow, less than 30 m, as erosion hot spots.

Miami Beach is located on a barrier island that is a fairly straight along a low wave energy coastline. The presence of the Bahamas Island chain and their extensive sand shoals block most all of the Atlantic Ocean swells (Figure 4-2). Wave action is generated between South Florida and the Bahamas because of the predominant easterly wind flow (Paxton, 2014). Swells generated by nor'easters off the North Carolina coast or from offshore Atlantic Ocean hurricanes rarely reach Miami Beach. There are three potential rip-current types that occur at the study site: bar-gap, structurally controlled, and flash. Due to the large quantity of sand present, bar-gap rip currents are the most common and persist in well-established channels. Structurally controlled rips occur along the Government Cut Jetty, which diverts the southerly-flowing longshore current offshore. Lastly, locally strong winds, which create confused sea states, will episodically produce flash rip currents.

4-2. Google Earth image indicating the location of Miami Beach on the Florida Peninsula. Also including part of the Bahamas Island chain that blocks most of the larger Atlantic Ocean wave activity from reaching Miami Beach.

More than 14 million visitors spent at least one night in the Miami area during 2013 according to the Greater Miami Convention and Visitors Bureau. Of these visitors, 74% stated their purpose was vacation; nearly seven out of every ten tourists visited a beach during their stay. These statistics do not include visits by the estimated 2.7 million residents of Miami-Dade County (U.S. Census, 2014). The City of Miami Beach Ocean Rescue made 2,914 rip current rescues during a 15-year timespan (USLA, 2016); however, rip-related drowning deaths are not provided. Three surf-zone fatalities at Miami Beach in 2015 were attributed by the National Weather Service (NWS) to rip currents (NWS, 2016). Miami Beach is listed as the third deadliest beach in the U.S. for rip fatalities, as determined by Paxton and Collins (2014). However, the City of Miami Beach was not currently promoting any rip-current awareness or educational campaigns at this time. The National Oceanic and Atmospheric Association's (NOAA) rip-current sign is affixed to all lifeguard towers; and in addition to the sign, each tower flies an up-to-date color coded wave and current warning flag (Figure 4-3). However, these efforts may be less effective because the lifeguard stands are neither evenly spaced along the beach nor not positioned at each beach entrance. In addition, the signs are small and easily missed because of the building's vibrant paint. Brannstrom et al. (2015) noted the need for NOAA signs to be posted and that they should be made less complicated and

4-3. NOAA rip current sign affixed to Miami Beach lifeguard stand (right side).

translated into additional languages, especially at Miami Beach.

Study implications

The combination of clear water, year-round favorable beach weather, and relatively low wave energy are what makes Miami Beach so inviting for bathers and so dangerous. The seemingly benign environment lures beachgoers with its sense of calm waters and a lack of danger. One of the overall goals of this present research is to help develop a rip-current awareness campaign using my results. My public survey will delineate the sociodemographic and behavioral characteristics that make beachgoers more likely or less likely to know of beach hazards, particularly rip currents. This information might be helpful to the City of Miami Beach in creating better coastal management policies more targeted to the at-risk populations.

BACKGROUND

Rip currents are considered by coastal scientists to be the most prevalent hazard on any surf beach. In recent years, researchers have utilized public surveys to gain information about beachgoers and rip currents (e.g., Brannstrom et al., 2014; Drozdowski et al., 2012; McCoy et al., 2010; Sherker et al., 2010; Williamson et al., 2012). My survey instrument follows the work of our predecessors. Some studies, such as McCoy et al. (2010), have found that the public was well informed. The majority (83%) of their respondents in South Carolina correctly described rip currents as channelized currents flowing away from the shore. Other scientists discovered more heterogeneity in beachgoer's understanding. Respondent's knowledge is contingent on their gender, age, nationality, and swimming ability.

Social heterogeneity of rip current knowledge

Internationally, research has shown that men are statistically more likely to drown in a rip current than women. This is supported by studies in Costa Rica where the majority of drownings (89%) involved males (Arozarena et al., 2015) and in Istanbul where it was determined that males compared to females are over seven times more likely to drown in a rip current (Barlas and Beji, 2016). Reasons for this gender bias include cultural norms, that is males are more likely to partake in over-confident and risky behavior, and/or that men drown while attempting to rescue other family members, especially children, caught in a rip current. Morgan et al. (2009) showed that male bias in water-related incidents could be attributed to their increased frequency and exposure to water activities. Williamson et al. (2012) observed males being significantly less likely to swim in safe locations. If knowledge and behavior coincide, then it is likely males will score lower on a rip-current knowledge survey than women.

Williamson et al. (2012) analyzed the age data of their respondents (14-19 years, 20-29 years, 30-49 years, and >50 years) at Australian beaches and found that the odds of making the safe choice in swimming location was three times lower for participants in the 20-39 years age group compared to the oldest participants (60+). A unique study by Drozdowski et al. (2012) only surveyed people in Australia who had survived encounters with rip currents. They determined that older respondents (65+) were more likely to be swimming at patrolled beaches and would signal for help if caught in a rip current; whereas, younger respondents are likely to have opposite behaviors and responses.

Studies have determined the link between age and rip-current incidents: younger beachgoers are more likely to be victims. Normalized data from the United Kingdom showed teenagers in general were the most at-risk demographic to be involved in rip current incidents (Woodward et al., 2013). Fifty-four percent of the fatalities attributed to rip currents in Istanbul were 18 to 35 years old (Barlas and Beji, 2016). Paxton (2014) calculated that largest age group of rip-related deaths in the United States for 2012 was 10-19 years old. However, none of these studies have considered why this relationship might exist. In this survey, it is presumed that older individuals have obtained more rip current knowledge, thus making them safer than young individuals with less knowledge of rip currents.

Miami Beach is the most popular beach in Florida, boasting of more than 21 million tourist visitors per year (Houston, 2008). Tourists come from all over the world to enjoy the subtropical weather and warm, clean, and clear ocean water. Non-residents might reasonably be expected to be at a disadvantage compared to the local residents when considering knowledge of beach hazards. Williamson et al. (2012) determined that international tourists showed poor knowledge of beach safety, had less overall beach exposure, and were three times less likely to make a safe swimming choice in comparison to Australia's regular beachgoers. Lifeguards have indicated that most tourists lack knowledge and experience about rip currents (Barlas and Beji, 2016). However, Houser et al. (2015) pointed out that even if warning signs or flags are posted, this has little to no effect on foreign tourists who might speak another language or are accustomed to different symbols and/or warning flags designating beach hazards.

Taking swimming ability into consideration in my survey, it might be expected that not only can stronger swimmers escape a rip current, but they also possess more knowledge pertaining to the mechanics of these currents. Stronger swimmers are likely to have been exposed to beach safety knowledge and/or had personal experiences with hazards. In Australia, stronger swimmers were significantly more likely to escape a rip (Drozdowski et al., 2015), and Brannstrom et al. (2014) found statistical significance in male beachgoers in Texas being able to swim 45 to 450 m while women reported an ability to swim shorter distances (<45 m); yet neither study linked swimming ability to rip-current knowledge. Williamson et al. (2012) determined that survey participants who rated their swimming ability as high were more likely to make a safe choice in swimming location. On the other hand, Drozdowski et al. (2012) found that survivors were often caught in a rip current because of overconfidence in their swimming ability and/or choosing to swim outside of patrolled areas or at unpatrolled beaches in Australia. Despite their knowledge, bathers still panicked when being pulled offshore by a rip current, thus strengthening the argument that risky behavior is a principal factor in becoming a victim (Drozdowski et al., 2012). While it is acknowledged that people may be strong swimmers and yet never swam at a beach, I believe I have accounted for this bias in two ways: survey responders were at the beach and attested to their frequent beach visits.

Distinct contributions of this study

Although the Miami Beach study was motivated and inspired by the work of prior researchers, this paper extends the current literature in three important ways. First, previous researchers had a distinct interest in some specific outcome such as rip-current

perception or survival skills, leaving a comprehensive assessment of rip current knowledge undone. My study encompassed a total of four essential aspects (i.e., definition, occurrence, risk, and fatality) of rip-current knowledge in order to achieve a more complete picture of beachgoer's understanding of the hazard. Secondly, my study examined the importance of race and ethnicity, marital status, and education as well as, swimming ability and frequency of beach visits, not all of which were considered in previous research. Marital status was also included in the survey as a measure of riskiness. Those who are married might be expected to exert more caution in everyday life, including trips to the beach. I utilized marital status as an approximation of respondent's enhanced caregiving. Another variable that has not been well researched is the importance of education level. Although it has been determined that age makes one less susceptible to rip risk, age does not always directly correlate with level of education. However, it may be reasonable to assume that those individuals who hold a higher degree will be more knowledgeable about waves and currents. Similar to swimming ability, those who tend to frequent the beach more often are likely to possess more knowledge of rip currents. These individuals have had more exposure to the hazard than those who visit the beach less frequently. In actuality, there seems to be a lack of research that connects the frequency of beach visits to the rip-current knowledge.

Few previous analyses have evaluated the relative importance of various explanatory factors in a systematic way. The present study addressed several determinates of rip-current knowledge simultaneously using multiple regression models. Beyond simple descriptions of bivariate relationships, this research approach achieved a

more accurate assessment of the net influences of different sociodemographic and behavioral characteristics.

DATA AND METHODS

Miami Rip-Current Literacy Survey

Miami Beach, Florida is a “hot spot” for rip current drownings (Paxton, 2014). In my 2015-2016 study, beachgoers at Miami Beach, who constitute the population exposed to the actual risk of rip currents, were surveyed. Adult respondents (i.e., aged 16 or older) were randomly selected to participate in the survey, which received International Review Board (IRB) approval at Florida International University (FIU). Sampling took place across the entire length of Miami Beach beginning at 85th Street in the north and ending at the jetty of the Port of Miami, this includes North Beach, South Beach, and South Point. It is important to note that a short period of data collection will fail to capture the seasonal variation in beach visitors. Therefore, public surveys were collected during 16 visits over 12 months between 2015 and 2016. With this design, the exposure to the risk of rip currents in the sample was resolved not only by human traits but also in time of year. Thirteen surveys were acquired on average each day, and data collection occurred between 8:00 AM and 5:00 PM. The day of the week, time, and location were noted for each survey to ensure the same population was not repetitively sampled.

The survey, which required approximately ten minutes to complete, was kept anonymous and brief, which helped avoid non-response and incompleteness as a result of interview fatigue. The response rate was 75%. Out of 270 attempts, 203 respondents agreed to participate and completed the interviews, giving us a statistically valid sample that included 50 at North Beach, 90 at South Beach, and 63 at South Point. Among those

who refused to participate, a major reason was the lack of English proficiency, which accounts for more than half of the non-responses.

My survey used four items to assess the respondent's knowledge of rip currents (see full survey in Appendix 3). Specifically, all our respondents were asked to evaluate each of the following statements using a five-point Likert scale (i.e., strongly agree, agree, neutral, disagree, and strongly disagree):

[Definition] A rip current is a fast moving offshore flow.

[Occurrence] Rip currents occur frequently (at least once a month) at Miami Beach.

[Risk] A rip current pulls people away from the shore.

[Fatality] Rip currents cause the most drownings each year at Miami Beach.

These raw survey items enabled gradational assessments of the four key dimensions of knowledge about rip currents. As shown later, I was also able to extract a factor out of these items, given their similar measurement structure as a composite measure of one's overall rip current literacy.

Sample description

In addition to assessing people's knowledge of rip currents, the survey also included the respondent's sociodemographic characteristics as well as behavioral features related to beach safety. To explore how such individual traits influenced beachgoer's knowledge of rip currents, the analysis was restricted to those who provided valid information to all variables in the multivariate models. This yielded an analytic sample consisting of 164 individuals.

A sociodemographic profile of visitors to Miami Beach throughout the year was acquired, and the analytic sample was gender-balanced with 52% male and 48% female

respondents (Table 4-1). Respondent ages ranged from 16 to 81, with an average age of 37. Across the age span, the modal group is 21-30, accounts for 38% of all beachgoers at Miami Beach who participated. In terms of race and ethnicity, a majority of the analytical sample was White (61%), followed by Hispanics (26%), Asian (4%), Black (3%), and Others (7%). It is worth noting that 72 respondents (44%) are foreign nationals, whom represent all of the racial/ethnic groups except Blacks. A total of 70% of the interviewees have a college education (43%) or higher (27%), yielding an average education length of 15.6 years. One-third (34%) of the interviewees are currently married; joint-classification by gender shows that women beachgoers are more likely to be married (41%) than men (27%).

4-1. Sample description (N= 164)

	Mean/%	SD
Male (%)	52%	
Age	37.1	15.2
Race and ethnicity (%)		
<i>Hispanic</i>	26%	
<i>Black</i>	3%	
<i>White</i>	61%	
<i>Asian</i>	4%	
<i>Other</i>	7%	
Years of education	15.6	2.12
Married (%)	34%	
Non-U.S. citizens (%)	44%	
Swimming ability	3.66	1.17
<i>Unable to swim (coded 1)</i>	2%	
<i>Can swim but not strongly (coded 2)</i>	18%	
<i>Strongly swim 25 meters (coded 3)</i>	23%	
<i>Strongly swim 100 meters (coded 4)</i>	26%	
<i>Strongly swim over 100 meters (coded 5)</i>	32%	
Frequency of beach visit	2.07	0.99
<i>First time (coded 1)</i>	35%	
<i>Yearly (coded 2)</i>	34%	
<i>Monthly (coded 3)</i>	20%	
<i>Weekly (coded 4)</i>	11%	

Source: Miami Rip Current Literacy Survey (2015-16).

Besides sociodemographic traits, two behavioral features were studied that were believed to influence one's knowledge of rip currents—swimming ability and frequency of visits to Miami Beach. In this analytic sample, 80% of respondents identified themselves as strong swimmers, reporting that they were able to swim 25 meters (23%), 100 meters (26%), and more than 100 meters (32%). In contrast, the majority of the sampled individuals are not frequent visitors to Miami Beach—a third (34%) of the respondents go to the beach once a year, and another third (35%) were visiting Miami for the first time when they participated in the survey.

Analytic methods

The outcome measurements address rip-current definition, occurrence, risk, and fatality as described above. While each item has its own substantive importance, they jointly provide an overall assessment of rip-current literacy. Therefore, I not only treated them as four distinct outcomes, but also constructed a composite scale to measure the respondent's comprehensive knowledge. A principle component analysis derived from the four items yielded a dominating factor with an eigenvalue of 1.29 and a scale reliability coefficient (i.e., Cronbach's Alpha) of 0.7. The item loadings on the factor indicate that it summarizes the correct answers to the four survey questions, which makes it appropriate to interpret the scale as an overall evaluation of rip current literacy. To make interpretation easier, I normalized the scale so that the factor scores had a mean of 0 and standard deviation of 1. The results are slightly different because of further sample restrictions wherein the cases without complete information on all the independent variables were eliminated; this normalized principal component factor is termed the "Rip Current Literacy Scale" (Table 4-2).

4-2. Rip current knowledge (N= 164)

	Mean/%	SD
Definition: A rip current is a fast moving offshore flow.	3.88	0.93
<i>Strongly disagree (coded 1)</i>	1	
<i>Disagree (coded 2)</i>	5	
<i>Neutral (coded 3)</i>	29	
<i>Agree (coded 4)</i>	35	
<i>Strongly agree (coded 5)</i>	30	
Occurrence: Rip currents occur frequently (~1/mo.) at Miami Beach.	3.46	0.86
<i>Strongly disagree (coded 1)</i>	3	
<i>Disagree (coded 2)</i>	1	
<i>Neutral (coded 3)</i>	56	
<i>Agree (coded 4)</i>	26	
<i>Strongly agree (coded 5)</i>	14	
Risk: A rip current pulls people away from shore.	4.26	0.86
<i>Strongly disagree (coded 1)</i>	1	
<i>Disagree (coded 2)</i>	4	
<i>Neutral (coded 3)</i>	13	
<i>Agree (coded 4)</i>	35	
<i>Strongly agree (coded 5)</i>	48	
Fatality: Rip currents cause the most drownings each year at Miami Beach.	3.73	0.97
<i>Strongly disagree (coded 1)</i>	2	
<i>Disagree (coded 2)</i>	5	
<i>Neutral (coded 3)</i>	38	
<i>Agree (coded 4)</i>	28	
<i>Strongly agree (coded 5)</i>	27	
Rip Current Literacy Scale	-0.03	1.00

Note: The Rip Current Knowledge Scale is the standardized factor score based on four component items.

Source: Miami Rip Current Literacy Survey (2015-16).

Four raw items as well as the composite scale was used to assess Miami beachgoer rip knowledge (Table 4-2). The sociodemographic heterogeneity and behavioral influences on such knowledge were further examined. Independent variables include gender, age, race and ethnicity, years of education, marital status, citizenship status, swimming ability, and frequency of beach visits (Table 4-3). For each independent variable, conditional means/proportions of the outcome variables are calculated. Such descriptive bivariate patterns, of course, are not free from confounding effects. Therefore, multiple regressions were estimated to assess the net influences of sociodemographic and behavioral characteristics on the respondents' knowledge of rip currents (Table 4-4).

4-3. Rip current knowledge by groups (N=164)

	Definition	% correct answers			R.C. Literacy
		Occurrence	Risk	Fatality	Scale
Sex					
Female	69	40	85	54	0.03
Male	60	40	81	56	-0.09
Age group					
16-20	64	50	79	50	-0.14
21-30	48	29	71	40	-0.49
31-40	82	39	89	54	0.01
41-50	71	52	90	71	0.19
51-60	80	40	92	68	0.47
61+	69	62	100	85	0.89
Race and ethnicity					
White	67	41	88	58	0.05
Hispanic	64	38	81	52	-0.09
Asian	50	33	50	67	-0.29
Black	60	20	60	20	-0.75
Other	55	45	73	45	-0.11
Level of education					
< HS	63	50	75	38	-0.23
HS graduate	64	27	45	55	-0.37
Some college	60	43	83	53	0.02
College graduate	70	41	89	54	0.03
Graduate	59	36	84	61	-0.06
Marital status					
Other	61	39	79	49	-0.16
Married	73	40	91	67	0.21
Citizenship					
U.S. citizen	71	53	92	60	0.21
Non-U.S. citizen	57	22	71	49	-0.35
Swimming ability					
Unable to swim	25	0	75	50	-0.61
Can swim but not strongly	55	41	76	66	0.06
Strongly swim 25 meters	65	41	73	49	-0.22
Strongly swim 100 meters	60	36	83	57	-0.03
Strongly swim over 100 meters	77	44	94	52	0.09
Frequency of beach visit					
First time	65	32	82	37	-0.36
Yearly	63	34	84	63	0.08
Monthly	67	55	79	58	0.11
Weekly	67	56	89	83	0.40

Source: Miami Rip Current Literacy Survey (2015-16).

4-4. OLS models predicting rip current knowledge (N=164)

	Definition	Occurrence	Risk	Fatality	Rip Current Literacy Scale
Gender (1=male)	-0.244 †	-0.215	-0.130	-0.013	-0.220
Age	0.014 *	0.011 *	0.016 **	0.022 ***	0.024 ***
Race and ethnicity (1=Hispanic or Black)	0.076	-0.104	-0.071	-0.050	-0.070
Marital status (1=currently married)	0.133	-0.161	0.110	-0.008	0.018
Years of education	-0.025	-0.005	0.030	0.016	0.009
Citizenship (1=Non-U.S. citizen)	-0.192	-0.403 **	-0.388 **	-0.258 †	-0.491 **
Swimming ability	0.184 **	0.026	0.148 **	-0.051	0.106 †
Frequency of beach visit	0.065	0.116 †	0.110 †	0.264 ***	0.225 **
Intercept	3.099 ***	3.172 ***	2.671 ***	2.462 ***	-1.590
R ²	0.127	0.126	0.176	0.231	0.287

Note: *** p<0.000; ** p<0.01; * p<0.05; † p<0.1 .

Source: Miami Rip Current Literacy Survey (2015-16).

RESULTS

Overall levels of rip current knowledge

The average scores for the four raw items are 3.88 for definition, 3.46 for occurrence, 4.26 for risk, and 3.73 for fatality (Table 4-2). They are all higher than the middle point of the 5-point Likert scale, which seems to suggest that the respondents' knowledge is generally on the positive side. However, the "neutral" option in our survey indicates the inability to endorse the correct statements. Qualitatively speaking, it falls in the same category with "disagree" and "strongly disagree;" therefore, only "strongly agree" and "agree" qualified as acceptable answers. Adding up those who chose "strongly agree" and "agree," it is clear that a majority of the respondents were able to endorse the definition of a rip current (65% correct) and knew what its effect on swimmers was (83% correct for risk). These findings do not yield an optimistic picture of beach safety awareness because more than one-third (35%) of the beachgoers have failed to acknowledge the definition of a rip current. The only correction rate that can be considered somewhat high is the 83% for the item risk. In addition, nearly half (45%) of the people sampled failed to recognize the fact that rip currents are the leading cause of drowning at Miami Beach and 60% do not know that they occur frequently in this area.

Social heterogeneity of rip current knowledge

The aforementioned overall averages are not uniformly distributed across subgroups. The distribution of sociodemographic and behavioral variables (Table 4-3) enables a comparison of rip-current knowledge across different subgroups. For each survey item, 31 group-specific correction rates were calculated, leading to a total of 124 correction rates in the entire table. Among these group-specific outcomes, only 58 rates

are greater than 60%, which means that nearly half of the subgroups hold insufficient knowledge about rip currents.

Women outperformed men in definition (by 9%) and risk (4%). The only exception is fatality where 56% male respondents selected the correct answers, yielding a 2% advantage over female respondents. Taken together, these give rise to a positive mean (0.03) for women and a negative mean (-0.09) for men on the composite Rip Current Literacy Scale. As the scale is normalized with a center at 0, this indicates that women's knowledge of rip currents is above the average level, while men are below average.

Overall, older beachgoers tend to score higher in rip-current literacy than young respondents. Although some exceptions were found, they mostly pertained to the modal age group, 21-30, whose correction rates were consistently the lowest. These patterns are parsimoniously summarized by the composite scale, which increases linearly over age except for the lowest point (-0.49) being at ages 21-30 (Table 4-3).

No strong patterns could be detected in terms of race and ethnicity. Whites achieved the highest correction rates for definition (67%) and risk (88%); whereas, Asians rated the lowest on these two items (50% on both). Nevertheless, they rank number one in fatality with a correction rate of 67%. Black respondents scaled the lowest on occurrence and fatality (20% on both). However, the patterns for Black and Asian respondents are subject to large chance error since they comprise only 7% of the total sample. Therefore, a more reliable contrast can be observed between the two largest groups—Whites and Hispanics. Judging by their Rip Current Literacy Scale scores, Whites are 0.05 standard deviations above the overall sample mean, while Hispanic respondents are 0.09 standard deviations below the mean.

In terms of education, college graduates performed the best on definition (70%) and risk (89%) and the least educated group (less than high school) scored the highest in occurrence (50%). While those who received a graduate education lead the highest correction rate on fatality (61%), they also gave the worst performance for definition (59%). Not surprisingly, there is a non-linear pattern across all educational levels for the conditional means of the composite scale.

The binary variable of marital status yielded a correction premium for the married beachgoers across all four raw survey items. The premium ranged from 1% for occurrence to 18% for fatality. Accordingly, the composite scale shows a substantial difference favoring the respondents who were married at the time of survey.

Compared to foreign nationals, a larger proportion of U.S. citizens were able to select the correct statements. The citizenship premiums, with a range from 11% (fatality) to 31% (occurrence), are by far the most pronounced (and reliable) group differences. As a result, U.S. citizens on average outperformed beachgoers from foreign countries by a large margin of 0.56 (0.21 vs. -0.35) standard deviations on the Rip Current Literacy Scale.

Regarding swimming ability, a linear relationship generally emerges in favor of those who can “strongly swim” for a distance. Relative to those who “can swim but not strongly” or are “unable to swim,” the strong swimmers as a whole perform better in all items but fatality. The conditional means of the composite scale show a steady increase in rip current knowledge (from -0.61 to 0.09) over swimming ability, except for a disturbance for those who “can swim but not strongly.” It is clear that the source of disturbance is that group’s knowledge regarding fatality.

As anticipated, frequency of beach visits showed a positive association with rip current knowledge. However, the pattern does not exactly persist for risk and fatality, which results in a slightly higher scale score for those who go to the beach once a year (0.08) than those who visit on a monthly basis (0.11). Across the entire span, frequent visitors clearly know more about rip currents (0.4) than occasional beachgoers, particularly those visiting Miami Beach for the first time (-0.36).

Net influences on rip current knowledge

Statistical tests were completed to determine if the findings could be generalized to the beachgoer population at Miami Beach. Also, as the independent variables were correlated with each other, it was necessary to estimate their net influences with statistical controls. As shown in Table 4-4, for each item an ordinary least squares (OLS) regression model was estimated with the independent variables. The same model was also assessed as a composite scale for an overall tighter interpretation. Coding schemes for the linear variables (i.e., age, years of education, swimming ability, frequency of beach visit, and the four outcome measures) can be found in Tables 4-1 and 4-2, and the dummy coding for gender, marital status, and citizenship are reported in Table 4-4. Due to the small sample sizes of respondents who marked their race and ethnicity as Asian, Black, and Other, I did not have sufficient statistical power to enable detailed comparisons. The race and ethnicity variable was dichotomized on a socioeconomic basis so that Hispanics and Blacks are combined and coded 1, while Asians and ethnicities of Other are lumped with White as the reference group (i.e., coded 0).

Across the four raw items, the coefficients for the male dummy are consistently negative. However, the effect is only significant for definition at the 0.1 level. Taken

together with the other three items, this contributes to a marginally significant (at 0.1 level) female premium in the overall Rip Current Literacy Scale—other things being equal, male beachgoer's average score is 0.22 standard deviations below women. The age effect is consistently positive for all four raw outcomes. The influences are all statistically significant, which gives rise to a highly significant (at 0.001 level) positive coefficient of 0.024 in the model predicting the composite scale. Citizenship status, on the other hand, has strong and consistent influences. Foreign nationals scored lower than U.S. citizens on all four items, three of which are statistically significant. For the composite scale, I observed two positive and significant coefficients for both behavioral variables of swimming ability and visitation frequency.

Race and ethnicity, marital status, and years of education did not make any difference in a beachgoer's rip-current knowledge at the population level (Table 4-4). The relative disadvantage of Hispanics and Blacks were reflected by the mostly negative coefficients. Contrary to the previous findings in Table 4-3, marriage had a negative impact on occurrence and fatality; more education helped with risk and fatality but lowered scores for definition and occurrence. None of these coefficients, however, were statistically significant. As a result, positive or negative influences do not go beyond the individuals in my analytic sample.

The final model for the Rip Current Literacy Scale provides a cleaner summary of the various influences on beachgoer's knowledge about rip currents. In terms of sociodemographic features, a gender gap favoring women (-0.22), an age premium (0.024), and a penalty for non-U.S. citizens (-0.491) was observed. In terms of beach-related behavior, stronger swimmers (0.106) and those who go to the beach more often

(0.225) possess better knowledge about rips. These are net effects, which are not only independent of each other but also of the marginal distributions of race and ethnicity, marital status, and education.

DISCUSSION

It is clear from this survey that beachgoers understand that rip currents pose a danger to swimmers because risk was the only category in which the majority of beachgoers consistently answered correctly. However, the poor response rates for the remaining three literacy items further indicates that visitors to Miami Beach are not sufficiently aware of their actual exposure to the risk of rip currents and the fatal consequences.

The descriptive results in Table 4-3 provide an idea of the bivariate relationships based on the analytic sample. Although differences were found in both the variables for gender and race, neither group had distinctions that were particularly pronounced. However, it was observed, to different degrees, that there is a female premium and a White premium over Hispanics. A roughly linear positive impact is evident regarding age, swimming ability, and frequency of beach visitation. Education was anticipated to exert a positive influence on people's knowledge of rip currents, but the descriptive results did not support this expectation. There are signs that more educated respondents know more about rip currents and at the same time, there are equally strong signs pointing to the opposite. A marriage premium and citizenship premium were also found. Albeit finding that non-strong swimmers are more cautious, it is only observed in respect to their responses for fatality but not for any of the other items that compose literacy.

With regard to the regression analysis, although female beachgoers are better informed of the definition of a rip current, there are no statistically significant gender differences in knowledge regarding how often rips occur, their effect on swimmers, and how much casualty rips cause. A 65-year-old beachgoer's rip current knowledge was expected to be 1 standard deviation above that of a 20-year-old (0.024 multiplied by a factor of 45), controlling for all other factors. As is common with all cross-sectional studies, this effect may reflect both cohort differences and personal aging. Another source of old age premium was survival bias—those who knew better had a greater chance to have survived rip currents and therefore are more likely to be petitioned in this survey at an older age. However, rip current drownings are relatively rare—it is highly unlikely that the results are significantly contaminated by such survival bias. It is important to remember that the sources of overall effects come from different substantive knowledge—for example, the female premium mainly comes from women's better understanding of definition, while the age effect is supported more widely in terms of definition, occurrence, risk, and fatality. Foreign visitors consistently scored lower than U.S. citizens; this is possibly due to a disadvantage for international tourists who come from afar for an escape of their familiar living environment and are therefore much less aware of beach safety issues. Consistent with the previous literature, swimming ability has positive influences on rip current knowledge, which are nonetheless limited to definition and risk. In addition, higher frequency of beach visitation also leads to better knowledge in terms of occurrence, risk and fatality. Although we determined that swimming ability correlates to beach-going frequency, being a strong swimmer still has an independently positive relationship with rip current literacy.

CONCLUSIONS

Unlike previous studies, this survey in Miami Beach showed an insufficient knowledge of beachgoers. For instance, among the 124 social groups presented in Table 4-3, 66 groups have a correction rate of only 60% or less; all of these respondents could be at risk of drowning if they were caught in a rip current during their beach trip. Four subgroups were determined as being the most at risk: young adults aged 21-30, poor swimmers, foreign tourists, and those who infrequently visit the beach. These findings concur with the concluding suggestion put forth by Caldwell et al. (2013) that better rip-current education would be able to improve beach safety and campaigns are needed to target at-risk groups.

Beach visitation frequency was found to be one of the strongest influencers on a beachgoer's knowledge of rip currents. The more times a person has been to the beach, the more exposure to hazards they have had, leading to better knowledge. The maturity that comes with age also has an influence; a positive correlation exists with age and rip current knowledge. Beachgoers who frequently enter the water and consider themselves to be strong swimmers were observed to have more of an understanding of rip-current mechanics. These visitors might have experienced the effect of a rip current in the past or obtained knowledge from being aware once they enter the water.

The survey also determined institutional-based education level does not play an independent role in a person's knowledge of rips; therefore, special measures outside of formal educations need to be taken. Gender, race, and marital status also do not have an impact on the respondent's knowledge. Other things being equal, falling within any of

these categories does not make a beachgoer more or less susceptible to the rip-current hazard. Beach experience helps visitors understand rip currents.

This is the first public survey conducted in South Florida and provides a unique insight to the lack of information about this potentially lethal hazard at Miami Beach, which draws millions of visitors each year. Using social surveys to obtain information from the public is not a new practice among coastal scientists; however, this study stands apart because a concrete, meaningful population was sampled during a year-round observational window. This analysis utilized sophisticated statistical techniques, including multivariate analysis, which enabled systematic tests to determine the net effects. The City of Miami Beach should utilize these outcomes to devise new rip current education methods for previously unbeknownst at-risk demographic groups.

V. BEACHGOERS' RECOGNITION OF RIP CURRENT HAZARD AT MIAMI BEACH, FLORIDA

ABSTRACT

Rip currents are the number one hazard to bathers at surf beaches. They form as water trapped on the beach moves in a concentrated flow offshore. Miami Beach, Florida, a popular tourist destination, is also one of the most deadly beaches in the U.S. due to rip fatalities. Surveys were used to quantify the public's recognition of rip currents, including their sociodemographic composition and behavioral characteristics. Responses were analyzed using regression models, which tended to indicate that education level, rip current literacy, and confidence in spotting a rip influenced the beachgoer's ability to recognize a hazard. However, the multivariate model showed a person's level of education is the only significant variable. A beachgoer's verbal understanding of rip currents does not relate to their visual recognition and *vice versa*. This study has gathered valuable information that can be used by Miami Beach to create rip-current awareness programs that target the most at-risk populations.

INTRODUCTION

Rip currents

Coastal scientists, following the publication of the first scientific article on rip currents by Shepard et al. in 1941, have continued to research this nearshore oceanographic phenomenon, most notably because of the hazard to the beach-going public. Rip currents are narrow flows in the surf zone that head in an offshore direction (Aagaard et al., 1997) and can be found on any shoreline that has substantial wave action. Rip currents will vary in strength according to wave height, wind velocity, tidal level, and

bathymetric controls among other factors. Some currents can become intense enough that the most advanced swimmer could not fight it; however, weaker rips also pose a threat to the average beachgoer. Beach safety is one public health concern where beaches are an important part of people's lives and a central attraction to visitors (Hatfield et al., 2012).

Rip danger and statistics

Rip currents are a recognized hazard at all beaches. Unsuspecting beachgoers lacking the necessary knowledge could easily venture into a rip current and find themselves being pulled offshore as a victim. There are major reasons that beachgoers perish in these hazards: they are not strong swimmers and suddenly find themselves in water over their head, they try to fight against the current, or a non-professional tries to assist a victim, resulting in one or both fatalities. Regardless of a person's ability to escape a rip current, panic is the dominant emotional state of most rescuees (Attard et al., 2015).

Between 2005 and 2009, the United States Lifesaving Association (USLA) recorded an average of 96 beach drownings per year. In the same number of years from 2001-2005, an average of 32 people died at surf beaches in Australia (Morgan et al., 2008). Lifeguards in both countries attribute about 80% of all rescues each year to rip currents. Although rip statistics may be most widely available in the United States and Australia, the hazard exists globally. For instance: rip currents cause 39 deaths annually in India (Arun Kumar and Prasad, 2014), 45% of lifeguard rescues each year in England are attributed to rips (Gallop et al., 2016), and preliminary research in Ghana indicated that as many as 15 people each week could be caught in life-threatening situations while swimming (Hammerton et al., 2013).

Study site

Lushine (2011) attributed 19 deaths each year in Florida to rip currents. In the United States, the four most deadly beaches are in this state, with Miami ranking third (Paxton and Collins, 2014). Miami Beach is a highly sought after destination for local, national, and international tourists alike. The coastal city of Miami boasts a population of 2.7 million residents (U.S. Census, 2014); and in 2013, 70% of an estimated 14.2 million overnight visitors frequented the beach during their stay.

Miami Beach is nearly 13 km long beginning at the Government Cut Jetty which maintains the inlet to the crucial Port of Miami (Figure 5-1). The beach's width varies from a few meters at erosion hot spots to hundreds of meters due to accretion on the jetty. Miami is a low energy coast with the Bahamas island chain blocking most Atlantic Ocean waves. Only occasionally do swells from nor'easters or hurricanes reach the shore.

5-1. Google Earth image of Florida, indicating the location of Miami Beach.

The large numbers of beachgoers seeking year-round favorable beach weather and relatively low wave energy make Miami Beach a “hot-spot” for rip-current incidents.

Nevertheless, this is the first rip current study to have been undertaken at Miami Beach.

Miami Rip Current Public Survey

Coastal researchers (e.g., Brannstrom et al., 2014; Caldwell et al., 2013; Gallop et al., 2016; Hammerton et al., 2013; Sherker et al., 2010; Williamson et al., 2012) used social surveys to determine beach-safety and rip-current knowledge of beachgoers. I have drawn upon their findings to create a site-specific public beach survey for Miami Beach, Florida. A distinct feature of my survey is the inclusion of multiple explanations of rip current knowledge identified in the previous literature so that a more comprehensive evaluation is possible.

A key survey tool researchers have utilized in previous studies was to present the respondent with a visual aid. Photographs allow researchers to determine beachgoer’s visual understanding of and vulnerability to the rip current hazard. There are five main types of rip currents as described by Leatherman (2012): bar-gap, structurally-controlled, flash, cusped, and mega rips. Of these five, only bar-gap, structurally-controlled, and flash occur locally at Miami Beach. Bar-gap rip currents, the most common, form as ocean water makes its way back from the swash zone and is funneled through a depression in the sand bar. Structurally-controlled rips only occur along groins or jetties that redirect the longshore current offshore. Flash rip currents are short lived and episodically appear during strong wind conditions that create confused sea states.

Beachgoers were shown two images displaying distinct types of rip currents (bar-gap and

flash) that also appear different visually – of which either could potentially occur at our study site.

LITERATURE REVIEW

Rip currents and beach safety knowledge

In recent years at other areas, surveyors have assessed their respondents' ability to identify the rip current(s) in photographs. One such study at Pensacola Beach, FL, found that only 15% of respondents could identify the rips in a series of three photographs of the same location (Caldwell et al., 2013). This survey method has also been utilized in multiple Australian studies where respondents were shown an image and asked to indicate where the rip currents were located. Williamson et al. (2012) determined that 43% of the locals were able to identify the rip channels whereas only 15% of international tourists could do the same. They also reported that men were significantly less likely to make a correct choice compared to women. Similarly, a separate study found that 48% of respondents were able to answer correctly (Sherker et al., 2010).

In addition to direct visual identification of rip currents, other researchers have chosen to focus on the respondent's ability to remain safe while at the beach. A survey at Texas beaches used five images of the same location in various sea states, asking respondents to identify the image that showed conditions that were "most dangerous for me to swim" (Brannstrom et al., 2014). A total of 57% respondents were able to correctly choose the most dangerous photograph. Correct selection was not significantly related to the respondent's gender, ethnicity, or level of education (Brannstrom et al., 2014). During an annual event in England, attendees were given the opportunity to take a rip-current quiz. They were asked to identify the safer place to swim in a photograph;

61% chose correctly (Gallop et al., 2016). In Ghana, beachgoers were asked to identify the safest place to swim on an image; 63% of respondents chose correctly – fisherman were the most likely to make safer swimming choices, whereas students and women were more likely to choose the location of a rip current (Hammerton et al., 2013).

Explanatory factors

Researchers (e.g., Caldwell et al., 2013; Sherker et al., 2010; Williamson et al., 2012) have established that beachgoers are over-confident when questioned about their ability to identify a rip current. Williamson et al. (2012) observed that 60% of respondents reported their ability to identify a rip current as moderate to high, even though 31% of them made an incorrect choice in rip location. Sherker et al. (2010) asked respondents if they “could tell what a rip current was”, 93% indicated they could. However, one-third of those incorrectly identified the current on the photograph. Only seven out of 97 participants at Pensacola Beach who claimed they could identify a rip current with high confidence actually identified the rip-current channels (Caldwell et al., 2013).

Researchers have also attempted to determine what other variables influence a beachgoer’s ability to recognize a rip current. Australian survey participants who rated their swimming ability as high were more likely to make a correct choice (Williamson et al., 2012). Sherker et al. (2010) found that a person who was moderate to highly confident in their ability to identify a rip was significantly more likely to avoid swimming in a rip current. They also determined that people with knowledge of rip currents or at the beach with children are significantly more likely to avoid swimming in a rip current.

EMPIRICAL STRATEGY

Sample design

Rip-current surveyors have collected data at a specific location or only during short intervals of time. In this study, responses were collected over 12 months between 2015-2016, allowing for a more accurate population sample. Miami Beach, FL is a very popular location for a variety of people visiting during particular times of the year. By surveying throughout 12 months, a true representation of the assortment of beachgoers was obtained, thereby removing bias towards people who may only be there at a particular moment.

This study was focused on visitors at Miami Beach, who constitute the population exposed to actual rip-current risk. In the past, researchers (e.g., Gallop et al., 2016; Sherker et al., 2010; Williamson et al., 2012) conducted all or some of their surveys away from the beach (i.e., at inland areas or during special events). While they obtained relevant information, a survey at the beach itself is likely to assess only respondents who are actually exposed to the potential rip-current hazard.

Miami Beach can be partitioned into three sections: North Beach, South Beach, and South Pointe--each appealing to a unique group. For instance, those looking for a quiet, relaxing beach trip tend to visit North Beach, while South Beach attracts the party crowd, and South Pointe is popular to year-round locals. To ensure even sampling, the location, time, and date were recorded for each survey. Potential adult (i.e., age of 16 or older) respondents were randomly selected and asked if they would answer questions regarding beach safety. Rip currents were not mentioned intentionally. Beachgoers were able to remain anonymous and finished the survey in approximately ten minutes. In total

203 responses were collected in their entirety from 270 attempts (50 at North Beach, 90 at South Beach, and 63 at South Pointe). The most common reason a beachgoer refused was due to their lack in English proficiency.

5-2. Google Earth image of Miami Beach's partitions: North Beach (85th Street to 29th Street), South Beach (29th Street to 6th Street), and South Pointe (6th Street to the Jetty).

Survey instrument

The use of a visual aid allowed me to differentiate between what a respondent claims to know and what they know in actuality. The images used display the two common rips present at Miami Beach: bar-gap and flash. The respondents were asked to choose from three locations on each image where they would enter the water. The first image (Figure 5-2) exhibited a bar-gap rip current with breaking waves on either side of calm water. Responses were marked correct only if the beachgoer chose location C because a feeder current at choice A leads into the rip current at B. The second visual (Figure 5-3) comprised of a flash rip, which was marked by suspended sediment in the

current. Beachgoers inured a correct answer for choosing either B or C. Therefore respondents had a one out of three chance of choosing correctly on the first and two out of three chance on the second photograph.

5-3. First image shown to beachgoers; rip current at B.

5-4. Second image of survey; rip current at A.

A rip-current's appearance greatly varies depending on factors such as bathymetric controls, water clarity, and meteorological conditions, among others. Consequently, employing one image to determine a beachgoer's understanding of rip currents is not sufficient. Using this study as an example, if respondents were only shown one picture they might be able to correctly answer; however, the same beachgoer would still be at risk if the other rip-current type was present on the same day of their visit to Miami Beach.

The use of two images lowers the probability of a respondent's correct answer being a guess. This repeated measurement made it possible to allocate the respondent an averaged score, leading to three possible outcomes: incorrect (coded 0), partially correct (coded 1), and correct (coded 2). Beachgoers who were deemed correct in both cases likely have an accurate understanding of rip currents, whereas those who were partially or fully incorrect remain at risk when visiting the beach during a rip-current event. This mean-based arrangement also allowed all responses to be considered, even those where the beachgoer only indicated an answer for one image. The use of multiple images, yielded an enhanced linear score outcome that enabled multiple regression models. This outcome captured the uncertainty or partial knowledge that exists in the study.

Previous researchers have utilized two different approaches when asking beachgoers to look at visuals in their survey. These questions lead to very different research outcomes. Some (e.g., Caldwell et al., 2013; Sherker et al., 2010; Williamson et al., 2012) wanted to determine the number of beachgoers who can identify a rip current, while others (e.g., Brannstrom et al., 2014; Gallop et al., 2016; Hammerton et al., 2013) were more concerned in beachgoer's safety. We asked respondents where they would

enter the water when shown both pictures. A question regarding safety rather than merely identification is more relevant in this study. Researcher's interest in beachgoer's rip-current knowledge was not disclosed before the initial image questions. Respondents were simply asked to take part in a study regarding beach safety. This allowed for unbiased responses. At no point were participant's answers to be influenced by the mention of rip currents.

In addition to this careful design, multiple variables were acquired including: gender, age, race and ethnicity, years of education, marital status, citizenship status, swimming ability, frequency of beach visits, rip current literacy, and confidence (Table

5-1). All independent variables are based on single survey questions except for rip-current literacy for which we constructed a composite scale from five separate items, which measured the respondent's knowledge regarding different aspects of rip currents.

Analytic procedures

The image test score is used to measure individual respondent's beach safety knowledge. While it is based on two binary variables and thus contains

no more than three possible points (0 for incorrect, 1 for partially correct, and 2 for

5-1. Sample description (N = 160)

	Sample distribution / Mean (SD)
Male	53.1%
Age	37.3 (15.3)
Race and ethnicity	
<i>White</i>	62.5%
<i>Asian</i>	3.8%
<i>Hispanic</i>	23.8%
<i>Black</i>	3.1%
<i>Other</i>	6.9%
Years of education	15.6 (2.1)
<i>< High school</i>	5.0%
<i>High school graduate</i>	6.9%
<i>Some college</i>	18.1%
<i>College graduate</i>	43.1%
<i>Post-graduate</i>	26.9%
Currently married	33.8%
Non-U.S. citizenship	42.5%
Swimming ability	
<i>Unable to swim</i>	2.5%
<i>Can swim but not strongly</i>	17.5%
<i>Strongly swim 25 meters</i>	22.5%
<i>Strongly swim 100 meters</i>	25.0%
<i>Strongly swim over 100 meters</i>	32.5%
Frequency of beach visit	
<i>First time</i>	35.6%
<i>Yearly</i>	34.4%
<i>Monthly</i>	19.4%
<i>Weekly</i>	10.6%
Rip Current Literacy Scale (normalized)	0.02 (0.94)
"I can spot a rip current from the beach."	
<i>Strongly disagree</i>	13.1%
<i>Disagree</i>	23.8%
<i>Neutral</i>	32.5%
<i>Agree</i>	18.8%
<i>Strongly agree</i>	11.9%

Source: Miami Beach Survey on Rip Current Literacy (2015-16).

correct), the additive score exists on a continuous scale. To explore its relationships with all explanatory factors, I first show its joint distributions with the independent variables (Table 5-2). In addition to conditional means, I also calculated the three-point percentage breakdowns by each of the independent variables – non-categorical independent variables

(i.e., age and the Rip-

Current Literacy Scale)

were collapsed into

discrete strata. The

conditional means

provide a more concise

description of the

bivariate relationships;

the two-way cross-

tabulations enable further

examination of the

qualitative patterns.

I then went

beyond simple

description to formally

test the influences of the

predictors. First, I

estimated a series of

5-2. Image test outcome by predictors (N = 160)

	Linear score	% Distribution		
		Both wrong	Patial correct	Both correct
Sample average	1.01	26	47	27
Female	0.99	27	48	25
Male	1.02	26	46	28
Age group				
16-20	0.79	43	36	21
21-30	0.97	25	53	22
31-40	1.07	25	43	32
41-50	1.33	19	29	52
51-60	0.92	32	44	24
61+	0.92	15	77	8
Race and ethnicity				
White	1.04	22	52	26
Asian	1.17	17	50	33
Hispanic	0.87	39	34	26
Black	0.80	40	40	20
Other	1.18	18	45	36
Years of education				
< High school	0.50	63	25	13
High school graduate	0.64	45	45	9
Some college	0.93	21	66	14
College graduate	1.03	25	48	28
Post-graduate	1.21	21	37	42
Currently married				
No	0.94	30	45	25
Yes	1.13	19	50	31
Non-U.S. citizenship				
No	1.00	27	46	27
Yes	1.01	25	49	26
Swimming ability				
Unable to swim	0.75	50	25	25
Can swim but not strongly	1.04	18	61	21
Strongly swim 25 meters	0.86	36	42	22
Strongly swim 100 meters	1.18	20	43	38
Strongly swim over 100 meters	0.98	27	48	25
Frequency of beach visit				
First time	0.96	28	47	25
Yearly	1.09	24	44	33
Monthly	0.94	29	48	23
Weekly	1.00	24	53	24
Rip Current Literacy Scale (normalized)				
(-2, -1]	0.96	29	46	25
(-1, 0]	0.97	28	47	25
(0, 1]	1.02	25	48	27
(1, 2]	1.11	21	46	32
"I can spot a rip current from the beach."				
Strongly disagree	0.86	19	76	5
Disagree	0.95	32	42	26
Neutral	1.04	23	50	27
Agree	1.10	27	37	37
Strongly agree	1.05	32	32	37

Source: Miami Beach Survey on Rip Current Literacy (2015-16).

bivariate regression models between the outcome and each independent variable. The outcome was treated as linear to enable ordinary least squares (OLS) estimation. For each model, the regression coefficients and the R^2 are reported so a comparison can be made between multiple predictors in terms of total effect and explanatory power. My ultimate goal is to evaluate the net influences of various explanations in the literature, for which I further estimated a multiple regression model. All model results are summarized in Table 5-3.

5-3. Linear regression models predicting the image test linear score ($N = 160$)

	Separate models			Full model	
	Coef.	s.e.	R^2	Coef.	s.e.
Male (ref. = female)	0.037	0.116	0.0006	0.077	0.130
Age	0.003	0.004	0.0039	-0.003	0.005
Race and ethnicity (ref. = White)			0.0181		
Asian	0.127	0.308		0.228	0.329
Hispanic	-0.172	0.140		-0.160	0.164
Black	-0.240	0.336		-0.202	0.377
Other	0.142	0.233		0.156	0.249
Level of education (ref. = < high school)			0.0650		
HS graduate	0.136	0.333		0.103	0.375
Some college	0.431	0.286		0.478	0.318
College graduate	0.529 **	0.267		0.552 *	0.301
Graduate	0.709 **	0.276		0.676 **	0.320
Currently married (ref. = unmarried)	0.186	0.122	0.0146	0.139	0.154
Non-U.S. citizenship (ref. = U.S. citizenship)	0.015	0.117	0.0001	-0.022	0.134
Swimming ability (ref. = unable to swim)			0.0261		
Can swim but not strongly	0.286	0.391		0.314	0.418
Strongly swim 25 meters	0.111	0.385		0.188	0.428
Strongly swim 100 meters	0.425	0.383		0.449	0.425
Strongly swim over 100 meters	0.231	0.379		0.264	0.419
Frequency of beach visit (ref. = first time)			0.0076		
Yearly	0.126	0.139		0.145	0.160
Monthly	-0.029	0.164		0.142	0.193
Weekly	0.035	0.203		0.139	0.239
Rip Current Literacy Scale (normalized)	0.046	0.062	0.0035	0.053	0.086
"I can spot a rip current from the beach."					
(ref. = strongly disagree)			0.0113		
Disagree	0.090	0.200		0.119	0.219
Neutral	0.181	0.190		0.279	0.218
Agree	0.243	0.209		0.244	0.237
Strongly agree	0.195	0.233		0.106	0.249

Notes: The full model has an R^2 of 0.1313. * $p < 0.1$; ** $p < 0.05$.

Source: Miami Beach Survey on Rip Current Literacy (2015-16).

DESCRIPTIVE STATISTICS

In addition to assessing the respondent's behavior towards beach safety, we collected information regarding their sociodemographic characteristics, beach behavior, and rip-current literacy. Although 203 questionnaires were collected, the sample was limited to include only those respondents who provided valid information for all variables applied in the model. This restricted the analytical sample size to 160 (Table 5-1).

Sociodemographic composition

Survey sampling took place over 12 months, from which a profile of visitors to Miami Beach was formulated. The sample is gender-balanced with 53% male and 47% female respondents (Table 5-1). The mean age was 37 but ranged from 16 to 81 years old. Beachgoers identified most often as White (63%), followed by Hispanic (24%), then other (7%); the remaining either described themselves as Asian or Black. Education level, a factor that was noticeably missing from most other surveys, was collected by highest degree obtained (i.e., high school, college, or post graduate) and later quantified into numerical years ranging from 10 to 18; the mean being 16 years of education and many respondents were college graduates (43%). Only 34% of respondents were married at the time. Lastly, the sample was nearly evenly spread amongst U.S. citizens (57%) and international tourists (43%).

Behavioral characteristics

Although beachgoers have little to no control over their sociodemographic factors, they do have charge of their behavior. I have included two behavioral features that are believed to influence one's knowledge of rip currents--swimming ability and frequency of visits to Miami Beach. Respondents were asked to choose their swimming

ability from unable to, not strong, and strongly swim 25 meters, 100 meters, or more. Most Miami Beach visitors claimed they could swim more than 100 meters (33%) while only 3% stated they could not swim. Another factor of importance is the frequency of beach visits; 36% of respondents were at Miami Beach for the first time and 34% come every year, whereas only 11% attend every week.

Each respondent was asked to evaluate the statement “I can spot a rip current from the beach” using a five-point Likert scale (i.e., strongly agree, agree, neutral, disagree, strongly disagree). This statement used in concordance with the images determines the beachgoer’s confidence level in their ability to identify a rip current. Neutral answers are considered to be uncertain because not knowing this fact, the beachgoer could be at risk to enter the water at a rip location. Only 12% indicated strong assurance by answering they strongly agreed and 19% agreed; all others (~70%) lacked confidence. Unlike the findings of past surveys (e.g., Brannstrom et al., 2014; Caldwell et al., 2013; Sherker et al., 2010), it can be stated that Miami Beach’s beachgoers are not confident in their ability to spot a rip.

Rip current literacy

The final section of the survey collected information pertaining to the beachgoer’s verbal knowledge of rip currents with regard to definition, occurrence, risk, fatality, and response. Respondents were asked to rate their level of agreement with the following statements using the same aforementioned Likert scale:

[Definition] A rip current is a fast moving offshore flow.

[Occurrence] Rip currents occur frequently (approximately once a month) at Miami Beach.

[Risk] A rip current pulls people away from the shore.

[Fatality] Rip currents cause the most drownings each year at Miami Beach.

[Response] If caught in a rip current, you should swim parallel to the shore.

I then fabricated a single composite parameter as a measure of each beachgoer's rip-current literacy. To make interpretation easier, I normalized the scale so that the factor scores had a mean of 0 and standard deviation of 1. However, as a result of sample restriction, Table 5-1 shows slightly different values (0.02 for mean and 0.94 for standard deviation).

ANALYTICAL RESULTS

Image test outcome by predictors

The aforementioned predictors were analyzed with respect to each respondent's choice in swimming location on both images (Table 5-2). As discussed in section 3.2, a score from 0 to 2 was given based on the average correctness for both pictures; zero indicating an unsafe location was chosen in each image and two if safe locations were picked in both. In regards to the sample as a whole, as shown in Table 5-2, the linear score was 1.01; 27% of beachgoers correctly identified the safest places to enter the water and 26% incorrectly identified these locations. A total of 47% beachgoers were partially correct – identifying the safest place in only one of the images.

Males were slightly more likely than females to correctly choose by a miniscule difference of 0.03. Beachgoers in the age group 41-50 were the most correct (1.33); however, a decrease in the respondent's ability to choose a correct answer was then seen after age 51. There was a large gap in recognition between races, those identifying as White or Asian scored much higher (1.04 and 1.17, respectively) than Hispanic (0.87)

and Black (0.80). Those beachgoers who obtained post-graduate degrees were far more likely to correctly answer both images (1.21) than those who have not finished high school (0.50). Married respondents scored higher (1.13) than their counterparts (0.94). A beachgoer's citizenship had little influence over their ability to safely enter the water.

Those who claimed to be able to strongly swim 100 meters scored an average of 1.18 and beachgoers who visited the beach on a yearly basis scored 1.09; the highest for each of their categories. However, no definitive relationship could be determined between both variables and the correctness of identifying a safe place to enter the water. A nearly linear relationship exists with confidence as agreement increases (Table 5-2, last rows). Those who only agreed had a higher score (1.10) compared to those who claimed to have the highest confidence (1.05).

Beach-going respondents were awarded a score from -2 to 2 for their literacy of rip currents (Fallon et al., 2017). Those who received a -2 to -1 were the lowest scorers, and hence had little to no understanding about rip currents. They also performed the most poorly (0.96) on the image recognition. Beachgoers who have a better understanding of rip currents scored higher (1.11) when asked to choose a safe place to enter the water in both images.

These descriptive results suggest that some sociodemographic traits, behavioral characteristics, and rip current knowledge make a difference in a beachgoer's ability to avoid potential risks at Miami Beach. Those respondents who are more advanced in education level, and especially those with more beach-going frequency and swimming ability will be more likely to choose a safe location to enter the water. Beachgoers, who scored higher on the rip-current literacy scale, meaning they have a better understanding

of rips, may also have a significantly better chance of safely entering the water. Other variables appeared to have little, or non-monotone, influences on a beachgoer's ability to recognize a hazard. Based on the conditional scores, a respondent's education level, rip literacy, and to a lesser extent, confidence in spotting a rip were the best predictors of a person's ability to recognize a rip current.

Linear regression models predicting the image test linear score

Using these same variables, OLS regression models were estimated, first with a set of bivariate models and then by utilizing a multivariate regression model (Table 5-3). While the directions of the influences were consistent with the descriptive findings in Table 5-2, the only variable that significantly influenced a beachgoer's ability to safely enter the water was their level of education. Specifically, those respondents who finished college were better able to pick the safest place (i.e., not entering the rip current) in both images they were shown. This is the case for both the bivariate models and the multivariate model.

Other sociodemographic and behavioral factors, including rip-current literacy and confidence, compiled by this survey had no statistically significant effects on the beachgoer's ability to avoid the rip risk at Miami Beach. A beachgoer's verbal understanding of rips could not be trusted as their ability to visually recognize rip-current hazards.

CONCLUSIONS

A survey of visitors to Miami Beach found that more than 60% of respondents were unable to correctly choose the safest place to enter the water in two images containing rip currents. Compared to most previous studies, Miami Beach visitors lack

confidence in their ability to spot a rip current from the beach. Further analysis found that education was the only variable that influenced their ability to choose correctly the safest place to enter the water. Those who received at least a college education are equipped with significantly superior beach safety knowledge.

While our analysis is restricted to the 160 respondents in our analytic sample, the findings are generalizable, for the first time, to a concrete and meaningful population of beachgoers who visited Miami Beach over the 12 months of the survey. This is also the first study of rip-current related, beach safety knowledge in South Florida. Furthermore, multiple regression models allowed me to systematically evaluate the relative importance of various explanations in the literature. As a result, we identified the distinct advantage of a college education (or above), whereas most other surveys did not factor this into consideration.

A survey of beachgoers has shown that rip currents remain a major threat to public safety at Miami Beach. Most visitors cannot recognize a rip and its risk, putting themselves in a dangerous and potentially fatal situation. It is clear that rip-current outreach and awareness are vital to and should be included in all beach-safety campaigns. Through this study, I have determined the most at-risk populations who should be targeted in order to mitigate the rip-current hazard. The City of Miami Beach needs to mount a larger effort as part of their coastal management program to protect the millions of visitors that come to this beach each year.

VI. CONCLUSION

The research focusing on the physical science of rip currents determined how they form by observing changes in beach morphology and state. Although understanding the mechanics of these currents is of interest, it is pertinent to know what measures need to be taken to abate the ensuing risk. The second part of this research determined the social implications of rips as a hazard to beachgoers. The overall goal of this study was to utilize scientific research to conclude how to make the public more aware of the dangers that rip currents pose to them.

The results presented in Chapter 2 question the traditional definition of rip current formation being directly related to wave action. This study utilized an extensive data set to relate wave steepness, collected by National Oceanic and Atmospheric Association (NOAA) buoys, to ridge-and-runnel appearance seen by a beach camera. In East Hampton, it was determined that bar gap rip-like currents occur as water drains from a shallow trough on the beach, concentrated through a hole in the ridge. The resultant currents act similarly to rips albeit without direct wave action. These ridge-and-runnels form a few days after an event of high wave steepness and nearly all events culminated in the breach and subsequent drainage of the runnel. Anticipation of ridge-and-runnels is likely to imply a greater risk of this new type of rip current; therefore, a method was proposed to add these observations to rip current forecasting models. However, these cycles of drastic increases in wave steepness followed by a gradual decay and the ensuing change in morphology are more common during the winter months when the surf along the south shore of Long Island is more active. Therefore, no beachgoers would be exposed to this hazard. A predictive index of this nature would only be useful at East

Hampton during rare instances when hurricane swell waves directly affect the coastline, but could be applied to other locations.

The meteorological and oceanographic conditions that are conducive for the occurrence of rip currents were explored in Chapter 3. The three most dangerous parks in Palm Beach County, in terms of rip-current rescues, were studied. The Anastasia Formation is exposed along the shoreline of the one beach, Ocean Reef Park; these rock structures create permanent rips. The remaining sites, Juno Beach Park and Kreusler Park, have an abundance of sand as a result of their proximity to piers and well-established, bar-gap rip current channels. The suggestion is made that rips in this area of Southeast Florida might be bar-gaps that are controlled by the beach rock underlying the sand suggesting another variation on the traditional rip-current types may be appropriate.

The data utilized in Chapter 3 were obtained from Palm Beach County lifeguard's historical records of wind and wave conditions present during rip-current rescues. This was the first study that was able to utilize multiple years of data with specific beach state information. This approach allowed researchers to ascertain when rip currents are most dangerous to beachgoers. The majority of rip rescues were executed during yellow warning flag conditions – moderate wind speeds and wave heights. Less than 10 rescues in the six years occurred when winds were greater than 13 kt. A bather is most likely to be caught in a rip when beach states appear deceptively inviting. It is probable that the conditions that create the strongest rips keep beachgoers from entering the water and ultimately away from this hazard. Therefore, it can be said that the most dangerous rip currents occur during moderate wind and wave conditions.

Surveys of beachgoers at Miami Beach revealed the sociodemographic and behavioral factors that influence a person's rip-current literacy and recognition of the hazard. This was the first study undertaken in South Florida; it was also unique because data was collected over a full year to capture the wide variety of visitors to Miami Beach. It was concluded that an overall deficiency in regards to rip-current knowledge exists as presented in Chapter 4; however, four subgroups were determined to be the most at-risk: young adults, poor swimmers, foreign tourists, and infrequent beach visitors. It is thought that beach experience is the most helpful factor in allowing for visitors to better understand waves and currents. This survey determined that level of education had no effect on a person's knowledge of rips but it was the only variable that had any influence on a beachgoer's ability to recognize the hazard. Chapter 5 discusses how more than 60% of survey respondents were unable to identify the safest place to enter the water on either of two photographs shown to them. Those beachgoers with at least a college education performed significantly better than the rest. When comparing the conclusions of Chapters 4 and 5, it is seen that a beachgoer's knowledge of rips has no influence on their ability to recognize the hazard, and vice versa. Ultimately, visitors who lack literacy or recognition of rip currents put themselves in a hazardous and potentially fatal situation. Populations who are most at risk, as described in these chapters, should be the targets of rip-current awareness campaigns.

Based on my research, I would like to suggest a few recommendations that managers could utilize to make their beaches safer. First, I believe lifeguards should continue to or begin to keep statistics of beach (i.e., wave and wind) conditions during rip current occurrences and rescues. Although most beaches do collect some of this data, I

have not seen any that take note of information regarding wave period and sea versus swell. Knowing this would greatly improve rip current predictive indexes. Additionally, social surveys of beachgoers would allow researchers to understand what at-risk groups should be targeted in rip-current awareness campaigns. For example, based on my findings at Miami Beach, Florida, a large portion of respondents were tourists; therefore, posting beach safety information at airports could be a valuable way to reach this group. Taking advantage of advances in technology, particularly smartphone applications would be another recommendation to coastal managers. These are just a few suggestions based on my specific research but most importantly coastal scientists worldwide should continue their studies to improve rip current understanding and beach safety.

Each year an estimated 100 people drown in rip currents throughout the United States, it is hoped that the findings of the research presented in this dissertation will help to lessen these tragic losses. Hopefully this dissertation will inspire future coastal scientists to continue working towards discovering more about the formation and social implications of this greatest hazard at surf beaches – rip currents.

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APPENDIX 1

The following tables are an inventory of all ridge-and-runnel events recorded at East Hampton, NY during the study's timespan.

Year: 2010

Month	Day	Duration
10	15	7
10	25	2
11	8	4
11	21	1
11	24	1
12	17	2
12	21	1
12	30	1

Year: 2011

Month	Day	Duration
1	3	4
1	17	1
1	20	8
3	14	4
4	14	4
4	19	3
5	1	3
5	12	2
8	26	6
9	6	3
9	23	1
10	7	1
10	25	6
11	8	2
11	15	4
12	14	2
12	24	4

Year: 2012

Month	Day	Duration
1	8	2
1	25	1
7	26	1
9	4	1
10	2	3
10	8	1
10	11	2
11	3	2
11	6	2
11	9	8

Year: 2014

Month	Day	Duration
2	10	1
2	17	1
4	3	2
4	24	2
4	28	1
5	5	3
5	9	1
5	21	1
6	16	1
10	28	4
11	7	2
11	10	2

Year: 2015

Month	Day	Duration
10	31	2
11	8	1
11	14	1
11	17	1
11	23	1
11	28	1

Year: 2016

Month	Day	Duration
1	1	1
1	29	2
2	6	2
2	12	2
3	7	1
3	9	1
3	12	2
3	27	1
3	29	2
4	6	1
4	9	3
4	13	3
4	20	2
5	3	3
5	12	3
5	18	1
5	22	1
5	27	1
5	29	1
6	14	1
6	17	2
6	21	1

APPENDIX 2

The following graphs indicate wave steepness prior to the observance of a ridge-and-runnel event.

APPENDIX 3

Miami Beach Public Survey

A. Field Conditions

To be filled out by interviewer beforehand

1. Date: _____
2. Time: _____
3. Location: _____

B. Sociodemographic Characteristics

1. Gender: 1. Male 2. Female
2. Race: 1. White 2. Asian 3. Hispanic 4. Black 5. Other
3. Citizenship: _____
4. Marital Status: 1. Married 2. Unmarried
5. Children: 1. Yes 2. No
6. Education level: 1. Less than H.S.
 2. H.S. graduate
 3. Some college
 4. College graduate
 5. Post graduate
7. Birth Year: _____

C. Behavioral Features

1. Swimming ability on a scale of 1-5: 1. Unable to swim
 2. Can swim but not strongly
 3. Strongly swim 25 meters
 4. Strongly swim 100 meters
 5. Strongly swim over 100 meters

F. Source of Information and Knowledge

1. Mark in the appropriate column: How many times per week you receive general information from **EACH** source.

	<1	1 to 7	>7
Television			
Newspaper			
Website			
Social Media			

2. Where does your knowledge of beach safety come from?

Choose **3 out of the following 6 sources** and rank them 1 (most) to 3 (least)

Mass Media (TV, books, news, internet)	
School	
Extra-Curricular Activities	
Family Members	
Friends	
Signs and/or Pamphlets	

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PUBLICATIONS AND PRESENTATIONS

Fallon, K. (2014). *Occurrence of Ridge and Runnels at East Hampton, New York*. Report presented at the annual meeting of the Association of American Geographers, Tampa, Florida.