Ocean Lifeguard Prevention and Rescue Activities in Newport Beach: Analyses using Activity Data Collected in Real-Time with a Computer Aided Dispatch System

William Koon

A thesis

Submitted in partial fulfillment of the

Requirements for the degree of

Master of Public Health

University of Washington

2017

Committee:

Ali Rowhani-Rahbar

Linda Quan

Charles Mock

Program Authorized to Offer Degree:

Global Health

University of Washington

Abstract

Ocean Lifeguard Prevention and Rescue Activities in Newport Beach: Analyses using Activity Data Collected in Real-Time with a Computer Aided Dispatch System

William Koon

Chair of Supervisory Committee:

Assistant Professor Ali Rowhani-Rahbar

Department of Epidemiology

Ocean lifeguards have protected bathers from drowning in developed countries for decades, and efforts to establish ocean lifesaving bodies in low- and middle-income countries are increasing. Given the importance and prevalence of the profession around the world, surprisingly few studies have investigated the nature of ocean lifeguard activity, and little is known about ocean lifeguard interventions in the drowning process. This thesis has two major objectives: (1) to characterize the nature of primary and secondary lifeguard drowning prevention interventions, specifically describing variation in time and location of lifeguard activity; and (2) to investigate the relationship between wave height and changing water levels with the occurrence of ocean rescue in the study location.

Data for this research were collected in 2015 and 2016 by lifeguards in Newport Beach, California, using a Computer Aided Dispatch (CAD) system. Lifeguard activity data was recorded in real-time, which provided intensely detailed records that were linked to external data collection systems. We described temporal trends, conducted scan statistic GIS analysis, and described the variant staffing elements of lifeguard primary and secondary prevention. Mixed effects negative binomial regression was used to examine the association between wave height and changing water levels with rescue frequency in the study location.

Lifeguard rescues did not happen homogeneously in time and space, and were statistically associated with wave height and water level changes. Importantly, varying effects of environmental variables were observed, indicating other factors undocumented in these data have a role in causing rescues. This research represents a first attempt at analyzing ocean lifeguard activity data collected in real-time with a Computer Aided Dispatch system.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I must thank several people without whom this project would not have been possible. First, I must recognize the members of my thesis committee and their valuable input on this work. Specifically, I would like to thank Dr. Linda Quan for her energy in helping to conceptualize this research, constant challenge to think about the big picture, and enduring patience with seemingly eternal red ink through the multiple revisions of these manuscripts.

Dr. Mellissa Moulton, fellow rip current enthusiast from the Applied Physics Laboratory at the University of Washington (UW), was immensely helpful in facilitating my learning of how the oceanographic elements of this work related to lifeguard interventions, and how to best communicate findings to the various audiences for whom this work was intended. Dr. Orvalho Augusto from the UW Department of Global Health and Dr. Jim Hughes from the UW Department of Biostatistics provided vital Biostatistics input for the modeling of environmental variables on rescue frequency. The quality of this work and presentation of these findings are in large part due to the expertise of these individuals. I am also grateful for the assistance of Kevin Wallis and forecasters at Surfline for the provision of historical near-shore wave estimates for this study.

Lastly, I would like to thank the Newport Beach Lifeguards. I am thankful to Assistant Fire Chief Rob Williams for his support of this project, Battalion Chief Mike Halphide for his assistance in data acquisition, and the rest of the Lifeguards that protect Newport Beach for their cooperation and assistance. This work only captures part of the incredibly complex nature of the responsibility bestowed upon this extraordinary group of people, hopefully it inspires further advances is their efforts to save lives from drowning.

Dedicated to Seattle's wettest year on record and to Linda Quan; without them you probably would not be reading this.

EXECUTIVE SUMMARY

Drowning is a global public health problem that disproportionately affects low- and middle-income countries. One strategy to reduce the burden of drowning is the utilization of trained lifeguards to watch, warn and rescue bathers in recreational settings including pools, water parks, and open water locations. High-income countries have utilized trained lifeguards in well-established departments for many decades, and recently there has been increased focus on training lifeguards in developing nations. To date, there have been relatively few peer-reviewed studies about ocean lifeguard activity. Considering ocean lifeguards are charged with protecting hundreds of millions of beach patrons every year around the world, scientific advancement in this field should be a priority. Historically, lifeguard data has been difficult to collect, leading to sparse records of poor quality and consequently few attempts at robust analysis.

Ocean Lifeguards in California are well-established professionals most commonly organized under county or municipal fire departments, as is the case in the City of Newport Beach. In 2015, Newport Beach Lifeguards began using a Computer Aided Dispatch (CAD) system to record lifeguard activity in real-time and increase efficient responses to emergencies, a groundbreaking advancement for the field. This new data collection system provides for intensely detailed records with time stamps and location information which allows for linkage to other data systems. These data provide the basis for this research, as far as we know, the first analyses to use real-time CAD recorded lifeguard activity.

This work was divided into two distinct parts; the following chapters represent the corresponding independent manuscripts in their entirety. Chapter One explores the nature of primary and secondary lifeguard drowning prevention through a public health lens, describing

where and when lifeguards intervene in the drowning process. Chapter Two specifically evaluates the association of wave height and water level variables with the frequency of ocean lifeguard rescues using multivariate regression analysis.

These data indicate the majority of lifeguard activity consists of primary drowning preventative actions targeted at specific groups of people on the beach. Important temporal and spatial patterns were observed in the distribution of preventative actions and rescues, potentially valuable information for lifeguard managers for risk management and the allocation of finite resources. The variability in time and location also raises questions about the mechanisms that cause such events to occur; of which environmental factors are a primary concern. Wave height and water levels were statistically associated with rescue frequency in these data, but multivariate regression analysis revealed substantial variation in their effect. This excess heterogeneity points to other casual factors that were undocumented in these data, such as human characteristics related to age, sex, race, residency, or swim ability.

This work represents the first steps in analyzing data collected by the new Computer Aided Dispatch system used by Newport Beach Lifeguards. While the detailed records form this system contain finite information about incidents on the beach, a vast improvement over previous collection systems, there are still many questions related to the people the Newport Beach Lifeguards warn and rescue at the beach. Determining other factors associated with rescue, including person characteristics of victims and geographic specific elements related to the surrounding environment where rescues take place, will be key in informing future policy or community education interventions aimed at reducing rescue and the drowning in the City.

Chapter 1. THE OCEAN LIFEGUARD DROWNING PREVENTION PARADIGM

1.1 BACKGROUND

Approximately 372,000 people die from drowning every year worldwide.(1) This count is likely an underestimation as 91% of fatal drownings occur in low- and middle-income countries where data is not collected or reliably recorded. International consensus based guidelines recommend swimming where there are lifeguards as an important strategy to prevent drowning.(2) Some data suggest lifeguards decrease fatal drowning risk, but most knowledge about open water lifeguard activity and effectiveness is anecdotal, experiential, based on expert opinion, or derived from incident counts of varying accuracy and dependability.(3-5)

In 2015, researchers from the International Drowning Research Alliance developed a systematic model of the drowning timeline in order to further clarify the drowning process.(6) The timeline establishes important phases of the drowning process and where interventions can stop drowning. It identifies interventions that are primary prevention, before a person is in distress in water, as well as secondary prevention following the moment of distress including response and mitigation. In doing so, it addresses the belief that the majority of lifeguard activity involves secondary prevention, conducting water rescues and resuscitation.

Relatively few studies have described what lifeguards actually do to prevent drownings, in part due to the difficult nature of data collection.(7, 8) The main barrier to establishing effective methods for recording lifeguard activity on beaches balancing the dual tasks of providing water safety and data collection.(9) This conflict has resulted in problematic collection methods that capture data influenced by social desirability bias from self-reported activity, recall bias from retrospective reporting (even if by a few hours), inaccurate measurements or counts (validity), and inconsistent reporting (reliability). Analytic research that characterizes the nature of lifeguard duties and expands the scientific basis for operational organization and practice would better inform lifeguard programs.

The purpose of this study is to characterize the spectrum of ocean lifeguard prevention actions in Newport Beach (NB), California; a location where lifeguards recently implemented real-time data collection of their interventions using a Computer-Aided-Dispatch (CAD) system. Specifically, we sought to describe primary drowning prevention as actions occurring in the pre-event stage, and secondary drowning prevention as ocean rescues occurring in the event stage. Additionally, we sought to describe variation of preventative actions and rescues by time and location in order to identify opportunities for increased efficacy of lifeguard primary prevention. We hope this study will provide further understanding of the work ocean lifeguards do, evidence for data driven policies and training, and inspiration for future research.

1.2 METHODS

This study is a retrospective analysis of lifeguard preventative actions and rescues recorded with a CAD system by NB Lifeguards from January 1, 2015 through December 31, 2016. CAD data was space-time linked to lifeguard work schedules to evaluate variation in staffing and activity. NB Lifeguards approved access to lifeguard CAD data and work schedules. Institutional Review Board approval was not required for this study as previously collected de-identified data used for this investigation do not meet the regulatory definition of human subjects research by the University of Washington Human Subjects Division.

1.2.1 *Study Location*

NB is a suburban beach city in Southern California, USA, with approximately 90,000 permanent residents. The city experiences mild weather conditions and year round tourism. NB represents 13 kilometers of Pacific Ocean beach, known for its surfing conditions; it includes famous surf break "The Wedge" with sections of beach exposed to large summer surf and dangerous rip currents. With approximately 10 million people visits per year, peak summer beach visitation can exceed 100,000 patrons per day; lifeguard rescue rates may exceed 50 rescues per hour.(10)

Organized as a branch of the NB Fire Department, lifeguards are responsible for patrolling 10 kilometers of ocean beachfront divided into three operational divisions. The department employs approximately 245 professional lifeguards; 15 full-time permanent lifeguards, and about 230 seasonal lifeguards. Lifeguards are trained as Emergency Medical Responders (some to the Emergency Medical Technician level) and are paid; none are volunteers. The department utilizes 13 lifeguard patrol vehicles, two rescue watercraft, three surf rescue boats, and 38 fixed lifeguard towers.

1.2.2 *Data Collection*

This study includes data relating to lifeguard preventative actions, rescues, and staffing. Lifeguard dispatchers record all interventions with the public in real-time via SunGard Systems Computer Aided Dispatch Integrated Public Safety Software. Lifeguards in towers and vehicles call dispatch via radio or closed circuit telephone to report activity and/or request additional resources. The dispatcher records the time, location, and nature of call (e.g. preventative action, rescue, first aid, etc.) into the system, and uses the information to organize incident response, allocate resources, and coordinate adequate aquatic coverage of the beach. Lifeguard interventions are classified into 89 different categories in the CAD system; those of interest for this study are preventative actions and rescues.

A preventative action is a verbal warning by a lifeguard to a beach patron regarding an aquatic hazard or danger, recorded as the number of patrons reached with the warning message. Preventative actions represent "reactionary" prevention on the drowning timeline, directed at a specific individual or group to stop an imminent danger. During the busy summer season, lifeguards often convey preventative actions with loud speakers from a vehicle or boat to large groups. In these larger addresses the number of patrons in the group is estimated.

A rescue is physical assistance by a lifeguard from the water to a place of safety (e.g. boat, shallow water, land), and recorded as the number of people rescued. Rescues in the beach environment represent secondary prevention, occurring in the event phase of the drowning timeline, after the person is in stress or distress. At the time of this study, lifeguards did not differentiate rescues based on severity; both a critical lifesaving rescue and a less serious physical assist, eg to someone scared or struggling in the water, were classified as "rescue."

Lifeguards maintain work schedules in Kronos Telestaff for Public Safety, a web-based staffing program that records work hours and positions for each employee. Work schedule data include a count of lifeguards working per hour, categorized by work assignment and operational division. We included active patrol hours only, times when lifeguards were watching the water or were capable to respond to an emergency. Excluded were hours for training, meetings, administrative duties, and nighttime standby.

1.2.3 *Data Analysis*

We used the Dplyr package in Rstudio to clean, link and calculate summary statistics.(11-13) Graphics and maps were created using R packages ggplot2 and ggmap,(14, 15) and Tableau Desktop version 10.1.7 [Computer Software]. Frequencies of lifeguard interventions and staffing by time and season were calculated to characterize temporal variation in lifeguard activity. Rates of interventions per 100 work hours were calculated to quantify activity standardized for the number of lifeguards working, and the ratio of preventative actions per rescue to explore the relationship between primary and secondary drowning prevention.

SaTscan^{TM} software, version 9.4.4, was used to detect geographic clusters of lifeguard rescues in the study area employing Kulldorf methods of a discrete Poisson purely spatial model.(16) The analysis compares observed cases (rescues) in a spatial cluster to the distribution of expected cases if locations of all cases were independent.(17) Monte Carlo replication was used to explore the distribution and determine statistical significance of the spatial clusters.(18) Frequency density maps with statistically significant geographic clusters of interventions in the study location were created to demonstrate variation in spatial distribution of preventative actions and rescues.

1.3 RESULTS

There were 423,071 unique lifeguard interventions recorded in the CAD system between January 1, 2015 and December 31, 2016 in NB. The majority of lifeguard interventions were Preventative Contacts (54.85%, n=232,065), followed by Public Contacts (32.26%, n=136,472), Surfer Warnings (6.53%, n=27,632), and Rescues (1.9%, n=8,046) (Table1.1). A total of 193,177 lifeguard work hours occurred during the study period (Table 1.2). Lifeguards were on active patrol or able to quickly respond to an emergency for 174,802 work hours (90.49%). These hours included special event work hours (n=3,405.75; 1.76%) where special events such as surf contests, private parties, or concerts took place at the beach and required a lifeguard to watch the water and/or respond to emergencies. Lifeguard non-patrol work hours totaled 18,375 hours (9.51%) for administration (n =8,633.5; 4.47%), training (n=5,692; 2.95%) and nighttime standby (n=2,648.5; 1.37%).

Table 1.1. Lifeguard Interventions by Month.
(% from monthly totals)

Intervention	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
Preventative Action	757 (0.33%)	1,877 (0.81%)	9,360 (4.03%)	6,757 (2.91%)	10,654 (4.59%)	42,665 (18.38%)	84,455 (36.39%)	42,295 (18.23%)	23,743 (10.23%)	7,444 (3.21%)	1,070 (0.46%)	988 (0.43%)	**232,065**
Public Contact	1,369 (1%)	2,468 (1.81%)	6,139 (4.5%)	7,284 (5.34%)	9,499 (6.96%)	26,087 (19.12%)	38,111 (27.93%)	23,095 (16.92%)	12,366 (9.06%)	5,182 (3.8%)	2,319 (1.7%)	2,553 (1.87%)	**136,472**
Surfer Warning	0 (0%)	2 (0.01%)	183 (0.66%)	235 (0.85%)	1,881 (6.81%)	4,547 (16.46%)	9,121 (33.01%)	7,592 (27.48%)	2,762 (10%)	1,280 (4.63%)	28 (0.1%)	1 (0%)	**27,632**
Other Intervention	392 (2.73%)	620 (4.32%)	921 (6.42%)	888 (6.19%)	1,014 (7.07%)	2,339 (16.3%)	3,021 (21.05%)	1,954 (13.62%)	1,178 (8.21%)	815 (5.68%)	679 (4.73%)	530 (3.69%)	**14,351**
Rescue	4 (0.05%)	31 (0.39%)	408 (5.07%)	206 (2.56%)	189 (2.35%)	1,255 (15.6%)	2,602 (32.34%)	1,834 (22.79%)	1,089 (13.53%)	409 (5.08%)	12 (0.15%)	7 (0.09%)	**8,046**
First Aid	25 (0.63%)	79 (1.98%)	177 (4.44%)	229 (5.75%)	192 (4.82%)	714 (17.91%)	1,147 (28.78%)	882 (22.13%)	304 (7.63%)	156 (3.91%)	58 (1.46%)	23 (0.58%)	**3,986**
Major Medical	11 (2.12%)	21 (4.05%)	27 (5.2%)	32 (6.17%)	30 (5.78%)	74 (14.26%)	129 (24.86%)	85 (16.38%)	43 (8.29%)	46 (8.86%)	13 (2.5%)	8 (1.54%)	**519**
Event Total	**2,558** **(0.6%)**	**5,098** **(1.2%)**	**17,215** **(4.07%)**	**15,631** **(3.69%)**	**23,459** **(5.54%)**	**77,681** **(18.36%)**	**138,586** **(32.76%)**	**77,737** **(18.37%)**	**41,485** **(9.81%)**	**15,332** **(3.62%)**	**4,179** **(0.99%)**	**4,110** **(0.97%)**	**423,071**

Table 1.2. Lifeguard Staffing by Division and Month.
(% from Monthly Totals)

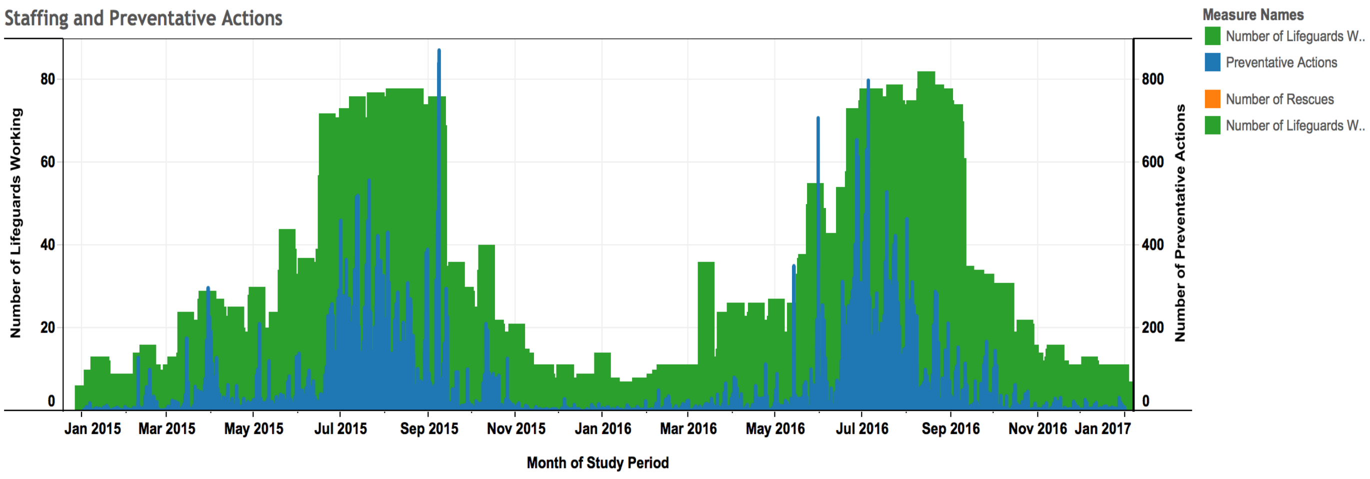
Work Hours	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
Division 1	132 (0.26%)	499 (0.99%)	1,391 (2.77%)	2,314 (4.61%)	2,793 (5.56%)	7,330 (14.59%)	13,582 (27.04%)	14,001 (27.87%)	5,761 (11.47%)	1,957 (3.9%)	456 (0.91%)	14 (0.03%)	**50,230**
Division 2	0 (0%)	163 (0.35%)	899 (1.92%)	1,577 (3.36%)	2,115 (4.51%)	7,146 (15.24%)	13,677 (29.16%)	14,375 (30.65%)	5,366 (11.44%)	1,354 (2.89%)	221 (0.47%)	8 (0.02%)	**46,901**
Division 3	0 (0%)	95 (0.47%)	395 (1.95%)	801 (3.95%)	1,217 (6.01%)	3,133 (15.46%)	5,499 (27.14%)	5,598 (27.63%)	2,443 (12.06%)	914 (4.51%)	167 (0.82%)	0 (0%)	**20,262**
Headquarters Division	3,719 (7.65%)	3,404 (7%)	4,436 (9.12%)	4,398 (9.04%)	4,685 (9.63%)	3,368 (6.93%)	4,649 (9.56%)	4,608 (9.48%)	2,456 (5.05%)	4,407 (9.06%)	4,161 (8.56%)	4,338 (8.92%)	**48,629**
Rescue Boats	25 (0.28%)	0 (0%)	145 (1.65%)	67 (0.76%)	282 (3.21%)	1,412 (16.08%)	2,731 (31.1%)	2,586 (29.45%)	1,251 (14.25%)	213 (2.43%)	0 (0%)	68 (0.77%)	**8,780**
Training Operations	0 (0%)	592 (10.4%)	1,238 (21.75%)	826 (14.51%)	1,195 (21%)	1,235 (21.7%)	606 (10.64%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	**5,692**
Other Non-Patrol Hours	1,022 (8.05%)	1,093 (8.62%)	1,206 (9.51%)	993 (7.83%)	866 (6.83%)	1,412 (11.13%)	863 (6.8%)	987 (7.78%)	1,199 (9.45%)	1,044 (8.23%)	1,013 (7.99%)	986 (7.77%)	**12,683**
Total Hours	**3,901** **(2.02%)**	**5,345** **(2.77%)**	**9,887** **(5.12%)**	**10,876** **(5.63%)**	**13,764** **(7.13%)**	**26,271** **(13.6%)**	**42,869** **(22.19%)**	**43,754** **(22.65%)**	**18,528** **(9.59%)**	**9,058** **(4.69%)**	**5,005** **(2.59%)**	**4,496** **(2.33%)**	**193,177**

1.3.1 *Temporal Variation in Primary and Secondary Prevention*

The majority of both lifeguard preventative actions (n = 169,415, 73%) and rescues (n=5,691, 70.7%) occurred during the summer months of June, July, and August. Weekends were the busiest days of the week for preventative actions and rescues, with 41.3% (n= 95,799) of preventative actions and 46.9% (n=3,771) of rescues occurring on Saturdays and Sundays. Figure 1.1 shows temporal tends by time of day and day of week for preventative actions and rescues. Lifeguards made 57.8% (n=134,075) of preventative actions and 64.6% (n=5,198) of rescues between the hours of 1:00 PM and 4:00PM. Hours of the week with the most preventative actions were Sundays at 2:00PM (n= 8,927; 3.85%), Sundays at 1:00PM (n= 8,098; 3.49%), and Saturday at 2:00PM (n= 7,552; 3.25%). Hours with the highest number of rescues were Saturdays at 2:00PM (n= 366; 4.55%), Saturdays at 3:00PM (n= 365; 4.54%), and Sundays at 2:00PM (n= 365; 4.54%).

Figure 1.1. Lifeguard Preventative Actions and Rescues by Hour of Day and Day of Week.

Although lifeguard staffing followed a seasonal pattern and was greatest during July and August, periods of high rescue activity occurred throughout the summer and into the months of September and October, when staffing levels were reduced (Figure 1.2). For the entire study period, the rate of preventative actions per 100 work hours was 132.8, and rescues per 100 work hours was 4.6. The highest rate of preventative actions per 100 work hours (210.4) occurred in July followed by June (190.7), September (137.4), March (128.8) and August (102.7). The month of July also had the highest rate of rescues per 100 work hours (6.48), followed by September (6.3), March (5.62), June (5.61) and October (4.62).



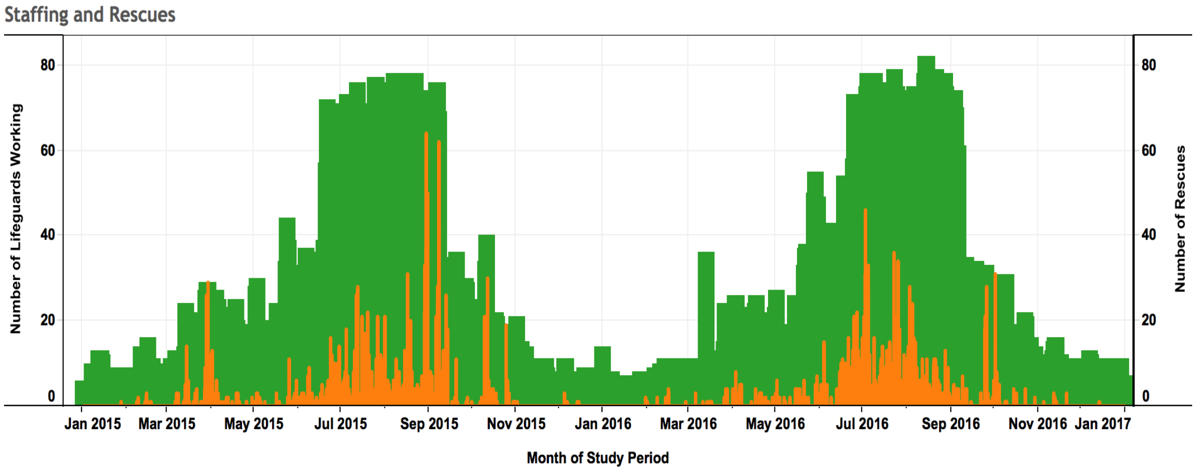


Figure 1.2. Lifeguard Staffing and Preventative Actions per Hour and Lifeguard Staffing and Rescues per Hour, 2015 and 2016

During the two-year study period, the ratio of preventative actions to rescues was 28.84. When summarized by hour of day, lifeguards made fewer preventative actions per rescue in the later hours of the day (Figure 1.3). There were 1,158 instances in the study period when dispatchers recorded both preventative actions and rescues at the same minute for the same lifeguard; usually when a lifeguard conducts different interventions at the same time or in quick succession, most commonly for different patrons. In simultaneous records, lifeguards made on average 8.32 preventive actions per rescue.

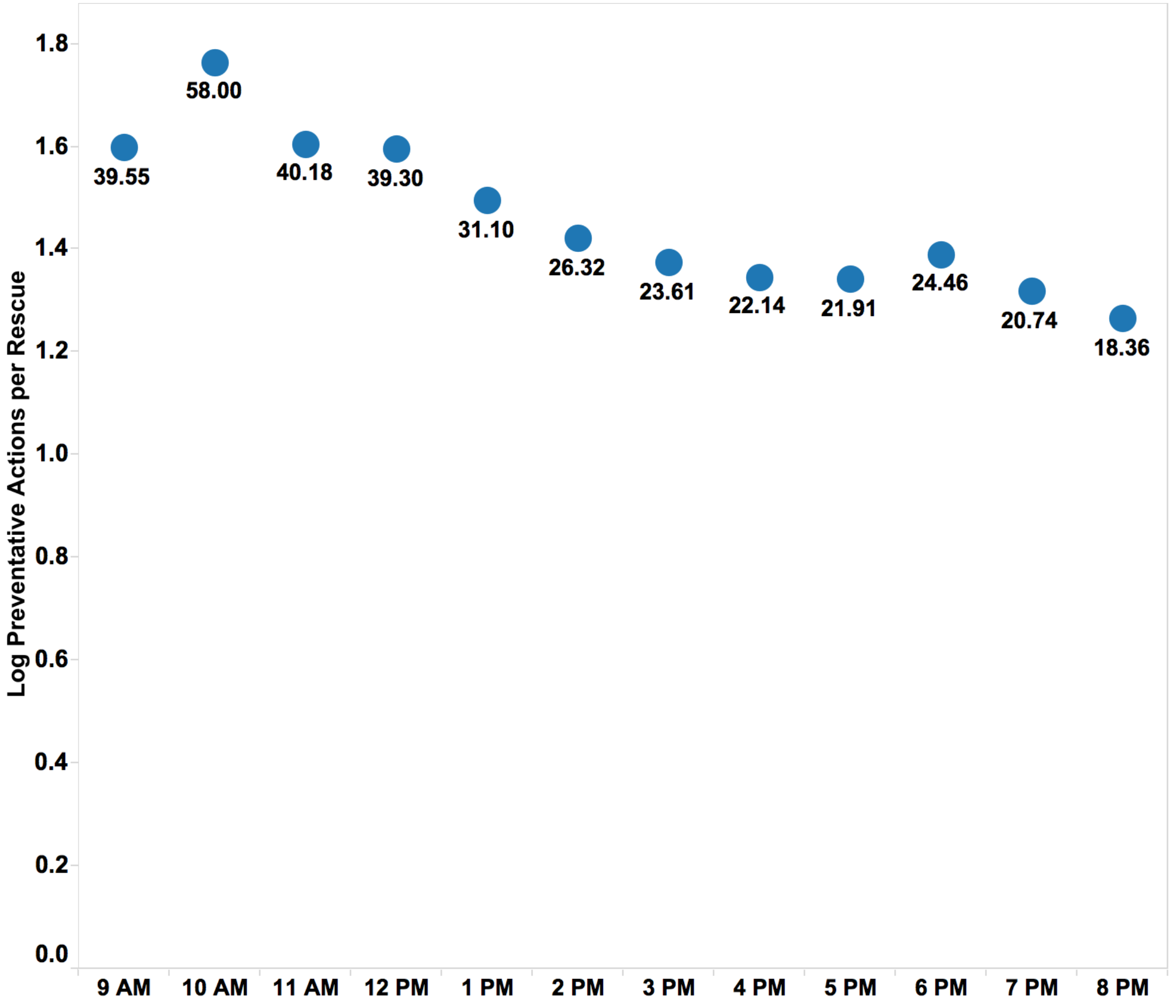


Figure 1.3. Log Ratio of Preventative Actions per Rescue by Hour of Day.

1.3.2 *Spatial Variation in Primary and Secondary Prevention*

Lifeguard preventative actions occurred relatively homogenously throughout the study area, but rescues occurred more frequently in certain locations. Frequency density and statistically significant clusters with corresponding relative risks, calculated as the estimated risk within a cluster divided by the expected risk in the rest of the study location,(18) are shown in Figure 1.4 for preventative actions and rescues. SatScan identified 15 statistically significant geographic clusters of preventive actions, and six for rescue activity. The vicinity of Towers 17, 18 and 19 was identified as the cluster with the most rescues during the study period (n=1,922;

23%); lifeguards in this location were 3.16 times as likely to conduct a rescue compared to lifeguards working in other locations on the beach (p<0.001).

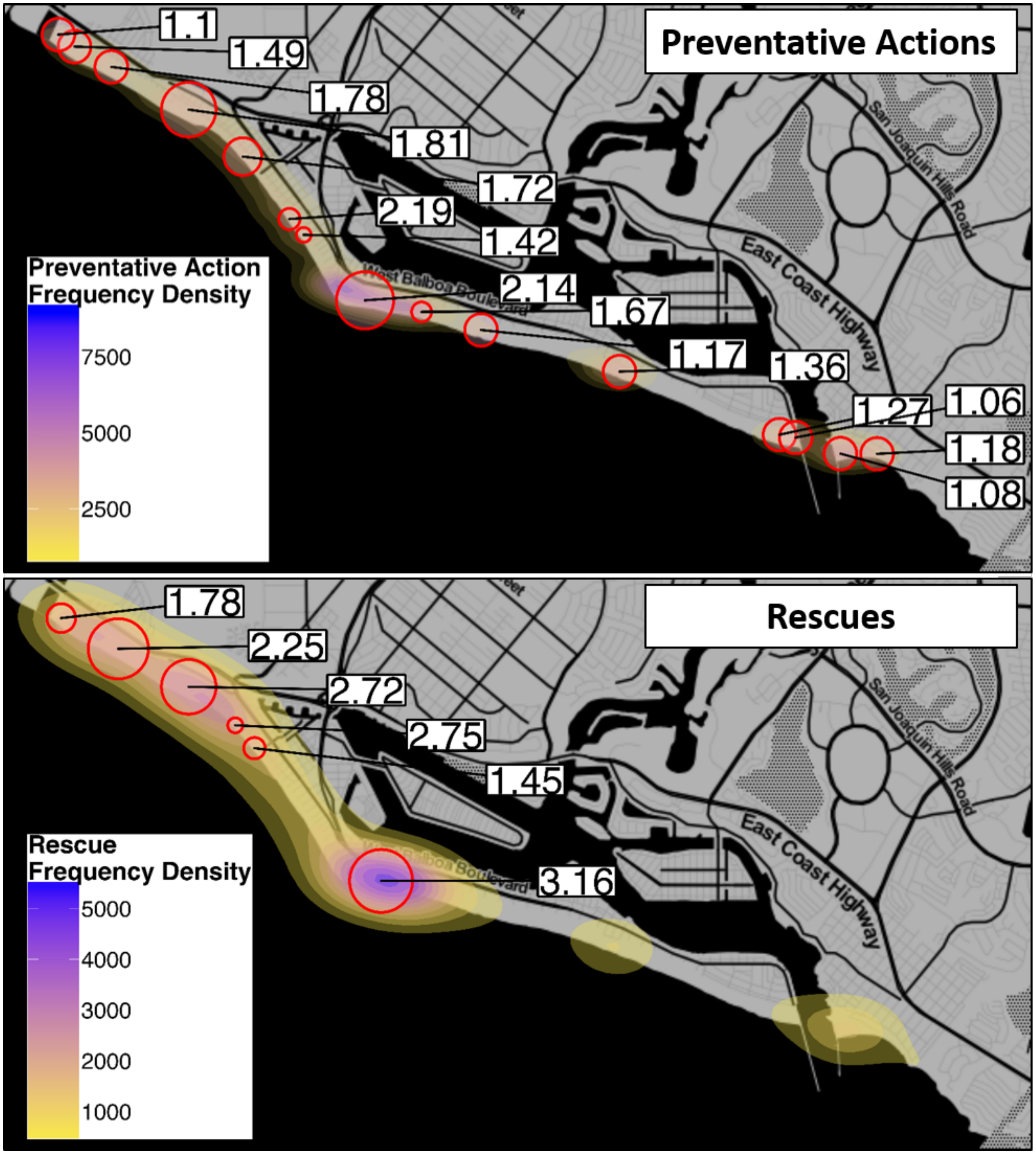


Figure 1.4. Frequency Density and Clusters of Preventative Actions and Rescues with Corresponding Relative Risks.

1.4 DISCUSSION

This study of ocean lifeguard interventions collected in real-time offers new insight to the nature of lifeguard primary and secondary drowning prevention. Primary prevention dominates ocean lifeguard activity. These data indicate the majority of all lifeguard interventions in the study location was the provision of primary drowning prevention (occurring in the pre-event stage of the drowning timeline). Additionally, it shows that lifeguard preventative contacts and ocean rescues do not occur randomly in time and space.

That the incidence of preventative actions and rescues was greater on weekends and in the afternoon was not surprising. However, these data show that the frequency of lifeguard interventions, especially rescues, is high in the shoulder seasons before and after summer when there are fewer lifeguards working. The high rate of rescues per 100 work hours in March (5.62) was likely due to an abnormally warm Easter week in March of 2015, lifeguards made 276 rescues during the last 5 days of that month. In the later summer months, ambient and ocean temperatures remained high, driving large crowds to the beach even though most schools were back in session. The high rates of preventative actions and rescues to work hours in September and October suggest that increased lifeguard staffing is warranted for these months.

Lifeguards provided more preventative actions per rescue earlier in the day, perhaps explained by fatigue, or more likely, increased numbers of beach patrons in the afternoon. For all interventions, lifeguards must weigh the risk of leaving the tower and reducing their supervision of bathers with the benefit of the action taken outside of the tower. When beach attendance is high, lifeguards may choose to forgo some preventative action in favor of maintaining superior views of patrons from the elevated tower position, only intervening when they deem a situation critical. Instances when multiple preventative actions and rescues were recorded at the same time for the same lifeguard may also be associated with increased numbers of beach patrons. Some degree of misclassification exists in situations where a lifeguard both rescues a bather and warns other patrons in the same instant, although not always. Accepting minimal measurement error, these records indicate that lifeguards frequently perform preventative actions and rescues in quick succession, within a very short time span.

The frequency of interventions varied among different areas with clusters of statistically significant increased likelihood for preventative actions versus rescues. One potential explanation for the spatial variation is beach population. Access to the beach differs throughout the study area; there are restaurants and piers with large parking lots in some spaces and residential housing with limited street parking in others. Although the number of people in a given location may affect frequency of interventions in that location, it is important to note that patterns of preventative action and rescue clusters were different. While clusters of preventative actions were identified all over the beach, rescue clusters were primarily restricted to the Division 1 area and near the Newport Point. The varying frequency in different locations of these interventions indicate that crowds are not the sole determinant of the occurrence of these incidents, a conclusion also reached by Morgan and Ozanne-Smith in their analysis of lifeguard surf rescues from Vicotria, Australia.(8)

This analysis has several potential uses. Allocating additional staff to areas where rescues are statistically more likely to occur may allow for higher levels of preventive actions, potentially increasing lifeguard effectiveness by decreasing the occurrence of rescue. Strategically assigning lifeguard vehicles and boats to high intervention areas could reduce emergency response times and minimize the operation of vehicles on the beach- an environmental impact and public safety consideration. Explaining the spatial variation, especially considering environmental factors related to ocean hazards, remains the concern of public health and EMS communities responsible for primary injury prevention and is an important future step for reducing rescues and injuries.

This study contributes to the understanding of lifeguards' role in primary and secondary prevention, but not how to reduce the need for these interventions. We do not know what caused lifeguard preventative actions or rescues; determining what specific patron behaviors or environmental elements spur these interventions may allow for better community education and control of beach patron risk exposure. These detailed, valid and reliable data on ocean lifeguard activity provide opportunities for managers, researchers and government decision makers. This information provides the basis for quality improvement, allocation of finite resources, and training of new lifeguards. Improving surveillance methods for lifeguard activity, with an aim to increase the validity and reliability of data collected, should be a priority for lifesaving agencies, as it will provide a broader evidence base from which to make decisions and create policy.

1.5 LIMITATIONS

This study has multiple limitations. The data consisted of incident characteristics but contained no information on person characteristics such as age, race, residence, swimming ability, or activities; and no information on the prevention advice given. Thus, the study could not identify groups at higher risk for rescue or beach injury and identify injury risks. Although CAD collection methods are assumed to be more accurate than previous recording efforts, there was still likely some degree of misclassification. Dispatchers learning the new system could have miscoded lifeguard interventions or failed to record interventions during times with high call volume. Since data from different sources were summarized and linked on an hourly basis (11:59 is in the 11:00 hour), measurement error was likely present, but probably minimal.

The rescue definition used by NB Lifeguards limits analysis as it does not separate situations when lifeguards assist people to shore from more serious situations involving drowning or injury. Other lifeguard systems use more in depth classifications for lifeguard interventions that would allow more useful analysis; the Royal National Lifeboat Institute in the United Kingdom has different designations for preventative actions (including sub groups for fate-to-face contacts, public announcements, and flag moving), assists, rescues, lives saved, and lives lost.(19)

1.6 CONCLUSION

Ideally, prevention efforts aim at intervening in the drowning process as early as possible. This study shows that Lifeguards provide a great deal of reactionary primary prevention with beach patrons in the pre-event stage and, to a lesser extent, secondary prevention when they provide rescues. Collaboration between lifesaving agencies, EMS, and the public health community to identify the causal mechanisms of variation that exist in these data could inform community education programs or policy changes that may reduce exposure to risk. What explains the different location and frequency of preventative actions versus rescues? How influential is variation in ocean conditions on the occurrence of rescue? Are person factors among beach patrons, their activities, or factors related to the adjoining environment (restaurant, bars, residences) associated with the occurrence of these interventions? How can communities be better prepared to enjoy the beach? Further study in these areas is a public health priority.

Chapter 2. THE ASSOCIATION OF WAVE HEIGHTS, WATER LEVELS, AND OCEAN LIFEGUARD RESCUES

2.1 BACKGROUND

Ocean beaches are dynamic settings where changes in weather and water conditions can alter the risk of drowning or injury. Environmental hazards, along with social dynamics and other demographic risk factors, play a significant role in drowning risk.(20-22) Ocean lifeguard familiarity and experience dealing with various elements in the beach environment are vital for anticipating dangerous situations and allocating appropriate resources to prevent drowning events. Lifeguards often prevent the need for rescue or injury by recognizing specific environmental hazards usually unidentified by the typical beach patron. For example, lifeguards protect members of the public by warning about rip currents, pointing out the location of submerged rocks at high tide, or informing parents with small children about in-shore holes where water depth changes suddenly.

Lifeguards are students of the ocean environment, taught to monitor changing conditions and adjust prevention practices accordingly. Introductory training programs teach lifeguards how waves, tides, wind, rip currents, and other environmental variables influence bather risk. The degree to which modern lifeguard training programs utilize scientific research on these variables is unknown, intuition and experience from older lifeguards and instructors has a central, if not dominant, role. While anecdotal evidence and expert opinion are unquestionably valuable, further analysis of oceanic and other environmental variables could benefit the lifesaving community and their patrons.

Multiple aspects in the coastal environment require both preventative actions and rescues by lifeguards. Lifeguards rely on experience with these variables in their locations to warn patrons and prepare for times of increased risk. In recent years, knowledge of physical variables of the coastal environment has expanded, mostly improving understanding of rip currents. These concentrated flows of water move away from shore to varying distances beyond the surf zone,(23) have been estimated to account for most surf lifeguard rescues in the United States and other locations,(24-27) and have dominated the literature on hazards in the beach environment.(25, 28) The risk of surf zone injury from shore-break has received some attention in the scientific literature,(29) and backwash, lateral currents, sandbars, inshore holes, and other hydrodynamic and morphologic factors have also been included as important determinants of rescue for lifeguard training programs.(30, 31) These processes arise from the interaction between different environmental variables, such as wave height or varying water levels, to form hazard processes that cause rescue. Both wave height and tidal water level are thought to be determinant of rescue frequency due to risk they present directly to bathers, their association with rip current frequency and velocity,(32-34) and their role in exacerbating risk from other hazards in the ocean environment.

Lack of detailed, valid and reliable data on lifeguard activity continues to be a barrier to generating evidence for understanding the relationship between lifeguard rescue frequency and other variables related to oceanic or weather factors, the surrounding geographic environment, or person characteristics of victims. The difficulty of collecting data on ocean lifeguard activity has been documented,(7, 9) and there are specific calls for further investigation on the effects of environmental conditions on lifeguard activity.(35) The development of rigorous methods for analyzing lifeguard activity data, beyond the basic reporting of incident statistics, must be pursued in order to expand the evidence base from which lifeguards operate.

The objective of this study was to investigate the association of wave height and tidal water level changes with the frequency of ocean lifeguard rescue occurrence in Newport Beach, California, using lifeguard rescue records collected in real-time from a Computer Aided Dispatch (CAD) system. A benefit of this data collection method is the ability to link detailed lifeguard activity data to other sources, allowing for the analysis of lifeguard rescues and various other factors. We hope the findings of this study will provide new knowledge for use in lifeguard training programs, insight helpful to front line lifeguards anticipating and preventing rescues, and information beneficial to supervisors and managers preparing staff and allocating resources to protect the public.

2.2 METHODS

We performed a retrospective cohort study of the relationship between wave height and water level changes and the occurrence of ocean rescues in a linked dataset of lifeguard interventions from Newport Beach, California. Newport Beach is a suburban city with eight miles of Pacific Ocean beach, patrolled year round by professional lifeguards employed by the Newport Beach Fire Department. Lifeguards divide the beach into three operational divisions (Divisions 1,2,3) for patrol purposes (Figure 2.1) and utilize fixed towers, vehicles, and boats. The linked dataset contains all ocean lifeguard rescues recorded by Newport Beach Lifeguards from January 1, 2015 through December 31, 2016, linked by time and location to weather and ocean variables contained in historical databases managed by the National Weather Service, the National Oceanic and Atmospheric Administration (NOAA), and Surfline.

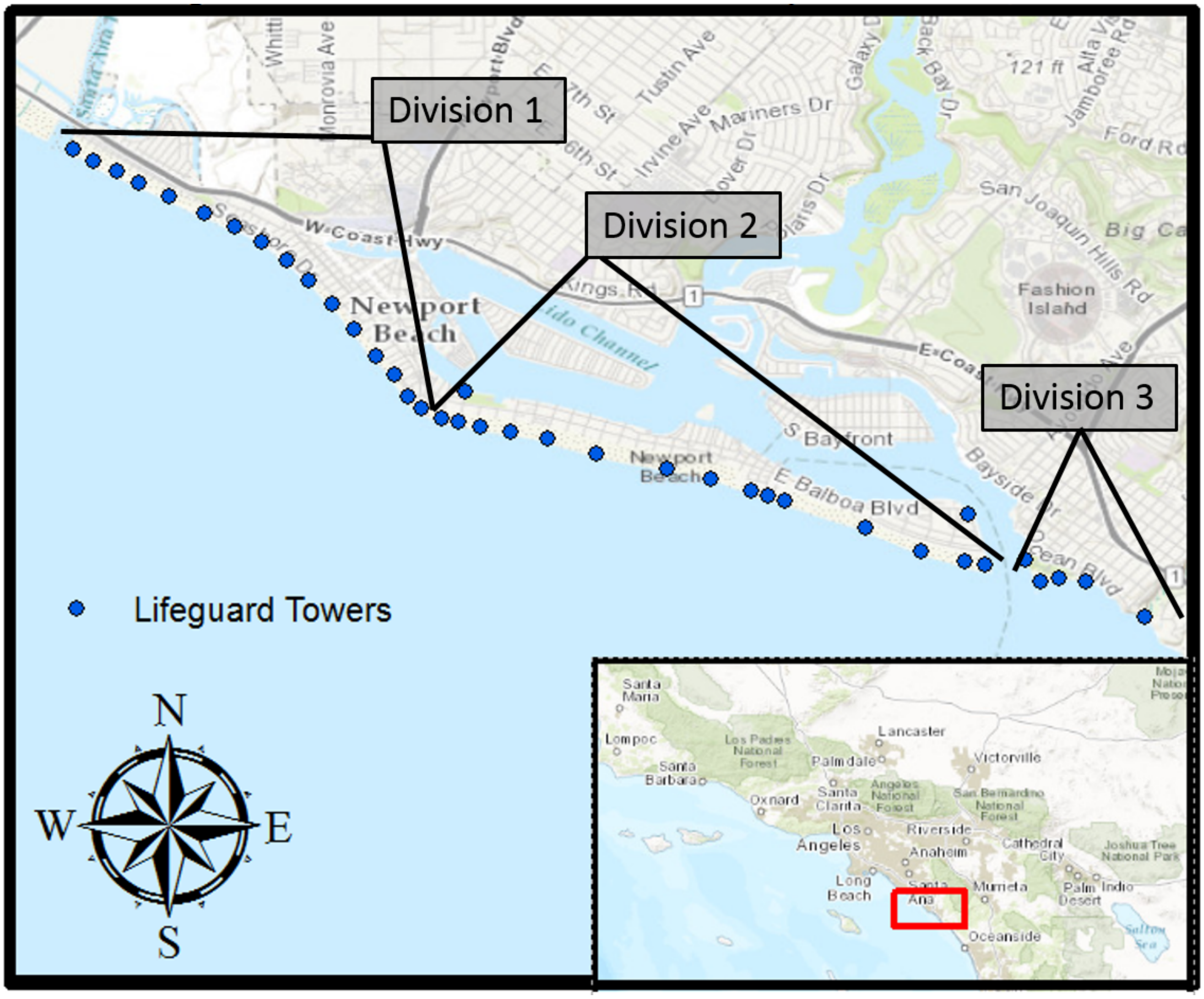


Figure 2.1. Map of Newport Beach with Operational Divisions and Lifeguard Towers.

Lifeguards record the time and location of all rescues and other interventions (preventative action, first aid, rule enforcement, etc.) in real-time via SunGard Systems Computer Aided Dispatch (CAD) Integrated Public Safety Software. A rescue is defined as physical assistance by a lifeguard from a place of danger in the water to a place of safety, and recorded in the system as the number of people rescued. Rescue data was linked by time and location to (1) weather measurements collected by the National Weather Service, (2) wave data measured by three NOAA buoys near the study location, (3) tidal water level information measured from a NOAA water level sensor at the Los Angeles Harbor entrance, and (4) visual near-shore wave estimates from Surfline forecasters for the Division 1 area. A detailed description of the variables and linkage process is in Appendix A. We summarized data by hour for each division. The final linked dataset included an hourly count of rescues, the hourly mean of continuous environmental variables, and the hourly mode of categorical environmental variables for each division.

2.2.1 *Data Analysis*

Our goal was to evaluate the total effects of three different environmental variables on the occurrence of ocean rescue in the study location: (1) wave height, (2) mean water level (primarily set by tidal elevation), and (3) rising vs. falling water level. The motivation to assess the effect of rising vs. falling water level on rescue frequency spawned from a belief among Southern Californian Lifeguards that times with an "outgoing" tide (falling water levels) tend to be more hazardous because of stronger rip currents. While the literature has explicitly clarified that rip velocity is not the result of tidal forcing, we thought it prudent to evaluate the influence of rising vs. falling water levels on rescue frequency in this this analysis.(36) We refer to rising vs. falling water level as water level direction from this point forward.

We performed multivariate analysis using mixed effects negative binomial regression, with hours as the unit of analysis to estimate incidence rate ratios and 95% confidence intervals (CI). Negative binomial regression can accommodate for potential over dispersion of count outcomes.(37) We included counts of "public contacts" as an offset variable, approximating beach population. Public contacts are recorded by lifeguards as interactions with the public not related to rescue, medical/first aid, or rule enforcement; and were correlated with visual estimates of beach attendance ($r = 0.77$). Directed acyclic graphs, developed based on lifeguard experience and previous literature, aided a priori confounder identification for multivariate analysis (Figure 2.2).(38)

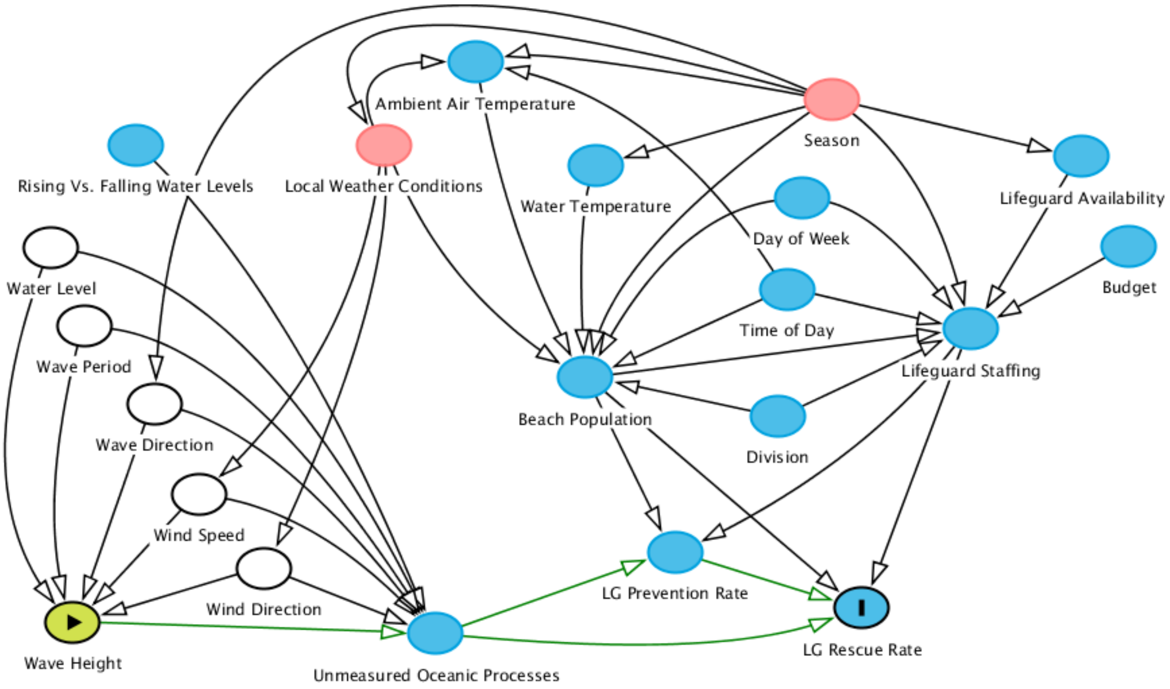


Figure 2.2. Directed Acyclic Graph (Wave Height Models)

We developed two models to assess the effects of wave height, one using open water buoy measurements from NOAA applied to the entire study location and the other using near-shore visual wave height estimates from Surfline applied to Division 1 only. Wave height as a continuous variable was entered into both models using linear splines, with knots at four feet for the NOAA model and five feet for the Surfline model, to evaluate varying effects for times with waves of different heights. Both wave height models controlled for wind speed, wave period, wind direction, mean water level, and wave direction relative to shore-normal. Clustering was accounted for with random intercept deviations for division, month, and day of the week in the NOAA model; and, month and day of the week in the Surfline model.

We developed separate models to assess the relationship between water level, a continuous variable, and rescue occurrence; and the influence of water level direction, a binary variable with falling water level as the reference variable, on rescue occurrence. Both models included an interaction term for division to evaluate for varying effects on different sections of beach, and accounted for clustering by adopting random intercept deviations for month and day of the week.

We used the graphical program DAGitty to develop directed acyclic graph, and Rstudio and Stata [Computer Software] for statistical analyses.(12, 13, 39, 40)

2.3 RESULTS

A total of 8,046 rescues were recorded in the Newport Beach Lifeguard CAD system during the study period. Descriptive statistics of the environmental variables of interest are presented by season in 2.3.

Table 2.1. Environmental Variables by Season

	Winter*	**Shoulder***	**Summer***	**Study Period***
	Mean (SD) Range	Mean (SD) Range	Mean (SD) Range	Mean (SD) Range
NOAA Wave Height	3.20 (1.49) 1.13-13.17	3.03 (0.86) 1.48-8.78	2.89 (.62) 1.65-5.41	3.06 (1.13) 1.13-13.17
Surfline Wave Height	3.16 (1.01) 1.0 - 7.5	3.03 (0.94) 1.0-6.5	2.97 (0.75) 1.0-5.5	3.07 (.93) 1.0-7.5
Tidal Water Level	2.65 (1.72) -1.51 - 7.37	3.16 (1.5) -0.64-6.96	3.47 (1.25) 0.04 - 6.81	3.03 (1.57) -1.51-7.37
Proportion Rising / Falling				
Water level Direction	0.90	1.11	1.28	1.05

*Season Winter: November, December, January, February, March; Shoulder: April, May, September, October; Summer: June, July, August

Multivariate analysis indicated wave height, water level, and water level direction change were associated with rescue frequency (Figure 2.3). Full results of multivariate regression models are available in Appendix B. We found important heterogeneity documented by the alpha parameter in all four negative binomial models, indicating the effects covariates had on rescue occurrence were highly variable (NOAA wave height model alpha =5.48; Surfline wave height model alpha =5.12; tidal water level model alpha =7.51; water level direction model alpha =7.62). In negative binomial regression, alpha is directly related to the amount of over dispersion in the data; increased levels of this parameter show amplified heterogeneity not accounted for by the covariates in the model.(41)

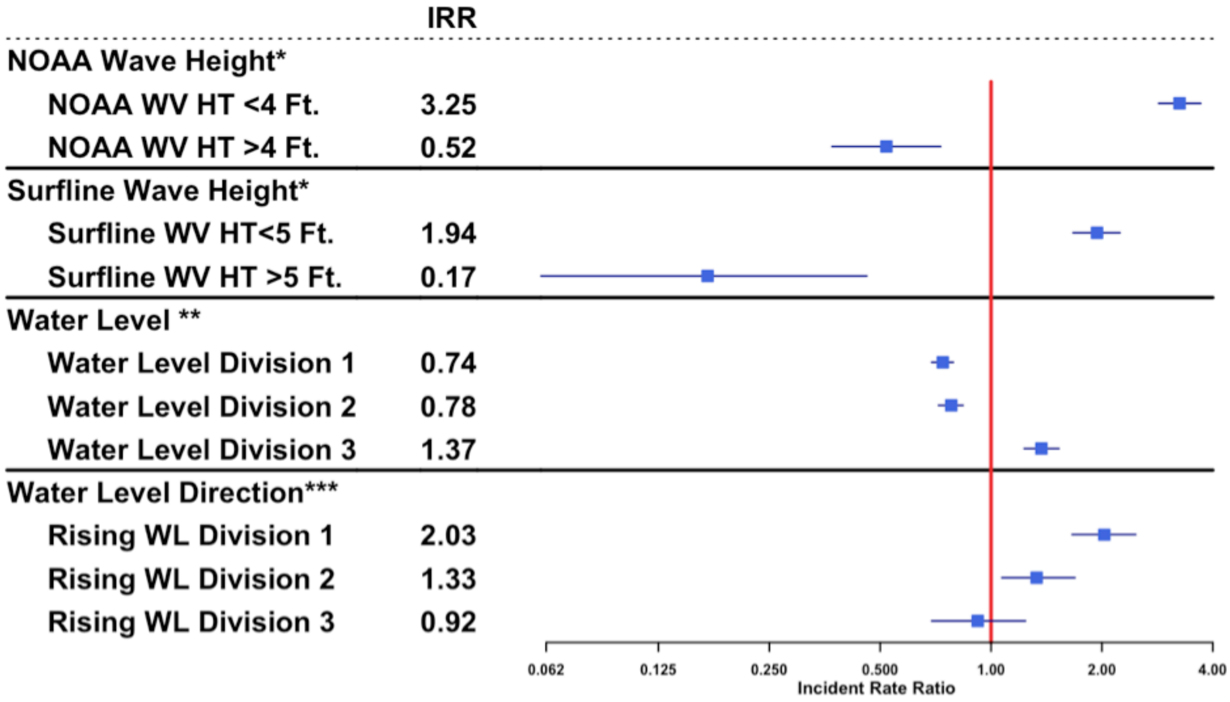


Figure 2.3. Mixed Effects Negative Binomial Regression Results

* Adjusted for wind speed, water level, shore-normal wave direction, wave period, wind direction; IRR indicates the ratio of change in rescue rate for a one-foot increase in wave height, limited to the corresponding wave height spline. IRR >1 indicates increased rescue frequency, <1 indicates decreased frequency

** IRR indicates the ratio of change in rescue rate for a one-foot increase in water level, for each corresponding Division. IRR >1 indicates increased rescue frequency, <1 indicates decreased frequency

*** IRR indicates the ratio of change in rescue rate between rising and falling water levels, for each corresponding Division. IRR >1 indicates increased rescue frequency, <1 indicates decreased frequency

Wave height, from both NOAA buoy measurements and Surfline visual estimates, was clearly associated with rescue frequency in this location. In both models, the effect of wave height varied significantly for hours when waves were larger (joint test for spline interaction: NOAA Model $p<0.001$, Surfline Model $p<0.001$). For hours with average NOAA buoy wave height measured under four feet, a one-foot increase was associated with a 3.25 times increase in the rate of rescues, after controlling for confounding variables (95%CI:2.91-3.79). This relationship changed with larger waves; when average NOAA buoy wave height was over four feet, one-foot additional wave height was associated with a 48% decrease in the rate of rescues (IRR:0.52; 95%CI:0.37-0.73). Similar results were observed in Division One from Surfline near shore wave estimates. Using Surfline estimates, rescue rates increased by a factor of 1.94 for every foot of increasing wave height under five feet, but decreased significantly when near shore wave height was estimated at over five feet (95%CI: 1.67-2.24).

The joint test of coefficients for interaction between water level and division was statistically significant: the effect of water level on rescue occurrence varied between the operational divisions in the study location ($p<0.001$). In Division 1, lifeguards tended to make fewer rescues as water level increased: a one-foot increase in tidal water level was associated with a 26% decrease in rescue rate (IRR:0.74; 95%CI:0.69-0.79). The estimated effect of tidal water level in Division 2 was similar to that of Division 1, but the opposite effect was observed in Division 3, where rescue rate increased as water level increased. A one-foot increase in water level in Division 3 was associated with 1.37 times as many rescues (95%CI:1.123-1.53).

For the water level direction model, IRR estimates showed that hours with rising water level experienced increased rescue frequency in Division 1 and Division 2, but rising vs. falling water level had no role in explaining varying rescue rates in Division 3. In Division One, the rescue rate was 2.03 times greater during hours with rising water level compared to those hours with falling water level (95% CI:1.66–2.47). Division 2 also pointed to increased rescue frequency on rising water level, and, although statistically insignificant, estimates for hours with rising water level in Division 3 indicated decreased rescue frequency.

2.4 DISCUSSION

In this retrospective cohort study using multivariate analysis of a linked dataset of CAD reported ocean lifeguard rescues and environmental variables, wave height, water level, and water level direction were associated with the rescue frequency. The effects of both water level and water level direction varied significantly by location.

We attempted to accommodate over dispersion in this data with the use of negative binomial regression, but high alpha parameters from all our models indicate other mechanisms were affecting rescue counts apart from the covariates we included. That these models did not account for most heterogeneity in the data is not surprising; the failure to fully attribute rescues to a few environmental factors points out the need to collect additional data in the beach environment. Our data and subsequent models did not include information on person factors or on the cause or type of rescue (assist versus critical). Person factors such as age, race, residency, swimming ability, or activity at time of rescue may explain additional variability in the data, and warrant further investigation. Although this excess heterogeneity limits our ability to explain the effects of these environmental variables on rescue frequency, this analysis contributes new information in this understudied field.

Our finding that wave height was statistically associated with rescue frequency conflicts with results reached by Morgan and Ozanne-Smith, who found no association between wave height and rescues in their study from Victoria, Australia, and hypothesized bathers at increased risk for rescue had relatively more frequent water exposure during times with smaller waves when conditions appeared safer.(8) The differences in results may be due to systematic differences in beach use by the study populations or environmental conditions in their respective locations, and points to limits in generalizability for research involving environmental variables and rescue frequency.

In Newport Beach, both the NOAA open water buoy estimates and Surfline visual near-shore estimates demonstrated a concave relationship between rescues and wave height, implying some factor or combination of factors significantly alters the association and decreases the frequency of rescues in larger surf. Several plausible explanations for the observed change in rescue frequency from big waves can be hypothesized. During times with large surf, lifeguards may be more preventative and contact beach patrons before they enter the water; alternatively, beach patrons may self-limit their exposure to risk out of fear or due to the obvious change in environment from bigger surf, also postulated by Dusek et al. in an analysis of rip current rescues in North Carolina.(42)

The varying effect of water level and water level direction on rescue frequency in different locations of the study area is an important finding, and potentially related to human factors or oceanic processes undocumented in these data. For the purpose of this study, we focused on the effect environmental variables of interest had on rescue frequency regardless of other mechanisms on the causal pathway to rescue, such as rip currents, shore-break, inshore holes, or sand bars. Better records of these processes may explain variability in rescue frequency, and would be valuable to future prevention and community education efforts.

These data show rescue frequency decreased at higher water levels in Division 1 and Division 2, but increased with higher water levels in Division 3. Previous research on rip current activity has documented rip velocity (and subsequent risk to bathers) increases at lower tidal water levels,(23) leading us to hypothesize that lifeguards in Division 1 and Division 2 made more rescues because of rip currents, but that some other causal process was operating in Division 3. The variance among the three geographic locations may be partly explained by human factors related to the population that frequents Division 3. Anecdotal information provided by lifeguards suggest that people who go to the beach in Division 3 are generally less water competent and may have lower swimming ability compared to those who visit other parts of the beach. A large parking lot makes access easy in this location, and there are generally smaller waves in this area due to the Newport Harbor jetty. The statistical association between increased rescue rates and higher water levels in Division 3 may be related to a non-swimming population confronted with deeper water in swim areas during higher tidal water levels.

Results from the water level direction model raise similar questions. We included this factor in our analysis because it is a common belief among Californian lifeguards that falling water levels are associated with currents pulling away from the beach and increase the likelihood and strength of rip currents, and ultimately the frequency of rescues. Conflicting with both lifeguard axiom and the current body of knowledge on rip currents, rising water levels in these data played a statistically significant role in the variation of Division 1 rescue frequency, but had no influence on rescue frequency in Division 2 or Division 3. That the direction of water levels would be statistically associated with rescue occurrence in one location and not others is surprising, and further points to other unmeasured determinants of rescue and limitations in generalizability.

These findings have practical implications for lifeguard operations. Evidence for increased rescue frequency in certain environmental conditions allows lifeguard supervisors to appropriately staff the beach and allocate resources for times when rescue occurrence may be greater. This information can also be used to train new lifeguards to more accurately and consistently communicate levels of risk to the public. Although specific estimates of association between environmental variables and rescue frequency identified in this study may not be generalizable to other beaches, operational and training implications of the findings may be of value to lifeguard training and response in other settings.

While the covariates we included in this analysis were statistically associated with rescue frequency and advance our understanding of the determinants of ocean rescue, they primarily expose the breadth of what remains unstudied, mainly the person characteristics of those rescued by lifeguards. The statistically significant estimates and joint tests for interaction, along with high alpha parameters from this regression analysis, affirm our notion that the determinants of ocean rescue are many, and our analysis was only able to capture a piece of the larger and more complex process.

2.5 LIMITATIONS

In addition to the parametric model constraints previously described, the study has several limitations. The total effect of environmental variables on rescue frequency observed in these data was modified according to division within the study location, signifying that inference from a particular section of beach should be generalized with caution to the entire study location or other beaches. This study is also limited in its generalizability to other locations where lifeguard services vary considerably in training requirements and operational activity.

Results from this analysis are limited by the measurements from various data collection systems used. We used the mean wave height measurement from three different NOAA buoys with varying depths and distances from shore. The NOAA wave height measurement does not represent swell interaction with the beach environment, a critical component of wave height and behavior in the surf zone. Future research using modeled near-shore wave height data for the study location would allow for increased accuracy for estimates of the relationship, and potentially prediction that could be used for operational purposes.

Using a more reliable population count over a proxy measurement for beach attendance may also improve modeling of environmental variables effect on rescue frequency. While not an ideal measure of population, using public contacts provided for a proxy indicator that could be allocated by division and by hour, and were assumed to be a more reliable indicator than visual estimates made by lifeguards. Estimating the number of people on a highly populated beach is very difficult; previous research has shown that agencies tend to overestimate beach visitation.(43) Future research should also consider use of a more accurate count of bather exposure, as opposed to general beach population.

Lastly, the study period occurred during El Niño years in which water temperatures were unusually warm throughout the winter months, and rain and thunderstorms occurred during the typically dry summer months. However, as climate change continues to alter global weather and ocean patterns, so does the risk for ocean bathers. Continued data collection and analysis are important to establish long-term trends in ocean lifeguard activities.

2.6 CONCLUSION

We successfully linked CAD reported lifeguard rescue data with other data systems to evaluate the effect of several water related environmental variables on the occurrence of ocean rescue. Wave height, tidal water level, and, the water level direction in one section of beach, were associated with rescue frequency. Importantly, heterogeneity unaccounted for by the covariates in multivariate regression was present, indicating other factors are important determinants of ocean rescues. Ascertaining why lifeguards are rescuing people from the water is paramount for efforts that aim to reduce these incidents. Identification of the multiple factors leading to rescue, especially those related to person characteristics, should be a priority for the lifesaving and injury prevention community.

REFERENCES

1. Global Report on Drowning: Preventing a Leading Killer. Geva, Switzerland: World Health Orginization, Prevention VaI; 2014.
2. Quan L, Bennett E, Moran K, Bierens JJLM. Use of a consensus-based process to develop international guidelines to decrease recreational open water drowning deaths. International Journal of Health Promotion and Education. 2012;50(3):135-44.
3. Hossain J, Mecrow T, Wills S, Willims D, Rahman A, Rahman F. 818 Effectiveness of seasafe lifeguard services in cox's bazar beach Bangladesh. Injury Prevention. 2016;22(Suppl 2):A292-A3.
4. Jeong J, Hong KJ, Shin SD, Ro YS, Song KJ, Lee EJ, et al. Relationship between drowning location and outcome after drowning-associated out-of-hospital cardiac arrest: nationwide study. The American Journal of Emergency Medicine. 2016;34(9):1799-803.
5. Branche M, Steward S, Koplan J, Binder S. Lifeguard effectiveness: A report of the working group. Atlanta, GA: Centers for Disease Control and Prevention, National Center for Injury Prevention and Control, 2001.
6. Szpilman D, Tipton M, Sempsrott J, Webber J, Bierens J, Dawes P, et al. Drowning timeline: a new systematic model of the drowning process. Am J Emerg Med. 2016;34(11):2224-6.
7. Harada SY, Goto RS, Nathanson AT. Analysis of lifeguard-recorded data at Hanauma Bay, Hawaii. Wilderness Environ Med. 2011;22(1):72-6.
8. Morgan D, Ozanne-Smith J. Surf lifeguard rescues. Wilderness Environ Med. 2013;24(3):285-90.
9. Williamson A. Feasibility study of a water safety data collection for beaches. J Sci Med Sport. 2006;9(3):243-8.
10. City of Newport Beach Marine Operations Division [cited 2017 April 22]. Available from: http://www.newportbeachca.gov/government/departments/fire-department/marine-operations-division.
11. Wickham H, Francois R. dplyr: A Grammar of Data Manipulation. 2016.
12. R Core Team. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing 2016
13. RStudio. RStudio: Integrated Development Environment for R. Boston, MA2016.
14. Wickham H. ggplot2: Elegant Graphics for Data Analysis. New York: Springer-Verlag; 2009.
15. Kahle D, Wickham H. ggmap: Spatial Visualization with ggplot2. The R Journal. 2013;5(1):144--61.
16. Kulldorff M. SaTScan: Software for the spatial, temporal, and spacetime scan statistics. 9.4.4 ed: Information Management Services Inc.; 2016.
17. Kulldorff M. A spatial scan statistic. Commun Stat-Theor M. 1997;26(6):1481-96.
18. Kulldorff M. SaTScan user guide. Boston: SaTSacan; 2015.

19. Fricker T, Dix D. Exploring the effect of lifeguard prevenative actions on beach safety. Poole, United Kingdom: Royal National Lifeboat Institute, Unit ROR; 2015 Research Project ID: 15-16.
20. Morgan D, Morgan D, Ozanne-Smith J. Surf Bather Drowning Risk and Exposure-Related Factors Identified by an Expert Panel. International Journal of Aquatic Research and Education. 2012;6(4):336-49.
21. Blay C. Drowning Deaths in the Nearshore Marine Waters of Kauai, Hawaii 1970-2009. International Journal of Aquatic Research and Education. 2011;5(3):284-324.
22. Short AD, Hogan CL. Rip Currents and Beach Hazards: Their Impact on Public Safety and Implications for Coastal Management. J Coastal Res. 1994:197-209.
23. Castelle B, Scott T, Brander RW, McCarroll RJ. Rip current types, circulation and hazard. Earth-Sci Rev. 2016;163:1-21.
24. United States Lifesaving Association. Rip Currents: United States Lifesaving Associaiton [cited 2017 May 3]. Available from: http://www.usla.org/?page=RIPCURRENTS.
25. Klein A, Santana G, Diehl E, De Menezes J. Analysis of hazards associated with sea bathing: Results of five years work in oceanic beaches of Santa Catarina State, southern Brazil. J Coastal Res. 2003:107-16.
26. Scott T, Russell P, Masselink G, Wooler A, Short A. Beach Rescue Statistics and their Relation to Nearshore Morphology and Hazards: A Case Study for Southwest England. J Coastal Res. 2007:1-6.
27. Lascody RL. East Central Florida Rip Current Program. National Weather Digest. 1998;22(2):25-30.
28. Short AD. Beach hazards and safety. In: Short AD, editor. Handbook of beach and shoreface morphodynamics. Chichester, United Kingdom: John Wiley & Sons; 1999. p. 293-304.
29. Puleo JA, Hutschenreuter K, Cowan P, Carey W, Arford-Granholm M, McKenna KK. Delaware surf zone injuries and associated environmental conditions. Natural Hazards. 2016;81(2):845-67.
30. United States Lifesaving Association. Open Water Lifesaving: The United States Lifesaving Association Manual, Third Eddition. Brewster BC, editor. New York, New York: Pearson Education, Inc.; 2017.
31. Surf Life Saving Australia. Public safety and aquatic rescue, 34th Edition. Chatswood, NSW Australia: Reed International Books Australia Pty Ltd; 2016.
32. Brander RW, Short AD. Morphodynamics of a large-scale rip current system at Muriwai Beach, New Zealand. Mar Geol. 2000;165(1-4):27-39.
33. Austin MJ, Masselink G, Scott TM, Russell PE. Water-level controls on macro-tidal rip currents. Cont Shelf Res. 2014;75:28-40.
34. Lushine JB. A study of rip current drownings and related weather factors. National Weather Digest. 1991;16(3):13-9.

35. Salvador AF, Penteado R, Lisboa FD, Corvino RB, Peduzzi ES, Caputo F. Physiological and metabolic responses to rescue simulation in surf beach lifeguarding. Journal of Exercise Physiology Online. 2014;17(3):21.
36. MacMahan J, Reniers A, Brown J, Brander R, Thornton E, Stanton T, et al. An Introduction to Rip Currents Based on Field Observations. J Coastal Res. 2011;27(4):Iii-Vi.
37. Cameron AC, Trivedi PK, Hammond P, Holly A. Regression Analysis of Count Data. Trivedi PK, Hammond P, Holly A, editors. Cambridge: Cambridge : Cambridge University Press; 1998.
38. Greenland S, Pearl J, Robins JM. Causal Diagrams for Epidemiologic Research. Epidemiology. 1999;10(1):37-48.
39. Textor J, Hardt J, Knuppel S. DAGitty: a graphical tool for analyzing causal diagrams. Epidemiology. 2011;22(5):745.
40. StataCorp. Stata Statistical Software: Release 14. College Station, TX: StataCorp LP; 2015.
41. Hilbe JM. Negative binomial regression. 2nd ed. Cambridge, UK ; New York: Cambridge University Press; 2011. xviii, 553 p. p.
42. Dusek G, Seim H, Hanson J, Elder D. Analysis of Rip Current Rescues at Kill Devil Hills, North Carolina. In: Leatherman SP, Fletemeyer JR, editors. Rip currents : beach safety, physical oceanography, and wave modeling. Boca Raton: Boca Raton : CRC Press; 2011.
43. King P, McGregor A. Who's counting: An analysis of beach attendance estimates and methodologies in southern California. Ocean and Coastal Management. 2012;58:17-25.

APPENDIX A: DATA LINKAGE AND VARIABLE DESCRIPTION

The dataset linkage was an exact deterministic process. We created a dataset with three records (one each for Division 1, Division 2, and Division 3) for every hour between 7:00AM and 8:00PM, for 2015 and 2016; a total of 28,509 records. We filtered Lifeguard CAD data to contain only rescues and public contact interventions, summarized the counts for each intervention by hour and division, and linked to the corresponding hour and division combination in the dataset.

Weather Variables

The National Weather Service and Federal Aviation Administration collect weather data from an Automated Surface Observing System (ASOS) at John Wayne (Orange County) airport that is accessible from weatherunderground.com.[1] The weather station is approximately 9.5 kilometers from the Newport Beach Lifeguard Headquarters building. We linked historical data for the following weather variables: wind speed, wind direction, precipitation, and weather conditions (clear, cloudy, overcast, fog, rain, thunderstorm, etc.). We summarized weather data by hour, calculating the mean of continuous variables and taking the mode of categorical variables. We linked weather data to each record by hour.

NOAA Tidal Water Level Data

NOAA sensors at the mouth of the Los Angeles Harbor (Station ID: 9410660) measure water level (e.g., tidal elevation) every six minutes, and is available from the NOAA Tides and

---

[1] Weather Underground. Weather History for KSNA: John Wayne- Orange County [Interactive Historical Weather Database]. Available from Weather Underground website: https://www.wunderground.com/history/airport/KSNA/

Currents website.[2] We offset the measurements to represent conditions near the Balboa Pier in Newport Beach, and calculated mean water level measurements for each hour in the study period. For water level direction (rising vs. falling), we calculated the slope (difference) between each hour's mean water level and the preceding hour's mean water level; positive numbers indicated hours with a rising tide and negative numbers indicated hours with a falling tide. We linked hour-mean water level and categorical water level direction to the dataset by hour.

NOAA Wave Data

NOAA collects wave and other ocean condition data from three offshore buoys near the study location: Buoy 46253 – San Pedro South, Buoy 46242 - Camp Pendleton, and Buoy 46224 – Oceanside. Historical data is available from the National Data Buoy Center.[3] We calculated the mean of hourly measurements for wave height, average wave period, and wave direction from the three buoys, and averaged them for a single hour-mean combined variable. We calculated a new wave direction variable from the acquired measurements. Previous research indicates rip current likelihood, and by association rescue frequency, is associated with incident wave direction relative to the local coastline orientation.[4, 5] A localized incident wave direction relative to shore-normal variable was calculated for each division by subtracting that division's coastline orientation from buoy wave direction, resulting in a measurement of wave direction angle relative

---

[2] NOAA Tides and Currents. Water Levels for 9410660 , Los Angeles CA [Interactive Dataset of Historical Water Levels]. Available from NOAA Tides and Currents website: https://tidesandcurrents.noaa.gov/waterlevels.html?id=9410660

[3] NOAA National Data Buoy Center. [Historical Water Levels]. Available from NOAA Tides and Currents website: http://www.ndbc.noaa.gov/

[4] Dusek G, Seim H, Hanson J, Elder D. Analysis of Rip Current Rescues at Kill Devil Hills, North Carolina. In: Leatherman SP, Fletemeyer JR, editors. Rip currents : beach safety, physical oceanography, and wave modeling. Boca Raton: Boca Raton : CRC Press; 2011.

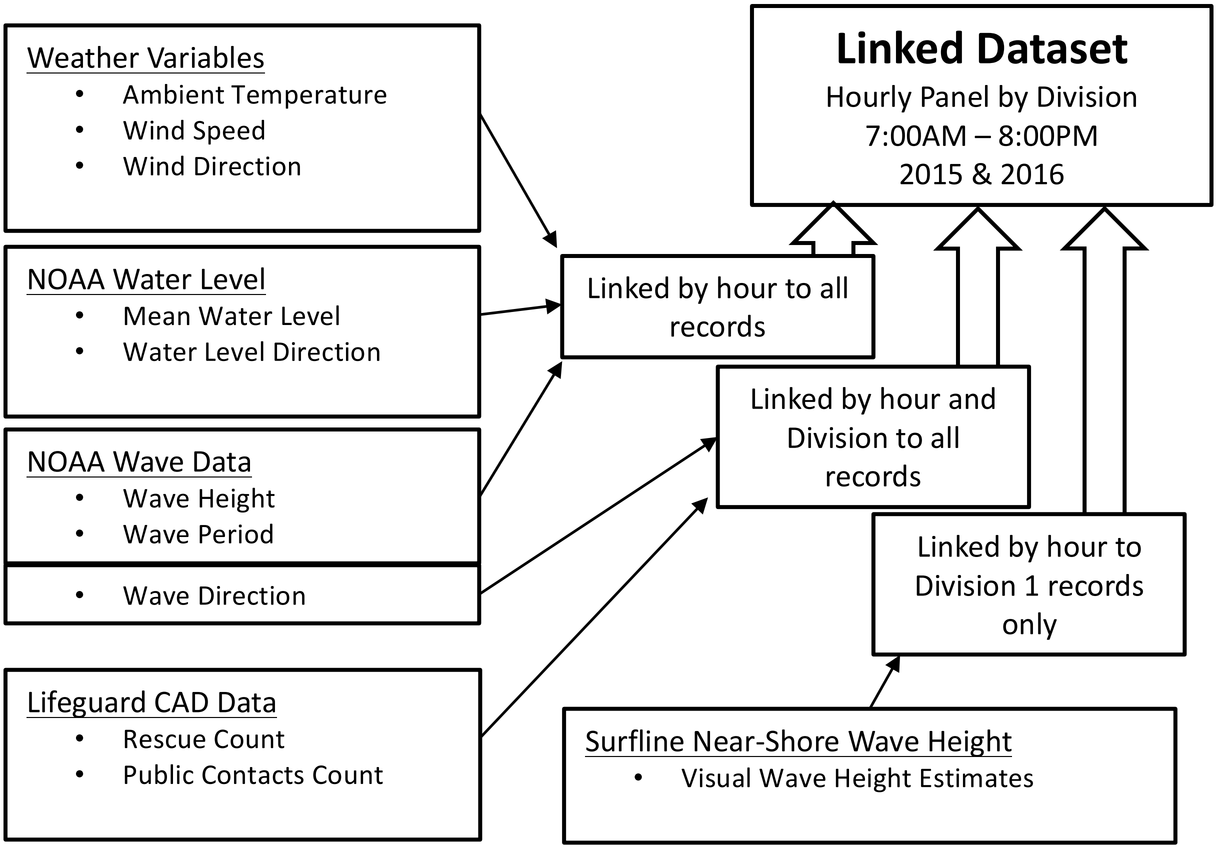
[5] Svendsen IA, Haas KA, Zhao Q, editors. Analysis of rip current systems. Coastal Engineering 2000 - Proceedings of the 27th International Conference on Coastal Engineering; 2000.

to that section of beach. Wave height and wave period were linked to each record by hour. We linked wave direction relative to shore-normal to each record by hour and division.

Surfline Near-shore Visual Wave Estimates

Professional Surfline wave forecasters record visual estimates of near-shore wave height once per day in person, or via fixed cameras, at two locations in the lifeguard Division 1 area of Newport Beach. Surfline approved use of historical data for this study. We calculated the average of the two measurements, and linked to the dataset for lifeguard rescues occurring in Division 1, using the daily Surfline estimate for all hours for that day.

Data Linkage Process



APPENDIX B: MULTIVARIATE REGRESSION ANALYSIS RESULTS

NOAA Wave Height Model

	IRR	Std. Err.	Z	P>|z|	95% CI
Constant	0.0000438	0.0000198	-22.16	0.000	0.000018 - 2.144579
NOAA Wave Height < 4 Feet	3.256116	0.2165039	17.75	0.000	2.858263 - 3.709347
NOAA Wave Height > 4 Feet	0.5178226	0.916532	-3.72	0.000	.3660333 - 0.732557
Wind Speed (MPH)	1.08418	0.0157299	5.57	0.000	1.053784 - 1.115453
Water Level	0.6810103	0.0587985	-4.45	0.000	0.574990 - 0.80657
Shore-Normal Wave Direction	0.9803506	0.0020793	-9.36	0.000	0.976283 - 0.984434
Wave Period[*]	1.35466	0.0375562	10.95	0.000	1.283015 - 1.430305
Wind Direction - None	0.684193	0.4063188	-0.64	0.523	0.2136384 - 2.19118
Wind Direction – East	0.3176742	0.1685857	-2.16	0.031	0.11226 - 0.898884
Wind Direction – North East	0.4918465	0.244247	-1.43	0.153	0.185835 - 1.30175
Wind Direction – North West	0.6001865	0.3383724	-0.91	0.365	0.198791 - 1.81207
Wind Direction – South East	0.689375	0.2882267	-0.89	0.374	0.303787 - 1.56437
Wind Direction – South West	1.247162	0.2401066	1.15	0.251	0.855160 - 1.81885
Wind Direction - South	0.8494718	0.1822159	-0.76	0.447	0.557907 - 1.29340
Wind Direction - Variable	0.7174967	0.1489496	-1.60	0.110	0.477654 - 1.0777
Wind Direction - West	1.45648	0.2875267	1.90	0.057	0.989161 - 2.14457
Ln(alpha)	1.700543	.0326615	52.07	0.000	1.63652 - 1.76455
Random Intercept: Division	0.0883756	0.2566612			0.00029 - 26.2059
Random Intercept: Division, Month	2.237327	0.7027516			1.20882 - 4.14089
Random Intercept: Division, Month, Day of Week	0.568168	0.1039864			0.396907 - 0.81332

Joint Test for interaction: NOAA Wave Height < 4 Feet, NOAA Wave Height > 5 Feet
Chi^2[2]: 318.01 Prob > Chi^2: <0.0001

---

[*] Reference Variable: Wind Direction - North

Surfline Wave Height Model

	IRR	Std. Err.	Z	P>|z|	95% CI
Constant	.0002601	0.0001665	-12.89	0.000	0.000074 - .000912
Surfline Wave Height < 5 Feet	1.937049	0.1437036	8.91	0.000	1.674914 - 2.240209
Surfline Wave Height > 5 Feet	0.1715919	0.0865365	-3.50	0.000	0.06385 -0.461074
Wind Speed (MPH)	1.107164	0.0231915	4.86	0.000	1.06263 - 1.153564
Water Level	0.4575829	0.0576776	-6.20	0.000	0.357418 - 0.585817
Shore-Normal Wave Direction	0.9974541	0.0029657	-0.86	0.391	0.991658 - 1.00328
Wave Period	1.351299	0.0576202	7.06	0.000	1.242956 - 1.469086
Wind Direction - None[†]	1.304995	0.9902836	0.35	0.726	0.294905 - 5.77477
Wind Direction – East	1.07e-09	7.88e-06	-0.00	0.998	0 - .
Wind Direction – North East	0.6670203	0.4245611	-0.64	0.525	0.191578 - 2.32237
Wind Direction – North West	0.4389276	0.4322992	-0.84	0.403	0.063686 - 3.02510
Wind Direction – South East	0.8148989	0.4598959	-0.36	0.717	0.2696001 - 2.46313
Wind Direction – South West	1.683277	0.4770693	1.84	0.066	0.965852 - 2.93359
Wind Direction - South	1.014525	0.322005	0.05	0.964	0.544623 - 1.88986
Wind Direction - Variable	1.046459	0.3177565	0.15	0.881	0.577105 - 1.89753
Wind Direction - West	1.880822	0.5487047	2.17	0.030	1.061747 - 3.331765
Ln(alpha)	1.633909	0.0466585	35.02	0.000	1.54246 - 1.725358
Random Intercept: Month	2.59708	1.163153			1.079589 - 6.247589
Random Intercept: Month, Day of Week	0.4913267	0.1422614			0.278553 - 0.866626

Joint Test for interaction: Surfline Wave Height < 5 Feet, Surfline Wave Height > 5 Feet
$Chi^2[2]$:79.47 Prob > Chi^2: <0.0001

[†] Reference Variable: Wind Direction - North

Water Level Model

	IRR	Std. Err.	Z	P>|z|	95% CI
Constant	0.0900224	0.0512157	-4.23	0.000	0.029517 - 0.274547
Water Level (Feet)	0.7433965	0.0277984	-7.93	0.000	0.690861 - 0.799926
Division - 2‡	0.5138049	0.09235	-3.70	0.000	0.36124 - 0.730787
Division - 3‡	0.026611	0.006653	-14.50	0.000	0.016301 - 0.043440
Water Level * Division 2§	1.049447	0.0555643	0.91	0.362	0.946003 - 1.16420
Water Level * Division 3§	1.84478	0.1241844	9.10	0.000	1.61675 - 2.10496
Ln(alpha)	2.016442	.0310664	64.91	0.000	1.95555 - 2.07733
Random Intercept: Month	3.582436	1.55411			1.530789 - 8.383811
Random Intercept: Month, Day of Week	0.6759126	0.163773			0.420383 - 1.08676

Joint Test for Interaction: Water Level * Division
$Chi^2[2]$:89.25 Prob > Chi^2: <0.0001

---

‡ Reference Group: Division 1
§ Interaction Term, Reference Group: Water Level * Division 1

Rising vs. Falling Water Level Model

	IRR	Std. Err.	Z	P>|z|	95% CI
Constant	0.0265503	0.0139685	-6.90	0.000	0.009467 - 0.074455
Water Level Direction - Rising[**]	2.025811	0.2061587	6.94	0.000	1.659494 - 2.47299
Division - 2[††]	0 .7607795	0.0872003	-2.39	0.017	0.607707 - 0.952408
Division - 3[††]	0.325522	0.0440343	-8.30	0.000	0.249709 - 0.424350
Water Level Direction * Division 2[‡‡]	0.6587868	0.099054	-2.78	0.006	0.490636 - 0.884565
Water Level Direction * Division 3[‡‡]	0.4563771	.0830553	-4.31	0.000	0.319458 -0.651977
Ln(alpha)	2.028434	.0311523	65.11	0.000	1.96737 - 2.08949
Random Intercept: Month	3.105827	1.356992			1.31908 - 7.31278
Random Intercept: Month, Day of Week	0.6611475	0.1591327			0.4124974 1.059682

Joint Test for Interaction: Water Level Direction * Division
Chi^2[2]:20.14 Prob > Chi^2: <0.0001

[**] Binary Categorical Variable, Reference Group: Water Level Direction - Falling
[††] Reference Group: Division 1
[‡‡] Interaction Term, Reference Group: Water Level Direction * Division 1