Exploring the relationship between tidal stage and surf beach fatal drowning

A report prepared for the Smart Beaches Project

This report describes preliminary results from research exploring relationships between various elements of the ocean tidal cycle with the occurrence of fatal drowning on surf beaches in Australia. The findings indicate lower water levels and times around low tide are statistically associated with the occurrence of fatal drowning on surf beaches, while phase of the tide (rising versus falling water levels) is not. This new evidence will aid decision-makers responsible for beach safety by enabling them to more accurately manage beachgoer risk and prepare for times when surf beach drowning events are more likely to occur.

1. Summary

Surf beaches are open-ocean beaches characterised by waves breaking across a wide zone (surf zone) and are ubiquitous features along the Australian coast. At surf beaches, both environmental and person-based factors contribute to risk, most likely in a synergistic fashion. Environmental hazards on surf beaches include breaking waves, dangerous shore breaks, large waves, surging waves, alongshore and rip currents, strong backwash off the beachface and tidal currents associated with tidal inlets. Person-based factors include swimming ability, choice of swim location, knowledge of surf hazards, beach behaviour and presence/absence of lifeguards.

Historically, ocean lifeguards and risk managers have relied on various elements of the tidal cycle to make decisions related to lifeguard operations and public safety. Ocean Live brought this concept to the fore with the development of an innovative application using this concept to communicate risk to beach goers using a straight forward traffic light system. Variation in water levels and tidal phases have been thought to pose risk to bathers both directly, through changing water depth, and indirectly via their association with other surf zone hazards, such as rip currents and waves. Rip currents are strong, narrow seaward flows that are considered the main hazard to ocean swimmers and bathers. They are fundamentally driven by the action of breaking waves, the intensity of which typically increases at lower water depths.

Although frequently used in lifeguard decision-making and other beach safety prevention efforts, there is little quantitative evidence that variations in tidal

Photo: Smart Beaches

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water levels, or the tidal cycle, actually results in increased occurrence of drowning or rescue.
Beach safety researchers from UNSW Sydney and managers of the Smart Beaches Project, in collaboration with Surf Life Saving Australia (SLSA), developed a series of hypotheses to evaluate if various elements of the tidal cycle were related to the occurrence of fatal drowning at surf beaches in Australia.

Fatal surf beach drowning incidents that occurred between 1 July 2004 - 30th June 2019 were extracted from SLSA's Coastal Fatality Database (n=558) and were linked by time and location to tidal data collected by the Australian Bureau of Meteorology (BoM). Tidal variables thought to impact swimmer risk, were calculated and tested to determine if statistical relationships existed between those variables and the incidence of fatal surf beach drowning.

This study provides evidence that lower water levels in a particular tidal cycle are associated with the occurrence of fatal drowning on surf beaches. A separate, but similar, evaluation found a statistical relationship between fatal drowning and a time window of hours around low tide. However, no relationship was found that linked the 'direction' of the tide (*i.e.* whether water levels were rising [flood] or falling [ebb]) with the occurrence of fatal drowning on surf beaches in Australia.

1.1 Research aim and objective

The aim of this study was to explore if a statistical relationship exists between fatal surf beach drowning in Australia and the stage of the tides. Specific objectives of this work were to:

1. Conduct statistical analysis to verify or refute a set of hypotheses in relation to the association between tidal variables and fatal surf beach drownings.
2. Advise the Smart Beaches Program on the nature and strength of statistical relationships, should any exist.
3. Produce a report of the analysis conducted.

The core of this research study, its aim and objectives, lies in the Smart Beaches' initiative to increase safety and improve public amenity through the use of cutting-edge technology. By better understanding the relationship between tides and fatal drowning, Smart Beaches will be able to more accurately apply real-time and predicted tidal measurements to future risk management decision-making aids.

Photo: Unsplash / Nick Dietrich

2. Methods and approach

Research questions to evaluate tidal variables commonly believed to be associated with increased risk at beaches were developed. The research questions, their popular hypotheses common in beach safety or lifeguard communities and results of the subsequent analyses are presented in detail in Section 3.

Question 1

Is the tidal phase associated with fatal drowning?

Phase of the tide refers to the stages of the tidal cycle where water levels are rising (incoming / flood tide), falling (outgoing / ebb tide), or turning from one to the other. This research question examines whether fatal drownings on surf beaches are more likely to occur in one phase over others.

Photo: Smart Beaches

Question 2

Is tidal water level associated with fatal drowning?

Tidal water levels refer to the elevation in meters of the ocean water at any given time, which changes throughout the day due to rise and fall of the tide. This question seeks to evaluate if surf beach drowning events increase with lower or higher water levels.

Photo:Ocean Live / Dean Harrigan

Question 3

Is there a relationship between fatal drowning and time-based elements of the tidal cycle?

This research question evaluated if certain temporal aspects of the tide were associated with increased likelihood of drowning on surf beaches. This research question was broken into multiple parts to explore potential associations between temporal aspects of the tidal cycle, specifically the time around low tide, and surf beach drowning events.

Question 4

Is fatal drowning associated with range of the tidal cycle? Does the relationship change with phase?

Range of the tidal cycle refers to the difference in elevation between the beginning and end of one phase of the tide. This is essentially the distance in meters between low and high tide, regardless of phase (rising or falling water levels). Tidal ranges vary according to cycles of the moon and sun, and thus are not the same every day. This research question seeks to understand if a relationship exists between larger or smaller ranges and drowning events on surf beaches, and if that relationship is influenced by the phase.


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2.1 Availability of surf beach drowning data

The SLSA Coastal Fatality Database includes information on every coastal fatality occurring in Australia between 1 July 2004 - 30th June 2019. Data on each fatality is curated from media sources and lifeguard reports when available, and validated with information from the National Coronial Information System (NCIS). This study included the 558 surf beach drownings with reliable timestamps to which tidal data could be matched. Surf beach drowning deaths were defined based on a series of decision rules including; i) the location had to be an open ocean surf beach (*i.e.* not within bays – including Port Philip Bay in Victoria, harbours, estuaries and other environments protected from ocean wave activity) that was confirmed by visual inspection of each site on Google Earth; and ii) involved in beach recreation activities as opposed to boating or personal water craft use, falls or jumps into water, land or rock-based fishing, non-aquatic transport, and SCUBA diving.

2.2 Measures of tidal variables

Tidal variables were calculated from hourly time measurements of tidal water levels obtained from 94 different tidal stations around Australia. Each surf beach drowning was linked to the tide measurement closest in time from the nearest available open ocean tidal station.

Phase of the tide was determined by comparing each hourly measurement to the measurement from the previous hour where a larger value of tidal stage indicated rising water levels (flood) and a smaller value indicated falling water levels (ebb). Hours with lower measurements in the immediately preceding and following hours were marked as being high tide, and hours with higher measurements in the immediately preceding and following hours were marked as being low tide.

As tidal ranges vary greatly around Australia, the tidal water levels for each hour were converted to the percent of that measurement's tidal range to allow comparison across multiple locations. Similarly, the mean tidal range for each location (tidal station) was calculated and used to standardize each tidal phase in the dataset, in order to identify if a tidal range was smaller, larger, or about the same as what could be considered 'normal' for that particular location.

2.3 Analysis

After defining the various tidal variables of interest, associations between those tidal variables and fatal drowning were analysed by fitting generalized linear mixed models in *R* [software program] using the *glmmTMB* package. This type of statistical model is helpful because it can provide estimates for the influence of the explanatory variables of interest, while also accounting for other factors that influence surf beach drowning. In addition to the variables of interest, the statistical models included information for time year, hour of day, and weekday versus weekend; and also included a 'mixed effects' term to account for the unknown variation between each of the different locations where tidal variables were recorded. By including this time, season, and location information, the models are able to test the relationship between the research variables of interest and surf beach drowning without the distortion of those other factors.

Photo: Taras Vyshnya

3. Key findings

This is one of the first studies to investigate the relationship between tides and drowning death in Australia. Lower tidal water levels and a specific window of time around low tide were shows to correlate with increased likelihood of fatal drowning on surf beaches in Australia (Figure 1). However, no relationship was found between fatal drowning and phase of the tide, other time related variables, and the range of the tidal cycle.

Results of specific research questions identified in Section 2 are presented below.

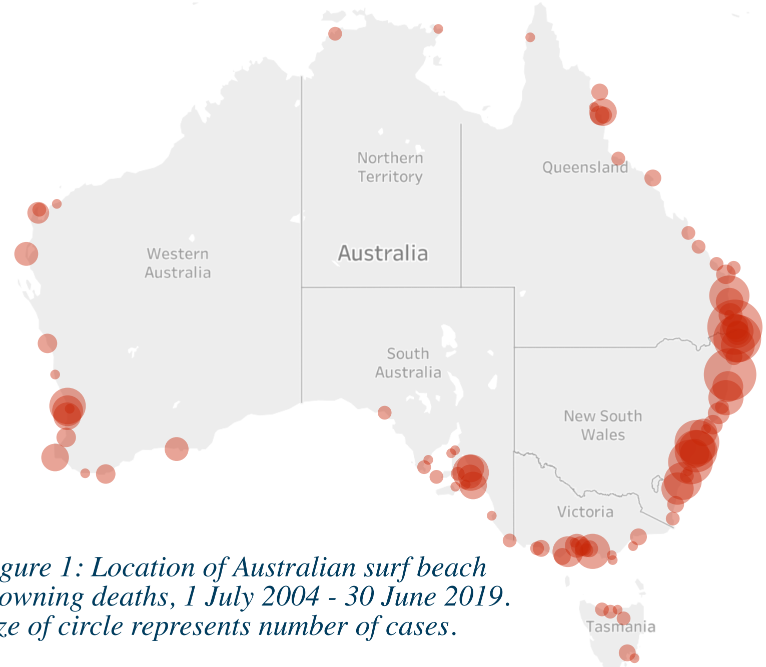


Figure 1: Location of Australian surf beach drowning deaths, 1 July 2004 - 30 June 2019. Size of circle represents number of cases.

3.1 Research questions, hypotheses and results

Question 1: *Is the phase of the tide associated with fatal drowning?*

This research question examined whether fatal drownings on surf beaches are more likely to occur on a particular phase of the tide, *i.e.* when the tide is falling or rising. This question sought to determine if variation in drowning rates could be explained by one of the four phases of the tide defined in the dataset (Figure 2). A popular hypothesis in beach safety and lifeguard communities is that outgoing (ebb) tides are more dangerous as rip currents are thought to flow faster during the outgoing tide, even though previous scientific studies have demonstrated that rip current strength and velocity are not the result of tidal forcing.

This analysis found no evidence of a statistical relationship between phase of the tide and fatal drowning on surf beaches.

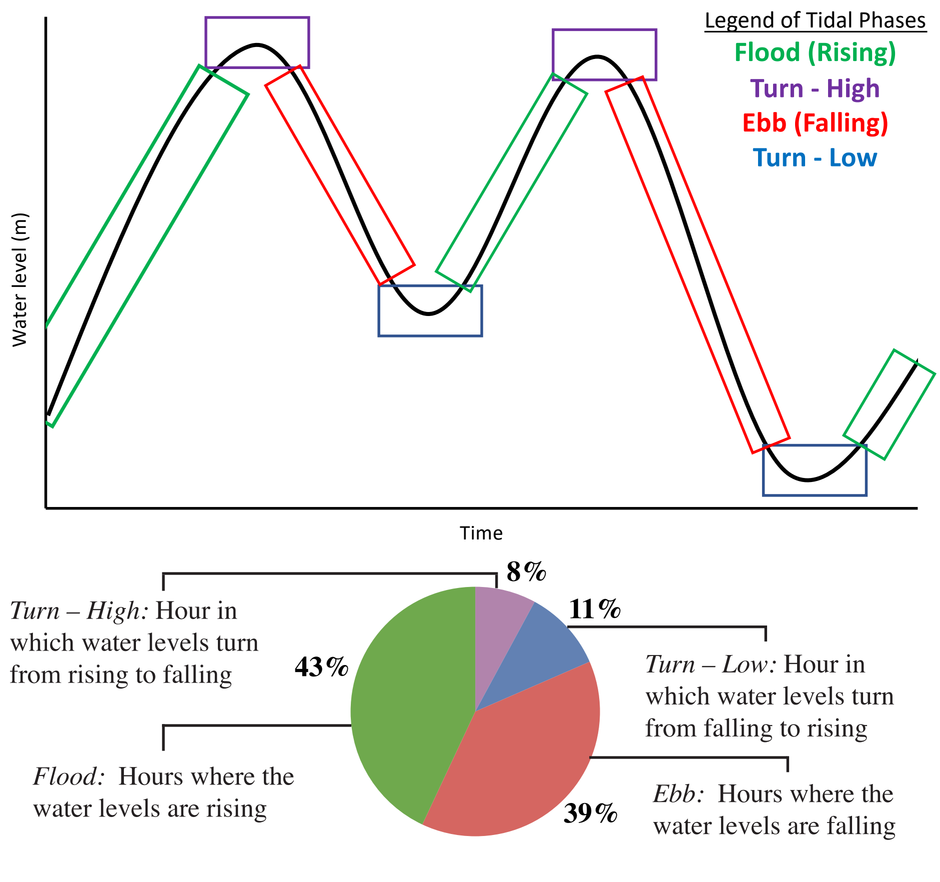


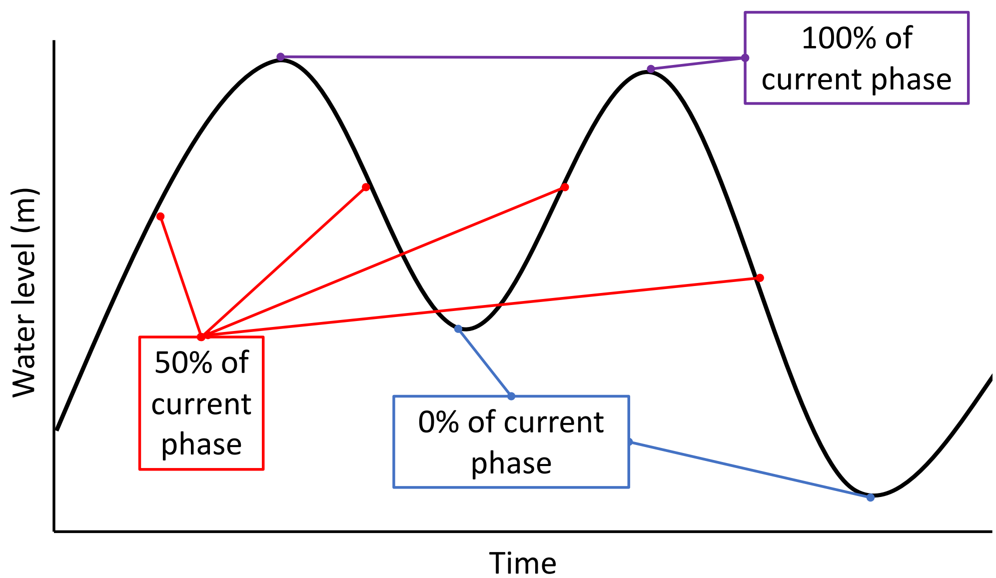
Figure 2: (Top) Phases of the tide represented on a tidal graph; (Bottom) Tidal phase definitions with percentage of fatal drownings occurring at each stage.

Question 2: *Is tidal water level associated with fatal drowning?*

This question evaluated the hypothesis that lower water levels are associated with an increased likelihood of fatal drowning on surf beaches. The model developed to evaluate this question used the proportion of the tidal cycle to standardize water levels across locations. This means that every water level, originally recorded in meters, was assigned a value between zero and one based on its tidal cycle, where zero was low tide and one was high tide.(Figure 3) This allowed for evaluation of the relationship between 'lower' and 'higher' water levels, relative to each location.

The majority (51%) of drowning events occurred at water levels less than 40% of their tidal cycle. About a quarter of drowning events (26%) occurred at water levels less than 10% of their tidal cycle, and one fifth (20%) occurred at water levels over 90% of their tidal cycle.

Further analysis shows there is evidence of a statistically significant association between fatal drowning and lower tidal water levels. Results indicate that fatal drowning at surf beaches are 26.7% more likely to occur during times when the tidal water levels are at low tide (0% of tidal phase) compared to high tide (100% of tidal phase), regardless of the actual water height in meters.



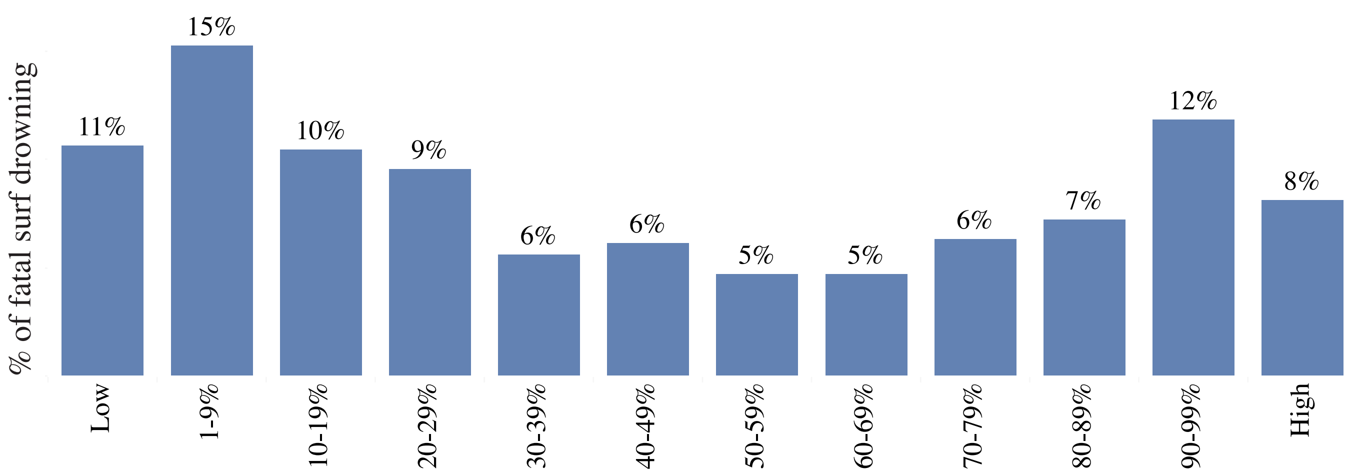


Figure 3: (Top) Visual representation of percentage of tidal cycle water levels; (Bottom) Percentage of fatal drowning events occurring in each group of tidal cycle percentages.

Question 3: *Is there a relationship between fatal drowning and time-based elements of the tidal cycle?*

This question examined if relationships exist between specific time intervals before or after low tide and the occurrence of fatal drownings. Figure 4 shows the percentage of drownings occurring in the hours before, after, and at low tide. Time of the tidal cycle is an especially useful factor for beach safety and prevention as it is predictable. Three separate models were developed to evaluate this relationship.

Time Model #1: *Trend*

The first time-based model evaluated for a trend between fatal drowning and the number of hours away from low tide. This model tested if the likelihood of fatal drowning on surf beaches increased or decreased as time approached and moved away from the low tide hour. While some in the beach safety community have hypothesized a convex relationship of increasing risk in times leading up to low tide and decreasing risk in times moving away from low tide, this analysis found no such trend.

There was no evidence for a linear association between fatal drowning and the number of hours before or after low tide.

Time Model #2: *Unrestricted*

The second time-based model removed the restriction that each hour relevant to low tide fit in a trend. Instead, this second model evaluated hours to or from low tide as their own individual categories, allowing the estimated associations to vary among each. A test of the overall effect of the hour categories evaluated if, when taken together, hours to or from low tide had any association with the occurrence of fatal drowning on surf beaches.

The second model was not statistically significant, indicating that individual hours before or after low tide were not associated with fatal drowning.

Time Model #3: *Window*

The third time-based model tested a hypothesis that a six-hour time window consisting of the hour in which low tide occurred, the three hours before, and the two hours after was associated with increased likelihood of drowning. Each measurement in the dataset was assigned either a "yes" or "no" depending on if it fit within the low tide time window. This hypothesis originated from a theory related to the 'Rule of Twelfths', an approach used in vessel navigation and sailing to estimate tidal water depths and guide a captain's decision to move into potentially shallow water. Applied to beach safety, the hypothesis suggests that, following the Rule of Twelfths, the defined time window represents the greatest change in tidal water elevation in each tidal cycle. Analysis of this question, and the pre-defined time window of three hours before and two hours after the low tide hour, was specifically requested by the Smart Beaches Project.

Results from this analysis indicate a statistically significant relationship between the low tide time window and fatal drowning. The likelihood of fatal drowning is increased during the low tide time window compared to times outside that time frame: fatal drownings are 1.21 times as likely to occur (21% more likely) in the low tide window.

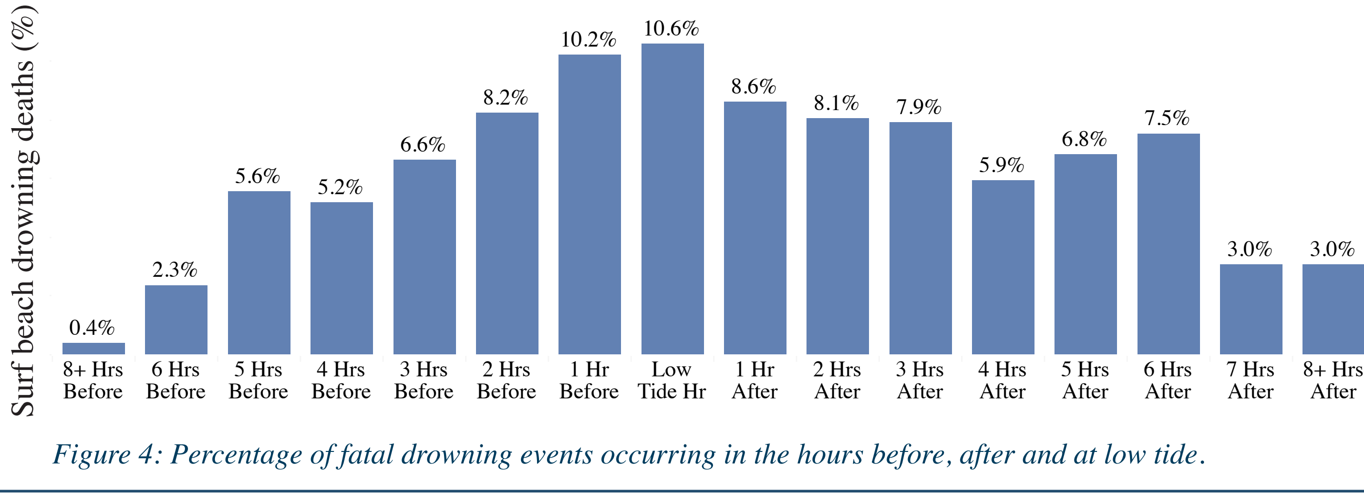


Figure 4: Percentage of fatal drowning events occurring in the hours before, after and at low tide.

Question 4: ***Is fatal drowning associated with range of the tidal cycle? Does the relationship change with phase?***

This question evaluated a two-part hypothesis: 1) That tidal cycles with large ranges are associated with drowning; and 2) that the effect of tidal range is more pronounced during the ebb tide, when water levels are falling. This hypothesis also addresses the commonly held belief among ocean lifeguards that time periods with large falling tides (Figure 5 - top) are more dangerous than other combinations of range and tidal phase, due to a presumption that rip currents flow faster and stronger off shore under these conditions.

To test this question, the statistical model included a measure that standardized the range of a given tidal cycle to the mean range of that location, allowing for comparisons across different locations where the size of tidal range varies. Additionally, the model included information on the phase (rising or falling as in Question 1) in a specific manner that evaluated if the relationship between range and fatal drowning changed depending on water levels were rising or falling.

The size of the tidal range was not associated with the occurrence of fatal drowning in this analysis. Furthermore, there was no evidence that phase modified the effect of tidal range on fatal drowning on surf beaches in Australia.

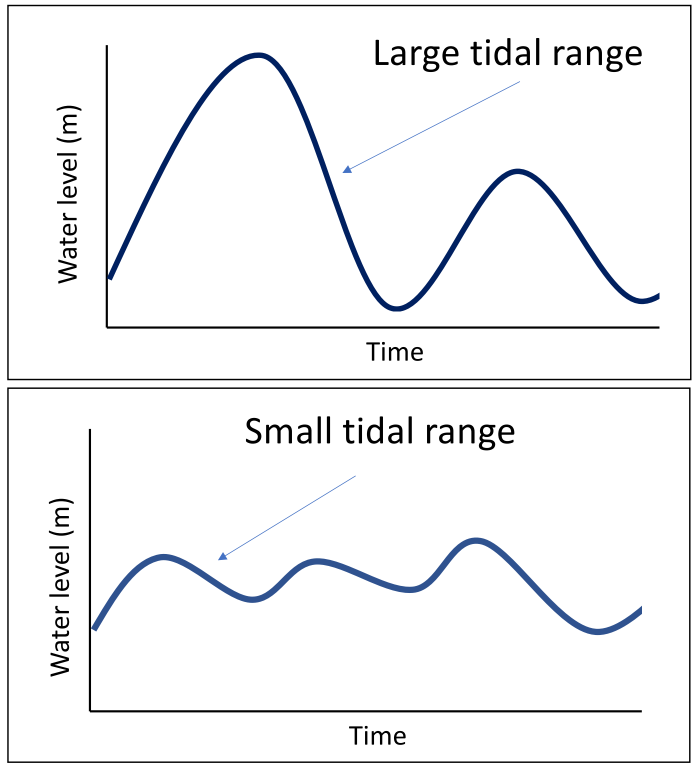


Figure 5: Visual representation of a large tidal range (top) and a small tidal range (bottom).

3.2 Limitations of the analysis

This study provides important evidence that some tidal factors are associated with increased likelihood of drowning. However, this analysis had several important limitations that should be noted along with the overall findings.

First, this analysis only evaluated tidal factors with the occurrence of fatal drowning, which is a rare event. The study did not include non-fatal drowning or rescues as these data are not readily available in a valid and reliable form suitable for finite analysis. Non-fatal drowning and rescues are also indicators of dangerous situations and would be helpful in evaluating a more holistic parametrisation of surf beach risk and relationships with different environmental variables. Collecting and managing high quality data on rescues and non-fatal drowning should be a priority for those working in beach safety.

Second, fatalities were linked to tide measurements from the nearest open water tidal station. It is possible that tide data in our dataset did not reflect precise conditions at the time of death, but the impact is likely minimal as the tidal measurements would differ on the order of minutes.

Lastly, this analysis evaluated tidal variables in isolation. It did not evaluate waves, water or ambient air temperature, beach type, human factors, or other elements which are known to influence risk of drowning on a surf beach.

This study provides important evidence that contributes to the understanding of risk on surf beaches by establishing that statistical *associations* exist between some tidal variables and the occurrence of fatal drowning. It does not, however, prove that these tidal variables *caused* the drowning, as the actual events were a combination of many factors.

4. Conclusions and future directions

This study contributes new understanding to the role that tides play in risk at surf beaches, providing evidence that lower water levels and a window of time around low tide were statistically associated with fatal drowning in these locations. The finding that a window of time around low tide was associated is not surprising, as this period essentially captures times with lower water levels. Additionally, this study did not find that tidal phase, or direction of the tide, played an important role in distinguishing times where surf beach fatal drownings were more likely. These findings (both the affirmed statistical associations and lack of evidence for others) align with the best scientific understanding of the rip current hazard: that rips are primarily driven by the action of breaking waves and their intensity typically increases at lower water depths.

While this work represents an important step forward, further analysis is needed to better understand which other environmental variables and human factors are associated with fatal drowning on surf beaches. On no beach is the risk of drowning determined by the tide alone. Analysing these other variables and factors, and how they contribute to risk of drowning on surf beaches both individually and synergistically is needed. Research exploring associations between fatal surf beach drowning and near shore wave height, beach type, and their interaction, should be prioritized.

Future research on these topics should consider alternative outcome measures, such as rescue and non-fatal drowning, to provide a more in-depth understanding of how these environmental variables influence risk. These analyses however, require higher quality data. Specifically, the collection of accurately time stamped lifeguard rescue data would present important linkage opportunities for future research.

Acknowledgements

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Data in the Coastal Fatality Dataset are validated with information from the National Coronial Information System (NCIS). Visit www.ncis.org.au for more information.

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Appendix - Statistical analysis

Statistical analysis was conducted using mixed effects Poisson regression. All statistical models included fixed effect adjustment terms for weekday vs weekend, hourly seasonality and yearly seasonality; and clustering was accounted for with the inclusion of random intercepts for location. Incident Rate Ratios (IRRs) with 95% confidence intervals and p-values of the variables of interest from each test are below. Further information on the methods and statistical results of this research will be available in a forthcoming research paper.

Test One: Phase of the tide

	IRR	95%CI	Pr(>|z|)
phase - ebb	*reference		
phase - flood	1.06	0.88 - 1.27	0.52
phase - turn.high	1.11	0.81 - 1.54	0.51
phase - turn. low	1.39	1.05 - 1.86	0.02

Test for significance of categorical variable “phase”:
Chisq[df] = 4.94[3]   p= 0.18

Test Two: Phase percent (water levels)

	IRR	95%CI	Pr(>|z|)
phase percent	0.73	0.57 - 0.92	0.01

Test Three: Time trend

	IRR	95%CI	Pr(>|z|)
hours from low	0.96	0.92 -1.01	0.13

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Test Four: Time unrestricted (hours as categorical variables)

	IRR	95%CI	Pr(>|z|)
0 (low tide)	*reference		
1 hour before	0.97	0.68 - 1.4	0.9
2 hours before	0.8	0.55 - 1.18	0.26
3 hours before	0.66	0.44 - 0.99	0.05
4 hours before	0.54	0.34 - 0.84	0.01
5 hours before	0.67	0.43 - 1.03	0.07
6 hours before	0.71	0.39 - 1.3	0.27
7 hours before	0	0 - INF	0.99
8+ hours before	0.28	0.07 - 1.15	0.08
1 hour after	0.82	0.56 - 1.2	0.3
2 hours after	0.78	0.53 - 1.15	0.21
3 hours after	0.78	0.53 - 1.15	0.25
4 hours after	0.6	0.39 - 0.91	0.02
5 hours after	0.7	0.47 - 1.06	0.09
6 hours after	0.87	0.59 - 1.29	0.49
7 hours after	0.87	0.51 - 1.5	0.63
8+ hours after	0.79	0.43 - 1.41	0.41

Test for significance of categorical variable “hours from low”:
Chisq[df] = 24.07[16]   p= 0.09

Test five: Time Window (3 hours before, two hours after low tide)

	IRR	95%CI	Pr(>|z|)
window - no	*reference		
window - yes	1.21	1.03 - 1.44	0.02

Test six: Tidal range

	IRR	95%CI	Pr(>|z|)
range ratio	0.77	0.57 - 0.92	0.15
phase-flood	0.8	0.48 - 1.35	0.41
phase-turn.h	0.71	0.29 - 1.72	0.45
phase-turn.l	1.64	0.76 - 3.53	0.21
range ratio : phase-flood	1.31	0.81 - 2.1	0.27
range ratio : phase-turn.h	1.56	0.68 - 3.6	0.29
range ratio : phase-turn.l	0.85	0.42 - 1.73	0.65