Natural Hazards (2024) 120:14571–14591
https://doi.org/10.1007/s11069-024-06746-3

ORIGINAL PAPER

Preventing beach goers from drowning: analysis of geomorphological and human data to better understand factors leading to surf rescues

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Received: 25 February 2024 / Accepted: 13 June 2024 / Published online: 20 July 2024

Abstract
Globally rip currents are the primary physical hazard facing swimmers on surf beaches. However, beach swimmers also face other hazards such as large waves, tidal influenced currents, and shorebreak waves. The aim of this study was to investigate factors leading to the increased likelihood of surf lifeguard rescues. Rescue data from Surf Life Saving Queensland's Lifesaving Incident Management System and Operations Console for 54 wave dominated beaches in South–East Queensland, Australia, from July 1st, 2016 to October 6th, 2021 was linked with wind speed and direction, air temperature, phase of tide, wave height and period, beach type, beach hazard rating, and beach swimmer numbers. Stepwise regression was performed to find independent predictors of rescue. There were 8515 rescues, with 3345 (39.3%) females and 5109 (60.0%) males (61 sex not recorded). There were no independent predictors of surf rescue but swimming outside the lifeguard patrol area was nine times more likely to result in rescue than swimming inside the patrol area. Increased rescues were noted at periods of increased rip activity. Rip currents (2992/6523, 45.8%) were the most frequently recorded contributing factor. Rescues occurred most frequently (5902, 69.3%) during the six hours of lower tide levels and during onshore winds (5463, 64.2%). Surf rescues increased with increasing wave height and period, air temperature, and wind speed but decreased as average values for each variable were surpassed. Beaches protected from the prevailing wave direction by headlands had a stronger relationship between rescues and wave height. Beaches adjacent to inlets with tidal flow had a stronger relationship between rescues and the ebb tide. Beach morphology, and hazard rating did not have a relationship with ratio of rescues per 100,000 swimmers. We found no independent predictors for surf rescue, however this study has, for the first time we believe, quantified the increased risk (×9) posed by swimming outside the patrol area. Open beaches, beaches protected by headlands and beaches with tidal inlets all had different relationships between rescues, tides and wave size. Our findings suggest that lifeguards may need to adopt new approaches to prevent rescues adjacent to the patrol area, as well as a revision of the general hazard rating being required.

Keywords Surf rescue · Beach morphology · Low tide · Hazard rating · Waves

Extended author information available on the last page of the article

1 Introduction

Visiting the beach is a popular pastime with annual beach visitations exceeding 500 million in Australia (Surf Life Saving Australia 2022) and 300 million in the United States of America (USA) (United States Lifesaving Association 2023). In 2022, over 60,000 beach rescues were performed in the USA (United States Lifesaving Association 2023) and 9000 in Australia (Surf Life Saving Australia 2022). During the 2021/22 financial year there were 141 coastal drownings in Australia (Surf Life Saving Australia 2022) and there were 159 reported in the USA in 2022 (United States Lifesaving Association, 2023). Fatal coastal drownings have been examined for risk factors (Segura et al. 2022; Koon et al. 2023b, 2023a) but such studies are often hampered by smaller sample sizes and a lack of detail regarding the circumstances of each event. The circumstances surrounding surf rescues performed by lifeguards are better documented and analysis of these (Stokes et al. 2017; Scott et al. 2014; Engle et al 2002; Castelle et al. 2024) may provide a better understanding of what leads to beach goers becoming at imminent risk of drowning and requiring rescue.

Rip currents are intense seaward-flowing currents originating in the surf zone and potentially extending hundreds of meters offshore where they dissipate in deeper water (Castelle et al. 2024). They are formed because water building up inshore due to the action of waves, seeks to return to its own level in the form of a current (Surf Life Saving Australia 2009) and have been identified as a major cause of surf rescue (Brighton et al. 2013; Da F. Klein et al. 2003). Rip currents as well as rip current velocity (Brander and Short 2001), rip current related rescues (Scott et al. 2014; Castelle et al. 2024) and rip related drownings (Castelle et al. 2019) have been shown to increase with low tide levels. Other beach hazards, such as tide-driven currents, shore-break waves (Puleo et al. 2016) increased wave height and lower tide levels (Koon et al. 2018), a lack of familiarity with beach conditions (Harada et al. 2011; Segura et al. 2022; Da F. Klein et al. 2003) as well as male sex, warm weather and offshore winds (Morgan and Ozanne-Smith 2013) have all been shown to increase the risk of surf rescue.

The aim of this study was to investigate factors leading to the increased likelihood of surf lifeguard rescues on beaches, utilizing geomorphological, environmental, and human data. This will include for the first time the location of the rescue with relation to the patrol area as well as the general hazard rating for each beach. We believe this study will inform the beachgoing public, surf lifeguards, lifesaving organizations and other beach safety stakeholders, and further assist them in the prevention of drowning.

2 Methods

This study was a retrospective observational study conducted using rescue data from Surf Life Saving Queensland (SLSQ) from July 1st, 2016 to October 6th, 2021 and is reported using The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (Von Elm et al. 2007). Ethics approval was obtained from Metro North Human Research and Ethics Committee (Project 49754) and James Cook University Human Research Ethics Committee (H8014).

2.1 Study location

Fifty-four wave dominated surf beaches between K'garri (formerly known as Fraser Island) in South–East Queensland (SEQ) and the New South Wales border were included in the study. The beaches included in this study are primarily located on the Sunshine Coast and the Gold Coast, in Queensland, Australia (see Fig. 1). The swell is predominantly from the south east, averaging between 1.1 and 1.2 m at the coast. Short (2000) and the tidal range in the study area is considered micro tidal (tidal range < 2 m) (Short 2000). Tides in the study area are predominantly semi-diurnal with an approximate 6 h cycle, however some cycles are in-excess of 6 h. The study area enjoys a subtropical climate.

In the 2021 National Census, the Sunshine Coast Region had a population of 394,666, making it Australia's ninth largest urban area by population (Australian Bureau of Statistics 2021). The Gold Coast is Australia's sixth largest urban area with a population of 625,087 (Australian Bureau of Statistics 2021). Both areas are popular tourist destinations, each with commercial airports and located approximately 100 km north (Sunshine Coast) and 100 km south (Gold Coast) of Brisbane, Australia's third largest city (population 2, 526, 238) (Australian Bureau of Statistics 2021). The Gold Coast in particular is a significant tourist destination with an international airport, direct rail links from Brisbane, multiple theme parks, beach front hotels and resorts, accommodation blocks and camping grounds. In 2022/23, there were 4.1 million domestic overnight visitors to the Gold Coast and 612,000 international overnight visitors (Tourism and Events Queensland 2023). The Sunshine Coast has no direct rail links with Brisbane and international flights only operate during the winter months from a single destination (Auckland, New Zealand). Despite this, there were 4.1 million domestic and 308,000 international overnight visitors to the Sunshine Coast in 2022/23 (Tourism and Events Queensland 2023).

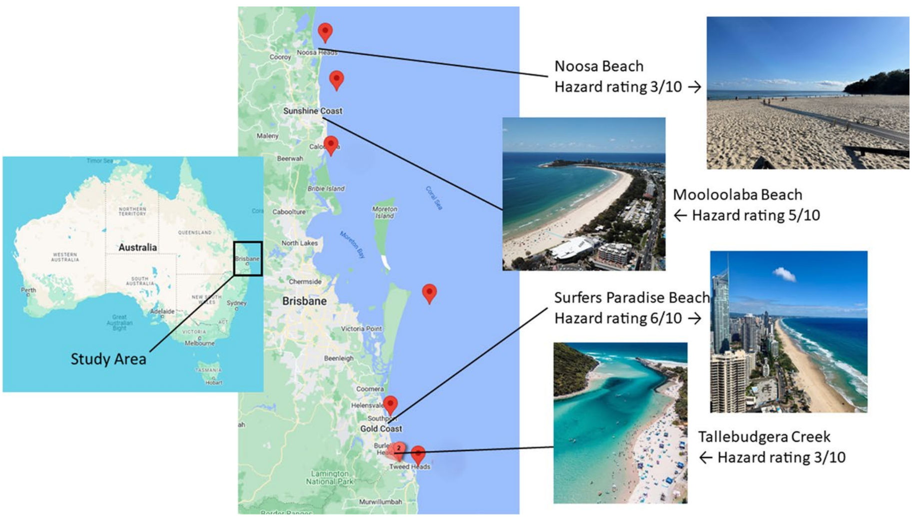

Fig. 1 Study location. Left hand panel map of Australia. Centre panel map of South-East Queensland with Waverider Buoy locations marked (Queensland Government 2024). Right hand panels photographs of four of the 54 study sites

2.2 Morphology and lifeguard data

Wave dominated beaches are those where waves are high (0.5–2.5 m) relative to tide range (<2 m) and are characterised by a relatively stable surf zone. The Australian Beach Safety and Management Program (ABSAMP) combines an analysis of beach type with typical wave conditions to derive an average hazard rating for Australia's 10,685 mainland beaches (Short 2000). The hazard rating ranges from 1 (safest) to 10 (least safe) (Short 2000). The hazard rating for the beaches included in this study ranges between 3 and 6 and was obtained from the Beachsafe App, published by Surf Life Saving Australia (Surf Life Saving Australia, 2022). The matrix for calculating beach hazard ratings is below (Table 1).

Rescues were defined as an SLSQ member(s) providing physical assistance to return the patient safely from the water to the shore. There was no differentiation between unconscious patients and those able to assist in their rescue. Rescue data was obtained from SLSQ's Lifesaving Incident Management System and Operations Console (LIMSOC) electronic database. Variables reported included date and time of the rescue, age and sex of the victim, location of the victim with relation to the area of beach patrolled by lifeguards and any identified contributing cause to the rescue. Swimmer numbers and their location with respect to the patrol area were also supplied by SLSQ.

2.3 Environmental data

Tide, wind speed, wind direction and air temperature data were supplied by the Bureau of Meteorology. Each rescue was matched by geographic location and categorized by the number of hours post the turn of the preceding tide. Rescues occurring more than 6 h after the start of the ebb tide (n = 285) or the flood tide (n = 86) were included with those occurring during the sixth hour, with each category designated 6+ for the purposes of the analysis. Wind speed, wind direction and air temperature are recorded three hourly and were matched to ± 90 min of the time of rescue as well as by geographic location. Winds have been shown to influence wave conditions in Western Australia (Masselink and Pattiaratchi 2001).We categorised wind direction in relation to the geographical axis of the beach. Alongshore winds were defined as coming from ± 20° of the geographical axis of the beach, in either direction. Onshore winds were defined as winds coming from the direction of the ocean towards land, transecting the axis of the beach at more than a 20° angle.

Table 1 Matrix for calculating prevailing beach hazard rating for wave dominated beaches (Short, 2000)

Beach type	Wave height							
	< 0.5 (m)	0.5 (m)	1.0 (m)	1.5 (m)	2.0 (m)	2.5 (m)	3.0 (m)	> 3.0 (m)
Dissipative	4	5	6	7	8	**9**	**10**	10
Long shore bar trough	4	5	6	**7**	**7**	8	9	10
Rhythmic bar beach	4	5	6	**6**	**7**	8	9	10
Transverse bar rip	4	4	**5**	**6**	7	8	9	10
Low tide terrace	3	**3**	**4**	5	6	7	8	10
Reflective	**2**	**3**	4	5	6	7	8	10

Bold gradings indicate the average wave height usually required to produce the beach type and its average hazard rating

Offshore winds were defined as winds coming from the direction of the land towards the ocean, transecting the axis of the beach by more than 20°. Alongshore winds were included in the analysis as the winds shown to influence wave climate in Western Australia are oblique to the shoreline (Masselink and Pattiaratchi 2001).

Wave height, period and ocean surface temperature data was obtained from the nearest offshore Waverider buoys, operated by the Queensland Government Hydraulics Laboratory (Queensland Government 2024). Location of the buoys is included in Fig. 1. Wave height (Hs), wave period (Tp) and ocean surface temperature were recorded half hourly and matched to ± 15 min of the time of rescue, as well as geographic location. Wave height measured at offshore buoy locations is not necessarily representative of breaking wave height along beaches due to wave sheltering and shoaling effects (Short 2000). In an attempt to account for this variation, wave height analysis was normalized using Hs divided by the mean for the location {Hs}.

2.4 Analysis

Statistical analysis was conducted using IBM SPSS (version 29, Armonk, NY: IBM Corp). Descriptive statistics were presented using median and inter-quartile range (IQR) when data were not normally distributed. Normality was assessed using the Shapiro–Wilk test. Categorical variables were described using frequencies and percentages. A stepwise regression analysis was performed to examine independent predictors of surf rescue. Prior to analysis, the dependent variable (ratio of rescues per 100,000 swimmers) was log transformed and the variable with the lower correlation with the dependent variable was removed when there were inter-correlated predictor variables (Pearson correlation coefficient > 0.6). A list of the 82 predictor variables included in the analysis is presented in Appendix 1. These variables were selected based on the previous work by Stokes (Stokes et al. 2017) as well as the listed hazards for each study location on the Beach safe App (Surf Life Saving Australia 2022). Two of the four predictors of surf rescue reported by Stokes (urban area within 10 km and intermediate beach morphology) were unable to be incorporated in our analysis. All but one of the locations is within 10 km of an urban area and all study sites are of intermediate morphology (Short 2000). We used the various types of intermediate beach morphology as described by Short for each location in our analysis (Short 2000). Headland beaches were defined as those protected by a southern headland, due to the predominantly southerly swell (Short 2000).

3 Results

3.1 General results

General results are presented in Table 2. Sex was not recorded in 61 cases (0.7%). The age of those rescued ranged from less than one year to ninety years old. One third (31.4%) of the swimmers were located outside of the patrolled area yet the vast majority of rescues (81.5%) occurred outside the patrolled area resulting in a relative risk for requiring rescue of 9.76 (95% CI 9.24–10.31) if swimming outside patrolled areas. The busiest day of the week was Sunday (1154/6330, 18.2%) but the second busiest day of the week was Tuesday (996/6330, 15.7%). Rescues most frequently occurred in the hours between 14:00 and 15:00 (1300, 15.3%) and between 15:00 and 16:00 (1191, 14.0%) (Fig. 2).

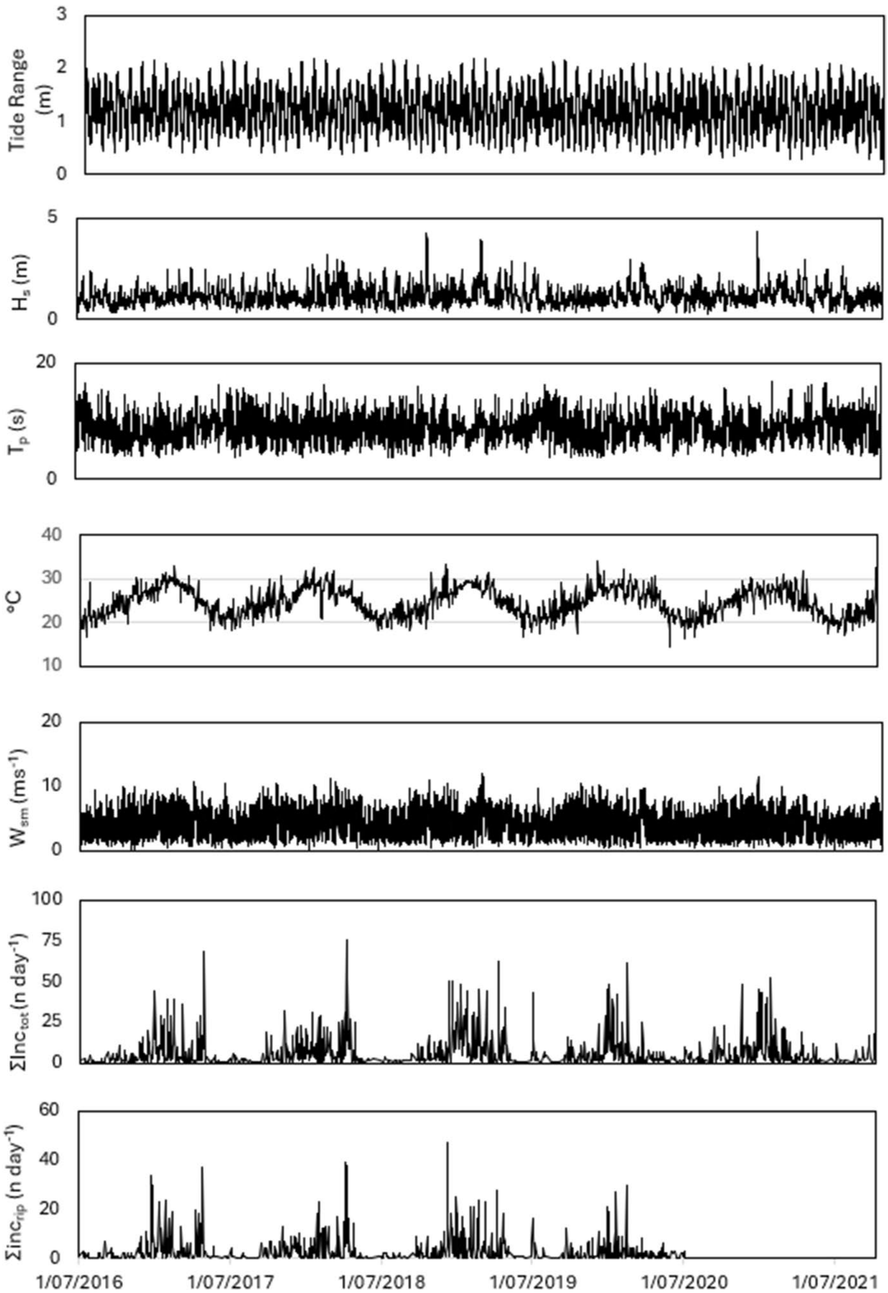

Fig. 2 Summary of hydrodynamic, meteorological and rescue data for the study period. Tidal range, significant wave height (Hs), peak wave period (Tp), maximum air temperature (°C), mean wind speed (Wsm), number of rescues each day (ΣInc_{tot}) and the number of rip-related rescues each day (ΣInc_{rip}). Of note, data regarding causative factors was not available after the 2019/20 season

Table 2 General results

	Beach visitors	Rescues
Total	78.5×10^6	8515
Swimmers in patrolled areas	15.1×10^6 (68.6%)	1573 (18.5%)
Swimmers in unpatrolled areas	6.9×10^6 (31.4%)	6942 (81.5%)
Males rescued	5109 (60.0%)	
Females rescued	3345 (39.3%)	
Age in years (median, IQR)	20 (12–32)	

Table 3 Contributing causes to rescues documented by lifeguards

Contributing cause	N (%)
None recorded	1992 (23.4)
Rip	2992 (35.1)
Tidal current	1629 (19.1)
Non-swimmer	558 (6.6)
Other	347 (4.1)
Wave	233 (2.7)
Gutter	226 (2.7)
Dangerous surf	142 (1.7)
Sandbank collapse	119 (1.4)
Strong winds	68 (0.8)
Fall	67 (0.8)
Medical	65 (0.8)
Deep drop off	62 (0.7)
Suspected self-harm	4 (0.0)

The regression model had an R^2 of 0.998, indicating it explained a high degree of the variability within the dependent variable (rescues per 100,000 swimmers). The various types of intermediate beach morphology had the strongest correlation with rescues per 100,000 swimmers (Pearson correlation co-efficient = 0.454) but there was no variable that was independently predictive (Appendix 1).

3.2 Rip current, tide and wave height

A contributing cause was documented by lifeguards in 6523 (76.6%) rescues (Table 3). Rip currents were the most frequently recorded cause of rescue (n = 2992, 45.8%). This did not differ with location inside (601/1250, 48.1%) or outside (2379/5252, 45.2%) the flagged area, or between sexes (female = 1153/2526, 45.6%, male = 1815/3939, 46.0%). Rip related rescues were twice as likely to occur during the lowest tide levels (2060/2992, 68.8%). Rip related rescues increased with wave height as it approached the mean, then decreased. The product of wave height and wave period has been reported as a useful marker of rip current activity (Scott et al. 2014). Maximum hazard is associated at, or just below, mean values for HsTp (Scott et al. 2014). There were no rescues when {HsTp} was less than 0.5, while 45.8% occurred when {HsTp} was between 0.5 and 0.99. See Fig. 3 below. The results were similar when rip related rescues were plotted against {HsTp}.

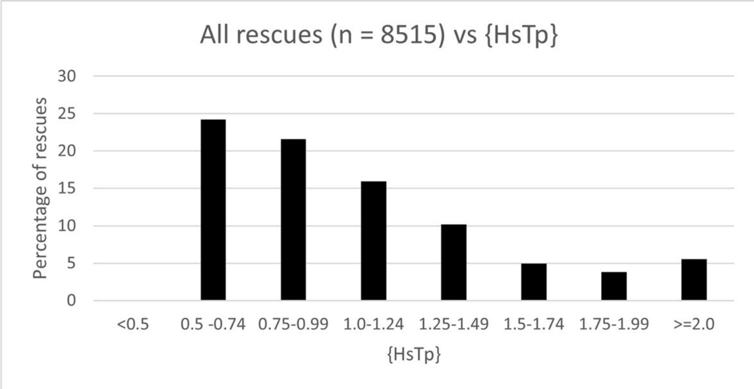

Fig. 3 All rescues versus {HsTp}

A majority (n = 5065, 59.4%) of the rescues occurred on the ebb tide however the lower tide levels (EBB 4 to FLOOD 3) were the most common phases with 5902 (69.3%) rescues (Fig. 4a). The relationship between phase of the tide and rescues was not consistent across all beaches. Beaches with inlets (Tallebudgera Creek, Currimundi, and Bulcock) had a stronger relationship with the outgoing tide with 72% (752/1045) of the rescues occurring during the ebb tide (Fig. 4b). Conversely, over 50% of rescues at Surfers Paradise occurred during the flood, or incoming, tide (244/456, 53.6%).

The highest proportion of rescues (2281/8515, 26.8%) occurred when the normalised significant height {Hs} was between 0.75 and 0.99. See Fig. 5a. In contrast, in the locations protected by a large headland such as Noosa, Mooloolaba, Kirra, Coolangatta, and Rainbow Beach, the highest proportion (423/1927, 22.0%) occurred when {Hs} was greater than or equal to 2 (Fig. 5b). The difference in mean wave height between the two populations was significant (1.107 vs. 1.565, $p < 0.001$) The relationship between wave period and rescues was normally distributed. The mean (± SD) wave period was 8.89 (± 2.34) seconds, which was associated with the highest number of rescues (689).

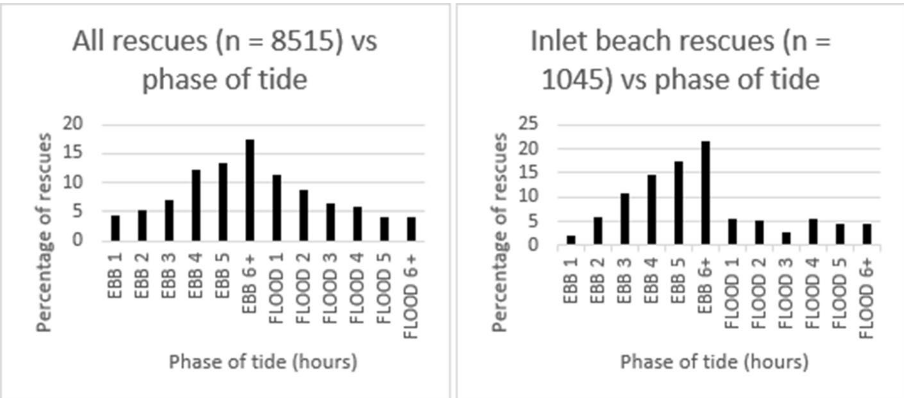

Fig. 4 **a** All rescues plotted against phase of tide. **b** Inlet beach rescues plotted against phase of tide

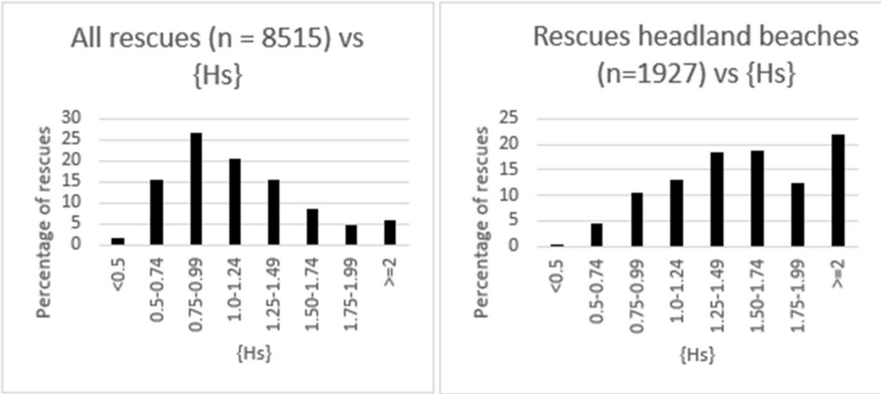

Fig. 5 **a** All rescues plotted against {Hs}. **b** Headland beach rescues plotted against {Hs}

3.3 Temperature, wind, beach location

The wind direction was onshore for 5463 (64.2%) of the rescues, alongshore for 1690 (19.8%), and offshore for 1358 (16%) of the rescues. Rescues increased as wind speed increased up until 25 km/h, then decreased (Fig. 6a). Two-thirds (66.5%) of rescues occurred when the air temperature was between 25 and 29.9 °C. Rescues decreased significantly when the temperature was 30 °C or above (Fig. 6b), despite the maximum daily recorded temperature exceeding 30 °C on 87 occasions during the study.

The number of rescues as well as the number and behaviour of swimmers varied considerably between locations. Beaches with the highest hazard rating of 6 had both the lowest rescue/swimmer ratio (4.96/100,000) and the highest (272.24/100,000). Two beaches with hazard ratings of 3 had rescue/swimmer ratios that were 6 times (Noosa, 31.77/100,000) and 26 times (Tallebudgera Creek, 128.21/100,000) higher than the safest beach with a hazard rating of 6. Thirty-eight (77.5%) of the 49 beaches with hazard ratings of 5 or 6 had lower swimmer/rescue ratios than the highest ratio (128.21/100,000) for a beach with

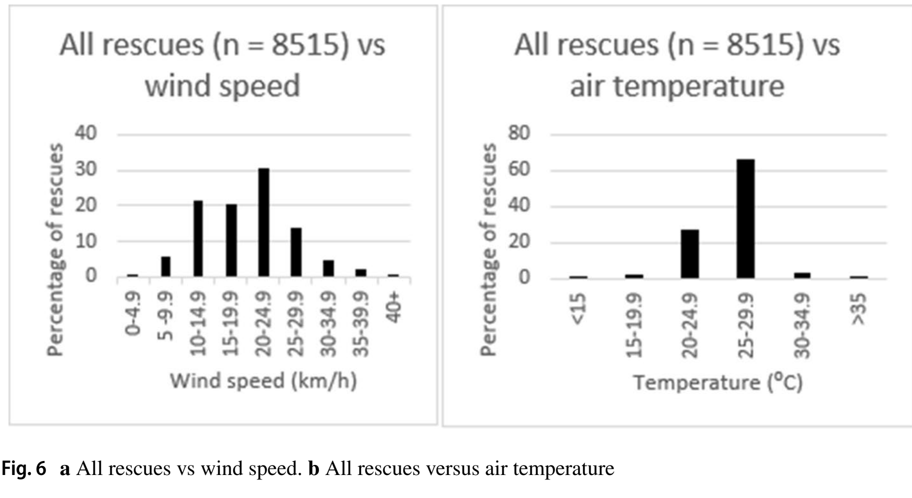

Fig. 6 **a** All rescues vs wind speed. **b** All rescues versus air temperature

a hazard rating of 3. Two beaches (3.7%) with hazard ratings of 3 (Noosa and Tallebudgera Creek) accounted for 21.29% of all rescues (1005 and 808 respectively) (Appendix 2).

4 Discussion

With drowning recognised as a global public health challenge there is a need to ensure that all areas of drowning prevention are addressed. Improving our understanding of geomorphological and human factors involved in surf rescues will aid drowning prevention at beaches whether they are patrolled by lifeguards or are unpatrolled. In this study a typical rescue was of a young adult, caught in a rip current located just outside of the patrolled area during lower tide levels. Waves were at or below average height, the air temperature was warm and the wind was onshore, similar to results from France (Castelle et al. 2018) and the UK (Scott et al. 2014). This study also found that variation in rescue to swimmer ratios between beaches was not explained by their physical hazard rating (ABSAMP).

The most striking result of the study is the ninefold increase in likelihood of requiring rescue for swimmers who are located outside of the patrolled area. More than half the total rescues occurred near (within 100 m) but outside the patrol area. This may be because swimmers feel sufficiently safe swimming near the patrol area but prefer the less crowded waters adjacent to it. However, they may be placing themselves at greater risk given the practice of establishing patrolled areas between identified rip currents (Surf Life Saving Australia 2009). This leaves the areas adjacent to the flags at high risk of rip currents affecting the swimmers there. The analysis of this result may also be more complicated than it first appears. Rip currents are fed by alongshore currents (Castelle et al. 2016). It is possible that a proportion of the swimmers rescued outside of the patrol area entered the water in the patrol area but were carried out of it by the alongshore currents feeding the adjacent rip currents. This requires further investigation. Our study confirms that there is no difference between sexes in the proportion swimming outside the patrolled area (Morgan et al. 2009; Sherker et al. 2010).

Our finding that rip currents contributed to 45.8% of rescues, is consistent with previously reported results (Brighton et al. 2013; Scott et al. 2007). Lifeguard rescues on macrotidal beaches in the UK have been shown to be maximal when {HsTp} is at or just below the mean, especially at lower tide levels (Scott et al. 2014) and a relationship between lower tide levels and increased velocity of rip current has been reported on Eastern Australian beaches (Brander and Short 2001). Our results across 54 microtidal beaches in Australia are very similar. A relationship between increased speed of rip current and increased wave height has also been reported (Castelle et al. 2016). However, the number of rip related rescues increased with wave height up until mean height, then decreased as wave height increased beyond the mean. There was no increase in rip related rescues with any wind direction. A majority (1912, 63.9%) of rip related rescues occurred during onshore winds, the rest occurred during alongshore winds (20.7%) and offshore winds (15.3%).

Lower tide levels were associated with twice as many rescues as the higher tide levels. Lower tide levels have previously been reported as a risk factor for surf drownings in other states of Australia (Morgan and Ozanne-Smith 2013; Koon et al. 2023a), the East and West coasts of the US (Koon et al. 2018), Southwest England (Scott et al. 2007) as well as for cervical spinal injuries on the Sunshine Coast, Australia (Thom et al. 2022). Added to these, our analysis suggests a generalizability to this finding. However, there were beaches where the relationship between surf rescue and tide level was very different. Surfers

Paradise, a very popular beach on the Gold Coast (see Fig. 1), had a majority of rescues occurring during the incoming or flood tide. Beaches with channels subject to tidal flow, (Tallebudgera Creek, Currimundi, and Bulcock) had over 70% of their rescues occurring on the ebb tide. Due to this variability, individual analysis of data for each beach should be performed to better inform the lifeguards and public.

There was an increase in rescues as wave height and wave period increased up to a point, after which the number of rescues decreased as the wave height and period increased. This is consistent with previous studies (Koon et al. 2018; Thom et al. 2022). This study has the advantage of including data from 54 different beach locations along more than 170 km of coastline. The point at which the number of rescues started to decrease with wave height and wave period were average conditions for SEQ (Short 2000). While heavy shorebreak waves are a known hazard in the study area and elsewhere (Thom et al. 2022; Puleo et al. 2016), they were not documented as a contributing cause in any rescue. However, on beaches protected by a headland from the South–East swell, there was a much stronger relationship between increasing wave height and rescues. Together with the differing relationship between phases of the tide, these differences highlight the need for individual beach hazard assessments.

Unfortunately, we did not have the data to measure if the number of swimmers decreased as wave height or wave period increased, although in one study of 204 people over a 10 days timeframe, wave height was reported as having no influence on the length of time people spend in the water (Morgan et al. 2009). The ratio of rescues per swimmer in our study (38.5 per 100,000) was lower than that reported in Victoria, with 128 per 100,000 (Morgan and Ozanne-Smith 2013) and Hawaii (70 per 100,000) (Harada et al. 2011). It is possible that this reflects an increase in rescues at more hazardous beaches, as the Victorian study included beaches with hazard ratings up to 10 (Morgan and Ozanne-Smith 2013), while our study included no beaches with a hazard rating above 6. Unfortunately, individual beach hazard ratings were not reported in either the Victorian study (Morgan and Ozanne-Smith 2013) nor the Hawaiian study (Harada et al. 2011). Two comprehensive analyses of beach geomorphology and surf rescues in the United Kingdom (Scott et al. 2007) and drownings in China (Li and Zhu 2018) did not include hazard ratings in their analyses. Consequently, we believe this study to be the first detailed analysis of the relationship between a hazard rating and surf rescue.

The variation in rescue rates between individual beach locations was striking, with over a 50-fold difference (4.96 vs. 272.24/100,000) between beaches with identical hazard ratings. There was a 20-fold difference (13.07 vs. 272.24/100,000 K) in rescue rates between beaches with the same morphology (low tide terrace/transverse bar and rip). The ratio of rescues per swimmer also varied between locations that were proximal to each other. For example, Noosa beach (hazard rating 3) had a rescue rate of 31.8/100,000 swimmers while Noosa West, 500 m further along the beach and with a higher hazard rating (5) has a lower rescue per swimmer ratio (25.4/100,000) (Table 1). Such proximal variation in surf rescues has also been reported in California (Koon et al. 2018) and Hawaii (Harada et al. 2011), implying that geomorphic hazards are only one part of the consideration when ensuring beach goers safety. All the included beaches are of intermediate morphology (Short 2000) which has previously been shown to be risk factor for surf rescues (Stokes et al. 2017). The regression analysis demonstrated that neither the general hazard rating nor the beach morphology were independently predictive of surf rescue. The hazard rating is listed for every beach in Australia in the Beachsafe website and application published by Surf Life Saving Australia. It is reasonable to expect that hazard ratings, as a de-facto marker of risk, are also included in operational planning and support by lifeguard providers. However, if the results of our paper can be validated, new approaches may be required to assessing the hazard to life for beaches.

Whilst local geomorphology and hydrodynamics undoubtedly influence rescue rates, it is clear human behaviours have a similar impact. The two beaches with the highest number of rescues, Noosa and Tallebudgera Creek are both very popular with families. The 16 kms of beach from Nerang Head to South Nobby Headland on the Gold Coast is the most heavily developed in Australia (See Fig. 1.) and is backed by beachfront hotels, holiday resorts, apartment blocks and houses for most of its length (Short 2000). All but one of the eight patrolled areas on this stretch of beach have rescue rates greater than 100 per 100,000 swimmers, The area around Surfers Paradise is very popular with international and interstate tourists, who may lack the skills and experience required to swim safely in open surf and Surfers Paradise in particular, has the highest rescue rate in the study of 272 per 100,000 swimmers. The exposure to risk by swimmers, as well as their ability to manage risk, was not in the scope of this study but clearly needs to be investigated further.

Male sex is recognised as a risk factor for drowning (Franklin et al. 2020) and has previously been reported as a risk factor for surf rescue (Morgan and Ozanne-Smith 2013; Castelle et al. 2018; Lawes et al. 2021). It is interesting to note that females represent less than 20% of coastal drownings (Koon et al. 2023b; Surf Life Saving Australia 2023) and 25% of all drownings in Australia (Roberts et al. 2023) but a much higher proportion (between 35 and 44%) of those requiring surf rescue (Morgan and Ozanne-Smith 2013; Tellier et al. 2019). The proportion of females rescued in our study (40%) was consistent with this. When visiting the beach males have been found to spend more time in the water than females, to enter the water more frequently than females and to venture out further from the shoreline (Morgan et al. 2009). Males are also less likely to swim in the area patrolled by lifeguards (Morgan et al. 2009), and are more likely to self- rate their swimming ability as highly competent compared with females (Surf Life Saving Australia 2022).

Younger age groups have been reported as a risk factor for surf rescue (Morgan and Ozanne-Smith 2013; Tellier et al. 2019) and this was reflected in our findings with 75% of those rescued aged 32 years or younger. In contrast, 75% of coastal drowning deaths are aged 30 years or older (Koon et al. 2023b). Combined with the differences in sex noted above, these differences suggest the population requiring rescue at the beach is different to the population that drowns. This is further reinforced by the fact that between 2004 and 2021, only 31 of the 1751 (1.8%) coastal drownings in Australia where the location was known, occurred in a patrolled area between the flags (Koon et al. 2023b). It is also testament to the effectiveness of the lifeguards.

Warm sunny days have been shown to be a risk factor in surf rescues in temperate climate of France and the United Kingdom (Scott et al. 2014; Castelle et al. 2018). In the sub-tropical climate of the study area, rescues also increased as the air temperature did, with a majority of rescues in temperatures between 25 and 30 °C. The busiest time of day for rescues were between 14:00 and 16:00 h, the warmest time of the day. However, despite the fact that there were 87 days during the study period where the maximum daily temperature exceeded 30 °C, less than 4% of rescues occurred on these days. The decrease in rescues when air temperature was above 30 °C is in contrast with the increase in drownings reported during heat wave conditions (Peden et al. 2023), though decreased beach attendance has been reported during heat waves (Castelle et al. 2024). This again suggests that people who drown at the coast and those that require surf rescue may be different populations.

In a similar result to wave height and air temperature, rescues increased with wind speed, and then decreased as wind speed surpassed average conditions (Bureau of Meteorology

2023). A different relationship between rescues and the wind direction was found to that reported previously (Morgan and Ozanne-Smith 2013; Scott et al. 2007) with two thirds (64.3%) of rescues occurring during onshore winds. The prevailing winds in coastal SEQ are onshore winds from the south–east (Short 2000), and afternoon sea breezes occur in the study area. Sea breezes have been shown to affect the local wave climate in Perth, Western Australia (Masselink and Pattiaratchi 2001), and are reported to have mean speeds between 5 and 7 m/s, which is similar to our results (See Fig. 2). These sea breezes have been shown to increase inshore wave height by up to 40% (Masselink and Pattiaratchi 2001), which may have a role in the increase in rescues as wind speed increases.

4.1 Limitations

This study utilised rescue and swimmer data recorded by SLSQ over a period in excess of 5 years, which was combined with geographical and meteorological data for analysis. While over 8500 rescues were analysed, we were unable to access rescue and swimmer data from the Gold Coast Lifeguard Service, which provides lifeguard coverage on weekdays for Gold Coast beaches. Similarly, we did not include data on rescues of swimmers performed by surfers, estimated to be a similar number to those performed by lifeguards (Attard et al. 2015). It is possible this additional data may have influenced the findings of our study.

This paper was based on modal beach state classifications, and not direct observation of the actual beach morphology at the time of each rescue. Beach states (as well as the hazard rating) are dynamic and change in response to increased wave size (See Table 1). However, given that the majority of rescues occurred at, or below (Hs), the use of modal beach state classifications was appropriate for our analysis.

Access to measures of exposure such as individuals' length of stay on the beach, amount of time spent in the water or swimming ability was unavailable. Accuracy in counting large and mobile populations at the beach is a well-recognised issue (Morgan 2018). However, it is likely that over the 5 years of the study and the multiple locations, the SLSQ swimmer numbers consistently reflect differences between each location, validating the differences in rescues/swimmer ratios between locations.

Waverider buoy data was used to estimate the height of waves at each location. It is well reported that local factors influence the height of breaking waves at beaches (Short 2000) and we were unable to account for these. However, observation of the height of breaking waves is fraught with its own difficulties with height underestimated by as much as 60% (Short 2000). We attempted to compensate for these difficulties by normalising the Hs for each Waverider location.

5 Conclusions

While there was no factor found to be independently predictive of the need for surf rescue, there is a ninefold increase in need for rescue when swimming outside of the patrol area. Rescues were most frequently precipitated by rips at low tide levels. Beaches protected by southerly headlands had a stronger relationship between number of rescues and increasing wave height. Beaches adjacent to channels subject to tidal flow has a stronger relationship with the ebb tide. The beach hazard rating did not have a relationship with the ratio of rescues per 100,000 swimmers.

These findings, for the first time, quantify the risk of swimming outside the patrol area. Our results can inform both public prevention campaigns as well as organizations with responsibility for beach safety. An awareness of the increased risk of swimming outside the patrol area may potentially initiate a change of lifeguard practice, as well as allocation of resources on the beach.

Further research needs to be conducted on the behaviours/attitudes and skills of those swimming adjacent to the patrol area, as well as more effective means of quantifying the hazard to swimmers at each beach. It is clearly more complicated than beach morphology and wave size.

Appendix 1

See Table 4.

Table 4 List of potential predictors of log (rescue risk)

Variable name	Data type	Data source
Latitude	Continuous	SLSQ
Longitude	Continuous	SLSQ
Swimmers in patrol area	Continuous	SLSQ
Swimmers outside of patrol area	Continuous	SLSQ
Total number of swimmers	Continuous	SLSQ
Surf craft users	Continuous	SLSQ
Number of beach users	Continuous	SLSQ
General hazard rating	Continuous	Beachsafe
Beach morphology	Continuous	BOQC
Mean summer sea temp	Continuous	QGHL
Mean summer max air temp	Continuous	BOM
Mean of summer significant wave height	Continuous	QGHL
Mean of summer wave period	Continuous	QGHL
Mean tide range	Continuous	BOM
Facilities: none	Binary	BOQC
Facilities: basic	Binary	BOQC
Facilities: good	Binary	BOQC
Facilities: resort	Binary	BOQC
Food vendors	Binary	BOQC
Toilets	Binary	BOQC
Shops	Binary	BOQC
Distance to nearest commercial airport	Continuous	Google maps
Campsite within 1 km	Binary	Google maps
Urban area within 1 km	Binary	BOQC
Enclosed by headlands	Binary	BOQC
Dunes	Binary	BOQC
Number of documented hazards	Continuous	Beachsafe
Accessible rock platform	Binary	Beachsafe
Beach erosion	Binary	Beachsafe
Beach exposure	Binary	Beachsafe
Beach rips	Binary	Beachsafe

Table 4 (continued)

Variable name	Data type	Data source
Bluebottles	Binary	Beachsafe
Boat traffic	Binary	Beachsafe
Deep water	Binary	Beachsafe
Drop off	Binary	Beachsafe
Fixed rips	Binary	Beachsafe
Flash rips	Binary	Beachsafe
Gutters	Binary	Beachsafe
Heavy shorebreak	Binary	Beachsafe
High surf	Binary	Beachsafe
High tide range	Binary	Beachsafe
Inlet	Binary	Beachsafe
Inshore holes	Binary	Beachsafe
Large unexpected waves	Binary	Beachsafe
Littoral current	Binary	Beachsafe
Long beach	Binary	Beachsafe
Long shore current	Binary	Beachsafe
Marine stingers	Binary	Beachsafe
Outfall	Binary	Beachsafe
Reefs	Binary	Beachsafe
Rip	Binary	Beachsafe
Rocks	Binary	Beachsafe
Shallow water	Binary	Beachsafe
Shallow sandbars	Binary	Beachsafe
Slippery rocks	Binary	Beachsafe
Slippery stairs	Binary	Beachsafe
Slippery surface	Binary	Beachsafe
Strong currents	Binary	Beachsafe
Structure	Binary	Beachsafe
Submerged objects	Binary	Beachsafe
Suction pipe	Binary	Beachsafe
Topographic rips	Binary	Beachsafe
Uneven ground	Binary	Beachsafe
Water pollution	Binary	Beachsafe
Winds	Binary	Beachsafe

SLSQ, surf life saving Queensland, beachsafe – beachsafe app, surf life saving Australia; BOQC, beaches of the Queensland coast; QGHL, Queensland government hydraulics laboratory; BOM, bureau of meteorology

Appendix 2

See Table 5.

Table 5 Summary data for individual beach locations, in ascending order of rescues per 100,000 swimmers

Beach location	Beach type (Short 2000)	Hazard rating	Total swimmers	Total rescues	Rescues per 100 k swimmers	Relative risk
Double Island point	TBR	6	564,503	28	4.96	–
North Peregian	RBB	6	94,991	6	6.32	1.27
Mooloolaba spit	LTT/R	5	1,647,573	121	7.34	1.48
Woorim	LTT	4	368,578	32	8.68	1.75
Buddina	LTT/TBR	6	198,902	26	13.07	2.64
Currimundi	TBR	6	540,666	74	13.69	2.76
Discovery	TBR	6	273,540	38	13.89	2.80
twin waters	TBR	6	275,495	41	14.88	3.00
Boardwalk	TBR	6	167,795	28	16.68	3.36
Mooloolaba	LTT/R	5	2,464,093	426	17.29	3.49
Yaroomba	TBR	6	74,372	13	17.48	3.52
Peregian	RBB	6	304,573	54	17.73	3.57
Cylinder	LTT	3	765,633	143	18.68	3.77
Coolum north	RBB	6	425,024	82	19.29	3.89
Dicky	LTT/TBR	5	686,804	159	23.15	4.67
Sunrise	RBB	6	123,685	29	23.45	4.73
Bokarina	LTT/TBR	6	50,864	13	25.56	5.15
Noosa West	TBR/LTT	5	546,837	140	25.60	5.16
Rainbow Bay	TBR	5	148,334	40	26.97	5.44
Greenmount	LTT/TBR	5	141,222	41	29.03	5.85
Alexandra Headland	TBR/LTT	5	1,363,358	407	29.85	6.02
Bulcock	TBR/Tidal channel	6	663,487	207	31.20	6.29
Noosa	TBR/LTT	3	3,162,970	1005	31.77	6.41
Rainbow	TBR	6	469,814	152	32.35	6.52
Wurtulla	LTT/TBR	6	207,847	70	33.68	6.79
Mudjimba	TBR	6	400,788	139	34.68	6.99

Table 5 (continued)

Beach location	Beach type (Short 2000)	Hazard rating	Total swimmers	Total rescues	Rescues per 100 k swimmers	Relative risk
Bilinga	LTT	6	23,464	9	38.36	7.73
Coolum	RBB	6	821,180	318	38.72	7.81
Kings	LTT/TBR	5	1,219,143	479	39.29	7.92
Marcoola	TBR	6	189,894	86	45.2	9.13
Sunshine	RBB	6	501,903	231	46.02	9.28
North Kirra	LTT	6	50,371	24	47.65	9.61
Kirra	R/LTT	4	99,522	51	51.25	10.33
Marcoola	TBR	6	189,894	86	45.2	9.13
Point lookout	TBR	6	232,688	175	75.21	15.16
Palm	LTT/TBR	6	55,365	43	77.66	15.66
Tugun	LTT/TBR	6	41,793	34	81.35	16.40
Maroochydore	TBR	5	900,254	740	82.19	16.57
Currumbin	LTT/TBR	6	63,606	57	89.61	18.07
Miami	LTT/TBR	6	66,197	62	93.66	18.88
Burleigh Heads	TBR	6	199,346	241	120.89	24.37
Pacific	LTT/TBR	6	46,598	57	122.32	24.66
Tallebudgera Creek		3	630,206	808	128.21	25.85
Mermaid	LTT/TBR	6	41,432	54	130.33	26.28
Northcliffe	LTT/TBR	6	42,298	68	160.76	32.41
Broadbeach	LTT/TBR	6	51,329	84	163.66	32.99
Coolangatta	LTT/TBR	5	61,703	102	165.31	33.33
Kurrawa	LTT/TBR	6	92,611	158	170.61	34.40
North Burleigh	LTT	6	80,815	141	174.47	35.18
Nobby	LTT/TBR	6	44,499	88	197.76	39.87
Southport	LTT/TBR	6	137,706	284	206.24	41.58

Table 5 (continued)

Beach location	Beach type (Short 2000)	Hazard rating	Total swimmers	Total rescues	Rescues per 100 k swimmers	Relative risk
Kawana	LTT/TBR	6	24,354	59	242.26	48.84
Tallebudgera	LTT/TBR	6	39,617	100	252.42	50.89
Surfers Paradise	LTT/TBR	6	164,561	448	272.24	54.89
Total			22,003,339	8515	38.54	7.77

LTT, low tide terrace; RBB, rhythmic bar and beach; R, reflective; TBT, transverse bar and rip

Author contributions All authors (OT, KR, SD, PL, RF) had a role in the conceptualization and design of the study, OT and KR had a role in the acquisition of the data, OT and RF had a role in analysis of data, all authors had a role in interpretation of the data, OT drafted the article, KR, SD, PL and RF provided critical revisions, all authors gave final approval of the version to be submitted and all agree to be accountable for all aspects of the work.

Funding Open Access funding enabled and organized by CAUL and its Member Institutions. The authors declare that no funds, grants or other support were received during the preparation of this manuscript.

Declarations

Conflict of interest Financial interests: The authors declare no relevant financial interests to disclose. Non-financial interests: Author OT is the State Medical Advisor for Surf Life Saving Queensland which provided the data.

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