

Article

Drowning Risk Analysis Comparing Surf Bather Subgroups

Damian Morgan ^{1,*} and Joan Ozanne-Smith ²

¹ College of Business, Law and Governance, Bebegu Yumba Campus, James Cook University, 1 James Cook Drive, Douglas, QLD 4815, Australia

² Department of Forensic Medicine, Victorian Institute of Forensic Medicine, Monash University, 65 Kavanagh Street, Southbank, VIC 3006, Australia; joan.ozanne-smith@monash.edu

* Correspondence: damian.morgan@jcu.edu.au

Featured Application: Risk analysis provides a preliminary or alternative method to analytical epidemiological study designs to identify risk factor contributions to injury problems, including drowning, accounting for risk exposure.

Abstract: The study assessed the utility of risk analysis for advancing knowledge on drowning risk factors. The setting was unintentional drowning of surf bathers in Australia. Bathers reported earlier exposure to selected risk factors (swimming ability, wave height associated with rip currents and surf bathing experience) and were observed for water exposure (in minutes). These data were then assembled in mathematical models. The analysis forecast relative drowning risk pertaining to risk markers representing selected surf bather subgroups (gender, age and water activity). Contextualized through previous study findings, comparison of results with a gold standard obtained from mortality data generated new surf bather drowning hypotheses suitable for future testing by rigorous analytical epidemiologic designs. The hypotheses were: (1) The male to female comparative surf bather drowning rate is explained primarily by differences in crude water exposure; (2) the association of cardio-vascular medical conditions with surf bather drowning is stronger for older surf bathers compared to younger surf bathers; and (3) other risk contributors to surf bather drowning are: Poorly calibrated perception of bathing ability (overconfidence) and use of alcohol. Nonetheless, drowning rates appear generally consistent with time exposure to water. The study findings may also support drowning prevention strategies targeting risk marker subgroups.

Keywords: drowning; risk analysis; risk factors; exposure; surf bathers

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1. Introduction

Unintentional drowning is a long-standing global health problem. Recent estimates suggest falling rates, though global fatalities remain substantial at around 300,000 persons in 2017 [1]. Factors contributing to unintentional drowning risk vary by person, circumstances and setting [2]. Effective drowning prevention strategies within and across settings will be supported through establishing relative risks of causal factors for specified locations. Yet most epidemiological studies of drowning remain descriptive, and though important for hypothesis generation, associations between exposure and injury remain unknown [3]. Risk analysis incorporating observed exposure measures is proposed here as a novel analytical method to identify drowning risk factors [4]. If proven, the method has the capacity to inform rigorous epidemiological studies on target variables and so capture design efficiencies.

To test the method, the specified setting is unintentional drowning on wave-dominated beaches in Australia. Coastal locations around the globe frequently sustain drownings [5]. Persons intentionally entering the water to bathe at these locations face putative causal drowning risk factors linked to swimming ability, wave height (and associated rip currents) and surf bathing experience [6,7]. In-water person factors such as fatigue, or

underlying factors contributing to this condition, including health status, may exacerbate drowning risk in high energy environments [8].

Blumenthal’s system approach model is used to represent a drowning event in this coastal setting (Figure 1) [9]. In this conceptualization, environmental or situational demands match the bather’s performance. The interaction of elements over time represents discrete pathways. A drowning event, consistent with respiratory impairment through submersion, is depicted where the pathways intersect [10]. Drowning at wave-dominated beaches under this scenario results from increased environmental demands through rip current manifestation, exacerbated by reduced performance from fatigue. Of course, for any drowning setting interactions of risk factors and exposures are complex suggesting full understanding of drowning risk requires multidisciplinary or interdisciplinary approaches [11,12].

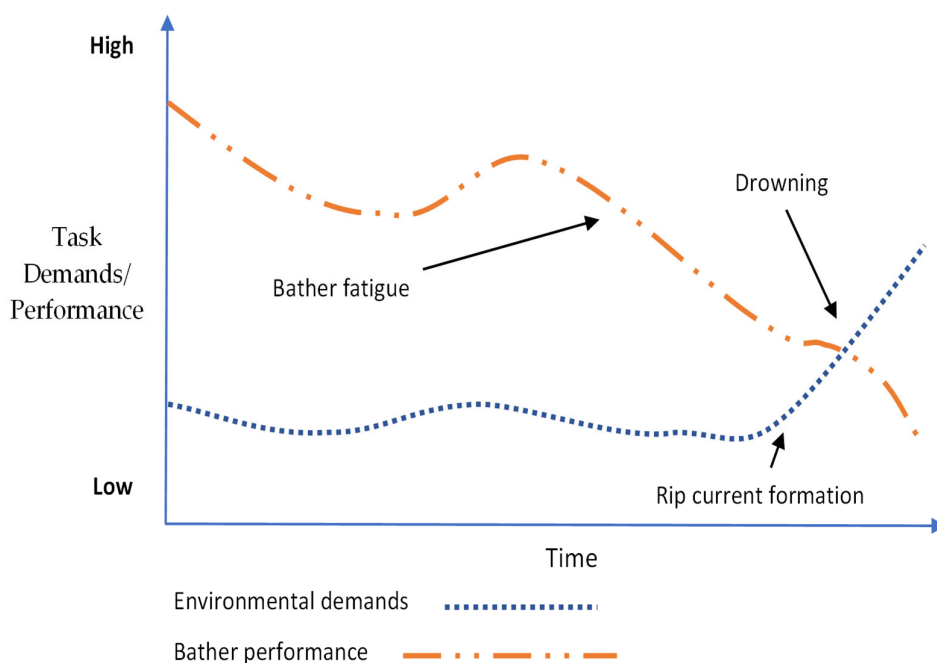


Figure 1. System approach model of surf bather drowning adapted from Blumenthal [9].

The proposed drowning risk analysis employs a quantitative method accounting for person factors, environmental hazards and population-level exposure to water. The method, if proven, may have applicability to other unintentional injury contexts with relatively low incident rates from frequent risk exposures.

1.1. Linking Exposure, Risk Markers and Causal Factors to Drowning Events

The necessity of exposure measures for causal risk factor identification are well understood in other injury contexts [13,14]. A process flowchart (Figure 2) for unintentional bather drowning at wave-dominated beaches links exposure to water, risk factor exposure, bathing outcome and risk markers [15]. Risk markers associate with drowning risk factors but are not causal. While bathers together face a total drowning risk from crude exposure, risk factors and bathing outcomes vary among individuals. Measuring

exposure components, risk markers and risk factors (and risk factor interactions) theoretically allows for a full risk analysis for a specified drowning setting (Figure 2).

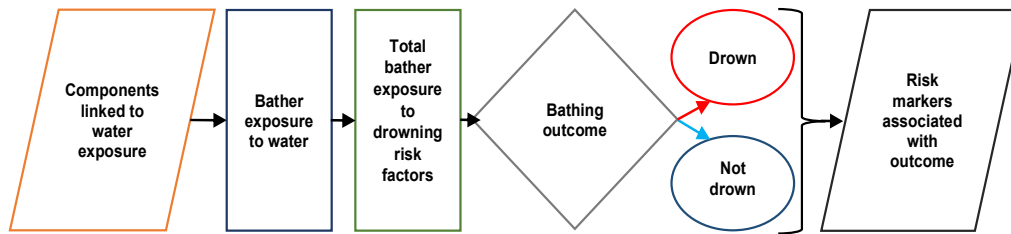


Figure 2. Flowchart depicting relationships among risk exposure, risk factors and risk markers [15]. Components may include time of day, daily temperature, day type, surf conditions or beach amenity [16]. Risk markers may include age, gender, ethnic background.

1.2. Available Surf Bather Data Applied to Mathematical Models

Datasets in published studies (Table 1) tested the proposed risk analysis based on mathematical models. Data were drawn from representative samples obtained from surf bathers in Victoria, Australia. Mortality data were Australia wide. Mathematical models are superior to humans in their ability to combine data from diverse information sources [17]. Contrasting to clinical judgment, mathematical models specify relationships between variables based on empirically derived data with reproducible outcomes [18,19]. Dawes and Corrigan indicate “the whole trick is to decide what variables to look at and then to know how to add them” [20] (p. 105).

Table 1. Data applied in drowning risk analysis.

Risk Analysis Element	Dataset Description	Data Source	Reports
Exposure components	Person-time crude water exposure (minutes)	Direct observation Self-report in situ	[21–24]
Risk markers	Gender: Male/female	Direct observation	[21–23,25]
	Age: <30 years/≥30 years	Self-report in situ	
Causal risk factors	Bather type: Wader/swimmer/surfer	Coronial records	[7,22,26]
	Swimming ability	Expert panel	
	Surf swimming experience	Specialist ratings	
Gold standard comparison	Wave height (rip current indicator)		
	Drowning mortality	Coronial records	[25]

In the present study, a drowning risk analysis applied mathematical models combining previously collected data to derive comparative drowning ratios (indicating relative risk) for surf bather risk-marker subgroups. To assess method validity a posed research question was: Does relative sub-group drowning risk derived from risk analysis align to a gold standard for comparative drowning rates?

2. Materials and Methods

The risk analysis determined relative drowning risk for selected Australian surf bather subgroups drawn from disparity in bathing time weighted by exposure to drowning risk factors. Differences calculated as ratios were then compared to a gold standard of comparative drowning rates from mortality data for the same subgroups. The five-step method is conceptualized in Table 2.

Table 2. Conceptual summary of study method.

Step 1
To specify total drowning risk factor contribution for each subgroup
Information sources and analysis: Mean subgroup score derived from bathers' self-reported swimming abilities, surf swimming experience and prevailing wave size (on day surveyed), weighted by each measured variable's modelled contribution to drowning risk [7,22]
Outcome: Subgroup score representing average total drowning risk from selected factors
Step 2
To specify comparative total water exposure time between subgroups
Information sources: Total time in minutes exposed to water by subgroup [23]
Outcome: Ratio of water exposure for selected subgroups
Step 3
To specify comparative subgroups drowning risk accounting for water exposure
Information sources and analysis: Subgroup total drowning risk (step 1) weighted by comparative water exposure (step 2)
Outcome: Derived ratio of total drowning risk for selected subgroups
Step 4
To specify comparative drowning rate between subgroups as the <i>gold standard</i>
Information sources: Ratio of drowning frequency for subgroups from mortality data for a defined period [25]
Outcome: Comparative rate of drowning frequency between selected subgroups
Step 5
Comparison of derived drowning ratio with comparative drowning rate
Information sources: Derived subgroup drowning ratio (step 3) and comparative subgroup drowning rate (step 4)
Outcome: Derived ratio from inferential data assessed against <i>gold standard</i> from mortality data

2.1. Linking Datasets

The risk analysis relies on conflating compatible data across five discrete datasets collected for Australian surf bathers. Data collection methods provided matching variable measures collected over corresponding time-periods [7,22,23,25,26]. For step 1 (Table 2), three factors (swimming ability, surf swimming experience and wave height) were ranked highest by an expert panel as causal risk contributors to surf bather drowning [26]. The three factors explained 75 percent of surf bather drowning risk when judged by surf beach specialists in a controlled study [7]. In the study, risk factor measures were anchored to empirically derived bather population ratings collected from bathers at surf beach locations [22]. Risk markers required for surf-bather subgroup identification were available across all datasets (Table 1).

2.2. Risk Analysis Calculations

The technical risk analysis procedure with formulas is presented in Appendix A. Appendix B provides a worked example of the method. An online Supplementary Materials provides spreadsheet calculations (BackMatter). A descriptive overview of the method consistent with Table 2 is given below.

Step 1 provides a mean rating of total drowning risk contribution from swimming ability, surf swimming experience and wave height for selected surf bather subgroups (e.g., risk marker *age* was sub-grouped as <30 years or ≥30 years) [26]. A unique bather risk score was derived from self-report data (N = 403) [22]. Scores were then weighted by each risk factor's modelled contribution (including interactions) to surf bather drowning, derived from specialist assessment based on repeated measures ANOVA [7]. From tallied risk scores, an average score represented the subgroup population's drowning risk.

Step 2 provided a ratio of total person-time crude water exposure between comparative subgroupings (e.g., males vs. females) derived from direct observation [23]. (The term *crude* here indicates that the measure of water time exposure does not capture individual variations in drowning risk associated with factors such as water depth or distance from shore.) Recorded person-time in water summed for each subgroup was recorded in minutes. The comparative total person time-in-water between subgroups was reduced to

a ratio in the simplest form (i.e., $\eta:1$) for convenience. The *antecedent* term (η) applied to the first subgroup and the *consequent* term (1) applied to the second subgroup.

Step 3 combined subgroup drowning risk (step 1) and the comparative ratio of total person-time water exposure (step 2) to produce a ratio of derived drowning risk. The calculated antecedent term in this ratio is obtained from the first subgroup's product of drowning risk and antecedent (η) ratio result for water time exposure. The ratio consequent term representing the second subgroup is the product of that subgroup's drowning risk and the unitary consequent from step 2. This calculation produced a relative ratio of drowning risk between subgroups, accounting for exposure to water. This ratio was reduced to its simplest form (i.e., $\eta:1$) for convenience.

To provide a point of reference gold standard comparison for the derived drowning ratio between subgroups, step 4 established the comparative specific drowning rate (*specific* being an absolute or real drowning rate for a specified period). This specific drowning rate is found by comparing the relative frequency of surf bather drowning for the subgroups from mortality data [25]. As in steps 2 and 3, relative subgroup drowning frequency is reduced to a rate in the simplest form (i.e., $\eta:1$).

The specific drowning rate provided a point estimate of the drowning proportions between subgroups from relatively small sample sizes ($N = 129$, for a four-year period). To assess sample reliability, a 95% CI was calculated for each specific rate antecedent using the adjusted Wald binomial method [27]. This test produces superior results for small samples when compared to other common binomial methods (e.g., Wald or Exact) [28].

For each subgroup comparison on the specific drowning rate, the first subgroup (antecedent) total and the group total were entered into an online tailored calculator to produce lower and upper range confidence intervals (CI) [29]. (Note: The binomial Score method was employed for one extreme distribution.) Upper and lower antecedent subgroup 95% CI scores were converted manually to an upper and lower comparative specific rate (reduced to the simplest form [$\eta:1$]).

Step 5 provided assessment by comparisons of subgrouping derived ratio of relative drowning risk (step 3) with comparative specific drowning rate point estimate and antecedent 95% CI (step 4).

2.3. Risk Analysis Assumptions and Subgroup Identification

The five steps (Table 2) followed a logical approach weighting drowning risk with water exposure. The method necessitated important assumptions concerning variable distributions, scale validities, additivity of scales items, linear patterns of risk contributions across variables or exposure levels and risk weightings based on subjective opinion. The possibility of these assumptions introducing unknown error is discussed under study limitations.

Subgroups marking drowning risk were determined on practical grounds. Gender was sub-grouped by male or female. Age was sub-grouped by <30 years and ≥ 30 years to gain adequate sample sizes while being proximate to self-report sample means (males 32.5 years; females 32.8 years) [22]. Bather activity was sub-grouped into waders (remaining in water depth ≤ 1 m), swimmers (in water depth >1 m without surfing equipment) or surfers (surfboard or body-board).

Nine subgroup comparisons were conducted: Four comparisons within risk marker groups for gender, age and activity (for activity, two comparisons were made—including or excluding waders to investigate consistency with mortality data); one comparison for gender by age (four subgroups); two comparisons for activity by gender; and two comparisons for activity by age. Within the last four comparisons, waders with or without surfing equipment (as opposed to swimmers and surfers beyond the swash zone) were excluded on the assumption that few, if any, *healthy* surf bathers in <1 m depth would drown [23]. (This assumption requires validation given a study reporting 5% of drownings across five American [US] states in one year were wading [30].) For drowning mortality data used in the risk analysis, water depth could not be determined [25].

3. Results

Results from risk marker subgroup comparisons are presented in Tables 3 and 4 and Figure 3. Table 3 specifies drowning risk contributions from risk factors and crude (water time) exposure ratios with the product of these two calculations being total drowning risk. Table 4 reports derived drowning ratios from comparative subgroup drowning risk and specific drowning rate plus 95% CI calculated from mortality data. Antecedent terms for the derived drowning ratio and specific drowning rates are illustrated also in Figure 3 for full visual assessment.

Two key comparisons are available for selected subgroups. The first concerns subgroup scores within ratios or rates (Table 4; subgroup 1:subgroup 2). An antecedent term >1 specifies subgroup 1 to hold relatively higher drowning risk (ratio) or drowning frequency (rate). The reverse applies for antecedent terms <1 . The second comparison falling at a broader level is between antecedent terms for derived ratios and specific rates (Figure 3). The specific rate antecedent together with confidence intervals provided a check on the results from risk analysis.

3.1. Comparisons within Subgroups

For gender, Table 3 shows that males had a lower contribution to drowning risk from the included factors but far higher crude exposure to water than females. This resulted in a male to female derived drowning ratio of 3.71:1 (Table 4). This ratio antecedent was below the specific drowning rate antecedent (6.11) but *just* within the specific drowning rate antecedent 95% CI (see worked example at Appendix B). By age group, bathers <30 years had both higher drowning risk contribution from the included factors and higher crude water time exposure. This was reflected in a derived drowning ratio of <30 years to ≥ 30 years of 1.78:1 (Table 4). The ratio antecedent was higher than that found for the specific drowning rate (0.44) and outside the antecedent 95% CI.

By age and gender subgroups, males ≥ 30 years had the lowest contribution to drowning risk from the included factors with the highest for females ≥ 30 years. The younger male subgroup had the highest crude water exposure time, with the older female subgroup lowest. This latter subgroup was used as the consequent base for ratios and rates which provided for comparisons among all four gender-age subgroups. The derived drowning ratio antecedent was highest for the younger male subgroup, followed by the older male subgroup and then the younger female subgroup (Table 4). In contrast, the comparative specific drowning rate antecedent was highest for the older male subgroup, followed by the younger male subgroup, then the older female subgroup. The antecedent for males ≥ 30 years versus females ≥ 30 years (8.33) was the only comparison among the above three to fall within the specific drowning rate antecedent 95% CI.

By activity, surfers had lower contributed drowning risk from included factors than both combined waders and swimmers and swimmers only. Surfers had higher crude water time exposure compared to both subgroups. For both comparisons, surfers had a relatively higher derived drowning ratio (1.45:1 and 3.28:1, respectively; Table 4) but a lower specific drowning rate (0.18:1). Both ratio antecedents were above the specific drowning rate antecedent 95% CI.

Table 3. Subgroup drowning risk based on risk factors and exposure to water.

Subgroups	Drowning Risk Contribution (DR)	Crude Water Time-Exposure Ratio (ER)	Total Drowning Risk (DR \times ER)
Within gender:			
Males	5.02	4.24	21.29
Females	5.74	1.00	5.74
Within age:			
<30 years	5.44	1.75	9.52
≥ 30 years	5.36	1.00	5.36

Gender by age:			
Males <30 years	5.05	13.93	70.33
Males ≥30 years	5.01	9.59	48.07
Females <30 years	5.70	4.55	25.95
Females ≥30 years	5.77	1.00	5.77
Within activity:			
Surf	4.26	1.96	8.35
Swim or wade	5.74	1.00	5.74
Surf	4.26	4.18	17.81
Swim	5.43	1.00	5.43
Activity by gender:			
Male swim	5.67	2.75	15.60
Female swim	5.17	1.00	5.17
Male surf	3.99	16.63	66.29
Female surf	5.79	1.00	5.79
Activity by age:			
Swim <30 years	5.36	2.30	12.32
Swim ≥30 years	5.50	1.00	5.50
Surf <30 years	4.40	1.39	6.12
Surf ≥30 years	4.14	1.00	4.14

For activity by gender, the surfer grouping results somewhat mirrored gender only differences (Table 3) but at a comparatively higher ratio (11.45:1) and rate (19.00:1; Table 4). For this comparison, the derived drowning ratio antecedent fell within the specific drowning rate antecedent 95% CI, although due to the small sample size and high proportion of male surfers, the specified range was large. In calculating binomial confidence intervals for extreme and small distributions, the binomial Score method may provide more precise endpoints compared to the adjusted Wald method [28]. The Score method revealed a comparatively smaller specific drowning rate antecedent 95% CI (3.24 to 111.36) but this result still bounded the derived drowning ratio antecedent for male surfers relative to female surfers.

Contrary to comparable overall gender results, female swimmers had lower drowning risk contribution relative to male swimmers (Table 3). However, male swimmers had higher water exposure resulting in a derived drowning ratio for male to female swimmers of 3.02:1; this compares to a higher (for males) specific rate of 5.35:1 and falls outside the specific drowning rate antecedent 95% CI (Table 4).

Table 4. Risk analysis drowning ratios and drowning rates.

Bather Subgroup Drowning Risk Comparison	Derived Drowning Ratio ^a	Specific Drowning Rate ^b	Specific Drowning Rate Antecedent 95% CI
Males:Females	3.71:1.00	6.11:1.00	3.71 to 10.11
<30 years:≥30 years	1.78:1.00	0.44:1.00	0.30 to 0.64
Males <30 years:Females ≥30 years	12.18:1.00	2.50:1.00	1.35 to 4.63
Males ≥30 years:Females ≥30 years	8.33:1.00	5.34:1.00	3.03 to 9.55
Females <30 years:Females ≥30 years	4.50:1.00	0.29:1.00	0.09 to 0.84
Surf:Swim or wade	1.45:1.00	0.18:1.00	0.11 to 0.30
Surf:Swim	3.28:1.00	0.18:1.00	0.11 to 0.30
Male swim:Female swim	3.02:1.00	5.35:1.00	3.19 to 9.03
Male surf:Female surf	11.45:1.00	19.00:1.00	2.93 to >999
Swim <30 years:Swim ≥30 years	2.24:1.00	0.38:1.00	0.25 to 0.58
Surf <30 years:Surf ≥30 years	1.48:1.00	0.82:1.00	0.35 to 1.92

Note: ^a derived from study data. ^b derived from mortality data.

For activity by age, the drowning risk contributions from included factors were relatively similar within both the swimming and surfing subgroups (Table 3). For swimmers

by age, drowning risk indicated by the derived drowning ratio (2.24:1; Table 4) was higher for the <30 years subgroup compared to the ≥ 30 years subgroup. In contrast, younger swimmers had a lower specific drowning rate (0.38:1; with the derived ratio antecedent being above the specific drowning rate antecedent 95% CI). For surfers by age, the derived drowning ratio indicated higher drowning risk for the younger age group compared to the older age group (1.48:1); the opposite was found for the specific rate (0.82:1). The ratio antecedent for surfers by age did however fall within the specific drowning rate antecedent 95% CI.

3.2. Comparisons between Subgroups

Of all subgroups, male surfers had both the lowest drowning risk contribution from risk factors (3.99) and highest water exposure (relative to their comparison subgroup). Female surfers had the highest drowning risk contribution from risk factors among all subgroups (5.79) plus the lowest total water exposure. More generally, subgroups found to have relatively lower drowning risk contribution from included factors had correspondingly high relative water time exposure. The two exceptions to this pattern were comparisons within age (<30 years vs. ≥ 30 years) and male vs. female swimmers (Table 3). For both comparisons, higher relative drowning risk contribution from risk factors for both younger bathers and male swimmers was combined with higher relative water-time exposure.

3.3. Comparisons between Risk Analysis Ratios and Drowning Rates

Figure 3 plots antecedent terms for the derived drowning ratio against the specific drowning rate on a Cartesian coordinate plane. The point distance from the origin reflects the relative difference in drowning risk between the subgroup comparisons for the ratio, specific rate or both. Distance from the equivalence line (i.e., equal ratio and rate antecedents) reflects the degree of disparity between ratio and rate antecedents. The three comparisons falling above the equivalence line (rate antecedent higher than derived ratio antecedent) were all contained within gender subgroups: Males vs. females, male swimmers vs. female swimmers and male surfers vs. female surfers. The remaining eight comparisons falling below the equivalence line (rate antecedent lower than derived ratio antecedent) included either age or activity groups (some with gender comparisons).

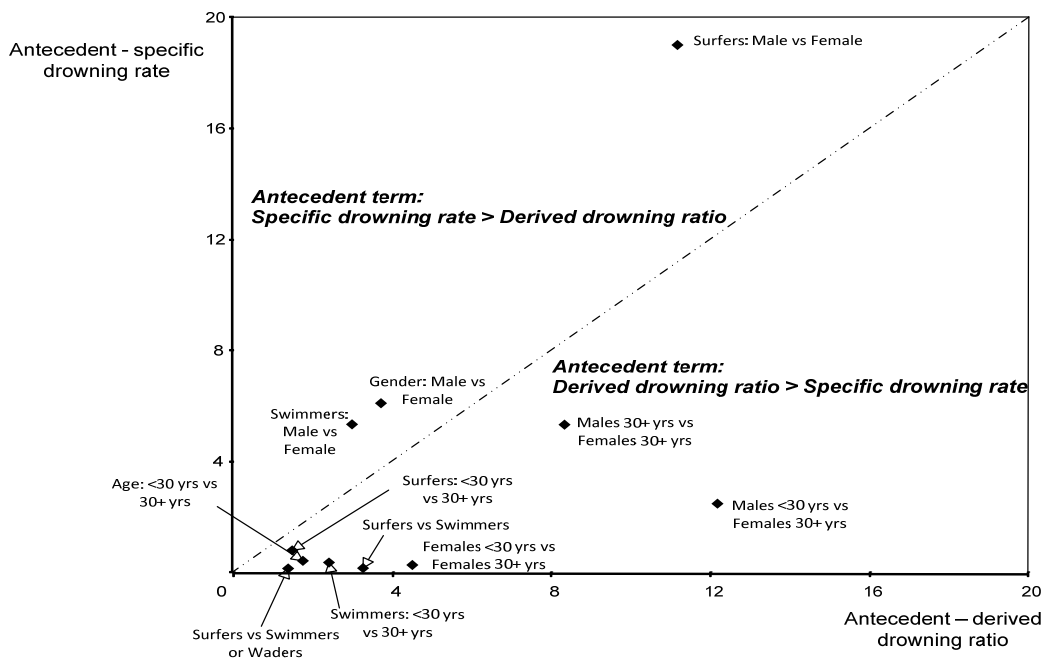


Figure 3. Comparisons of risk analysis drowning ratios and specific drowning rates.

3.4. Comparison Categories of Drowning Risk

Table 5 provides a summary from the risk analysis (as a relative drowning forecast) against recorded drownings by placing subgroup comparisons within four categories (reflecting Figure 3). For category 1 (two subgroup comparisons), drowning forecast was above that recorded without statistical difference between measures. Category 2 (one subgroup comparison) drowning forecast was also above that recorded but with statistical difference. Category 3 (two subgroup comparisons) and 4 (six subgroup comparisons) drowning forecasts were below that recorded with no statistical difference for the former and statistical difference for the latter.

Table 5. Summary results for comparison between derived drowning ratio and specific drowning rate for subgroups within risk marker groups.

	Drowning Subgroup Comparison	Relative Drowning Forecast ^a	Comparison with Recorded Drownings	Statistical Difference? ^b
1	Male vs. Female	4 to 1	Recorded drownings above forecast	No
	Male surf vs. Female surf	11 to 1		
2	Male swim vs. Female swim	3 to 1		Yes
3	Males ≥30 years vs. Females ≥30 years	8 to 1		No
	Surfers <30 years vs. Surfers ≥30 years	1 to 1		
4	<30 years vs. ≥30 years	2 to 1	Recorded drownings below forecast	Yes
	Males <30 years vs. Females ≥30 years	12 to 1		
	Females <30 years vs. Females ≥30 years	5 to 1		
	Swim <30 years vs. Swim ≥30 years	1 to 1		
	Surf vs. Swim or wade	1 to 1		
	Surf vs. Swim	3 to 1		

Note: ^a Ratio antecedent rounded to nearest integer; ^b From rate antecedent 95% CI.

4. Discussion

The study developed and tested a method to generate a comparative ratio of drowning risk between subgroups of surf bathers within risk marker groups based on data

collected for a specified surf bather location in Victoria, Australia. The derived drowning ratio combined specified risk contributions from three scale-measured candidate factors (swimming ability, surf swimming experience and wave height) weighted by crude exposure time to water to produce a drowning forecast. These forecasts, presumed representative of Australian surf bather subgroup populations, were assessed against corresponding specific drowning rates ascertained from Australia-wide surf bather drowning mortality data.

Table 6 lists proposed general explanations for similarities and differences between drowning forecasts (ratios) and recorded drownings (rates) in consideration of rate antecedent 95% CI. Explanations for discrepancies between forecast and recorded drownings consider possible roles of risk factors uncaptured in the risk analysis. Limited generalizability of water exposure estimates beyond the state of Victoria may also explain study findings (Table 5). Specific results are discussed below in the context of these general explanations.

Table 6. Speculative explanations for comparisons between drowning forecast and drowning rate based on risk markers.

Drowning Risk Contributor	Forecast Equivalent to Rate	Forecast not Equivalent to Rate
Risk factors	Total significant drowning risk captured by the three included factors in the mathematical model. Or Total significant drowning risk not captured by the included three factors; one or more uncaptured factor had an <i>even</i> drowning risk contribution within subgroups. And	Significant drowning risk from one or more uncaptured factor has an <i>uneven</i> impact within subgroups. And/or
Risk exposure	Exposure estimate is valid for Australian surf bather subgroups.	Exposure estimate is not valid for Australian surf bather subgroups.

Note: Equivalence based on comparison of the derived ratio antecedent with the specific rate antecedent 95% CI (Table 4).

4.1. Factors Accounted and Unaccounted in the Risk Analysis

For three causal risk factors analyzed, relative to other subgroups, female surfers carry the highest absolute drowning risk and male surfers lowest (Table 3). Relative to female surfers, male surfer mean scores for self-rated swimming ability, surf bather experience and wave height exposure all specified lower risk (online data Supplementary Materials). Yet male surfer time exposure to water relative to female surfers was higher by a factor over 16 (Table 3). Hence, while a male surfer may (on average) face lower drowning likelihood relative to a female surfer, drowning risk at the population level reverses this individual pattern by accounting for water exposure. Other subgroups may be similarly considered suggesting that population exposure to water has a major bearing drowning frequency.

The drowning ratio derived from risk analysis excluded influences from numerous possible risk (or protective) factors identified elsewhere [5]. These factors, associated with person, behavior or environment, include: Adverse health condition onset, alcohol use before bathing, swimming alone, other social or psychological factors (e.g., overconfidence) that influence bathing decisions, water depth, swimming fatigue and hazards such as rocks, sandbars, wind or tide.

Nevertheless, the study results are consistent with theoretical propositions discussed below. Further, regarding the above-stated suggestion, matching patterns between drowning forecasts and recorded rates provide evidence that comparative drowning frequencies between surf bather subgroups are largely proportional to differences in crude water exposure. That is, all surf bathers exposed to water face drowning risk regardless of their associated risk markers [7].

4.2. Subgroup Comparisons within Risk Marker Subgroups

Speculative explanations (Table 6) can be applied to results reported in Table 5. Comparison category 1 includes gender only and gender by surf activity comparisons. For both comparisons, males sustained a higher than forecast drowning frequency, possibly explained (following Table 6) by drowning risk factors associated with male gender (or protective factors associated with being female) uncaptured in the risk analysis. Given true, then a logical inference is that uncaptured drowning risk factors have a disproportionate influence on drowning risk within gender groupings, at the population level (e.g., having greater proportional risk for males).

Examples of uneven gender patterns of surf bather exposure to candidate risk factors have been documented [22]. Factors include males' more frequent use of alcohol before bathing, greater likelihood of bathing alone, bathing in deeper water farther from shore and overconfidence in their bathing abilities. Accounting for these factors in the risk analysis would almost certainly result in closer alignment between risk analysis ratios and specific drowning rates. Nonetheless, for comparison category 1, ratios fell within the 95% CI for rates (Table 5) suggesting that uncaptured factors have a relatively minor influence on drowning risk relative to risk and exposure measures employed in the risk analysis.

Comparison category 2 (Table 5) contained the male and female swimmer subgroup. As for comparison category 1, the drowning forecast was below the recorded rate, and for this subgroup, fell outside the 95% CI. Risk contributions from factor(s) uncaptured in the ratio calculations are proposed to have significant impact on actual drowning risk for this subgroup. This explanation finds support in earlier self-report data where, relative to female wave swimmers, male wave swimmers have lower surf beach experience, are more likely to consume alcohol before bathing and have higher confidence (likely overconfidence) to return to shore if caught in a rip current [22]. These factors may work in combination, resulting in male wave swimmers facing a significantly higher drowning risk relative to female activity-counterparts at the population level.

For comparisons category 3 (Table 5) drowning forecasts were above corresponding recorded drownings. Both comparisons involving age subgroups fell within the 95% CIs. The result for males and females ≥ 30 years suggests an uncaptured factor contributes uneven drowning risk for women (as males in the subgroup were forecast to drown at higher rate than found) though the effect is not significant (based on the rate antecedent 95% CI). A previous study found males to be overrepresented on patrolled surf beaches [22] reducing relative rescue likelihood for females.

The comparison category 3 of surfers by age (<30 with ≥ 30 years) forecast the younger group at higher drowning risk whereas records indicate the opposite (Table 4). As the forecast fell within the 95% CI, all significant factors may have been captured in the risk analysis or negligible (or balanced) impact of uncaptured factors may influence drowning risk for the subgroup. For example, older surfers may be exposed to deeper water, lower fitness or more testing surf conditions where increased drowning risk is counterbalanced by greater experience or circumspection in the water activity.

Comparison category 4 (Table 5) listed six subgroups. For all, drowning forecasts were above recorded drowning and outside 95% CIs. Four comparisons here included a younger versus older age. A mortality study found cardio-vascular health conditions to be associated with 26% of surf bather drownings [25] and age is a risk marker associated with cardio-vascular health conditions [31,32]. Cardio-vascular conditions therefore presumably contributed proportionally greater risk to older bathers, uncaptured in the risk analysis. This likely explained inflated forecasts for age group comparisons (as those aged <30 years formed subgroup 1 in comparisons).

Two bathing activity (only) subgroups were within comparison category 4 (Table 5). Referring to the risk analysis (Table 3), surfers carried lower average risk but higher proportional water exposure when compared to other bathers (Table 3). If all factor contributions to drowning risk were equal, then by accounting for water exposure only, surfers would be expected to drown at a relatively higher rate than swimmers. Yet the reverse

was found in the mortality data. Surfers may be distinguished from other bathers by higher mean surf experience and the use of floatation devices [22,23]. Floatation devices such as surf and body boards may provide protection from drowning, but this effect has yet to be scientifically verified.

4.3. Study Implications

The study's primary research contribution is a method development specifying relative drowning risk for surf bather subgroups accounting for exposure. The findings suggest the method is suitable for preliminary assessment of drowning risk while providing an alternative or precursor to traditional analytical epidemiological designs. The method sheds light on how captured and uncaptured candidate risk factors may combine, in tandem with water exposure, to produce differing levels of drowning risk within surf bather subgroups. Secondly, it has capacity to associate putative causal factors with risk markers including gender or age (Figure 2).

Drowning risk studies aim to inform prevention strategies. This study's findings add evidence for swimming ability, surf beach experience and wave height being factors that influence drowning risk for surf bathers. Hypothesizing for the role of other factors identified in earlier studies ensues from the risk analysis. Significantly, the study shows the important role of exposure to water in influencing drowning risk. The findings therefore support the critical use of surveillance for coastal bathers; a strategy undergoing change and improvement through use of new technologies including drones [33].

4.4. Study Limitations

Restrictive assumptions inherent to this study and underpinning datasets prevent drawing definitive conclusions. The study's value is realized through raising propositions concerning drowning risk factor contributions to guide further investigation. Key limitations entail generalizability of datasets, the validity of measures and a circumscribed criteria base for derived risk measures.

4.4.1. Generalizability of the Datasets

Study findings were limited by the predictive drowning ratios based on samples collected within Victoria, Australia (Table 1). Strictly, results generalize only to bathers using a small number of Victoria's surf beaches over one summer. While samples were assumed to be representative of all Australian surf bathers in the absence of further data, testing is required for confirmation.

Excluded risk factors were proposed to explain differences in antecedents between derived drowning ratios from risk analysis and specific drowning rates from Australia-wide mortality data. Rate and ratio differences may be partially explained by dissimilar exposure patterns and candidate risk factor profiles characteristic of surf bather deaths in locations outside the Victorian sampling frame. Future studies should extend temporal and spatial sampling frames while deriving comparative specific drowning rates over longer periods to improve estimate precision.

4.4.2. Validity of Measures

The validity of measures employed presents potential limitations. For example, the precise wave size allocated to each bather (i.e., exposure to wave size recorded simultaneously with self-report data) was based on a time-point observation [22]. Moreover, self-reported time visiting a beach in the previous 12 months was used as the proxy measure for surf swimming experience which may be imprecise given that males were documented to spend relatively longer in the water per visit [22,23].

Drowning risk factors wave height and surf bather experience both are crude measures of drowning risk. Nuanced risk contributions may transpire from wave type (plunging, surging, spilling) or wave frequency. Similarly, the essential protective benefit

from surf bather experience may arise from personal decision-making being calibrated with extant sea conditions. These propositions required further assessment.

The research design was intended to produce results that approximated reality. By seeking both parsimony and clarity, the method necessarily disregarded several possible influences on drowning risk including unknown interactions between candidate risk factors or risk factors and water exposure (Figure 1). However efforts to reduce bias by including all relevant variables in statistical models may actually have disbenefits [34].

For full theoretical confidence in the ecological validity of the study method, all drowning risk factors in operation require accounting; adding prohibitive complexity and virtual impossibility in practice. Given the variables used in this study were considered the most critical in surf bather drowning, results from more complex research designs may lead to only marginal improvement in precision [26]. The method sought to address a balance between methodological complexity and practical application to a defined at-risk population. By identifying the factors most influential for surf bather drowning risk, with contributions confirmed by specialist ratings, arguably, a close to optimal representation of reality generalizable to bathers using Australian surf beaches has been established [7]. Further methodological testing is required to assess this claim.

4.4.3. Applicability of Limited Criteria

A third limitation concerns strict criteria used by surf beach specialists to rate drowning risk in a scenario-based foundation study [7] of characteristics about the person, the beach type, prevailing weather conditions and behaviors. Effect sizes applied in this study were valid for bathers meeting the scenario as specified (e.g., bathing without equipment or bathing alone). Error from that study's results was discarded in this study on the assumption of being random noise. Regardless, few beachgoers contributing self-report data for this study would match controlled behavioral and exposure patterns used to specify applied risk factor contributions [22]. More precise research should tailor specialist rating for scenarios that better reflect behaviors of the subgroup analyzed (e.g., expert ratings for surfers using equipment).

5. Conclusions

This study attempted to forecast surf bather drowning risk using a mathematical representation. In meeting requirements for monotonicity, the mathematical specification was presumed to represent relative drowning risk with greater accuracy compared to judgements by experts provided with the same raw data [17]. This conclusion is supported by numerous studies documenting superior judgements by mathematical models compared to experts or clinicians under similar conditions [18].

The variables selected as contributors to drowning risk were identified by expert ranking to be the most influential. Each had demonstrated statistically significant association with drowning risk when rated by surf specialists. Variable weightings were taken from an experimental study design that quantified each factor's contribution to drowning risk. The specification of drowning risk from a combination of linear and configural terms provided a subtle sign of the expert [35]. Drowning risk calculated from factors, using data drawn from selected bather subgroups, was weighted by comparable water-exposure time data collected by a reliable direct observation method.

Despite the stated limitations, the findings demonstrate the method to be useful for forecasting drowning risk and generating hypotheses for further study through analytical epidemiology and/or risk assessment procedures. The study findings do not provide definitive answers to why subgroups drown at different rates but offer a basis to guide theoretical propositions about the roles of selected risk factors and the influence of water time exposure on relative drowning rates. Further research in high-risk water settings such as inland waterways may confirm the value of this risk analysis method for drowning and other defined injury problems.

Supplementary Materials: The following are available online at <https://doi.org/10.25955/61778323d7eab>, Data calculation spreadsheet.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Availability to foundation datasets used for this study listed on cited papers in Table 1. All data reported for this paper is available also directly from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Technical procedure in five steps.

The five steps described in Table 2 are detailed here in mathematical form.

Step 1 Estimation of total drowning risk for a surf bather subgroup from selected factors (based on self-report dataset):

$$Trc[sg\#] = \frac{\sum_{ki=1}^{ni} (Es[sa] * sa) + (Es[se] * se) + (Es[wh] * wh) + (Es[se \times wh] * (se \times wh))}{ni}$$

Trc—total risk contribution from selected drowning factors

Es[sa, se or wh]—effect size for selected drowning factor calculated by partial η^2

k_i—respondent score in subgroup

i—dataset employed

n_i—subgroup sample size

sa—swimming ability drowning factor

sg#—subgroup

se—surf experience drowning factor

wh—wave height drowning factor

The equation in step 1 combines linear summated terms plus a multiplicative term representing factor interaction [36] (pp. 3–7). All terms in the equation were found to be statistically significant contributors to drowning risk in a linear (or close to linear) pattern, based on specialist ratings [7]. Including a configural term in predictive equations had the advantage of better differentiating an individual bather's patterns of scores [37] (p. 122). Effect sizes calculated by partial η^2 were used as coefficients (weights) for the three candidate risk factor variables and a single interaction of two factors found to be significant predictors of surf bather drowning in the repeated measures ANOVA model [7]. The weights were: 0.82 for swimming ability, 0.85 for surf swimming experience, 0.93 for wave height and 0.15 for the interaction of surf swimming experience and wave height. The significant interaction in the model was represented by the product of the included two variables [38] (p. 445).

Step 2 Calculation of the comparative ratio of total person time water exposure for surf bather subgroups (based on direct observation dataset):

$$Awe[sg1]:Cwe[sg2] = \frac{\sum_{ki=1}^{ni} sg1}{\sum_{ki=1}^{ni} sg2}: 1$$

Awe—antecedent in ratio of total person time (minutes) water exposure—subgroup 1
Cwe—consequent in ratio of total person time (minutes) water exposure—subgroup 2
ki—respondent score in subgroup
i—dataset employed
ni—subgroup sample size
sg#—subgroup

Step 3 Prediction of comparative drowning risk for surf bather subgroups by combining results for step 1 (drowning risk contribution) and step 2 (relative water exposure):

$$Addr[sg1]:Cddr[sg2] = \frac{Trc[sg1] \times Awe[sg1]}{Trc[sg2]}: 1$$

Addr—antecedent in ratio of derived drowning risk—subgroup 1
Awe—antecedent in ratio of total person time (minutes) water exposure—subgroup 1
Cddr—consequent in ratio of derived drowning risk—subgroup 2
sg#—subgroup
Trc—total risk contribution from selected drowning factors

Step 4 Calculation of comparative specific drowning rate for selected subgroupings (based on mortality dataset) and 95% CI for antecedent:

$$Asdr[sg1]:Csdr[sg2] = \frac{\#sg1}{\#sg2}: 1$$

Asdr—antecedent in ratio of specific drowning rate—subgroup 1
Csdr—consequent in ratio of specific drowning rate—subgroup 2
sg#—subgroup
#—frequency within subgroup

95% CI for antecedent (*Asdr[sg1]*)-Adjusted Wald binomial test for confidence intervals
i Enter numerator frequency and subgroup total frequency into online calculator to find *Low 95% CI* and *High 95% CI*

$$ii \text{ } Asdr[sg1] \text{ lower boundary: } Csdr[sg2] = \frac{Low95\%CI * (\#sg1 + \#sg2)}{(1 - Low95\%CI) * (\#sg1 + \#sg2)}: 1$$

$$iii \text{ } Asdr[sg1] \text{ upper boundary: } Csdr[sg2] = \frac{High95\%CI * (\#sg1 + \#sg2)}{(1 - High95\%CI) * (\#sg1 + \#sg2)}: 1$$

Specific comparative rates calculated in step 4 are a time-bound subset of ratios [39] (p. 152). For the calculations here, the period was four years (2001 to 2005). The confidence interval may be interpreted as the range within which 95 percent of specific drowning rates sampled from the population would fall. Alternatively, this interval can be thought of as having a 95 percent chance of containing the true comparative drowning rate between subgroups.

Step 5 Comparison of derived drowning risk ratio (step 3) against the specific drowning rate (step 4) and antecedent 95% CI by subgroup:

$$Addr[sg1]:Cddr[sg2] \Leftrightarrow Asdr[sg1]:Csdr[sg2]$$

Asdr[sg1] 95% CI: lower boundary to upper boundary

Addr—antecedent in ratio of derived drowning risk—subgroup 1
Asdr—antecedent in ratio of specific drowning rate—subgroup 1
Cddr—consequent in ratio of derived drowning risk—subgroup 2
Csdr—consequent in ratio of specific drowning rate—subgroup 2
sg#—subgroup

Appendix B

Worked example of method in five steps (see also online Supplementary Materials). Subgroup comparison within gender for males vs. females.

Step 1—subgroup drowning risk (grouped by a specified risk marker variable)

$$Trc[sg\#] = \frac{\sum_{ki=1}^{ni} 0.82sa + 0.85se + 0.93wh + 0.15(se \times wh)}{ni}$$

$$Trc[sg1] - Males = \frac{973.90}{194} = 5.02$$

$$Trc[sg2] - Females = \frac{1200.31}{209} = 5.74$$

Result: Males (sg1) had relatively lower mean contribution to drowning risk from selected factors (*Trc*) compared to females (sg2).

Step 2—Ratio of total person time exposure to water

$$Awe[sg1]:Cwe[sg2] = \frac{\sum_{ki=1}^{ni} sg1}{\sum_{ki=1}^{ni} sg2}: 1$$

$$Males:Females = \frac{5668 \text{ min}}{1338 \text{ min}}: 1 = 4.24: 1$$

Result: Males (sg1) have relatively higher water exposure (*Awe*) compared to females (*Cwe*).

Step 3—Derived drowning risk

$$Addr[sg1]:Cddr[sg2] = \frac{Trc[sg1] \times Awe[sg1]}{Trc[sg2]}: 1$$

$$Males:Females = \frac{5.02 \times 4.24}{5.74}: 1 = 3.71: 1$$

Result: Males (sg1) have relatively higher derived drowning risk (*Addr*) compared to females (*Cddr*), accounting for differences in water exposure (*Awe*) and total contributed drowning risk from factors (*Trc*).

Step 4—Specific drowning rate and 95% CI for antecedent

$$Asdr[sg1]:Csdr[sg2] = \frac{\#sg1}{\#sg2}: 1$$

$$Males:Females = \frac{110}{18}: 1 = 6.11: 1$$

Result: Males (sg1) have relatively higher specific drowning rate (*Asdr*) compared to females (*Csdr*). This rate of 6.11 is higher than the derived drowning risk ratio for males (*Addr*) of 3.71.

95% CI for antecedent (*Asdr[sg1]*) = 6.11 (proportion of 0.8594)

Adjusted Wald binomial test for confidence intervals:

lower limit = 0.7878

upper limit = 0.9100

$$Malegrouplowerboundary = \frac{0.7878 \times 128}{(1 - 0.7878) \times 128} = 3.71$$

$$Malegroupupperboundary = \frac{0.9100 \times 128}{(1 - 0.9100) \times 128} = 10.11$$

Result: The males (sg1) specific drowning rate (*Asdr*) is 6.11, relative to females. The 95% CI for this specific drowning rate (*Asdr*) comparison has a lower boundary of 3.71 and upper boundary of 10.11.

Step 5—Derived drowning ratio compared to specific drowning rate—males to females

$$Addr[sg1]:Cddr[sg2] \Leftrightarrow Asdr[sg1]:Csdr[sg2]$$

$$3.71:1 \Leftrightarrow 6.11:1$$

*sdr*antecedent (males) 95% CI:3.71 to 10.11

Result: The male (sg1) to female (sg2) derived drowning ratio (*Addr:Cddr*) antecedent of 3.71 is lower than the male (sg1) to female (sg2) specific drowning rate (*Asdr:Csdr*) antecedent of 6.11 but this falls within (just) the 95% CI for the specific drowning rate antecedent term (*Asdr*) of 3.71 to 10.11.

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