

## RESEARCH ARTICLE

# Coastal drowning: A scoping review of burden, risk factors, and prevention strategies

William Koon<sup>1,2\*</sup>, Amy Peden<sup>2,3</sup>, Jasmin C. Lawes<sup>1,2,4</sup>, Robert W. Brander<sup>1,2</sup>

**1** School of Biological Earth and Environmental Sciences, University of New South Wales, Sydney, New South Wales, Australia, **2** Beach Safety Research Group, University of New South Wales, Sydney, New South Wales, Australia, **3** School of Population Health, University of New South Wales, Sydney, New South Wales, Australia, **4** Surf Life Saving Australia, Sydney, New South Wales, Australia

\* [w.koon@unsw.edu.au](mailto:w.koon@unsw.edu.au)



## Abstract

### Objective

Coastal drowning is a global public health problem which requires evidence to support safety initiatives. The growing multidisciplinary body of coastal drowning research and associated prevention countermeasures is diverse and has not been characterised as a whole. The objective of this scoping review was to identify key concepts, findings, evidence and research gaps in the coastal drowning literature to guide future research and inform prevention activities.

### Methods

We conducted a scoping review to identify peer reviewed studies published before May 2020 reporting either (i) fatal unintentional coastal drowning statistics from non-boating, -disaster or -occupational aetiologies; (ii) risk factors for unintentional fatal coastal drowning; or (iii) coastal drowning prevention strategies. Systematic searches were conducted in six databases, two authors independently screened studies for inclusion and one author extracted data using a standardised data charting form developed by the study team.

### Results

Of the 146 included studies, the majority (76.7%) were from high income countries, 87 (59.6%) reported coastal drowning deaths, 61 (41.8%) reported risk factors, and 88 (60.3%) reported prevention strategies. Populations, data sources and coastal water site terminology in the studies varied widely; as did reported risk factors, which most frequently related to demographics such as gender and age. Prevention strategies were commonly based on survey data or expert opinion and primarily focused on education, lifeguards and signage. Few studies ( $n = 10$ ) evaluated coastal drowning prevention strategies.

### Discussion

Coastal drowning is an expansive, multidisciplinary field that demands cross-sector collaborative research. Gaps to be addressed in coastal safety research include the lack of

## OPEN ACCESS

**Citation:** Koon W, Peden A, Lawes JC, Brander RW (2021) Coastal drowning: A scoping review of burden, risk factors, and prevention strategies. *PLoS ONE* 16(2): e0246034. <https://doi.org/10.1371/journal.pone.0246034>

**Editor:** Sherief Ghozy, Mansoura University, EGYPT

**Received:** October 29, 2020

**Accepted:** January 12, 2021

**Published:** February 1, 2021

**Peer Review History:** PLOS recognizes the benefits of transparency in the peer review process; therefore, we enable the publication of all of the content of peer review and author responses alongside final, published articles. The editorial history of this article is available here: <https://doi.org/10.1371/journal.pone.0246034>

**Copyright:** © 2021 Koon et al. This is an open access article distributed under the terms of the [Creative Commons Attribution License](https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

**Data Availability Statement:** All relevant data are within the paper and its [Supporting Information](#) files.

**Funding:** The authors received no specific funding for this work, however, WK's doctoral studies are

supported through a University International Postgraduate Award scholarship funded by UNSW Sydney.

**Competing interests:** The authors have declared that no competing interests exist.

research from lower resourced settings, unclear and inconsistent terminology and reporting, and the lack of evaluation for prevention strategies. Advancing coastal drowning science will result in a stronger evidence base from which to design and implement effective countermeasures that ultimately save lives and keep people safe.

## Introduction

Drowning is the process of respiratory impairment from submersion or immersion in liquid and is considered a major global health problem [1,2]. The burden of drowning is disproportionately high in low-income countries and among males, children and young people [2,3]. Drowning outcomes include death and a range of non-fatal outcomes from survival with no lasting consequence to survival with permanent neurological impairment [4]. The individual, community and societal cost of drowning is immense, multi-faceted and worthy of research that informs robust prevention efforts.

Countermeasures intended to prevent or reduce drowning are most effective when evidence based. Research which delineates the nature and extent of the problem and identifies causal factors to be addressed via intervention is therefore an a priori step in countermeasure development [5]. For drowning, the type of body of water (e.g. swimming pool, river, ocean etc.) is an important consideration which informs prevention efforts as the populations and circumstances of different water sites vary [6]. In most countries, unintentional drowning occurs more frequently at natural water sites, compared to pools or bathtubs [7].

The International Classification of Diseases' (ICD) 'natural water' category is broad and does not specify subcategories such as lake, beach, river etc. [8]. The 2015 Utstien-style Guidelines for Reporting Drowning recommend 'Body of water' as a supplementary data item, providing some water type categories and the caveat that the list should be 'modified as needed to include local hazards' [1]. While varying coding practices have limited large scale analysis of drowning at specific water sites, these data do exist in many reporting systems and are frequently available in peer reviewed and grey literature. Drowning incidence at different types of natural water sites varies by location: in some communities, inland waterways are the primary sites of drowning [9,10] while coastal waters represent a major hazard in others. For example, 948 drowning deaths, 85% of all drowning cases, occurred in the sea over a five-year period in a coastal province in Iran [11]; 399 fatal and non-fatal drowning events, 90% of drowning all incidents, occurred at the coast across a 10-year period in Marseille, France [12]; and 78 drowning deaths, 76% of all drowning fatalities, occurred in the ocean in Port Elizabeth, South Africa [13].

Defining coastal bodies of water for the purposes of drowning data management and prevention activities has taken different forms [14,15]. While no international consensus list of coastal drowning water sites exists, an operationalised definition for coastal waters might include beaches, harbors, bays, rock platforms, estuaries, wetlands, lagoons, saltwater marshes, natural occurring saltwater canals and intercoastal waterways, large inland seas such as the Black Sea or the Caspian Sea, the Great Lakes in North America and the open ocean itself. These diverse environments present challenges to coastal drowning research and prevention efforts: coastal hazards are variant and complex [16–18], their study involves many different scientific disciplines and subsequent control measures are the domain of multiple sectors. Maritime safety likely represents the most robust drowning prevention initiatives; centuries of seafaring and large-scale public and private investment have resulted in a mature field of safety

science which supports all manners of ergonomic, education and enforceable policy countermeasures [19]. While arguably not as advanced as its naval counterpart, nearshore coastal drowning prevention and safety also has a rich history and rapidly developing scientific basis [20–22].

Early coastal safety research frequently took the form of epidemiologic studies: descriptive case series from the 1960's identified the importance of beach rescuers [23], difficulty in measuring exposure [24], and the dangers of certain activities such as scuba diving [25]. In the 1980s, seminal work by Wright and Short typified geomorphological beach states which later became the basis for the Australian Beach Safety and Management Program (ABSAMP) and other similar risk management systems used around the world [26–29]. Studies on the rip current hazard have evolved from observations of sticks floating out to sea in the 1940s to complex experiments involving Global Positioning Satellite (GPS) drifters and, recently, human dimensions involving identification and escape strategies [16,30–32]. The past decade has seen an increase in coastal drowning and safety studies employing multidisciplinary and social science methods and advances in specific areas such as beach safety [22], rock platforms and rock fishing [33], and surf lifeguarding [34].

While obviously expansive, the extent, range and nature of coastal drowning research has not been characterised as a whole. Scoping reviews are useful for this purpose; they aim to identify key concepts, findings, evidence and research gaps of a particular field of study [35]. Scoping reviews are conducted systematically with rigorous and transparent methods but differ from traditional systematic review or meta-analysis methods [35]. In a scoping review, the primary interest is the identification and mapping of characteristics and concepts in a field of work versus the evaluation of a clinically meaningful question to inform practice [36]. The breadth of coastal drowning research, scale of coastal drowning prevention efforts and the absence of any existing effort to this effect justify a broad assessment of this nature.

The primary aim of this review was to systematically characterise peer-reviewed coastal drowning research to better understand the science driving associated safety initiatives. Specifically, we sought to identify key concepts and factors studied, describing how they have been analysed and discussed, in order to synthesize present understanding and highlight gaps in the field. The review focused on fatal unintentional coastal drowning from non-boating, -disaster or -occupational origin, and employed an analytic framework based on coastal drowning study characteristics, epidemiological burden, risk factors and prevention strategies. Underpinning this study is the belief that a critical examination of the state of coastal drowning science will clarify current understanding of the field and help plot a course for future research and prevention activities which seek to save lives.

## Materials and methods

We identified and conducted a scoping review of the published coastal drowning literature using the five-stage Arksey and O'Malley framework [35], with incorporated recommendations from Levec et al. [37]. We also utilised a modified Preferred Reporting Items for the Systematic Reviews and Meta-Analyses (PRISMA) methodology to guide the review (S1 File) [38,39].

### Stage one: Identifying and refining research questions

For a manageable review of such a broad topic, we refined the scope of inquiry to focus on fatal unintentional coastal drowning, excluding boating, disaster and occupational aetiologies. While many drowning prevention countermeasures are universal, those involving intentional drowning or submersion from boating, disaster (e.g. flood, tsunami, hurricane) or

occupational situations involve some specific mechanisms. Many of the key concepts and evidence from research in these drowning sub-fields are distinct, and several systematic reviews exist specific to these subjects [40–44]. This refined focus was further guided by three domains consistent with a public health approach: epidemiological burden, risk factors and primary prevention strategies [45].

### Stage two: Identifying relevant studies

The multidisciplinary nature of coastal drowning as a field of research means that relevant studies come from a diverse array of journals. We searched MEDLINE, MEDLINE epub, EMBASE, Environment Complete, CINAHL and SPORTDiscus databases for peer reviewed articles published in English or Spanish up to 30 April 2020. With the aid of a specialist librarian, these databases were selected strategically because they index journals from a variety of disciplines which have previously published relevant coastal drowning studies.

The complete search strategies for each database are available in [S2 File](#) but generally followed a format of 'drown\* AND' keywords related to coastal water sites (e.g. 'ocean', 'sea', 'beach', 'harbor', 'coast' etc.), limited to human studies. Notably, through the iterative process of developing database search strategies we discovered that multiple relevant studies from health sciences journals were not appearing in our searches based solely on coastal water site terms. Many studies reported and discussed coastal drowning in the text, but primarily focused on swimming pool drowning and therefore only included that information in the title, abstract and searchable metadata. We therefore opted to include 'swimming pool\*' in our search of health science databases to ensure we captured all potential studies. We also manually checked references of included studies to identify additional papers which met the inclusion criteria, and cross referenced our own databases of relevant studies to ensure maximum inclusion.

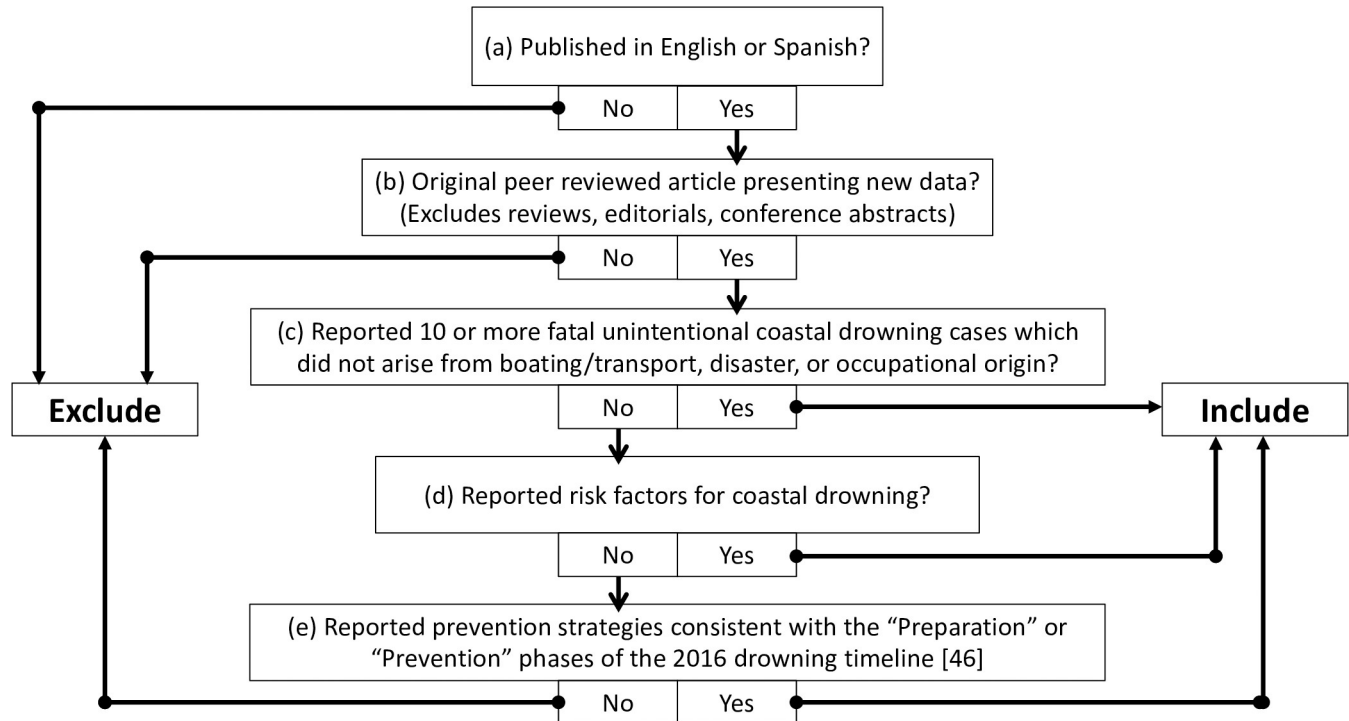
### Stage three: Study selection

Study inclusion criteria followed an iterative development process as recommended by Levac et al. [37]. Studies included in this scoping review must have: (a) been written in English or Spanish, (b) been an original peer-reviewed article presenting new data (e.g. not a review, editorial, or conference abstract); and either (c) reported 10 or more fatal unintentional coastal drowning cases which did not arise from boating/transport, disaster, or occupational origin; (d) reported risk factors for unintentional fatal coastal drowning; and/or (e) reported prevention strategies consistent with the "Preparation" or "Prevention" phases of the 2016 drowning timeline ([Fig 1](#)) [46]. For criteria (a), author WK is fluent in Spanish and screened those studies. For criteria (c), reported drowning statistics, we excluded studies which only reported drowning cases from 'natural' or 'open' bodies of water if we could not determine that those water sites were coastal, and those reporting less than 10 coastal drowning cases.

Two authors (WK and AP) independently screened titles and abstracts using the online software Covidence and remained in contact throughout the process as recommended by Levac et al. to discuss disagreements, challenges and uncertainties [46,47]. WK and AP reviewed full texts of remaining papers separately, (82% agreement, Cohen's Kappa = 0.64) and discussed disagreements until reaching consensus. A third reviewer (RB) was available to determine final inclusion but was not required.

### Stage four: Charting the data

One author (WK) completed data extraction using a standardised form developed by the study team. The form ([S3 File](#)) involved four sections: study information (country and year of publication, aims etc.), epidemiological burden, risk factors and prevention strategies. The form



**Fig 1. Study inclusion-exclusion decision tree flow chart.**

<https://doi.org/10.1371/journal.pone.0246034.g001>

was piloted on five randomly chosen studies to ensure usability and accurate data capture [37]. The development and pilot process identified the need for a series of rules to ensure consistency, detailed below.

**Stage 4.1: Charting epidemiological data.** Among other information, we endeavoured to record the number of reported coastal drowning deaths reported in each study and the terminology used to identify those cases as ‘coastal’. We only noted the primary data on coastal drowning deaths reported and analysed each study, generally in the results section, and excluded information referenced, but not analysed, for example information reported in an introduction or background section. If a study reported both fatal and non-fatal unintentional drowning in the coastal environment, we extracted only data related to drowning cases which we could confirm as fatal. We noted if studies reported intentional or boating cases separately, extracting only data relating to the unintentional/non-boating cases where possible and noting all coastal drowning deaths when not specifically separated. Where two or more papers used the same dataset for the exact same timeframe, we only extracted the reported cases one time from the paper providing the most information (e.g. a paper reporting cases and risk factors over a paper only reporting cases).

**Stage 4.2: Charting data on risk factors.** To better understand coastal drowning epistemology, we purposefully adopted a broad approach in charting associated risk factors. Drowning is a process with several phases before death [46], we therefore recorded information on indicators that may be associated with fatal outcome and those pertaining to other preceding/proximal outcomes, such as those related to knowledge, attitudes, ability etc. which could increase coastal drowning risk [48]. For a comprehensive perspective, hereafter we refer to indicators, whether in reference to fatal or preceding/proximal outcomes, proven causal association or not, as risk factors. We noted the risk factor (e.g. male, young age, weekend etc.), the outcome associated with that factor (e.g. fatal coastal drowning, low swimming skills, unsafe

swim choice, etc.) and the method for determining the risk factor (e.g. statistical analysis of epidemiological data, descriptive analysis of survey data, etc.).

For epidemiological studies reporting counts of fatal coastal drowning by some category, we noted the group with the most deaths as a risk factor and the method determining the risk factor as 'higher proportion of cases'. For example, in a study presenting the number of coastal drowning deaths by age group, the age group with the most deaths would be noted as a risk factor determined by higher proportion of cases. Additionally, we only charted risk factors based on epidemiological data (fatal drowning cases) if they specifically related to coastal water sites. We did not include those factors based on data from, or intended for, non-coastal or multiple bodies of water where information for the coastal environment couldn't be isolated. Although many risk factors are likely to be ubiquitous, we were interested in identifying those factors which have been characterised in the literature as specific to coastal drowning.

**Stage 4.3: Charting data on prevention strategies.** For those studies that reported prevention strategies, we extracted information on the recommendation/strategy and the data or evidence on which it was made, if any. Prevention strategy recommendations made without supporting data were classified as 'expert opinion'. Each prevention recommendation was categorized based on its focus, such as education, lifeguards, signage etc. for summary. As the primary aim of this scoping review was to identify and characterise key concepts and factors in the coastal drowning literature, and not provide a critically appraised synthesised result for a specific clinically meaningful question, we did not perform methodological limitations or risk of bias assessments [36].

### Stage five: Presenting the data

Charted data were summarised via numerical summary and thematic analysis [35,37], and reported as single cohort of studies and separately by the domains described in stage one: epidemiological data, risk factors or prevention strategies. For presenting data on risk factors, we described the number of times factors were identified in the papers as 'risk factor reports.' Summarising the data in this way allowed us to map not only the unique factors identified in the literature, but also the number of times they have been studied, have used different analyses and employed different outcome measures.

## Results

Database searches identified 1,167 unique studies, 110 remained after screening and full-text review. An additional 36 relevant studies were identified by hand-searching references, resulting in 146 included studies (Fig 2; S1 Table). Of these, 22 (15.1%) reported fatal coastal drowning statistics, risk factors and prevention strategies, while the remaining studies reported one or a combination of the three domains. Although a small number of studies published in Spanish were reviewed in the screening stage, none met inclusion criteria resulting in a final cohort of only English language studies.

### Study characteristics

More than half the studies (52.7%) came from Australia and the United States (49 [33.6%] and 28 [19.2%] respectively), 13 studies (8.9%) were from New Zealand and five (3.4%) each were from Iran, South Africa and the United Kingdom. Five studies (3.4%) included data from more than one country, and the remaining 36 studies (24.7%) came from 19 countries (Table 1). Classified according to World Bank Country Income and Lending Groups at the time of publication (or nearest year from available data), 112 studies (76.7%) were from high income countries, 21 studies (14.4%) came from upper middle-income countries, 9 studies



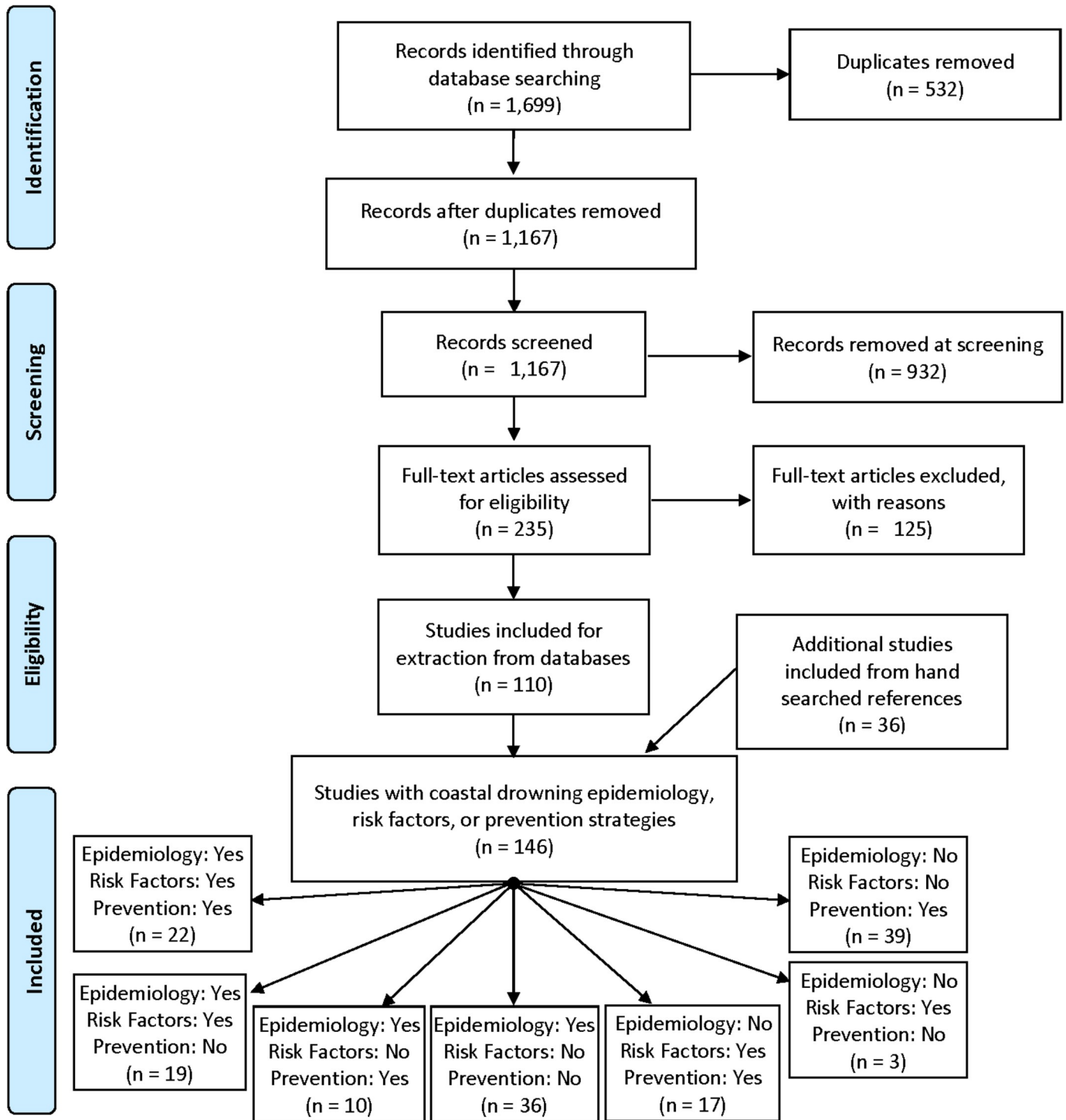


Fig 2. Modified PRISMA-ScR flow chart.

<https://doi.org/10.1371/journal.pone.0246034.g002>

(6.2%) were from lower middle-income countries, and no studies were from low-income countries [49]. Of the five multi-country studies, two were global surveys with responses from multiple countries and three only included data from high income nations. The earliest study

**Table 1. Number of studies based on country of included data.**

Country	Number of Studies	Percent of total
Australia	49	33.6%
USA	28	19.2%
New Zealand	13	8.9%
Iran	5	3.4%
Multiple	5	3.4%
South Africa	5	3.4%
UK	5	3.4%
Brazil	4	2.7%
Spain	4	2.7%
France	3	2.1%
India	3	2.1%
Turkey	3	2.1%
China	2	1.4%
Costa Rica	2	1.4%
Korea	2	1.4%
Pakistan	2	1.4%
Singapore	2	1.4%
Fiji	1	0.7%
Finland	1	0.7%
Ghana	1	0.7%
Israel	1	0.7%
Mexico	1	0.7%
Norway	1	0.7%
Scotland	1	0.7%
Thailand	1	0.7%
United Arab Emirates	1	0.7%

<https://doi.org/10.1371/journal.pone.0246034.t001>

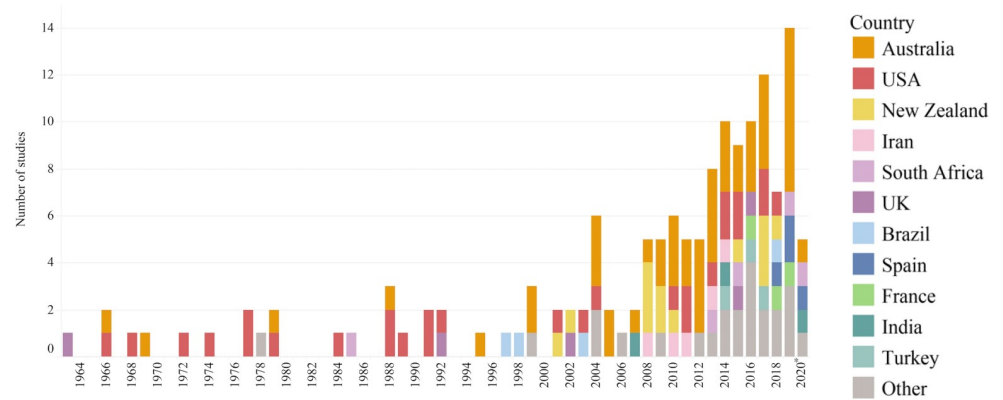
included in this review was published in 1963 from the United Kingdom [23]. Since then, studies reporting coastal drowning statistics, risk factors and prevention strategies have steadily increased to date (Fig 3). This cohort of coastal drowning research was published in 66 different journals; the three most frequently represented disciplines were non-injury-specific health/medical sciences (62 studies, 42.5%), followed by the physical sciences (32 studies, 21.9%), and those which were injury- or safety-specific (18 studies, 12.3%; Table 2).

### Epidemiological burden

Of the 146 included studies, 87 (59.6%) reported a combined 21,095 coastal drowning deaths using various terminology to indicate coastal waters (Table 3). About a quarter of these papers (n = 21, 24.1%) grouped terminology from more than one body of water into a single category (e.g. “Ocean and Bay”). Most studies (n = 57, 65.5%) included multiple types of bodies of water, including non-coastal sites. In these multi-water site studies, coastal drowning typically represented between 10% and 40% of drowning deaths reported; coastal waters represented the category with the most deaths in half the studies (n = 29, 50.9%).

**Case inclusion and data sources.** The geographic catchment for case inclusion varied with many studies (n = 36, 41.4%) reporting data at the country level, a quarter (n = 22, 25.3%) at the state or provincial level, one fifth (n = 17, 19.5%) at the regional or sub-state level, nine (10.3%) at the local government (city/town/municipal) level, and three (3.4%) at the sub-





**Fig 3. Studies by publication year.** \*Note, 2020 current through April 30.

<https://doi.org/10.1371/journal.pone.0246034.g003>

municipal level. Five of the state/province studies included multiple states or provinces. Of the country level studies, two included multiple countries and, separately, two were partially complete: both reported national data excluding a single state.

Most studies (n = 67, 77.0%) included all ages of drowning deaths, while 11 (12.6%) reported only adults and nine (10.3%) included only children and/or adolescents (0–19 years). The majority of studies (n = 80, 92.0%) included only drowning cases while seven (8.0%) included drowning and other causes of death. Many studies (n = 34, 39.1%) only included cases from a specific cohort, such as drowning deaths from the beach (n = 10, 11.5%), rip currents (n = 7, 8.0%), SCUBA/skin diving or snorkelling (n = 5, 5.7%), or incidents involving a lifeguard or lifesaver (n = 5, 5.7%). The majority of studies (n = 50, 57.5%) used multiple data sources to report coastal drowning statistics (Table 4).

**Reporting of intentional, boating, and occupational drowning.** Studies which focused solely on intentional, boating, disaster or occupational drowning were excluded at the screening stage, but several of the included studies contained various facets of these sub-topics. Occupational drowning cases were included or discussed in six papers, but none reported work-related deaths by body of water, thus the number of non-occupational coastal drowning deaths

**Table 2. Peer-reviewed academic journals with three or more included studies.**

Journal	Count of studies (%)	Journal Discipline
International Journal of Aquatic Research & Education	13 (8.9%)	Industry specific
Natural Hazards	13 (8.9%)	Physical sciences
Ocean & Coastal Management	9 (6.2%)	Physical sciences
International Journal of Injury Control & Safety Promotion	7 (4.8%)	Injury/safety
Journal of Coastal Research	7 (4.8%)	Physical sciences
Medical Journal of Australia	7 (4.8%)	Other health/medical sciences
Accident Analysis & Prevention	5 (3.4%)	Injury/safety
Australian & New Zealand Journal of Public Health	4 (2.7%)	Other health/medical sciences
Health Promotion Journal of Australia	3 (2.1%)	Other health/medical sciences
Natural Hazards & Earth System Sciences	3 (2.1%)	Physical sciences
PLOS ONE	3 (2.1%)	Interdisciplinary
Public Health Reports	3 (2.1%)	Other health/medical sciences
Resuscitation	3 (2.1%)	Other health/medical sciences
Tourism Management	3 (2.1%)	Industry specific

<https://doi.org/10.1371/journal.pone.0246034.t002>

**Table 3. Number of studies by coastal terminology used in drowning death body of water categories.**

Coastal water category terminology	Number of studies (N = 87)
Ocean	29 (33.3%)
Sea	23 (26.4%)
Beach	21 (24.1%)
Bay	11 (12.6%)
Not specific <sup>a</sup>	10 (11.5%)
Surf	9 (10.3%)
Other <sup>b</sup>	9 (10.3%)
Saltwater	8 (9.2%)
Harbour	8 (9.2%)
Region specific body of water	6 (6.9%)
Coast	3 (3.4%)
Rocks	3 (3.4%)
Lagoon	2 (2.3%)
Canal	2 (2.3%)

<sup>a</sup> Confirmed coastal only papers, no specific terminology for body of water used.

<sup>b</sup> Other terminology includes saltwater ocean pool, estuary, tidal creek, saltwater inlet, saltwater sound, saltwater jetty, shoreline, lake surf (North American Great Lakes), and marine environment.

<https://doi.org/10.1371/journal.pone.0246034.t003>

from these studies is unknown. The majority of studies did not clearly differentiate between boating and non-boating cases: 32 studies (36.8%) did not include or address boating in any way and 23 studies (26.4%) included or discussed boating in some manner, but did not report boating and non-boating cases separately. In 14 studies (16.1%), boating cases were not discussed, but were unlikely to be present as they focused on specific cases such as rip current or SCUBA drowning. Eleven studies (12.6%) reported coastal boating and non-boating drowning separately, and seven (8.0%) explicitly included only non-boating cases. While most studies (n = 36, 41.4%) included only unintentional cases, more than one third (n = 32, 36.8%) did not address or discuss intentionality in any way. Eleven studies (12.6%) included, but did not report intentional cases separately by water site, five (5.7%) included and did report intentional cases by water site and three (3.4%) did not discuss but were unlikely to include intentional cases based on the study focus (e.g. bystander rescuer, SCUBA).

## Risk factors

One hundred seven unique factors were identified from a total of 228 risk factor reports in 61 of the included studies (41.8%). The majority of risk factor reports (n = 120, 52.6%) used epidemiological data; 84 (36.6%) used survey data, 20 (8.8%) used expert panel techniques and four (1.8%) was a qualitative study.

**Outcomes and analysis.** Fatal coastal drowning was the primary outcome in the majority (n = 137, 60.1%) of risk factor reports: 120 from epidemiological data and 17 from a single study which employed an expert panel technique to determine factors that influence a user's risk of drowning at surf beaches [50]. Fatal coastal drowning risk factor reports using epidemiological data (n = 120) were most frequently identified by a higher proportion of cases (n = 98, 43.0%), followed by statistical analysis with a significant result (n = 14, 6.1%) and a reported incidence or prevalence rate (n = 8, 3.5%).

Preceding/proximal outcomes were used in 91 (39.9%) risk factor reports, and related to knowledge (n = 22, 9.6%), skills or abilities (n = 19, 8.3%), behaviour or practice (n = 18, 7.9%)

**Table 4. Data sources from studies which reported coastal drowning statistics.**

Data Source	Single sourced studies (n = 37)	Studies with multiple data sources (n = 50)	Total (n = 87)
Death certificate or coroner data	17	38	55 (63.2%)
Media reports	6	21	27 (31.0%)
Police records	2	23	25 (28.7%)
Hospital data	-	20	20 (23.0%)
Lifeguard or beach rescue data	3	10	13 (14.9%)
Emergency Medical Services	1	9	10 (11.5%)
Other <sup>a</sup>	1	11	12 (13.8%)
Questionnaire	1	6	7 (8.0%)
Unclear	4	-	4 (4.6%)
Other medical data source (i.e. Clinic, Private Practice, Drowning Centres)	-	4	4 (4.6%)
Other rescue service (e.g. fire department)	2	2	4 (4.6%)

<sup>a</sup> Other data sources include various government agencies (e.g. Ministry of the Interior, Ministry of Health), industry equipment malfunction reports (generally for SCUBA studies), and non-profit organizations.

<https://doi.org/10.1371/journal.pone.0246034.t004>

decision-making (n = 17, 7.5%), and awareness or risk perception (n = 15, 6.6%). Of these preceding/proximal outcome risk factors (n = 91), the majority (n = 65, 71.4%) were identified by statistical analysis of survey data, 19 (20.9%) were identified by descriptive survey data, four (4.4%) were identified via qualitative methods, and three (3.3%) were identified through expert panel techniques (Table 5).

**Factors studied.** Most of the 228 risk factor reports related to the person (n = 180, 78.9%), followed by the environment (n = 26, 11.4) and time (n = 22, 9.6%). Reported risk factors most frequently related to gender, behaviour/activity, age, and race/ethnicity, and the single most frequently reported risk factor was being male (Table 6, S2 Table).

## Prevention strategies

Over half of the included studies (n = 88, 60.3%) recommended coastal drowning countermeasures. A principal prevention focus was education, recommended in 70 studies (79.5%), followed by various strategies related to lifeguards and signage, discussed in 24 (27.3%) and 19 (21.6%) studies, respectively. Prevention recommendations were most frequently supported by survey analysis (31 studies, 35.2%), followed by expert opinion without explicit supporting data (24 studies, 27.3%) and epidemiological information (21 studies, 23.9%). Ten studies (11.4%) made recommendations based on analysis which aimed to evaluate a specific strategy. Table 7 shows how many papers recommended strategies within each prevention category by the evidence base presented to make the recommendation.

The 70 studies which discussed education strategies made varied recommendations. Nearly half (n = 32, 45.7%) suggested the promotion of specific educational messages, most frequently related to swimming in lifeguard supervised areas (e.g. “swim between the flags”, “swim in front of a lifeguard”), rip currents (identification of, and escape/survival) and personal ability (e.g. “know your limits”). Rip current education was discussed in 24 studies (34.3%), 16 (22.9%) recommended campaigns or the use of mass media, 13 (18.6%) discussed lifeguard supervised zones or flagged patrol areas, and seven (10%) each recommended school-based programs and teaching skills such as resuscitation or basic rescue techniques. About one third of the educational strategy studies (n = 31.4%) included recommendations on *how* to conduct

**Table 5. Number of risk factor reports by preceding/proximal outcomes (not fatal drowning) and analysis used to identify the risk factor.**

Outcome Category	Preceding/Proximal Risk Factor Outcome	Description of survey data	Statistical analysis of survey data	Qualitative	Expert Panel	Total
Awareness or perception of risk						
	Low awareness or perception of risk, threat, vulnerability or response efficacy	2	9	1	-	12
	Overestimation of/overconfidence in ability to cope with risk	-	3	-	-	3
Behaviour or practice						
	More likely to have difficulty in the water			-	3	3
	Drink alcohol while fishing	-	2	-	-	2
	Less likely to see beach safety flags or signs	-	1	-	-	1
	Less likely to check weather before fishing	-	2	-	-	2
	Less likely to heed warning from flags/sign/lifeguard	4	1	1	-	6
	Less likely to signal for help	1	-	-	-	1
	Swims at the beach more (increased exposure)	-	3	-	-	3
Decision-making or knowledge						
	Less likely to make safe swim choice or decision	1	16	-	-	17
Knowledge						
	Low rip/ocean knowledge	9	5	-	-	14
	Low safety knowledge	-	6	1	-	7
	Lower self-efficacy in local knowledge and sea experience	-	1	-	-	1
Skill or ability						
	Less likely to correctly identify hazards	-	5	-	-	5
	Low swim ability (self-reported)	-	6	1	-	7
	Lower surf swim confidence	-	3	-	-	3
	Lower swimming ability confidence	2	-	-	-	2
	No CPR Skills	-	2	-	-	2
<b>Total</b>		<b>19</b>	<b>65</b>	<b>4</b>	<b>3</b>	<b>91</b>

<https://doi.org/10.1371/journal.pone.0246034.t005>

these activities; the most common related to working with specific priority populations ( $n = 6$ , 8.6%) and elements related to cultural or linguistic appropriateness ( $n = 5$ , 7.1%).

Of the prevention strategy studies, relatively few ( $n = 10$ , 11.36%) involved evaluation. Hatfield et al. [51] and Houser et al. [52] both evaluated rip current information campaigns, Davoudi-Kiakalayeh [53] and Moran [54] evaluated multi-year safety programs with several different components, and Wilks et al. [55] and Barcala-Fuerlos et al. [56] both evaluated beach safety education programs for children. Matthews et al. [57] tested the effect of different variations of beach signage, Warton et al. [58] conducted a global survey exploring the effect of a reality-based television show (*Bondi Rescue*) on beach safety attitudes and knowledge, and McCarroll et al. [32] and Van Leeuwen et al. [59] conducted human trial experiments to determine which rip current escape method was most effective and thus worthy of promotion.

## Discussion

This scoping review of 146 coastal drowning studies provides insight into the collective understanding of the coastal drowning problem and the science underpinning efforts to progress safety in this area. Our goal was to identify key concepts and factors in the peer reviewed coastal drowning literature and while some points of synthesis were identified, this review primarily shows the vast heterogeneity of science in the field. The factors and topics studied, how they have been investigated and what new knowledge they contributed are wide ranging and

Table 6. Number of risk factor reports by risk factor in each group by outcome and analysis used.

Risk Factor Group	Fatal Coastal Drowning Outcome				Other Preceding/proximal outcome				Total
	Higher proportion of cases	Statistical analysis of epidemiological data	Expert panel/judge technique	Higher incidence or prevalence rate	Expert panel/judge technique	Description of survey data	Qualitative methods	Statistical analysis of survey data	
Gender	21	1		1		1		15	39
Behavior/activity	14	1	8			4		3	30
Age	14	1		4		4		6	29
Residence	9			1		2	4	11	27
Race/ethnicity	2			1		3		19	25
Time (Hour, Day, Season)	22								22
Other Demographic or Person Factor	4	3	1	1		3		5	17
Beach Characteristics (physical/social) or water conditions	5	4	4		1				14
Knowledge, belief, level of experience			2		1	1		4	8
Weather	4	4							8
Skill	1				1	1		2	5
Dangerous condition warnings or signage	2		2						4
Total	98	14	17	8	3	19	4	65	228

<https://doi.org/10.1371/journal.pone.0246034.t006>

diverse. The populations included, data sources employed, and terminology used varied widely. A myriad of risk factors for coastal drowning and other preceding/proximal outcomes have been identified through analysis of different types of data using various methods. Recommended prevention strategies most frequently related to education, were commonly based on survey data or expert opinion alone and were rarely evaluated. Of note, the field's scientific agenda to date has been, and continues to be, dominated by research from a small number of high-income countries.

Table 7. Number of papers by prevention strategy and supporting evidence.

Evidence base for recommendation	Prevention Strategy Group				
	Education	Lifeguards	Signage	Other <sup>a</sup>	Grand Total <sup>b</sup>
Survey Data	28	5	6	3	31
Expert opinion—no supporting data presented	14	7	6	4	24
Epidemiological information	11	10	1	6	21
Specific evaluation of strategy	9	1	2		10
Other data <sup>c</sup>	8	1	1	2	8
Data from physical science methods (GIS, Geomorphological beach survey, Rip current drifter experiment etc.)	4	1	3	1	5
Grand Total	70	24	19	16	88

<sup>a</sup> Other prevention strategies related to designated swim areas (n = 6), public rescue equipment (n = 4), guidelines or policy (n = 3), lifejackets (n = 3), technology (n = 2), design and implementation of a beach safety management program (n = 1), a call for collaboration around beach safety efforts (n = 1), and a recommendation to prioritize a certain population with beach safety interventions (n = 1).

<sup>b</sup> Totals may be more than 100% as some papers made more than one recommendation per category, based on different data.

<sup>c</sup> Other data includes beach usage information (n = 3), qualitative data (n = 2), image analysis (n = 1), video content analysis (n = 1) and expert panel techniques (n = 1).

<https://doi.org/10.1371/journal.pone.0246034.t007>

## Coastal drowning as a field of research

The multidisciplinary nature of coastal drowning prevention as a field of practice and research is undoubtedly beneficial, but made this review particularly difficult. Lack of consistent terminology and absence of coastal-specific searchable metadata in databases made identifying studies in the early phases of this review challenging; a quarter of the final included articles were found by hand searching references from database identified papers. Moreover, coastal drowning studies are published in a wide array of journals, which might limit exposure of important work across disciplines. Although frequently framed as an injury prevention or public health issue [60], those attempting to find coastal drowning research must look outside these fields, and even beyond the health sciences for relevant studies. As there appears to be no distinct 'home' for coastal safety research, breaking down silos and facilitating interdisciplinary and cross sector collaborative research is imperative for future progress in the field.

The most striking research gap identified by this review was the paucity of studies on coastal drowning from non-high-income settings, where the burden of drowning is much greater [2,3]. Although we do not know the proportion of coastal water drowning deaths from many lower resource locations, robust estimation models from the Global Burden of Disease (GBD) study associated "landlocked" nations with decreased drowning mortality, meaning countries with coastlines had systematically higher estimated drowning mortality [3]. These lower-income coastal communities, not the high-income nations which have traditionally dominated coastal safety research, are most likely to benefit from advances in coastal drowning prevention science and practice.

## Epidemiological burden

Our attempt to chart data from the published literature on the epidemiological burden of fatal unintentional non-boating non-occupational coastal drowning proved to be problematic, but in itself identified a gap and provided important learnings. Only 20 studies, less than a quarter of those which reported fatal drowning cases, allowed us to extract unintentional non-boating cases, and none reported occupational drowning separately by body of water. While a limitation of this review's original intent, the effort highlighted the importance of collecting and reporting these types of data. Information from the "Precipitating event" core category of the Utstien-Style Guidelines for Reporting Drowning, which would include intentionality, boating, disaster etc., is imperative to establishing factors in the drowning process which can be prioritized for intervention [1]. Without these data, advancing research to actionable prevention schemes becomes difficult.

Inclusion of these and other types of data may have been a function of data sources used and/or populations studied, which are frequently determinants of one another. Coroner and death certificate data were used in the majority of studies, and in many it was the only data source. While vital statistics records in some regions offer robust research opportunities, others require linkage with other systems to provide rich enough datasets for meaningful analysis. Of note, data systems which gather information from the scene of the drowning such as police, lifeguard, fire department or other emergency service reports provide important data not found in clinical or death records. Whenever possible, scene-based data should be prioritized in tandem with forensic information to establish linked datasets which offer opportunities to study factors from across the drowning process.

Terminology varied in the identification of coastal bodies of water as locations for drowning, inhibiting meaningful conclusions on the relative burden to other types of bodies of water. While various categories of coastal water sites represented the most deaths in half of the studies that reported multiple bodies of water, different and inconsistent use of terms limit the



usefulness of such a finding. The water site category with the most deaths depends entirely on the vocabulary used to report results. For example, a study describing drowning deaths in terms of 'saltwater' and 'freshwater' might report an overwhelming number of 'freshwater' cases, but the same study using water site categories of 'ocean', 'lake', 'swimming pool' and 'bathtub' may show 'ocean' to have the most deaths as 'freshwater' cases are spread into other groupings. A standardized list of terms with definitions for different types of bodies of water may seem to be a logical path toward improvement, but such a list is likely to be cumbersome and has the potential to exclude local context important for countermeasure development. Future movement towards such a list should carefully consider its usefulness and potential limits.

## Risk factors

Research identifying risk factors related to fatal and other relevant preceding/proximal outcomes is a cornerstone of the coastal drowning field. The plethora of factors studied, many multiple times with different outcome measures, is a strength of this body of work. Reviewing factors associated with preceding/proximal non-death outcomes alongside those associated with fatal results offers a richer, more contextualised understanding and could be helpful for designing countermeasures. Conversely, nearly 43% of the risk factor reports were based only on a greater proportion of cases, less a reflection of increased likelihood of outcome and more so of burden influenced and potentially skewed by varying populations, sample selection, exposure or any number of other confounders. Only six papers, four published pre-1990, identified risk factors based on higher incidence or prevalence rates. Various complications with presenting population-based drowning rates have been identified [61], and measuring exposure has and continues to be a major challenge [24,62]. Future studies seeking to identify coastal drowning risk factors should strive to present both case counts and incidence or prevalence rates as both are important for prioritized interventions.

Limitations notwithstanding, several important risk factors were identified in this review as relevant for coastal drowning, some of which have also been recognized as risk factors for other bodies of water [63]. The clearest of these is being male, a group identified for being at particular drowning risk in several specific studies [64–66], and in other systematic drowning reviews [10,67]. Age was also highlighted as a risk factor for coastal drowning by several studies. Although clear consensus was lacking (age groups used were not consistent), most studies that discussed age identified the young adult and teenage years as life periods of higher risk (S2 Table). Other frequently cited person-based risk factors included race and ethnicity, mostly identified by statistical analysis of survey data; and residency related factors such as being a tourist, living near the coast, or being born in another country. Where coastal drowning specific risk factors align with universal drowning risk factors (i.e. being male), collaboration on countermeasure strategies among drowning prevention organisations is vital.

Only nine papers included risk factor reports ( $n = 22$ ) related to physical or social beach characteristics, water conditions, or weather. A hallmark of multidisciplinary coastal safety research is the intersection of the physical science, namely oceanography and coastal geomorphology, and disciplines such as public health and psychology relating to the human beings who interact with the coastal environment. Yet, surprisingly, few studies have correlated water or other environmental conditions to increased likelihood of fatal drowning. Some studies have investigated lifeguard rescues with ocean conditions [68–70], but several questions remain as to the nature of the causal relationship between these factors and coastal drowning. Future research characterizing these associations, and the interaction between environmental and person-based factors, would be of great benefit to those involved in prevention efforts.

## Prevention strategies

The majority of studies discussed prevention strategies specific to coastal drowning. Collectively, the recommendations were vague, based on limited evidence or expert opinion and primarily related to three themes: education, lifeguards, and signage. Moreover, evaluation of coastal drowning prevention efforts is largely missing from the field, thus providing little guidance to those tasked with funding and implementing such strategies.

Education was the most frequently discussed coastal drowning prevention strategy in this cohort of peer reviewed literature, and along with the provision of lifeguard supervision, likely represents the principle coastal drowning prevention activity worldwide [71]. Although an important component, it is important to note that increased knowledge or awareness alone does not necessarily lead to changes in safety behaviour [72]. Some studies incorporated health theory and/or behaviour change approaches [51,73–79], which are likely to make education efforts more efficacious [80], but many studies provided only ambiguous suggestions for educating the public or increasing awareness. Education efforts that seek to improve knowledge, increase awareness of risk and inform attitudes and beliefs play a central role in a cohesive systems level approach to preventing coastal drowning, however, future research must consider return on investment and if viable, the optimal messages, methods and age at which this education should be delivered.

Recommendations related to lifeguards (e.g. establishing or expanding services, swimming in front of, increasing funding for etc.) were included in several studies. There is no doubt that trained lifeguards are a reliable coastal drowning prevention strategy, but robust empirical evidence for their effectiveness is still scarce in the literature. The seminal report on lifeguard effectiveness was published by the United States Centers for Disease Control in 2001 and consisted primarily of expert opinion and a select number of case studies [81]. In the years since, research measuring the specific contributions by lifeguards to reducing or preventing drowning has made remarkably little progress [82]. Though evidence for lifeguard effectiveness from observational epidemiological studies or cost benefit analysis methods could make justifying existing or establishing new lifeguard services easier, lifeguards cannot be in all places at all times. It is therefore important to also invest in strategies which instil and motivate safe behaviour and practices around water among coastal users.

Signage was also a frequently recommended prevention strategy. Despite some water safety sign standards [83], uniformity is a persistent challenge and evidence exploring impact on behaviour suggests effectiveness is limited [57,84]. Moreover, traditional static signs are expensive (California State Parks estimated it would cost over \$2M USD to add and update signs throughout the system) [85] and some land managers are now developing and implementing various forms of digital safety signs on beaches [86]. A number of important research questions related to coastal safety signage remain [87]; better evidence is needed to support an expensive strategy that could serve both a public liability and a public health/injury prevention purpose.

The dearth of prevention strategy evaluation is a major gap in the field that must be addressed by coastal drowning practitioners and researchers seeking to advance science that saves lives and prevents injury. Lack of evaluation of educational and other coastal safety programmes is not necessarily surprising [71], as confusion about the nature of program evaluation and limited funding for monitoring and evaluation has resulted in poorly conducted assessment in other injury areas [88]. Evidence that prevention programs and strategies work, or importantly, that they do not, is critical not only for strategic use of limited resources, but also for the design of future effective programs and initiatives. Evaluation research is most impactful when applied in contexts where it is needed most, which highlights another

significant challenge. Established coastal safety organisations in high income countries are probably best positioned in terms of resources and personnel to monitor, evaluate and share their work, but will their findings also be relevant for lower resourced settings? Are lessons transferable between settings with different beach and coastal hazards, safety and regulatory environments, economic realities, or cultural relationships with the water? Prioritising evaluation culture in the organisations that have the means, as well as bridging the gap to communities that don't, will be critical for continued progress in coastal drowning prevention and safety efforts.

## Limitations

Coastal drowning is an expansive area of research. This is the first study to attempt a broad review of the scope and nature of the field's published literature and should be considered with some limitations. First, it is possible that we did not capture every study meeting our inclusion criteria, although several steps including extensive manual searches were taken to ensure as broad a search as possible. While the results were charted and presented according to a framework rooted in epidemiological burden, risk factors and prevention strategies, the sheer volume and variety of information in these studies means that some coastal drowning topics included in the studies reviewed were not reported or discussed in this manuscript. Future reviews with specific aims and questions, versus a broad scoping purpose, may be better suited to evaluate these topics.

Importantly, the numerical summaries presented in this scoping review are not a substitute for meta-analysis methods which appraise and synthesize evidence to produce a clinically meaningful result. The results from this review reflect the state of coastal drowning research and do not account for the fact that many studies included were case series from specific datasets or geographic regions. Several risk factor reports from different studies conflicted, and in many areas a clear consensus was lacking. Future analysis addressing a specific question of this nature may offer new insight in these subjects, but a critical lesson is the importance of local data to drive prevention efforts.

Results of any one study should be taken with caution if they are to be applied to another geographic region. Similarly, the results from this review were dominated by studies from Australia and the United States and are likely a reflection of the places where research has been conducted, and the interests of the individual and groups or researchers involved, versus any sort of global consensus or understanding. Additionally, this review did not include epidemiological burden or risk factor information from non-fatal drowning cases, motivated in part by a desire to establish a more manageable review. Notwithstanding, we would expect to find similar results and derive comparable conclusions had we also included non-fatal information, although future research confirming such would be valuable.

## Conclusions

The coastal drowning literature is extensive and includes wide-ranging focus areas approached by multiple disciplines and various perspectives. This heterogeneity is both a challenge and a benefit. Standardisation in some areas would surely drive the science forward: consensus-based terminology and reporting practices would allow for richer data and improved comparisons across locations; a streamlined research agenda with identified objectives and prioritised questions to be addressed would propel prevention efforts towards the populations most in need; and established best practice for coastal drowning prevention program evaluation would ensure effective use of limited resources. Conversely, the disparate approach to coastal drowning research in the past 60 years has allowed for creative investigation of essential, ground-level questions that has pushed boundaries and driven the field in new directions.

The next generation of coastal drowning and safety science must build upon the advances of previous work by recognizing which areas have been studied thoroughly and where further attention is needed most. Coastal drowning researchers must address gaps in research from lower resourced settings and the lack of prevention strategy evaluation. The multidisciplinary nature of coastal drowning research offers collaborative opportunities to advance science underpinning prevention efforts seeking to save lives and keep people safe.

## Supporting information

### **S1 Table. Included studies abstract table.**

(XLSX)

### **S2 Table. Number of risk factor reports for each specific risk factor with related risk factor outcome by supporting data.**

(XLSX)

### **S1 File. Preferred reporting items for systematic reviews and meta-analyses extension for scoping reviews (PRISMA-ScR) checklist.**

(PDF)

### **S2 File. Coastal drowning scoping review search strategies.**

(PDF)

### **S3 File. Coastal drowning scoping review data extraction form.**

(PDF)

## Acknowledgments

The authors thank Cheng Siu, UNSW Academic Services Librarian (Medicine), for her expert assistance with the database searches for this review, and Dr. Linda Quan, Harborview Injury Prevention and Research Center, for her input on the manuscript.

## Author Contributions

**Conceptualization:** William Koon, Amy Peden, Jasmin C. Lawes, Robert W. Brander.

**Data curation:** William Koon, Amy Peden.

**Formal analysis:** William Koon.

**Writing – original draft:** William Koon.

**Writing – review & editing:** William Koon, Amy Peden, Jasmin C. Lawes, Robert W. Brander.

## References

1. Idris AH, Bierens J, Perkins GD, Wenzel V, Nadkarni V, Morley P, et al. 2015 revised Utstein-style recommended guidelines for uniform reporting of data from drowning-related resuscitation: An ILCOR advisory statement. *Circ Cardiovasc Qual Outcomes*. 2017; 10(7): e000024. <https://doi.org/10.1161/HCQ.000000000000024> PMID: 28716971
2. World Health Organization. Global report on drowning: preventing a leading killer. Geneva: World Health Organization, 2014. Available from: <https://www.who.int/publications/i/item/global-report-on-drowning-preventing-a-leading-killer>.
3. Franklin RC, Peden AE, Hamilton EB, Bisignano C, Castle CD, Dingels ZV, et al. The burden of unintentional drowning: global, regional and national estimates of mortality from the Global Burden of Disease 2017 Study. *Inj Prev*. 2020 Feb 20. <https://doi.org/10.1136/injuryprev-2019-043484> PMID: 32079663

4. Beerman S, Bierens J, Clemens T, Meddings D, Rahman A, Szpilman D. Clarification and categorization of non-fatal drowning: A draft position statement for review and input by the global drowning community. Toronto: World Health Organization, 2018. Available from: <https://www.who.int/publications/m/item/clarification-and-categorization-of-non-fatal-drowning>.
5. McClure R, Stevenson M, McEvoy S. Intervention development: Introduction. In: McClure R, Stevenson M, McEvoy S, editors. *The scientific basis of injury prevention and control*. Melbourne: IP Communications; 2004. pp. 175–201.
6. Branche C, van Beeck E. The epidemiology of drowning: summary and recommendations. In: Bierens J, editor. *Drowning: prevention, rescue treatment*. 2nd ed. Berlin; New York: Springer; 2014. pp. 81–83. [https://doi.org/10.1007/978-3-642-04253-9\\_8](https://doi.org/10.1007/978-3-642-04253-9_8)
7. Lin CY, Wang YF, Lu TH, Kawach I. Unintentional drowning mortality, by age and body of water: an analysis of 60 countries. *Inj Prev*. 2015; 21(e1): e43–50. <https://doi.org/10.1136/injuryprev-2013-041110> PMID: 24944343
8. World Health Organization. *International classification of diseases and related health problems, 10th revision*. Geneva: World Health Organization; 2007. Available from: <http://www.who.int/classifications/apps/icd/icd10online>.
9. Gupta M, Bhaumik S, Roy S, Panda RK, Peden M, Jagnoor J. Determining child drowning mortality in the Sundarbans, India: applying the community knowledge approach. *Inj Prev*. 2020. <https://doi.org/10.1136/injuryprev-2020-043911> PMID: 32943493
10. Peden AE, Franklin RC, Leggat PA. Fatal river drowning: the identification of research gaps through a systematic literature review. *Inj Prev*. 2016; 22(3): 202–9. <https://doi.org/10.1136/injuryprev-2015-041750> PMID: 26728005
11. Saberi Anary SH, Sheikhezadi A, Ghadyani MH. Epidemiology of drowning in Mazandaran province, north of Iran. *Am J Forensic Med Pathol*. 2010; 31(3): 236–42. <https://doi.org/10.1097/PAF.0b013e3181e804de> PMID: 20548217
12. Bessereau J, Fournier N, Mokhtari T, Brun PM, Desplantes A, Grassineau D, et al. Epidemiology of unintentional drowning in a metropolis of the French Mediterranean coast: a retrospective analysis (2000–2011). *Int J Inj Contr Saf Promot*. 2016; 23(3): 317–22. <https://doi.org/10.1080/17457300.2015.1047862> PMID: 26082429
13. Donson H, Van Niekerk A. Unintentional drowning in urban South Africa: a retrospective investigation, 2001–2005. *Int J Inj Contr Saf Promot*. 2013; 20(3): 218–26. <https://doi.org/10.1080/17457300.2012.686041> PMID: 22594939
14. Surf Life Saving Australia. *National Coastal Safety Report 2020*. Surf Life Saving Australia; 2020. Available from: [https://issuu.com/surflifesavingaustralia/docs/ncsr\\_2020\\_rgb\\_issuu\\_final](https://issuu.com/surflifesavingaustralia/docs/ncsr_2020_rgb_issuu_final).
15. New Zealand Resource Management Amendment Act of 1993. Public act No. 65; 1993. Available from: <http://www.legislation.govt.nz/act/public/1993/0065/latest/DLM302693.html>.
16. Castelle B, Scott T, Brander RW, McCarroll RJ. Rip current types, circulation and hazard. *Earth-Sci Rev*. 2016; 163: 1–21. <https://doi.org/10.1016/j.earscirev.2016.09.008>
17. Kennedy DM, Sherker S, Brighton B, Weir A, Woodroffe CD. Rocky coast hazards and public safety: moving beyond the beach in coastal risk management. *Ocean Coast Manag*. 2013; 82: 85–94. <https://doi.org/10.1016/j.ocecoaman.2013.06.001>
18. Castelle B, Brander R, Tellier E, Simonnet B, Scott T, McCarroll J, et al. Surf zone hazards and injuries on beaches in SW France. *Nat Hazards*. 2018; 93(3): 1317–35. <https://doi.org/10.1007/s11069-018-3354-4>
19. Weintrit A. *Marine navigation and safety of sea transportation*. Boca Raton: CRC Press; 2009.
20. Heldring B. Brief History of Maatschappij tot Redding van Drenkelingen [The Society to Rescue People from Drowning]. In: Bierens J, editor. *Drowning: prevention, rescue treatment*. 2nd ed. Berlin; New York: Springer; 2014. pp. 3–6. [https://doi.org/10.1007/978-3-642-04253-9\\_1](https://doi.org/10.1007/978-3-642-04253-9_1)
21. Vervaecke H. The History of Lifesaving. In: Bierens J, editor. *Drowning: prevention, rescue treatment*. 2nd ed. Berlin; New York: Springer; 2014. pp. 7–14. [https://doi.org/10.1007/978-3-642-04253-9\\_2](https://doi.org/10.1007/978-3-642-04253-9_2)
22. Brander R. Beach safety research. In: Finkle C, Makowski C, editors. *The Encyclopedia of Coastal Science*. Encyclopedia of earth science series: Cham: Springer; 2018. [https://doi.org/10.1007/978-3-319-48657-4\\_40-2](https://doi.org/10.1007/978-3-319-48657-4_40-2)
23. Hale E. Analysis of fatal drowning accidents which occurred in 1961. *J R Nav Med Serv*. 1963; 49: 233–236. PMID: 14066689
24. Adams AI. The descriptive epidemiology of drowning accidents. *Med J Aust*. 1966; 2(27): 1257–61. <https://doi.org/10.5694/j.1326-5377.1966.tb91982.x> PMID: 5957600
25. Webster DP. Skin and scuba diving fatalities in the United States. *Public Health Reports*. 1966; 81(8): 703–711. PMID: 4958248

26. Wright LD, Short AD. Morphodynamic variability of surf zones and beaches: a synthesis. *Mar Geol.* 1984; 56(1–4):93–118. [https://doi.org/10.1016/0025-3227\(84\)90008-2](https://doi.org/10.1016/0025-3227(84)90008-2)
27. Short AD, Williamson B, Hogan CL. The Australian beach safety and management program—Surf Life Saving Australia's approach to beach safety and coastal planning. 11th Australasian Conference on Coastal and Ocean Engineering: Townsville, Qld. Barton, ACT: Institution of Engineers, Australia, 1993: 113–118. Available from: [search.informit.com.au/documentSummary;dn=560087890263399;res=IELENG](http://search.informit.com.au/documentSummary;dn=560087890263399;res=IELENG).
28. Short AD, Hogan CL. Rip currents and beach hazards: Their impact on public safety and implications for coastal management. *J Coastal Res.* 1994: 197–209. Available from: <http://www.jstor.org/stable/25735599>.
29. Short A, Brander R. Beach hazard and risk assessment. In: Bierens J, editor. *Drowning: prevention, rescue treatment.* 2nd ed. Berlin; New York: Springer; 2014. pp. 287–92. [https://doi.org/10.1007/978-3-642-04253-9\\_41](https://doi.org/10.1007/978-3-642-04253-9_41)
30. Shepard F, Emery K, La Fond E. Rip currents: a process of geological importance. *J Geol.* 1941; 49(4): 337–69.
31. Brander RW, MacMahan JH. Future challenges for rip current research and outreach. In: Leatherman S, Fletemeyer J, editors. *Rip currents, beach Safety, physical oceanography and Wave modelling.* Boca Raton: CRC Press; 2011. pp. 1–29.
32. McCarroll R, Brander R, MacMahan J, Turner I, Reniers A, Brown J, et al. Evaluation of swimmer-based rip current escape strategies. *Nat Hazards.* 2014; 71(3): 1821–46. <https://doi.org/10.1007/s11069-013-0979-1>
33. Mitchell RJ, Ware L, Bambach MR. The role of evidence, standards and education in rock fishing safety in New South Wales, Australia. *Aust N Z J Public Health.* 2014; 38(6): 579–84. <https://doi.org/10.1111/1753-6405.12247> PMID: 25169699
34. Tipton M, Wooler A. *The science of beach lifeguarding.* Boca Raton: CRC Press, Taylor & Francis Group; 2016.
35. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *Int J Soc Res* 2005; 8(1): 19–32. <https://doi.org/10.1080/1364557032000119616>
36. Munn Z, Peters MD, Stern C, Tufanaru C, McArthur A, Aromataris E. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Med Res Methodol.* 2018; 18(1): 143. <https://doi.org/10.1186/s12874-018-0611-x> PMID: 30453902
37. Levac D, Colquhoun H, O'Brien KK. Scoping studies: advancing the methodology. *Implement Sci.* 2010; 5(1): 69. <https://doi.org/10.1186/1748-5908-5-69> PMID: 20854677
38. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS med.* 2009; 6(7): e1000097. <https://doi.org/10.1371/journal.pmed.1000097> PMID: 19621072
39. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Ann Intern Med.* 2018; 169(7): 467–73. <https://doi.org/10.7326/M18-0850> PMID: 30178033
40. Haw C, Hawton K. Suicide and self-harm by drowning: A review of the literature. *Arch Suicide Res.* 2016; 20(2): 95–112. <https://doi.org/10.1080/13811118.2015.1025120> PMID: 26359547
41. Alderman K, Turner LR, Tong S. Floods and human health: a systematic review. *Environ Int.* 2012; 47: 37–47. <https://doi.org/10.1016/j.envint.2012.06.003> PMID: 22750033
42. Yari A, Ostadtaghizadeh A, Ardalan A, Zarezadeh Y, Rahimiforushani A, Bidarpoor F. Risk factors of death from flood: Findings of a systematic review. *J Environ Health Sci Engineer.* 2020 Jul 24. <https://doi.org/10.1007/s40201-020-00511-x> PMID: 33312668
43. Hamilton K, Demant D, Peden A, Hagger M. A systematic review of human behaviour in and around floodwater. *International journal of disaster risk reduction.* 2020; 47: 101561. <https://doi.org/10.1016/j.ijdrr.2020.101561>
44. Lincoln J. Occupational drownings. In: Bierens J, editor. *Drowning: prevention, rescue treatment.* 2nd ed. Berlin; New York: Springer; 2014. pp. 139–42. [https://doi.org/10.1007/978-3-642-04253-9\\_22](https://doi.org/10.1007/978-3-642-04253-9_22)
45. Sleet DA, Hopkins KN, Olson SJ. From discovery to delivery: Injury prevention at CDC. *Health Promotion Practice.* 2003; 4(2): 98–102. <https://doi.org/10.1177/1524839902250750> PMID: 14610978
46. Szpilman D, Tipton M, Sempsrott J, Webber J, Bierens J, Dawes P, et al. Drowning timeline: a new systematic model of the drowning process. *Am J Emerg Med.* 2016; 34(11): 2224–6. <https://doi.org/10.1016/j.ajem.2016.07.063> PMID: 27575579
47. Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia. 2019. Available from: [www.covidence.org](http://www.covidence.org).



48. Gielen AC, Sleet D. Application of behaviour-change theories and methods to injury prevention. *Epidemiol rev.* 2003; 25(1): 65–76. <https://doi.org/10.1093/epirev/mxg004> PMID: 12923991
49. The World Bank. Country and lending groups: historical classification by income. Washington D.C.: The World Bank, 2020. Available from: <https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups>.
50. Morgan D, Ozanne-Smith J. Surf bather drowning risk and exposure-related factors identified by an expert panel. *Int J Aquatic Res Educ.* 2012; 6(4): 336–49. <https://doi.org/10.25035/ijare.06.04.08>
51. Hatfield J, Williamson A, Sherker S, Brander R, Hayen A. Development and evaluation of an intervention to reduce rip current related beach drowning. *Accid Anal Prev.* 2012; 46: 45–51. <https://doi.org/10.1016/j.aap.2011.10.003> PMID: 22310042
52. Houser C, Trimble S, Brander R, Brewster BC, Dusek G, Jones D, et al. Public perceptions of a rip current hazard education program: “Break the Grip of the Rip!”. *Nat Hazards Earth Syst Sci.* 2017; 17(7): 1003. <https://doi.org/10.5194/nhess-17-1003-2017>
53. Davoudi-Kiakalayeh A, Mohammadi R, Yousefzade-Chabok S, Jansson B. Evaluation of a community-based drowning prevention programme in northern Islamic Republic of Iran. *East Mediterr Health J.* 2013; 19(7): 629–37. <https://doi.org/10.26719/2013.19.7.629> PMID: 24975308
54. Moran K. Rock-based fisher safety promotion: A decade on. *Int J Aquatic Res Educ.* 2017; 10(2): 1–13. <https://doi.org/10.25035/ijare.10.02.01>
55. Wilks J, Kanasa H, Pendergast D, Clark K. Beach safety education for primary school children. *Int J Inj Contr Saf Promot.* 2017; 24(3): 283–92. <https://doi.org/10.1080/17457300.2016.1170043> PMID: 27142223
56. Barcala-Furelos R, Carbia-Rodriguez P, Peixoto-Pino L, Abelairas-Gomez C, Rodriguez-Nunez A. Implementation of educational programs to prevent drowning: What can be done in nursery school? *Med Intensiva.* 2019; 43(3):180–2. <https://doi.org/10.1016/j.medin.2017.08.005> PMID: 29054299
57. Matthews B, Andronaco R, Adams A. Warning signs at beaches: Do they work? *Saf Sci.* 2014; 62: 312–8. <https://doi.org/10.1016/j.ssci.2013.09.003>
58. Warton NM, Brander RW. Improving tourist beach safety awareness: the benefits of watching Bondi Rescue. *Tour Manag.* 2017; 63: 187–200. <https://doi.org/10.1016/j.tourman.2017.06.017>
59. Van Leeuwen B, McCarroll R, Brander R, Turner I, Power H, Bradstreet A. Examining rip current escape strategies in non-traditional beach morphologies. *Nat Hazards.* 2016; 81(1):145–65. <https://doi.org/10.1007/s11069-015-2072-4>
60. Franklin R, Scarr J. A framework for prevention. In: Bierens J, editor. *Drowning: prevention, rescue treatment.* 2nd ed. Berlin; New York: Springer; 2014. pp. 153–63. [https://doi.org/10.1007/978-3-642-04253-9\\_25](https://doi.org/10.1007/978-3-642-04253-9_25)
61. Mitchell RJ, Williamson AM, Olivier J. Estimates of drowning morbidity and mortality adjusted for exposure to risk. *Inj Prev.* 2010; 16(4): 261–6. <https://doi.org/10.1136/ip.2009.024307> PMID: 20696716
62. Morgan D, Ozanne-Smith J. Development and trial of a water exposure measure of estimated drowning risk for surf bathers. *Int J Aquatic Res Educ.* 2013; 7(2): 116–35. <https://doi.org/10.25035/ijare.07.02.04>
63. Quan L. Review of Risk Factors. In: Bierens J, editor. *Drowning: prevention, rescue treatment.* 2nd ed. Berlin; New York: Springer; 2014. pp. 123–6. [https://doi.org/10.1007/978-3-642-04253-9\\_18](https://doi.org/10.1007/978-3-642-04253-9_18)
64. Moran K. (Young) Men behaving badly: dangerous masculinities and risk of drowning in aquatic leisure activities. *Ann Leis Res.* 2011; 14(2–3):260–72. <https://doi.org/10.1080/11745398.2011.615719>
65. Croft JL, Button C. Interacting factors associated with adult male drowning in New Zealand. *PLoS One.* 2015; 10(6): e0130545. <https://doi.org/10.1371/journal.pone.0130545> PMID: 26083689
66. Lawes JC, Ellis AE, Daw S, Strasiotto L. Risky business: a 15-year analysis of fatal coastal drowning of young male adults in Australia. *Inj Prev.* 2020; In Press. <https://doi.org/10.1136/injuryprev-2020-043969> PMID: 33239312
67. Tyler MD, Richards DB, Reske-Nielsen C, Saghafi O, Morse EA, Carey R, et al. The epidemiology of drowning in low-and middle-income countries: a systematic review. *BMC public health.* 2017; 17(1):1–7. <https://doi.org/10.1186/s12889-016-3954-4> PMID: 28049454
68. Morgan D, Ozanne-Smith J. Surf lifeguard rescues. *Wilderness Environ Med.* 2013; 24(3): 285–90. <https://doi.org/10.1016/j.wem.2013.02.001> PMID: 23787403
69. Koon W, Rowhani-Rahbar A, Quan L. Do wave heights and water levels increase ocean lifeguard rescues? *Am J Emerg Med.* 2018; 36(7): 1195–201. <https://doi.org/10.1016/j.ajem.2017.12.006> PMID: 29254666
70. Tellier E, Simonnet B, Gil-Jardine C, Castelle B, Bailhache M, Salmi LR. Characteristics of drowning victims in a surf environment: a 6-year retrospective study in southwestern France. *Inj Epidemiol.* 2019; 6: 17. <https://doi.org/10.1186/s40621-019-0195-x> PMID: 31245266

71. Moran K. Beach safety education. In: Tipton M, Wooler A, editors. *The science of beach lifeguarding*. Boca Raton: CRC Press, Taylor & Francis Group; 2016. pp. 245–252.
72. Wright M. Beach safety education: A behavioural change approach. In: Tipton M, Wooler A, editors. *The science of beach lifeguarding*. Boca Raton: CRC Press, Taylor & Francis Group; 2016. pp. 235–244.
73. Ballantyne R, Carr N, Hughes K. Between the flags: an assessment of domestic and international university students' knowledge of beach safety in Australia. *Tour Manag*. 2005; 26(4): 617–622. <https://doi.org/10.1016/j.tourman.2004.02.016>
74. Hamilton K, White KM, Wihardjo K, Hyde MK. Targets to promote swimming between the flags among Australian beachgoers. *Health Promot Internation*. 2016; 31(4): 908–14. <https://doi.org/10.1093/heapro/dav079> PMID: 26276797
75. McCool J, Ameratunga S, Moran K, Robinson E. Taking a risk perception approach to improving beach swimming safety. *Int J Behav Med*. 2009; 16(4): 360–6. <https://doi.org/10.1007/s12529-009-9042-8> PMID: 19288204
76. Moran K. Rock-based fishers' perceptions and practice of water safety. *Int J Aquatic Res Educ*. 2008; 2(2): 128–39. <https://doi.org/10.25035/ijare.02.02.05>
77. White KM, Hyde MK. Swimming between the flags: A preliminary exploration of the influences on Australians' intentions to swim between the flags at patrolled beaches. *Accid Anal Prev*. 2010; 42(6): 1831–8. <https://doi.org/10.1016/j.aap.2010.05.004> PMID: 20728634
78. Willcox-Pidgeon S, Kool B, Moran K. Perceptions of the risk of drowning at surf beaches among New Zealand youth. *Int J Inj Contr Saf Promot*. 2018; 25(4): 365–71. <https://doi.org/10.1080/17457300.2018.1431939> PMID: 29415615
79. Williamson A, Hatfield J, Sherker S, Brander R, Hayen A. A comparison of attitudes and knowledge of beach safety in Australia for beachgoers, rural residents and international tourists. *Aust N Z J Public Health*. 2012; 36(4): 385–91. <https://doi.org/10.1111/j.1753-6405.2012.00888.x>
80. Sleet DA, Gielen AC. Developing injury interventions: the role of behavioural science. In: McClure R, Stevenson M, McEvoy S, editors. *The scientific basis of injury prevention and control*. Melbourne: IP Communications; 2004. pp. 214–232.
81. Branche CM, Stewart S. (Editors). *Lifeguard effectiveness: a report of the working group*. Atlanta: Centers for Disease Control and Prevention, National Centers for Injury Prevention and Control; 2001. Available from: <https://stacks.cdc.gov/view/cdc/11284>.
82. Gilchrist J, Branche C. Lifeguard effectiveness. In: Tipton M, Wooler A, editors. *The science of beach lifeguarding*. Boca Raton: CRC Press, Taylor & Francis Group; 2016. pp. 29–36.
83. Wills S, George P. *Water Safety Signs and Flags*. In: Bierens J, editor. *Drowning: prevention, rescue treatment*. 2nd ed. Berlin; New York: Springer; 2014. pp. 303–308. [https://doi.org/10.1007/978-3-642-04253-9\\_44](https://doi.org/10.1007/978-3-642-04253-9_44)
84. Brannstrom C, Lee Brown H, Houser C, Trimble S, Santos A. “You can't see them from sitting here”: Evaluating beach user understanding of a rip current warning sign. *Appl Geogr*. 2015; 56: 61–70. <https://doi.org/10.1016/j.apgeog.2014.10.011>
85. California Department of Parks and Recreation Budget Change Proposal; State Beaches and Parks Smoking Ban (SB9), No. 3790-070-BCP-2019-GB. Sacramento: Department of Parks and Recreation, 2019. Available from: [https://esd.dof.ca.gov/Documents/bcp/2021/FY2021\\_ORG3790\\_BCP3388.pdf](https://esd.dof.ca.gov/Documents/bcp/2021/FY2021_ORG3790_BCP3388.pdf).
86. Council Auckland. *Safeswim switches on digital signs at local beaches*. Auckland: Auckland Council, 2019. Available from: <https://ourauckland.aucklandcouncil.govt.nz/articles/news/2019/08/safeswim-switches-on-digital-signs-at-local-beaches/>.
87. Wooler A, Tipton M. Future additions and further research. *The Science of Beach Lifeguarding*: CRC Press Inc; 2016. p. 281–92.
88. Turner C, McClure R. Program evaluation. In: McClure R, Stevenson M, McEvoy S, editors. *The scientific basis of injury prevention and control*. Melbourne: IP Communications; 2004. pp. 359–371.