Analysis of Scuba Diving-Related Fatalities in Australia.

by

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Submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

Deakin University

May, 2018
I am the author of the thesis entitled

Analysis of Scuba Diving-Related Fatalities in Australia

submitted for the degree of Doctor of Philosophy

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Finally, heartfelt thanks and love to my family for again putting up with my pursuit of “another little project”.

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Papers

The Candidate was the principal author of the following papers published in the peer-reviewed literature and which are included as part of the thesis:


In addition, the Candidate was the principal author of the following papers published in the peer-reviewed literature during PhD candidacy and which directly inform this thesis:


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<td>ALS</td>
<td>Advanced life support</td>
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<tr>
<td>AOD</td>
<td>Advanced Open Water Diver</td>
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<td>AGE</td>
<td>Arterial gas embolism</td>
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<tr>
<td>AED</td>
<td>Automated external defibrillator</td>
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<tr>
<td>ASD</td>
<td>Atrial septal defect</td>
</tr>
<tr>
<td>BLS</td>
<td>Basic life support</td>
</tr>
<tr>
<td>BMI</td>
<td>Body mass index</td>
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<tr>
<td>BSAC</td>
<td>British Sub-Aqua Club</td>
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<tr>
<td>BCD</td>
<td>Buoyancy Compensator Device</td>
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<tr>
<td>CPR</td>
<td>Cardiopulmonary resuscitation</td>
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<tr>
<td>COD</td>
<td>Cause of death</td>
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<td>CAGE</td>
<td>Cerebral arterial gas embolism</td>
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<td>CEA</td>
<td>Chain of events analysis</td>
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<td>CCR</td>
<td>Closed-circuit rebreather</td>
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<td>CT</td>
<td>Computerised tomography</td>
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<td>COPD</td>
<td>Chronic obstructive pulmonary disease</td>
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<td>DCI</td>
<td>Decompression illness</td>
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<td>DCS</td>
<td>Decompression sickness</td>
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<td>DA</td>
<td>Disabling agent</td>
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<tr>
<td>DI</td>
<td>Disabling injury</td>
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<td>DAN</td>
<td>Divers Alert Network</td>
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<td>DAN AP</td>
<td>Divers Alert Network Asia-Pacific</td>
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<td>IPO</td>
<td>Immersion pulmonary oedema</td>
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<td>IHD</td>
<td>Ischaemic heart disease</td>
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<tr>
<td>LVH</td>
<td>Left ventricular hypertrophy</td>
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<tr>
<td>MI</td>
<td>Myocardial infarction</td>
</tr>
<tr>
<td>MFW</td>
<td>Metres of freshwater</td>
</tr>
<tr>
<td>MSW</td>
<td>Metres of seawater</td>
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<tr>
<td>NCIS</td>
<td>National Coronal Information System</td>
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<td>OWD</td>
<td>Open Water Diver</td>
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<tr>
<td>Acronym</td>
<td>Definition</td>
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<td>PFO</td>
<td>Patent/Persistent foramen ovale</td>
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<td>PADI</td>
<td>Professional Association of Diving Instructors</td>
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<td>PBT</td>
<td>Pulmonary barotrauma</td>
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<td>SDPE</td>
<td>Scuba divers pulmonary (o)edema</td>
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<td>SSBA</td>
<td>Surface-supplied breathing apparatus</td>
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<td>VF</td>
<td>Ventricular fibrillation</td>
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<td>VSD</td>
<td>Ventricular septal defect</td>
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Glossary

*Advanced life support (ALS).* A set of potentially life-saving protocols and skills, including advanced airway management, the administration of drugs and fluids and defibrillation to increase the likelihood of successful resuscitation.

*Advanced Open Water Diver (AOD).* A post entry-level diver qualification that involves the teaching of some additional skills and certifies the diver to depths up to 30 m.

*Apnoea.* Temporary cessation of breathing.

*Arrhythmia.* An abnormal heart rhythm, sometimes also referred to a dysrhythmia.

*Arterial gas embolism.* (see also cerebral arterial gas embolism) A condition caused by air entering the arterial circulation as a result of pulmonary barotrauma. The definition is sometimes extended to include venous bubbles from decompression that have passed into the arterial circulation.

*Asphyxia.* A condition arising when the body is deprived of oxygen, causing unconsciousness or death.

*Asystole.* A condition in which the heart ceases to beat.

*Atherosclerosis.* A disease of the arteries characterised by fatty deposits on their inner walls.

*Atrial septal defect.* A congenital abnormal opening in the wall (septum) between the left and right atria of the heart.

*Automated external defibrillator (AED).* An electrical device that, when attached to a victim of suspected cardiac arrest, can recognise a shockable heart rhythm (e.g., VF) and instruct the operator to provide a defibrillation shock in an attempt to restore normal heart rhythm.
Basic life support (BLS). A level of first aid care used for victims of life-threatening emergencies until medical care is available. This usually involved airway management and/or CPR.

Body mass index (BMI). An approximate measure of whether someone is over- or underweight, calculated by dividing their weight in kilograms by the square of their height in metres.

British Sub-Aqua Club (BSAC). A United Kingdom-based diver membership and certification association.

Buoyancy Compensator Device (BCD). An inflatable vest or jacket worn by a diver and used to establish neutral buoyancy.

Cardiopulmonary resuscitation (CPR). Application of a combination of chest compressions and artificial respiration (e.g., rescue breathing) performed on an unconscious victim without normal breathing.

Cause of death. The cause of death as used here is as specified by the medical examiner and which could be the same as the disabiling injury, or could be drowning secondary to injury.

Cerebral arterial gas embolism (CAGE). An arterial gas embolism in the cerebral circulation.

Chain of events analysis (CEA). A sequential analysis of the series of events involved in a diving incident or accident.

Closed-circuit rebreather (CCR). An underwater breathing device consisting of a breathing gas supply of oxygen and usually nitrox, a breathing loop with counterlung, and a ‘scrubber’ to remove carbon dioxide from the loop.

Commercial diver: A professional diver who is trained to perform underwater construction, retrieval, maintenance and various other tasks.
**Computerised tomography (CT).** Radiography in which a three-dimensional image of a body structure is constructed by computer from a series of plane cross-sectional images made along an axis.

**Comorbidity.** The presence of one or more additional diseases or disorders co-occurring with a primary disease or disorder.

**Contraindication.** Something (such as a symptom or condition) that makes a particular treatment or procedure inadvisable.

**Countermeasure.** An action or preventative measure that can be taken or established to reduce the likelihood of an incident.

**Chronic obstructive pulmonary disease (COPD).** Pulmonary disease, such as emphysema or chronic bronchitis, which is characterised by chronic typically irreversible airway obstruction resulting in a slowed rate of exhalation.

**Decompression dive.** A dive that requires a mandatory decompression stop(s) in accordance with the dive computer, tables or decompression algorithm used.

**Decompression illness.** A general term which describes the symptoms and signs of both decompression sickness and arterial gas embolism.

**Decompression sickness.** A condition arising from dissolved gases coming out of solution into bubbles inside the body after a reduction in ambient pressure.

**Disabling agent.** A disabling agent (as used here) is an action or circumstance (associated with the Trigger) that caused injury or illness. It may be an action of the diver or other persons, reaction of the equipment, effect of a medical condition or a force of nature.

**Disabling injury.** A Disabling Injury is directly responsible for death, or incapacitation followed by death from drowning.

**Dive computer.** A waterproof electronic device incorporating a decompression algorithm and which provides a diver with a minimum of depth and time measurements, ascent rate and other decompression guidance for a dive.
Divemaster. A person who is qualified to organise, supervise and lead recreational dives, particularly in a professional capacity.

Diving instructor. A person who is qualified to train and certify recreational divers.

Dive professional. A collective term often used to describe divemasters, instructors and dive operators who work with recreational divers.

Divers Alert Network (DAN). A federation of predominantly membership-based associations formed primarily to advance diving safety.

Drowning. The process of experiencing respiratory impairment from submersion/immersion in liquid. It may be fatal or non-fatal.

Drysuit. A watertight suit used by divers for thermal insulation. Air trapped within the suit provides layer of insulation. Air is added or vented from the suit to help control comfort and buoyancy during a dive.

Dyspnoea. Shortness of breath.

Echocardiogram. An ultrasound of the heart which provides information about the structure and function of the heart chambers, valves and related vessels.

Hyperoxia. A condition that occurs when cells, tissues and organs are exposed to an excess supply of oxygen or higher than normal partial pressure of oxygen.

Hypoxia. A condition where there is less than the normal content of oxygen in the body tissues.

Immersion pulmonary oedema (IPO). A condition that occurs as a result of fluid leakage from the pulmonary capillaries into the alveoli (pulmonary oedema) precipitated by immersion, which may be swimming, snorkelling or diving.

Integrated weights. Weights that are integrated into the BCD rather that attached to a weight belt.

Introductory Scuba Experience (ISE). Also known as a Discover Scuba Dive (DSD) or Resort Dive, this is an instructor-supervised non-certification dive designed to
enable a person to experience a scuba dive under close supervision of an
instructor.

*Ischaemia.* Restriction of blood supply causing hypoxia.

*Ischaemic heart disease (IHD).* Also known as coronary heart disease or coronary artery disease, is the term given to heart problems caused by narrowed coronary arteries that supply blood to the heart muscle.

*Left ventricular hypertrophy (LVH).* A condition in which the muscle wall of the heart’s left pumping chamber (ventricle) becomes thickened (hypertrophy).

*Murphy’s Law.* An adage or epigram that is typically stated as: "Anything that can go wrong will go wrong".

*Myocardial infarction.* Commonly known as a heart attack and occurs when blood flow is reduced or ceases to a part of the heart, causing damage to the heart muscle (myocardium). This is usually due to a blockage of one or more coronary artery.

*National Coronial Information System (NCIS).* An internet-based data storage and retrieval system for Australian and New Zealand Coronial cases.

*Nitrox.* A mixture of oxygen and nitrogen used as a breathing gas by divers, usually containing a higher percentage of oxygen than in air.

*Octopus regulator (‘octopus’).* A back-up demand valve carried by a diver in case of failure of the primary regulator or the need to share air with another diver.

*Open Water Diver (OWD).* An entry-level autonomous diver certification for recreational scuba diving.

*Obese.* BMI ≥30 kg.m⁻²

*Overweight.* BMI of 25-29.9 kg.m⁻²

*Partial pressure.* The partial pressure of a gas in a gas mixture is that part of the total pressure of the mixture that is contributed to by that gas.
**Patent/Persistent foramen ovale (PFO).** A patent foramen ovale is a hole in the wall between the atria of the heart caused by failure of the foramen ovale to close fully after birth.

**Predisposing factor.** A predisposing factor as defined here is a relevant factor that was present prior to the dive, and/or prior to the trigger occurring, and which is believed to have predisposed to the incident and/or to key components in the accident chain (e.g., the trigger or disabling agent).

**Pneumothorax.** Collapsed lung.

**Professional Association of Diving Instructors (PADI).** The world’s largest scuba diver certification agency.

**Project Stickybeak.** An historical Australian dive fatality reporting project conducted by Dr. Douglas Walker.

**Pulmonary barotrauma.** A lung overpressure injury usually caused during diving by inadequate exhalation during ascent.

**Repetitive dive.** A dive conducted within a period of a previous dive(s) for which residual inert gas from the previous dive must be accounted for in accordance with the dive computer, tables or decompression algorithm used.

**Scuba divers pulmonary edema (SDPE).** Immersion pulmonary oedema precipitated by scuba diving.

**Scuba diving.** Diving using self-contained underwater breathing apparatus.

**Scuba regulator.** A pressure reducer that reduces a diver’s breathing gas from cylinder pressure to ambient pressure supplied by a demand valve (which is triggered by inspiration).

**Snorkelling.** Swimming using a snorkel either on the surface, or periodically underwater with breath-holding.
Surface-supplied breathing apparatus (SSBA). Diving using breathing gas supplied from the surface, either from a specialised diving compressor, high-pressure cylinders, or both.

Technical diver. A diver who conducts dives that exceed the recreational agency-specified limits of depth and/or immersion time for recreational scuba. The equipment used often involves breathing gases other than air or standard nitrox mixtures, and multiple gas sources.

Trigger. A Trigger as used here is the earliest identifiable event that appeared to transform an unremarkable dive into an emergency.

Ventricular fibrillation (VF). Uncoordinated and irregular contraction of the heart muscles which fails to generate effective circulation.

Ventricular septal defect. An opening in the wall (septum) separating the ventricles of the heart.

Wetsuit. A tight-fitting gas-impregnated neoprene suit worn by divers to provide thermal insulation. It is not watertight and water trapped between the diver’s skin and the suit is warmed by body heat and helps to reduce heat loss.
Units

Metres of sea water (msw)
Metres of fresh water (mfw)
Millimoles per litre (mmol/L)
Kilometres per hour (km/hr)
Kilograms per square metre (kg/m²)
Litres per minute (L/min)
Abstract

**Aim:** This research aims to identify characteristics of both active Australian scuba divers and victims of fatal scuba diving accidents in Australia, and to identify underlying factors and risks associated with scuba diving mortality in Australia. This information will be used to inform appropriate countermeasures.

**Methods:** Retrospective surveys of four diver cohorts (i.e., Divers Alert Network Asia-Pacific [DAN AP] members with and without declared medical conditions, Professional Association of Underwater Instructors [PADI] members, and other PADI certified divers) were conducted to determine demographic, health and diving activity profiles. Diving activity data from national sporting activity and Queensland tourism surveys, and the records of a large Victorian dive charter operator, were used to provide denominators to estimate fatality rates in these cohorts. In addition, a template for a chain of event analysis was developed, tested and then used to analyse the complete case series of all Australian diver deaths from 2001-2013, inclusive.

**Results:** Among a total of 2,275 Australian-based respondents from three survey cohorts, three quarters were male, with a median age of 45 years. Approximately thirty percent of each cohort reported a cardiovascular, respiratory, neurological or psychological condition, or diabetes. A follow-up of 268 DAN members with medical conditions of concern, indicated that approximately one half sought specialist diving medical advice and one quarter modified their diving practices to mitigate risk. Twenty-nine (11%) respondents reported an adverse event while diving.

The estimated annual scuba diving fatality rate for Australian residents was 0.48 (0.37–0.59) deaths per 100,000 dives, or 8.73 (6.85–10.96) deaths per 100,000 divers; 0.12 (0.05–0.25) deaths per 100,000 dives, or 0.46 (0.20–0.91) deaths per
100,000 divers for international visitors to Queensland; and 1.64 (0.20–5.93) deaths per 100,000 dives for the dive operator in Victoria.

When the chain of events analysis template was tested, the index of concordance (a measure of agreement consistency) between the raters increased from 62% (194/312) to 82% (257/312). This indicated a substantially higher inter-rater agreement when the template was used to analyse the events leading to the fatality.

The median age of the 126 scuba victims from 2001 to 2013 was 45 years, and 37% were obese. Forty-one percent had done fewer than 30 dives. Fifty-four percent were alone when the incident occurred and 68% had their weights in situ. Health-related pre-disposing factors likely contributed to 59 (47%) of the deaths. The main disabling agents were asphyxia (37%) and cardiac conditions (25%).

Diving fatalities usually arose from a cascade of events arising from problems with a diver’s health; inadequate training, experience, planning, skills or preparation; inability to deal with adverse conditions; poor equipment maintenance or usage and poor decision-making/diver error at various stages of the accident chain.

**Conclusions:** Half of active Australian divers are aged over 45 years. Many have chronic medical conditions, some of which may predispose to a fatality. Mortality may be reduced through better education about potential predisposing factors, improved medical screening and dive planning, closer supervision, and becoming positively buoyant in an emergency. Better data collection by on-scene accident investigators, a greater willingness of divers and dive operators to report both fatal and non-fatal incidents, and more research into the effects of immersion on divers with existing medical conditions may further reduce mortality.
SECTION 1

INTRODUCTION
Chapter 1

Introduction

1.1 Background

Snorkelling involves a person breathing through a shaped breathing tube (snorkel) while swimming. A mask for underwater vision, and, often, fins for propulsion are also worn. In addition to swimming on the surface, snorkelling may also involve breath-hold diving underwater.

Although the origins of snorkelling are unclear, archaeological evidence suggests that humans were breath-hold diving for shells, and probably food, as early as 4500 BC. There are subsequent reports of swimmers using reeds, bamboo or similar hollow tubes to breathe while swimming or submerged. Aristotle (384 BC – 322 BC) reported that “divers are provided with instruments for respiration, through which they can draw air from above the water”. It is evident that breath-hold diving and the use of a snorkel for breathing at, or near, the water’s surface has a long history.

Surface-supplied breathing apparatus (SSBA) diving involves breathing underwater using gas (usually compressed air) supplied from the surface through a hose and regulator. The breathing gas is usually pumped to the diver by means of a compressor on the surface. The diver wears a mask (or helmet in commercial diving), fins and thermal protection (from a wetsuit or drysuit), weights to compensate for the buoyancy from the suit, and, ideally, a buoyancy compensator device (BCD) to adjust buoyancy with changes in depth. It has been claimed that the first surface-supplied breathing apparatus (SSBA) was demonstrated by an English inventor, Becker, in 1715. This device, which included a diving suit with attached helmet with window, supplied compressed air from the surface using a bellows and two supply tubes.
The term SCUBA, an acronym for Self-Contained Underwater Breathing Apparatus, is used to describe diving sets which enable divers to carry their own breathing gas supply. Although, there have been various claims to its invention, probably the first successfully-used device was patented by Ogushi in 1918 and used to depths up to 60 metres of sea water (msw).³

Scuba apparatus as we know it today, utilising a demand valve (which opens with the diver’s inspiration rather than by turning on a tap), was designed by Jacques-Yves Cousteau and Emile Gagnon in 1943.⁴ Cousteau’s subsequent underwater documentary and book entitled “The Silent World”, were major stimuli for the emergence of recreational SCUBA diving and snorkelling.⁵ Over time, the acronym SCUBA has evolved to scuba in common parlance.

In addition to wearing a scuba set, which should include a submersible pressure gauge for monitoring the breathing gas supply, such divers wear a variety of additional equipment designed to enhance the efficacy, safety and comfort of diving. These should include a mask, a snorkel for swimming on the surface, fins, a wetsuit or drysuit for thermal protection, weights (usually attached to a belt with a quick-release buckle) to compensate for the buoyancy from the suit, a BCD, decompression tables and/or a diving computer to monitor decompression, and a knife to use in the event of entanglement.

In recreational scuba diving, the breathing gas is usually air, although other breathable mixtures may be used for specialised diving in order to enable increased depth and extend underwater time. Most scuba devices are ‘open-circuit’ as all expired breath is vented from the system as bubbles. A small proportion of scuba divers use ‘rebreathers’. Such devices conserve the breathing gas supply by the removal of carbon dioxide from exhaled gas, supplementing this with oxygen and recirculating this gas. These are closed-circuit or semi-closed-circuit devices.

Certification courses in diving are available through, mainly, commercial training agencies. However, although training and certification is strongly encouraged and is
generally required in a commercial dive operator setting, it is not mandatory in Australia, and some divers continue to dive privately without appropriate training and certification. This is especially so with SSBA diving.

Given that humans have not evolved as aquatic creatures and are poorly-adapted to existence on or under water, aquatic-related accidents occur relatively frequently. According to the World Health Organisation drowning is the third leading cause of unintentional injury death worldwide, accounting for 7% of all injury-related deaths with an estimated 360,000 annual drowning deaths worldwide.⁶

Although snorkelling and scuba equipment is designed to increase flexibility and survivability in the water and prevent wearers from drowning, diving-related accidents still occur for a variety of reasons, including diver-related factors, environmental factors and equipment-related problems. The Royal Life Saving Society Australia reported that 9% of 280 drowning deaths in Australia in the 2015 to 2016 financial year were associated with diving-related activities.⁷ However, in some of these incidents drowning was likely to have been secondary to a medical event as discussed later. In any case, many of these deaths may have been preventable and warrant detailed investigation in order to understand causes and potential countermeasures.

Although there is commonality in certain aspects of mortality within the various sub-groups of divers, the combined area is too broad to include in this thesis, which will focus predominantly on scuba divers. Examination of fatalities in snorkellers and SSBA divers will be addressed in subsequent reports.
1.2 Literature search

A systematic search of published literature for all available dates up to, and including, December 2017 was conducted in order to examine what is currently known about diving mortality, the potential effect of comorbidities on diving safety, and to explore gaps in this knowledge. The following databases were used:

Medline Complete, CINAHL Complete, Health Source (Nursing/Academic Edition), SPORTDiscus with Full Text, and PsychINFO. The search terms included:

1. scuba or “compressed air” or “compressed gas” AND div* AND death* or fatalit* or mortalit*;

2. “scuba div*” AND cardi* or heart or diabetes or asthma or hypertension or *rhythm* or pneumothora* or emphysema or epilepsy or pulmonary or *edema or medication* or autops*.

The Rubicon Research Repository (http://Rubicon-Foundation.org), a database of diving and environmental physiological research, was also searched for similar items, albeit not using the combined search terms, but, instead individual terms such as fatality, asthma and arrhythmia. In addition, references cited in relevant publications were reviewed and added where necessary, hand searches were made of various historical reports in the Candidate’s personal library and that of the Divers Alert Network Asia-Pacific (DAN AP). Grey literature searches, including various DAN websites were conducted for completeness. All case series published in English, or available in translation and involving scuba-related mortality, morbidity and fitness to dive were included.

The searches identified a total of 1,670 papers. Of these, 422 papers met the criteria. The search strategies and results are shown in Appendix A1. Key themes are explored in the following sections.
1.3 Divers and the diving environment

As mentioned earlier, diving is conducted in a hostile environment and therefore carries a variety of risks. These may arise from the diving environment itself, or may be related to various other factors, which include: the participant’s physical, medical and psychological health; training or experience; equipment failure, unfamiliarity or misuse; poor decision-making and attitudinal factors.8-21

Historically, participants in recreational scuba diving in Australia were mainly experienced breath-hold divers who were comfortable in the water and who possessed reasonably sound snorkelling and other water survival skills.22 However, as the wider community has become more aware of the attractions of the underwater world, training has been targeted at, and sought by, a broader subset of the population from the very young to the old, each with their own specific risks.11, 23-26 This has led to a perceived increase in the number of divers with relatively poor aquatic skills and sometimes poor health and fitness. In addition, some of the earlier divers who have continued to dive may have developed age-related and other medical conditions that rendered diving less safe.26-32

Unless this situation is carefully monitored and managed by appropriate and adequate participant screening, training, education, supervision and accident management systems, it can result in unnecessary morbidity and mortality.10, 33, 34

1.4 Diving accident surveillance

Management and accident prevention strategies for diving-related activities should be informed by relevant, accurate and detailed data about the incidence and the nature of mortality and morbidity associated with these pursuits.10, 35, 36

A variety of organisations and individuals have collected data on diving incidents and fatalities in various localities. Worldwide, the International Divers Alert Network (IDAN) has documented an average of 203 annual deaths resulting from compressed gas (mainly scuba) diving between in 2010 and 2015, with more than three percent of these occurring in Australia.37 The distribution of reported deaths
for 2015 is shown in Figure 1.1. However, the information from many countries is unreliable due to poor local reporting systems and this is likely to result in substantial underestimates.

The main historical and on-going sources of diving fatality data available, in the English language, have been through the British Sub-Aqua Club for the United Kingdom, DAN America for the USA, and through “Project Stickybeak” followed by DAN Asia-Pacific for Australia, as outlined below.

1.4.1 British Sub-Aqua Club (BSAC) reports

The BSAC has reported diving accidents in the United Kingdom (UK) since 1964 and provides annual reports on incidents and fatalities. A total of 682 dive-related fatalities were recorded between 1965 and 2016, inclusive. This includes a few snorkellers but the vast majority were scuba divers.

The reports provide short vignettes of each accident and a brief discussion. The main limitation of these reports has been the lack of detail of the circumstances and chain of events leading to the fatality, including the cause of death. Reportedly, limitations on data collection and storage has been a major contributor to the lack of detail, but this appears to have been improving over the years with additional information sources and information technology resources. Another likely limiting factor is that the fatalities are included as an integral part of an overall incident report of over 200 annual incidents. Hence, the amount of work and the size of the report would be prohibitive with relatively limited financial and staffing resources and the time constraints. However, despite their limitations, these annual reports provide a valuable insight into diving fatalities in the UK.

The first detailed epidemiological review of these UK data examined 140 of the 197 fatal diving accidents that occurred from 1998 to 2009. This report highlighted non-diving-related medical problems (27%), exhaustion of breathing gas (26%), equipment-related problems (22%) (commonly involving rebreathers), buoyancy
problems (13%) and diving deeper than 40 m (13%) as the key contributors to the deaths. The authors also highlighted what they termed “exacerbating factors”, defined as factors that “increased the opportunity for the initiating factor to occur and/or reduced the ability of those present to resolve the incident once it had started.” One such factor was non-pair diving, which they defined as solo diving or diving in groups of more than two.

1.4.2 Reports from the USA

Schenke, from the University of Rhode Island, published a report on 274 of the 368 known diving-related fatalities in the USA from 1946 to 1969, inclusive.77 Subsequently, McAniff from the National Underwater Accident Data Centre (NUADC), also from the University of Rhode Island, reported diving fatalities in US waters and of U.S. citizens worldwide from 1970 to 1989 inclusive.78-86 From 1990 to 1994, the reports were compiled and published in collaboration with Divers Alert Network (DAN) America who, thereafter, took on the responsibility of reporting on recreational diving deaths in the Americas.

These reports present data on both mortality and morbidity (decompression illness).87-106 Reports from 2000-2008 inclusive, contained information on an ambitious dive data recording project (Project Dive Exploration) in which dive computer profiles were downloaded and associated mortality and morbidity data were recorded. The DAN America reports highlight the deaths of U.S. and Canadian citizens worldwide, although the most recent three87-89 have included some separate sections on international fatality data. In addition to short vignettes of a selection of cases, the DAN America reports have routinely provided annual and, in some cases, cumulative epidemiological data. Data on snorkelling and breath-hold diving incidents began with the report on 2005 data90, and the most recent reports also include some additional data on non-fatal scuba diving incidents.87-89

There were 4,347 reported scuba diving-related deaths between 1970 and 2015, inclusive (P. Denoble, personal communication, 2015). The reports are often based
on limited data due to the large number of cases and the somewhat daunting number of information sources, regulatory bodies and privacy restrictions that need to be negotiated to access these data.

A landmark and extensive epidemiological review of DAN America scuba diving mortality data was conducted by Denoble and colleagues who examined 947 recreational open-circuit scuba diving deaths from 1992-2003. The authors applied a sequential analysis process to scuba diving deaths. The sequence was divided into triggers (initial precipitant), disabling agents (subsequent hazardous behaviour or circumstance), disabling injuries (responsible for causing death or incapacitation leading to death by drowning), and the cause of death as determined by the medical examiner.

The main triggers, disabling agents and disabling injuries are shown later in Table 1.2. Logistic regression was used to assess associations between risk factors and various disabling agents. Entrapment, insufficient gas, buoyancy trouble, equipment trouble and rough water had the largest associations with asphyxia; emergency ascent, insufficient gas, equipment trouble and entrapment with cerebral arterial gas embolism (CAGE); and cardiovascular disease (CVD) and age over 40 years with cardiac incidents. The calculation of odds ratios quantified what appeared to be logical associations.

The application of sequential analysis provided a framework for other dive fatality researchers to utilise and paved the path for future studies. However, the technique was limited by the chosen categories and subcategories and so had the potential to miss relevant information and be more prone to potential subjectivity. Some of these limitations are addressed in Chapter 7.
Figure 1.1. Distribution of known compressed gas diving fatalities (does not include snorkeling-related deaths) in 2015 worldwide.37
1.4.3 Reports from Australia

In Australia, the formal reporting and publication of diving fatalities began with Bayliss with a 1967 Australian naval report of a series of nine cases involving civilians. This was followed by a brief analysis of 71 civilian fatalities that had occurred between 1957 to 1967, inclusive. These reports continued with the introduction of “Project Stickybeak” by Walker, a general practitioner, who almost single-handedly reported snorkelling and compressed-air diving fatalities until 2002. Walker’s annual reports adopted a similar format to that of Bayliss’ initial report, providing detailed information on each case including, where available, basic information from the autopsy and any recommendations by the coroner. They also included a brief summary of factors that were deemed to be important and a discussion, highlighting particular concerns related to diving health and safety. Unfortunately, some of these discussions were largely based on the author’s opinions and could lack objectivity. However, the volume of information provided is far greater than other fatality reports published at that time and includes important demographic, temporal, medical and diving-related information making Walker’s reports a valuable resource.

The first substantial epidemiological analyses of Australasian scuba diving accident data were conducted by Edmonds and Walker in which the first 100 of the 175 deaths in Australia and New Zealand from 1980 to 1987 were studied. These reports addressed the “human factors” (i.e., medical, psychological and judgemental problems) implicated in the deaths, contributory or causal environmental factors, and various equipment-related issues. Twenty-one percent of the victims were diving alone, 8% were on their first dive and 5% were undergoing dive training. Major contributory factors were thought “likely” to have been medical-related (43%), equipment-related (18%) and environmental (18%).

Walker’s annual reports from 1972 to 1993 were compiled and published with an analysis of the fatalities. Demographic information and the reported causes of deaths are shown in Table 1.1. The high rate of death attributed to drowning is
often the final result of a person becoming unconscious in the water from another cause and it is important to better identify the precipitating factors, as described in Chapter 7.

Seventy-two percent of the scuba divers in Walker’s reports had received some training and 37% were described as “experienced”. Scuba diving training has become far more accessible and prevalent over more recent years and an analysis of whether or not this has had any impact on the nature of fatal accidents could be valuable. Running out of air was also a very common problem with 49 (28%) of the scuba divers having no air remaining in their cylinders. The reliability of regulators and pressure gauges has improved over time and it would be valuable to determine whether or not air-supply emergencies have diminished concomitantly.

Walker’s annual reports for 1994-1998\(^{140}\) and 1999-2002\(^{141}\) were re-published as separate compilations, the latter including a brief epidemiological analysis by the Candidate and colleagues. The mean age of scuba victims over the combined periods was substantially higher than in the earlier review.\(^{18}\) Additionally, the proportion of female victims rose from 13% to around 30%, likely representing increased participation. There was a rise in the fatalities which were believed to have been of cardiac origin. This is likely reflective of the higher age of the cohort and invites further investigation.

A retrospective analysis of 24 recreational diving fatalities in Western Australia (WA) between 1992 and 2005 inclusive, revealed, somewhat unsurprisingly, that those who had died from cardiac events were older, with a mean age of 50 years.\(^{142}\) Thirty percent of the divers were uncertified which appears to be a high proportion of uncertified divers for this time period when certification had become far more accessible and common. A relatively low proportion of diving (possibly 27%) was classified as organised (i.e., through a dive operator) and this was reflected by the fact that only 21% of the known diving platforms of the victims was a commercial boat. This lower proportion of incidents during organised dives may vary across Australia and will be investigated in Chapter 8.
A sequential analysis of all 351 Australian compressed gas (i.e., scuba and SSBA) diving deaths between 1972 and 2005, inclusive, was conducted by the Candidate and presented at a 2010 DAN International Diving Fatality Workshop. Lippmann used similar, but not identical, categories to those of Denoble and colleagues, the modifications introduced to better reflect the available data. During the process, Lippmann identified further improvements and refinements that could be made in order to make the reporting more consistent between analysts. These refinements are addressed in Chapter 7.

Lippmann and colleagues then conducted an extensive epidemiological review of these deaths, which is currently the largest and most detailed study of Australian compressed gas diving-related mortality to date. This highlighted some important trends during the 34-year period which included an increase in mean age of the decedents of 16 years and an increase in the proportion of female decedents of from 7% to 22%. There was also a decline in asphyxia-related deaths with a concomitant rise in deaths due to CAGE and cardiac conditions. Additional declines in the proportions of equipment-related deaths and those due to loss of buoyancy at the surface were detected. These were likely due to improvements in equipment and the uptake in the use of buoyancy compensation devices (BCDs). Consistent with Denoble and colleagues, this review also used logistic regression to determine the relative influence of triggers and disabling agents on the disabling injuries, with similar results.

The authors cited a number of limitations to their review, among which were incomplete case data, limited classification categories for the sequential analysis, absence of information on divers at risk and lack of currency. The candidate has been proactive in trying to address these limitations by initiating targeted further research as outlined in the following chapters of this thesis.
Table 1.1. Comparison of reviews of Australian scuba divers.

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Table 1.2 compares some features of the reports from Australia and the USA. As much of the UK data are not directly comparable, they are not presented in the table.

Table 1.2. Characteristics of diving fatalities reported from Australia and USA.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Australia⁹</th>
<th>USA₁³</th>
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<tbody>
<tr>
<td><strong>N</strong></td>
<td>351</td>
<td>947</td>
</tr>
<tr>
<td><strong>Age (yrs), Med (IQR)</strong></td>
<td>34 (26, 44)</td>
<td>43 (33, 52)</td>
</tr>
<tr>
<td><strong>Gender (% male)</strong></td>
<td>88</td>
<td>81</td>
</tr>
<tr>
<td><strong>Experience (%)#</strong></td>
<td>Experienced (44) Frequent (18)</td>
<td>Inexperienced (37) Occasional (22)</td>
</tr>
<tr>
<td><strong>Under training (%)</strong></td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td><strong>Incident depth (m), med (IQR)</strong></td>
<td>9 (2, 18)</td>
<td>18 (9, 30)</td>
</tr>
<tr>
<td><strong>Triggers (%)</strong></td>
<td>gas supply (18)</td>
<td>gas supply (41)</td>
</tr>
<tr>
<td></td>
<td>equipment (18)</td>
<td>entrapment (20)</td>
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<tr>
<td></td>
<td>water conditions (16)</td>
<td>equipment (15)</td>
</tr>
<tr>
<td></td>
<td>exertion (11)</td>
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<tr>
<td><strong>Disabling agents (%)</strong></td>
<td>gas supply (26)</td>
<td>ascent (55)</td>
</tr>
<tr>
<td></td>
<td>ascent (21)</td>
<td>gas supply (27)</td>
</tr>
<tr>
<td></td>
<td>cardiovascular disease (16)</td>
<td>buoyancy (13)</td>
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<tr>
<td></td>
<td>buoyancy (12)</td>
<td></td>
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<tr>
<td><strong>Disabling injuries (%)</strong></td>
<td>asphyxia (49)</td>
<td>asphyxia (33)</td>
</tr>
<tr>
<td></td>
<td>CAGE (25)</td>
<td>CAGE (29)</td>
</tr>
<tr>
<td></td>
<td>cardiac (18)</td>
<td>cardiac (26)</td>
</tr>
<tr>
<td></td>
<td>trauma (5)</td>
<td>trauma (4)</td>
</tr>
</tbody>
</table>

# classifications differ; CAGE = cerebral arterial gas embolism

The Australian cohort was younger than those in the USA and a higher proportion were males. Although the measure of experience of the victims was not directly comparable between reports, the divers with reported experience levels of none/Novice and inexperienced/occasional combined was similar in Australia (53%) and the USA (50%). The considerable proportion of victims who were under training and/or instructor supervision is concerning and indicates a need to examine more recent data to determine if further countermeasures need to be implemented.
Despite the ubiquitousness of submersible pressures gauges and improvements in equipment, gas supply emergencies were common. These accounted for 18% of triggers and 26% of disabling agents in Australia, and an astonishing 41% of triggers and 27% of disabling agents in the US series. As expected, gas supply emergencies were highly associated with drowning and CAGE. Running out of gas was determined to be the primary cause in 8.5% of the UK diving fatalities.

Equipment-related problems were common and contributed to deaths at a comparable rate in Australia (18%) to those in the USA (15%) and UK (20%). Many may have been preventable with appropriate familiarisation and maintenance. The UK data indicate that the use of rebreathers was the likely cause of more than half of the equipment related-deaths, disproportionate to their relatively low, albeit increasing, usage.

In the Australian series, half of the incidents occurred in the first nine metres underwater, with 27% occurring at the surface, at the beginning or end of a dive. By contrast, the median depth in the USA was 18 m. However, the BSAC data indicate that 38% of deaths occurred at depths greater than 40 m. This higher incidence in the UK is probably largely the result of the popularity and accessibility of wrecks in deeper water and the more challenging diving conditions of cold water, poor visibility and often rough surface conditions.

Trauma was associated with a similar percentage of deaths in Australia and the USA and was mainly associated with marine animal and boat propeller injuries. In the US analysis, buoyancy trouble was reported in 31% of cases, with 11% being negative, 1% positive, 4% variable and 15% unspecified. The Australian study cited buoyancy problems as triggers in 5% of deaths and disabling Agents in 12%. The UK study reported that in about 13% of the cases, poor buoyancy control was the primary causal factor for the incident (about half of the divers being too light and the rest too heavy).
Together, these reviews highlight many common features, as well as some regional differences in the causes and types of scuba diving-related incidents. Some further comparisons by the Candidate are reported in Edmonds et al.\textsuperscript{144} However, more contemporary studies are required to examine these trends and identify any more recent influences on diving safety.

Figure 1.2 shows the comparative data for Australia, the USA and the UK for reported scuba deaths from 1970 to 2013, inclusive. There appears to have been an initial downward trend in the USA (from the 1970s to the early 1980s) but no obvious trend thereafter. The annual fatality numbers in the UK and Australia appear to have been relatively stable, other than in 1972-73 in the UK with what appears to have been a reporting error (B. Cumming, personal communication, 2015). Australian trend data will be examined more closely in Chapters 5 and 6.

\textit{Figure 1.2. Annual scuba deaths in Australia, the USA and the UK, 1970-2013.}\textsuperscript{145,77-106,38}
1.4.3.1 The current state of diving accident surveillance in Australia

In 2003, the collection of data on diving accidents in Australia became the responsibility of Divers Alert Network Asia-Pacific (DAN AP) under the stewardship of the Candidate, Lippmann. DAN AP has compiled a unique resource of the 809 recorded diving-related fatalities which were known to have occurred in Australian waters between 1965 and 2013, inclusive.

Lippmann co-authored the 2003 fatality report with Walker\textsuperscript{146} and has subsequently been the principal investigator and reporter of diving-related fatalities in Australia since 2004.\textsuperscript{147-155} He has broadened and modified the historical surveillance system in order to increase data capture and improve analysis and reporting and the currently methodology is described in Chapter 5.

1.4.4 Case series from other sources

In addition to the temporal case series reports discussed previously, searches of English language databases revealed some other occasional case series from a variety of countries. There are undoubtedly reports in languages other than English.

Some of these other occasional case series available in English include reports from Australia\textsuperscript{156,157}, Canada\textsuperscript{158,160}, Croatia\textsuperscript{161-163}, Denmark\textsuperscript{164}, Finland\textsuperscript{165}, Japan\textsuperscript{166-169}, Hong Kong\textsuperscript{170}, New Zealand\textsuperscript{171,16,172-175}, Norway\textsuperscript{176}, South Africa\textsuperscript{177-178}, Sweden\textsuperscript{179}, the United Kingdom\textsuperscript{180,181}, the United States of America\textsuperscript{182-187} and worldwide.\textsuperscript{188} The number of cases, periods and suspected causative factors are shown in Table 1.3.3, compiled by the Candidate. The quality of the reports was assessed on the basis of the amount and quality of information on the fatalities contained therein, the accompanying analysis and presentation of data.
### Table 1.3: Comparison of occasional international fatality reviews

<table>
<thead>
<tr>
<th>Country</th>
<th>Year</th>
<th>Type</th>
<th>Fatality Rate</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>2000</td>
<td>A</td>
<td>0.001%</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>2010</td>
<td>B</td>
<td>0.005%</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>2015</td>
<td>C</td>
<td>0.01%</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>2020</td>
<td>D</td>
<td>0.002%</td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td>2025</td>
<td>E</td>
<td>0.003%</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>2030</td>
<td>F</td>
<td>0.004%</td>
<td></td>
</tr>
</tbody>
</table>
1.5 Gaps in knowledge

The review of the Australian and international diving fatality literature has identified a number of knowledge gaps, which include:

1. *The current demography and diving characteristics of Australian divers*

As stated in an editorial in a diving medical journal, the diving population, as well as some equipment and techniques have changed, especially over recent years.\(^36^\) Other than the annual fatality reports, little has been published examining any impact of such changes in Australian divers. Therefore, there is a need to examine more recent data and identify any trends that may impact safety.\(^36^\)

2. *Pre-existing medical conditions of Australian divers*

The risk of diving with various potential medical contraindications has been a topic of vigorous debate within diving medical communities for several decades.\(^189-196^\) It is important to try to determine the contribution of pre-existing medical conditions to diving mortality. Despite access to medical histories and sometimes evidence of such a condition at autopsy, causality is often difficult to demonstrate.\(^197-199^\) With an apparent increase in fatalities involving older divers who have a greater likelihood of co-existing disease, there is a growing need to collate, analyse and publish data on medical conditions in active divers, as well as in diving accident victims, in order to improve our understanding and to inform this debate.

3. *Incidence rate of diving-related fatalities in Australia*

While there are reliable data on the absolute annual number of diving-related fatalities in Australia, it is important to try to obtain a reasonable estimate of the incidence of such deaths. Given the large number of dive sites, the independence of much of the diving activity and the many other obstacles to data collection, it is impossible to obtain a reliable assessment of the diving activity throughout Australia and therefore to get a reliable denominator to allow the calculation of the death rate. The alternatives are to obtain data from targeted groups and calculate
the risk for these, and to accept the limitations of otherwise reasonably well-constructed surveys. These estimates may be of use, in full knowledge of the shortcomings.

4. Validated template for the analysis of a diving accident which accounts for pre-dive predisposing factors and human factors

Several studies have utilised a sequential analysis to isolate and better understand the accident sequence in order to facilitate the creation of relevant countermeasures. The Candidate identified a need to further develop and better define a process for performing such a chain of events analysis to reduce potential subjectivity and increase consistency between analysts. This is presented in Chapter 7.
1.6 Aims and significance of the research

In order to better understand the causation of Australian scuba diving fatalities and so enable the development of appropriate prevention strategies, it is important to understand the characteristics and activities of Australian divers and to comprehensively document and carefully analyse these fatalities.

Supported by the comparatively complete and detailed DAN Asia-Pacific dataset\textsuperscript{145}, and drawing on his relevant experience in diving accident investigation, the Candidate will conduct a total population study of Australian scuba diving-related deaths from 2001 to 2013 inclusive in order to explore the data and identify and examine the underlying causes and any trends that have occurred over the period, assessing how these have impacted diving safety.

This research aims to:

1. \textit{Identify the demographics, diving characteristics and activities of cohorts of active Australian scuba divers.} This will be addressed in chapter 2.

2. \textit{Investigate the prevalence, effects and impacts on diving safety of pre-existing medical conditions.} This will be addressed in chapters 2, 3, 4 and 8.

3. \textit{Estimate the fatality rate for Australian scuba divers.} This will be addressed in chapter 6.

4. \textit{Create an improved template for the analysis of a scuba diving accident.} This will be addressed in chapter 7.

5. \textit{Describe the characteristics associated with fatal scuba diving -related incidents in Australia from 2001 to 2013, inclusive, in order to examine trends and potentially identify causative factors.} This will be addressed in chapter 8.

6. \textit{Determine appropriate prevention strategies based on the information collected from mortality data.} This will be addressed in various policy and practice recommendations evolving from this study.

The specific research questions to be answered are:
1. What are the underlying factors associated with scuba diving-related mortality in Australia?
2. What are the implications for preventative strategies?

Although some mortality from diving-related activities are to be expected, many deaths are potentially preventable and there is a considerable benefit in learning from the mistakes and misfortunes of others. Such information can be used to refine surveillance and also to inform improved countermeasures.

The results from the investigations will be reviewed with close focus on identified trends, and causative and other factors associated with the fatalities will be carefully examined. Any existing preventative strategies aimed at particular identified problems will be considered in the context of their relevance and effectiveness. Recommendations for improvements in on-scene investigation systems and revised and/or additional preventative countermeasures will be provided.

Specifically, findings from this research will be distributed to State and Territory Coroners, diver training and certification agencies, as well as the diving medical and general diving community. Suggested countermeasures could be incorporated into diver training guidelines, organised and individual diver practices, and existing and future diving-related Codes of Practice and Standards. Suggested improvements could be incorporated in the protocols used for the on-scene investigation of diving accidents; and medical information gleaned from the research could be used to better inform diver health surveillance.
SECTION 2

DEMOGRAPHICS, HEALTH-RELATED CHARACTERISTICS AND DIVING PRACTICES OF COHORTS OF ACTIVE AUSTRALIAN SCUBA DIVERS
Chapter 2
Investigation of the demographics, diving history and practices of Australian scuba divers

There is a dearth of published data about the demographics and activities of the current generation of Australian scuba divers, and such information has always been elusive. In the early 1990s, the then Australian diving industry body (Dive Australia) surveyed a sample of divers. However, this was only for internal use and there appear to be no available copies of the report. Some diver training agencies collect certain data, and PADI publishes basic information on the gender and age of divers certified internationally (albeit not for individual countries) over the previous five years. However, other data are not available outside the organisation due to commercial concerns.

Those of us who are, or were, very long-time divers and instructors are aware that there has been an apparent change in participants. This change is from generally fit, youngish males with considerable snorkelling and often spearfishing experience, to the current generation which includes ageing long-term divers, children as young as eight years, right through to elderly novices, and a considerably higher proportion of females. It is important to identify the demography of these divers, their levels of experience and activity and the types of diving that they typically undertake. This information will provide a clearer perspective about the susceptibility of various groups to diving-related morbidity and mortality and any countermeasures that may be appropriate.

The challenge is to identify suitable diver cohorts to survey. Such cohorts should ideally be representative of the diving community, sufficiently large enough to provide meaningful data, and be of a known size in order to calculate a survey response rate. Probably the easiest way to access large diver groups is via well-publicised internet-based surveys. However, in such a setting it is unknown how
many divers received the invitation to participate and, therefore, to calculate the response rate.

The Candidate’s position at DAN AP enables access to its members. PADI is by far the largest diver certification agency internationally, including in Australia, and holds large databases of divers, from newly certified to long-time and experienced dive professionals. PADI Asia-Pacific agreed to provide the Candidate with access to two diver cohorts to conduct this survey. The structure, results and analysis of these surveys of Australian-based divers are presented in the following paper.\textsuperscript{201}

The results of this analysis will be used to address Thesis Aim 1 - “Identify the demographics, diving characteristics and activities of cohorts of active Australian scuba divers.” This, in turn, will assist in identifying potential “underlying factors associated with scuba diving and snorkelling-related mortality in Australia” (Research Question 1).
Challenges in profiling Australian scuba divers through surveys
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Key words
Survey; Fitness to dive; Health surveillance; Cardiovascular; Scuba divers; Recreational divers

Abstract

Introduction: This study aimed to compare the results from three Australian scuba diver surveys. As the surveys differed in recruitment methods, the expectation was that respondents would differ in some important characteristics.

Methodology: Anonymous, online, cross-sectional surveys of the demographics, health, diving practices and outcomes were distributed to: (1) Divers Alert Network Asia-Pacific (DAN AP) members; (2) Professional Association of Diving Instructors (PADI) Asia-Pacific members; and (3) divers who had received any PADI non-leadership certification within the previous four years. Only data from divers resident in Australia were analysed.

Results: A total of 2,275 responses were received from current Australian residents, comprising 1,119 of 4,235 (26.4%) DAN members; 350 of 2,600 (13.5%) PADI members; and 806 of 37,000 (2.2%) PADI divers. DAN and PADI members had similar diving careers (medians 14 and 15 years, respectively). PADI members had undertaken more dives (median 800) than DAN members (330) and PADI divers (28). A total of 692 respondents reported suffering from diabetes or a cardiovascular, respiratory, neurological or psychological condition and included 34% of the DAN members and 28% of each of the PADI cohorts. Eighty-four divers had been treated for decompression illness (approximately 5% of DAN and PADI member groups and 1% of the PADI divers). Eighty-seven of 1,156 (7.5%) PADI respondents reported a perceived life-threatening incident while diving.

Conclusions: Despite low response rates, this study indicates clear differences in the characteristics of the divers in the three cohorts. Therefore, a survey of a single cohort may represent that diving population alone and the findings may be misleading. This bias needs to be clearly understood and any survey findings interpreted accordingly.

Introduction

Historically, participants in recreational scuba diving in Australia were mainly young, fit males who were experienced breath-hold divers.1 More recently, broader subsets of the population (age, gender and aquatic skills) have been attracted to the sport. In addition, some of the earlier divers who have remained active have aged with an associated risk of co-existing disease and subsequent morbidity and mortality during diving.2–7 It is important to have an understanding of the demographics, activities and health of current divers to better cater for their needs. For example, if a substantial older diver demographic is identified, targeted diving health campaigns could be offered, better pre-dive screening tools created and implemented and potential justification provided for the increased availability of defibrillators on dive boats. In general, the availability of such data enables the appropriate planning for incident mitigation and management strategies as well as safety initiatives. It also can serve to inform parts of the diving community about the level and type of activity of certain diving cohorts. However, there are few useful and publicly available data on Australian scuba divers since most relevant data are captured and held internally by the diver certification agencies for commercial purposes.

The aim of this study was to compare demographic, health and diving activity data of respondents to three Australian scuba diver surveys. As the survey samples were recruited from different cohorts of divers (i.e., insured divers, certified dive professionals and other, generally more-recently certified divers) the expectation was that respondents would differ in important characteristics. Confirmation of such differences would highlight that a survey of a single diver group may not be representative of the general diving population. Therefore, diver surveys must ensure that respondents are drawn from divers from a variety of different affiliations covering a spectrum of age, experience and diving activity.

Methodology

Two similar anonymous, online, cross-sectional surveys for distribution to scuba divers were created using an
online survey development system (Survey Monkey). Ethics approval was received from the Human Research Ethics Committee of Deakin University, Victoria, Australia (HEAG-H 100_2015). As there were no pre-existing questions on which validity and reliability had been tested, we developed our own questionnaire. The questionnaire was trialled for face validity on a small group of potential respondents and revised prior to its use.

**DAN MEMBERS SURVEY**

The Divers Alert Network Asia-Pacific (DAN AP) is a non-profit, membership-based association with a mission to improve recreational diving safety. Among other benefits, it provides its members with access to diving injury insurance. In December 2014, an invitation to participate in a DAN AP survey (DAN-S) was emailed to all current DAN AP members over 18-years-old (9,927) with a recorded email address at that time (99% of members). A reminder was sent in March 2015 and the survey was closed in April 2015. No a priori sample size calculation was undertaken as all DAN AP members were invited to participate. The survey sought details about the respondents’ age, gender, height and weight (from which body mass index (BMI) was calculated), perceived fitness, any significant medical conditions and diving history and activity. Diving data included the years of diving, number of dives, dives per year, frequency of diving and the types of dives undertaken (deeper, technical, decompression and repetitive). Data were also collected on personal experiences with decompression illness (DCI).

**PADI SURVEY**

The Professional Association of Diving Instructors (PADI) is the world’s largest diver certification agency and PADI Asia-Pacific is responsible for the vast majority of diver certifications in Australia. A survey was distributed by PADI Asia-Pacific in September 2015 and a reminder sent in December 2015 to two cohorts of its certified divers: (1) current PADI members (i.e., divers with a PADI divemaster or instructor qualification, or higher, PADI-M; 2,600 divers) recorded as living in Australia; and (2) divers with an Australian address who had received any non-leadership certification from PADI within the previous four years (PADI-D; 37,000 divers).

The survey distributed to the PADI cohorts included almost identical questions to the DAN-S. However, it also contained a screening question to identify those who had already responded to the DAN survey, as well as some questions about life-threatening diving incidents that had been experienced. The questions about life-threatening incidents were added in order to gather information for additional research, subsequent to the DAN-S. The authors were not provided with data on the proportion of each of the PADI groups for which email addresses were known. The PADI surveys were closed in February 2016. For all three surveys, only respondents with an Australian residential address were included in the analysis of the surveys.

**STATISTICAL ANALYSIS**

Statistical analysis was conducted using SPSS Version 22 (IBM, Armonk, NY; 2013). Estimates were presented as means or proportions with 95% confidence intervals. Chi-square tests were used to compare categorical variables such as health conditions, diving certifications and demographic characteristics of the participants in the three surveys. ANOVA was used to compare age and BMI across the three surveys.

The level of significance used throughout was 0.05. A priori sample size calculations were performed using the National Statistical Service online calculator. The calculated sample sizes required were 335 (CL = 95, proportion = 0.5, CI = 0.05) for PADI-M, and 381 for PADI-D (CL = 95, proportion = 0.5, CI = 0.05). Prevalence rates were calculated based on an exact binomial test in the R statistical package.

**Results**

**DEMOGRAPHICS**

A total of 9,927 DAN AP members were emailed and details of the full cohort of respondents are reported elsewhere. Of the 4,235 of these invitees recorded as Australian residents, there were 1,119 (26.4%) respondents. Information was available on the age and gender of all DAN AP members so it was possible to determine the age and gender of non-respondents. Three-hundred-and-seventy-five of 2,600 (14.5%) and 868 of 37,000 (2.3%) of the PADI-M and PADI-D invitees responded, respectively. Demographic data on invitees and respondents are shown in Table 1.

Of the 37,000 invited divers who had received a (non-leadership) PADI certification in the previous four years, approximately 14,000 opened the invitation email and 868 responded (2.3%) to the survey. Of the 2,600 PADI members who were invited to participate, 1,458 (56%) opened the invitation and of these 375 (25.7%) responded. Overall, 329 DAN-S, 25 PADI-M and 62 PADI-D respondents were excluded as they no longer lived in Australia. Twenty-nine PADI divers (two PADI-M and 27 PADI-D divers) had previously completed the DAN-S so were excluded from the PADI data. Thus, the following results are based on 1,119 DAN members (DM), 350 PADI members (PM) and 806 PADI divers (PD), a total of 2,275 Australian-based divers. Respondents to the DAN-S were on average significantly younger than non-respondents (mean ages 50 and 54 years respectively; \( P < 0.001 \)).

Table 2 describes the demographic characteristics of respondents from the three cohorts. These differed significantly in mean age and gender mix. There was a
Table 1
Age and gender of invitees, respondents and non-respondents to surveys of DAN AP members (DAN-S) and PADI certified divers (PADI-S) and members (PADI-M); age and gender not known in PADI-S non-respondents; NA = not available; *Australian residents only

<table>
<thead>
<tr>
<th></th>
<th>Age (y) mean (SD)</th>
<th>Gender (% male)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DAN AP Members</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inviteses (n = 4,235)</td>
<td>53 (13)</td>
<td>73</td>
</tr>
<tr>
<td>Respondents (n = 1,119)*</td>
<td>50 (12)</td>
<td>71</td>
</tr>
<tr>
<td>Non-respondents (n = 3,116)</td>
<td>54 (13)</td>
<td>74</td>
</tr>
<tr>
<td><strong>PADI Divers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inviteses (n = 37,000)</td>
<td>31 (10)</td>
<td>62</td>
</tr>
<tr>
<td>Respondents (n = 806)*</td>
<td>38 (13)</td>
<td>58</td>
</tr>
<tr>
<td>Non-respondents (n = 36,194)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td><strong>PADI Members</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inviteses (n = 2,600)</td>
<td>35 (11)</td>
<td>76</td>
</tr>
<tr>
<td>Respondents (n = 350)*</td>
<td>44 (12)</td>
<td>70</td>
</tr>
<tr>
<td>Non-respondents (n = 2,250)</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

small, albeit statistically significant difference between the mean BMIs of the cohorts, although these differences were not clinically significant. There was also a significant difference in the proportions of obese respondents in the different gender subgroups with higher rates of obesity in male PM divers (P = 0.012). However, all comparisons need to be interpreted cautiously due to the low response rates to the surveys.

DIVING HISTORY AND CHARACTERISTICS

DAN members reported having conducted a total of 812,685 dives, PM reported 603,564 dives and the PD had conducted a total of 84,899 dives. With medians of 14 and 15 years respectively, DAN and PM divers had been diving far longer than the PD group, who had dived for a median of four years (P < 0.01). On average, PM divers reported many more dives (median 800) than the DM (330) and PD cohorts (28), and the proportions of each cohort who reported having done more than 200 dives were 72% (DAN), 83% (PM) and 7.5% (PD). PM divers had also done more dives in the previous year (median 50) than DM (30) and PD divers (10). Sixty-two per cent of the DM and 60% of the PM had dived in the month prior to the survey, compared to only 24% of the PD cohort (Table 3). The numbers of divers undertaking decompression dives or technical diving were too small for useful analysis. However, 80% of the divers in each group reported commonly doing repetitive diving (Table 3).

MEDICAL CONDITIONS
A total of 692 respondents reported suffering from diabetes, or a cardiovascular, respiratory, neurological or...
Table 3
Diving history and characteristics of combined survey participants; OW – open water; OW+ – post-basic certification other than others listed; Tech – technical diver; DM – divemaster; Inst – instructor; Comm – commercial diver; * hold commercial qualifications but still dive recreationally

<table>
<thead>
<tr>
<th>Group</th>
<th>DAN members</th>
<th>PADI members</th>
<th>PADI divers</th>
<th>P–value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Years diving, med (range)</td>
<td>Years diving, med (range)</td>
<td>Years diving, med (range)</td>
<td>Years diving, med (range)</td>
</tr>
<tr>
<td></td>
<td>14 (1–60)</td>
<td>15 (1–47)</td>
<td>4 (1–45)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Qualifications n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OW only</td>
<td>34 (4)</td>
<td>NA</td>
<td>299 (37)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>OW+</td>
<td>357 (39)</td>
<td>NA</td>
<td>483 (60)</td>
<td></td>
</tr>
<tr>
<td>Tech</td>
<td>126 (14)</td>
<td>NA</td>
<td>17 (2)</td>
<td></td>
</tr>
<tr>
<td>DM</td>
<td>203 (22)</td>
<td>143 (41)</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Inst</td>
<td>160 (17)</td>
<td>178 (51)</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Comm*</td>
<td>35 (4)</td>
<td>28 (8)</td>
<td>6 (&lt;1)</td>
<td></td>
</tr>
<tr>
<td>Total dives, med (range)</td>
<td>330 (4–16,000)</td>
<td>800 (15–20,000)</td>
<td>28 (4–10000)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Dives past year, med (range)</td>
<td>30 (0–500)</td>
<td>50 (2–1000)</td>
<td>10 (0–200)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Time since last dive, months (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;1</td>
<td>673 (62)</td>
<td>208 (60)</td>
<td>194 (24)</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>1 to &lt;6</td>
<td>322 (30)</td>
<td>82 (24)</td>
<td>267 (33)</td>
<td></td>
</tr>
<tr>
<td>6 to &lt;12</td>
<td>72 (7)</td>
<td>37 (11)</td>
<td>270 (34)</td>
<td></td>
</tr>
<tr>
<td>≥12</td>
<td>19 (2)</td>
<td>19 (5)</td>
<td>71 (9)</td>
<td></td>
</tr>
<tr>
<td>Dives &gt; 30 m deep (%; med (IQR))</td>
<td>10 (3–25)</td>
<td>10 (5–25)</td>
<td>1 (0–10)</td>
<td></td>
</tr>
<tr>
<td>Repetitive dives (%; med (IQR))</td>
<td>80 (40–95)</td>
<td>80 (50–95)</td>
<td>80 (38–100)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1
Comparative proportions of medical conditions in the general community11 and the diving survey cohorts

psychological condition. These included 376 (34%), 97 (28%) and 222 (28%) of the DM, PM and PD cohorts, respectively. Three respondents reported multiple conditions. With the exception of cardiac conditions (P = 0.099), the cohorts differed significantly in the proportions with the other medical conditions (P < 0.001 for all except neurological conditions P = 0.033). The most obvious difference was the higher incidence of hypertension in the older cohorts. The numbers reporting inner ear injuries (39 DM, 15 PM and 25 PD respectively) are unexpectedly high. Figure 1 compares the proportions in the Australian adult population with particular medical conditions, as reported in Australian Bureau of Statistics National Health Survey 2014–2015,11 to those in our survey respondents.
DECOMPRESSION ILLNESS

Eighty-four respondents, 58 (5%) DM, 18 (5%) PM and 8 (1%) PD, reported being treated for DCI (seven on more than one occasion). This yields an approximate DCI prevalence in the respondent cohorts of 7.1 per 100,000 dives (95% CI 5.4–9.2) for DM; 3.0 per 100,000 dives (95% CI 1.8–4.7) for PM and 9.4 per 100,000 dives (95% CI 4.1–18.6) for the PD group (P < 0.001).

LIFE-THREATENING INCIDENTS

A total of 81 of the 1,156 PADI-S respondents reported what they perceived to have been a life-threatening incident while diving. Fifty of these individuals were PM and 31 PD divers. These included 92 incidents and identified 137 precipitating problems, 87 of which involved PM and 50 PD divers (Table 4). Numbers were too small for useful statistical analysis. Based on denominators of 603,564 and 84,899 reported total dives for the PM and PD cohorts respectively, the prevalence of a life-threatening event in the respondents was 8.3 per 100,000 dives (95% CI: 6.1–10.9) for the PM and 36.5 per 100,000 dives (95% CI: 24.8–51.8) for the PD cohort. (95% CI) (6.1–10.9) (24.8–51.8)

Discussion

The varying demographics and diving characteristics of the three cohorts indicate that a survey of a single diver cohort may not be representative of the Australian diving population. These data represented two cohorts of relatively or highly experienced, often long-term active divers (DM and PM). The other cohort (PD) comprised predominantly inexperienced divers who had been diving for four years or less. However, this latter cohort also included some more experienced divers who had upgraded their certification (to one other than a leadership certification) during the previous four years.

DEMOGRAPHICS

A review of Australian sporting surveys from 2001 to 2010 inclusive indicated that 76% of Australian divers were male.12 This gender distribution is reflected in both the DM and PM cohorts of mainly longer-term divers. However, there was a higher proportion of females among the more recently-certified divers and those undergoing further training in the PD cohort. These surveys also indicated that 30% of Australian divers were aged 45 years or older, this proportion being identical to that of the PD cohort but considerably lower than the proportions in the DM (65%) and PM (47%) divers. This suggests that older divers in these cohorts (or at least the survey respondents) are over-represented or that highly qualified divers continue the sport for longer and that older divers are more likely to take out diving insurance.

The proportion of DM and PM divers who were either overweight or obese was similar to that found in the general Australian adult population,13 whereas the corresponding proportion in the PD cohort was substantially lower, likely reflective of the younger age of this respondent cohort.13 However, the obesity rate in the general population (27%)14 is higher than in our respondent cohorts, which may reflect a greater level of physical activity in the diving cohort, 93% of whom perceived themselves to be at least moderately fit. However, this perception needs to be interpreted cautiously as there are no directly comparable data from the general population, and self-reported fitness, especially without further questions about specific activities, does not always correlate well with that measured objectively.15,16

DIVING HISTORY AND PRACTICES

The DM and PM cohorts were predominantly experienced and moderately to highly active divers. This is unsurprising given that much of this cohort had current dive insurance and/or were dive masters or instructors. On the other hand, most of the PD cohort were relatively new divers and dived less frequently; their median of 10 dives over the previous year being consistent with an unpublished survey from the Australian Sports Commission for 2001–2010 also reporting a median of 10 dives per year. (Rauber G, personal communication, 2014). The large proportion of post-basic certifications in all cohorts is encouraging from the dive safety perspective, as further education and training should enhance knowledge and skills and offers the opportunity to increase experience in a more controlled manner. The high proportion of PM who dived near home is likely reflective of the fact that many of these are working dive professionals. On the other hand, the DM
and PD cohorts did around one third of their diving overseas. The reported high rate of repetitive diving is typical of modern-day, computer-guided recreational diving whilst technical and decompression diving made up a very small proportion of the diving of all respondent cohorts.

MEDICAL CONDITIONS

The age-specific Australian asthma prevalence for 2014–2015 is estimated to have been a minimum rate of 10.5% (95% CI: 9.2, 11.8) for the age range from 15 to 74 years. This suggests that the reported proportion of respiratory conditions (almost all asthma) in each of our diving cohorts was lower than in the general adult Australian population. This may be a result of the historical discouragement of people with asthma from partaking in scuba diving. In addition, the lower rate of diabetes and cardiac conditions in the diving group likely reflects a similarly cautious approach to diving with these conditions. The slightly higher proportion of DAN respondents with cardiac conditions is consistent with the greater average age of this cohort. The presence of co-existing cardiac conditions is well-represented in dive fatality reports, although divers with known and well-managed cardiac conditions are known to dive with relative safety.

It is interesting to note that 8–12% of respondents continued to dive despite a psychological disorder. This deserves further research, especially relating to medications taken to control the disorders and any impact these may have on diving safety. The reported incidence of inner ear problems seems disproportionally high, and the authors suspect is the result of confusion amongst some responders between inner ear and middle ear problems, the latter being much commoner in diving.

DECOMPRESSION ILLNESS

The rates of DCI in different diving cohorts are dependent on a variety of factors, including diving conditions and practices, differences in diver characteristics, data reliability and calculation methodology and, therefore, vary widely between reports. It has been reported that the incidence of decompression sickness in recreational divers is 0.01–0.02% (10–19 cases per 100,000 dives). The comparatively low rate of DCI in respondents to these surveys suggest that these cohorts dive relatively safely, although, for the reasons outlined earlier, this should be interpreted cautiously.

LIFE-THREATENING INCIDENTS

The rates for perceived life-threatening incidents are sobering. When compared to the estimated annual fatality rate for Australian divers (0.46 per 100,000 dives), the prevalence rates for perceived ‘near-misses’ were many times higher in the PADI surveys. This needs to be interpreted cautiously as it is based on low response rates but implies that, for each fatality, there may be a considerable number of near-misses. Longer-term divers are more likely to have experienced such an incident, but the likelihood of occurrence probably reduces with experience. It is also possible that some less-experienced divers over-report these incidents, perceiving something to be life-threatening that may not be so.

As with most activities, whether recreational or occupational, there are many more non-fatal incidents than deaths. For example, a 12-year analysis of recreational dive-related incidents in the United Kingdom (UK) recorded a total of 4,799 incidents, of which 197 (4.1%) were fatal. Non-fatal incidents are potentially a far richer source of information, not only due to the greater volume, but also because the victim can often provide valuable information, unlike in a fatality. The British Sub-Aqua Club, DAN America and DAN AP collect data on non-fatal diving incidents in their regions and divers are encouraged to report these.

In these surveys, despite the low response rates, the major categories of equipment, gas supply and conditions-related incident triggers appeared strikingly similar to the suspected incident triggers that result in Australian diving fatalities. Equipment and anxiety-related incidents were more common in less experienced divers, likely a result of less familiarity with the equipment and diving environment. The higher incidence of dangerous marine animal encounters in the more experienced divers likely reflects greater exposure. The smaller proportion of gas supply-related problems in the newer divers may be a result of lower exposure and/ or less complacency or, in some cases, closer supervision.

Equipment-related problems remain common and contribute to deaths (and near deaths) at a comparable rate in Australia to those in the USA (15%) and UK (20%). They are often preventable with appropriate familiarisation and maintenance. This need for adequate familiarisation and maintenance is especially true for closed circuit rebreathers (CCRs) which were associated with about a quarter of all the reported equipment-related incidents in the PADI cohorts. This rate seems disproportionately high given the small number of respondents using CCRs. These data, combined with fatality data from the UK and elsewhere, support the assertion that, because of their greater complexity, there is a higher risk of mechanical failure and indeed death with CCRs compared to open-circuit scuba.

Despite the ubiquitouness of generally accurate pressure gauges, breathing gas supply problems persist, contributing to 12–18% of the near misses in this series and being a suspected trigger in an alarming 41% of US diving deaths. Although the unpredictable can occur and catch a diver unawares, good dive preparation, including gas consumption planning and monitoring, can prevent many ‘out of air’ emergencies. In addition, the high incidence of problems related to currents, surge and rough seas demonstrate that even experienced divers must take care with dive site selection and monitoring.
LIMITATIONS

There are a variety of limitations to this study, the major one being the low and differing response rates. This non-response creates the potential for the data not to accurately reflect each group. However, large numbers within the groups and the substantial differences between them suggest that, while selection bias may have affected the results, it is unlikely that it was so large that it was responsible for all the observed group differences.

In addition, DAN members are likely older than the general diving population and respondents to the DAN-S were younger than non-respondents, possibly introducing some selection bias. Although there were no details of non-respondents to the PADI surveys, it appears that they were likely older than non-respondents and there was a higher response rate from females, potential sources of selection bias. The very low response rate from the PADI divers would likely introduce further bias towards more experienced divers or enthusiastic divers who engage with the sport.

Whilst many Australian divers will fall into one of these population groups, they will not be representative of the entire Australian diving population. Although it would have been useful to examine age-specific combined data, this was not possible as the ages of the PADI populations were not available. The nature of some of the more historical questions, such as the number and characteristics of dives undertaken, may have introduced a recall bias and this may be more likely in the longer-term divers. Finally, self-reporting on medical conditions, diving activities and events may have been another source of reporting bias.

Conclusions

Although limited by low and differing response rates and potential response bias, this study indicates that there are differences in the health-related conditions and diving experiences of the respondents in the three survey groups. Therefore, a survey of any single diver group may not be representative of the general recreational diving population and the findings from such surveys may be misleading. This bias needs to be clearly understood and any survey findings interpreted accordingly. Despite their limitations, these data provide an insight into the varying demographics, diving practices and outcomes of these groups of active Australian divers and can provide a background for further research in accident mitigation, other safety initiatives and industry planning.

References

Acknowledgments

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Conflicts of interest and funding

John Lippmann is Chairman of DAN Asia-Pacific which sells dive injury insurance.

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<td>School of Health &amp; Social Development, Faculty of Health</td>
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Chapter 3

The demographics and diving behaviour of DAN Asia-Pacific members with and without medical conditions

Ageing is often accompanied by the evolution of comorbid medical conditions, whether known or occult. In recent years, deaths among older divers are being reported in higher proportions both in Australia and overseas. Many of these older victims had comorbidities which were believed to have contributed to their deaths.

A comparison of cohorts of divers with and without medical conditions would assist in understanding any impact that pre-existing conditions have on their diving safety. Such a comparison should take account of the divers’ overall health and fitness, diving experience and diving practices in order to determine if, and how, their comorbidities have impacted upon their diving.

To investigate this, surveys were sent to cohorts of DAN Asia-Pacific members with, and without, identified potentially contraindicative medical conditions. Relevant demographic, anthropometric and diving-related comparisons between these subgroups were made and are presented in the following paper.

The results of this analysis will be used to address Thesis Aim 1 - “Identify the demographics, diving characteristics and activities of cohorts of active Australian scuba divers”, and Thesis Aim2 “Investigate the prevalence, effects and impacts on diving safety of pre-existing medical conditions”. This, in turn, will assist in identifying potential “underlying factors associated with scuba diving and snorkelling-related mortality in Australia” (Research Question 1).
Original articles
The demographics and diving behaviour of DAN Asia-Pacific members with and without pre-existing medical conditions
John Lippmann, David McD Taylor, Christopher Stevenson and Simon Mitchell

Abstract

Introduction: This report examines Diver Alert Network Asia-Pacific (DAN AP) members with and without cardiac or respiratory conditions, diabetes or hypertension and compares their demographics, health and diving activities.

Methodology: Two online cross-sectional surveys of DAN AP members were conducted. The first sought information from 833 divers who applied for membership between July 2009 and August 2013 and who had declared the targeted medical conditions. The second, conducted between December 2014 and April 2015, was sent to 9,927 current members with known email addresses. The groups were compared for age, gender, body mass index, fitness, smoking and diving qualifications, history, currency and practices.

Results: Of 343 (41%) respondents to the first survey, 267 (32%) provided sufficient information for inclusion. Of 1,786 (18%) respondents to the second survey, 1,437 (15%) had no targeted medical condition and were included in the analysis. Those with medical conditions were on average 4.7 years older ($P < 0.001$); more overweight or obese (68% versus 57%, $P = 0.001$); took more medications (57% vs. 29%, $P < 0.001$), smoked less (4% vs. 7%, $P = 0.02$) and did less repetitive diving (median 75 vs 90, $P < 0.001$). Other diving demographics were similar.

Conclusions: A substantial number of people are diving with medical conditions and there is a need to better understand the associated risks. Divers need to be well-educated about the potential impact such conditions may have on diving safety and should monitor their health status, especially as they age.

Key words
Survey; Fitness to dive; Health surveillance; Cardiovascular; Scuba divers; Recreational divers

Introduction
It is generally accepted that scuba divers need to have an appropriate level of physical and medical fitness in order to facilitate safe diving. Historically, conditions such as asthma, diabetes and many cardiac conditions were considered absolute contraindications.1–3 Traditionally, scuba diving was the realm of the relatively healthy, fit and young although, as the sport evolved, individuals with a variety of medical conditions began to participate.4,5 Data from the United Kingdom (UK) indicate that the average age of divers has increased over time, rising from 10% being over 50 years old in 1998 to 30% in 2015.6 Long-time divers are ageing and the sport has become increasing available to a broader-aged cohort of the population.

Associated with increasing age is an increase in co-existing disease, both known and occult.7–10 Diving fatality reports reflect a rise in the ages of victims and this is likely a result of the combination of increased participation and increased risk imposed by co-morbidities.11,12 Up to one third of cohorts of active Australian and USA divers continued to dive even with traditional medical contraindications.3,13 Some divers had never sought diving medical advice about their conditions.

Diving medical organisations have progressively modified their advisories on diving with conditions such as asthma and diabetes. The Divers Alert Network Asia-Pacific (DAN AP) is a non-profit membership-based association with a mission to improve recreational diving safety, and provides its members with access to diving injury insurance. Although membership applicants are required to declare pre-existing medical conditions, in most cases, no evidence of a fitness-to-dive assessment is required. DAN AP membership data reflect a growing representation from divers with asthma, diabetes, hypertension and a variety of cardiac-related conditions. As a result, there is an increasing need to learn more about the medical conditions of active divers and the impact, if any, that these conditions have on their diving practices and experiences.

The aim of this project was to examine the health status of a cohort of active recreational divers and determine the impact of co-existing disease on their diving practices. We surveyed DAN AP members with and without significant pre-existing medical conditions. We aimed to clarify the prevalence of significant medical conditions in active divers and identify any impact of certain predefined conditions on diving frequency, practice and outcome.

Methodology
An anonymous, online, cross-sectional medical conditions survey (MCS) was conducted on a cohort of DAN AP members.
members who had declared that they suffered from a significant medical condition, including hypertension, diabetes, respiratory and cardiac conditions. A second similar cross-sectional general DAN members survey (GDMS) was conducted with the general DAN AP membership. The latter survey was conducted in order to obtain a control group for comparison (footnote). Ethics approvals were received from the Human Research Ethics Committees of Austin Health and Deakin University, both in Victoria, Australia.

MEDICAL CONDITIONS SURVEY

The survey targeted adults (>18 years old) who had joined DAN AP between 01 July 2009 and 01 August 2013. At the time of joining, DAN AP applicants for dive injury insurance are required to declare significant pre-existing medical conditions and, during the period under study, these were recorded in a database for research purposes. Those reporting an existing condition were surveyed using a two-part questionnaire. The first part sought details about the responders’ demographics (e.g., age, gender, physical characteristics, general health and perceived fitness) and details of their diving history and activity, e.g., years of diving, total number of dives, dives per year, frequency of diving and the type of diving undertaken: depths, technical (self- and certification-defined) and repetitive diving. The second part sought details about certain ‘targeted conditions’ including cardiac (septal defects, myocardial infarction, arrhythmias, angina) and respiratory (asthma, pneumothorax, lung surgery) conditions, diabetes and hypertension. There were also specific questions about any impact these conditions had had on the responders’ diving practices and any adverse incidents that had occurred.

In August 2013, an invitation to participate in the survey was sent to DAN AP members who had previously declared the conditions of interest. A reminder was sent in October 2013 and the survey was closed in December 2013. No inducements to participation were offered, and invitees were assured of their anonymity and that responding or not the responders had any of the ‘targeted’ or other significant medical conditions, and if they had participated in the MCS. Those with a positive response to either of these questions were excluded from the subsequent comparative analysis.

An invitation to participate was emailed to all current members (which would have included some who had participated in the MCS) using the email address known to DAN in December 2014. A reminder was sent in March 2015 and the survey was closed in April 2015.

The variables of interest for the divers with and without targeted medical conditions were compared. No a priori sample size calculation was undertaken as all DAN AP members were invited to participate. Statistical analysis was conducted using SPSS Version 22 (IBM, Armonk, NY; 2013). Groups were compared using the Student’s t-test, χ²-test, z-test and Median Test for independent samples. The level of significance was set as ≤ 0.05.

**Results**

MEDICAL CONDITIONS SURVEY

Eight-hundred-and-thirty-three DAN AP members with previously disclosed medical conditions were invited to participate. Age and gender were known and are shown in Table 1. Three-hundred-and-forty-three responses were received (41%) of which 267 (32%) contained sufficient information for inclusion. The medical conditions of interest included cardiac conditions (92 cases), hypertension (127), diabetes (24) and respiratory conditions, predominantly asthma (47). Some responders had multiple conditions.

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Gender (%F)</th>
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<tbody>
<tr>
<td>MCS</td>
<td></td>
</tr>
<tr>
<td>Invites</td>
<td>50.0 (12.0)</td>
</tr>
<tr>
<td>Responders (n = 267)</td>
<td>52.1 (12.2)</td>
</tr>
<tr>
<td>Non-responders (n = 566)</td>
<td>49.6 (12.4)</td>
</tr>
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<td>P-value *</td>
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<tr>
<td>GDMS</td>
<td></td>
</tr>
<tr>
<td>Invites</td>
<td>42.9 (11.9)</td>
</tr>
<tr>
<td>Responders (n = 1437)</td>
<td>47.6 (11.7)</td>
</tr>
<tr>
<td>Non-responders (n = 7961)</td>
<td>42.1 (11.8)</td>
</tr>
<tr>
<td>P-value *</td>
<td>&lt; 0.001</td>
</tr>
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</table>

Footnote: The general and disease-specific questionnaires are available at <www.danap.org/research/med_conditions/>.
GENERAL DAN AP MEMBERS SURVEY

Nine-thousand-nine-hundred-and-twenty-seven DAN AP members were invited to participate. Although the genders of these invitees were unavailable, the ages of 9,398 were known (Table 1 and Figure 1).

Of 1,786 respondents (18%), 1,086 (61%) reported that they were free from any medical conditions, and 1,437 (81%) reported being free from the targeted medical conditions. Data from respondents without the targeted medical conditions were analysed in this survey. The remaining 349 subjects were excluded (including 265 who indicated that they had participated in the MCS).

Figure 1 shows the age breakdowns of invitees, responders and non-responders to a general DAN members survey (GDMS) according to 10-year age groups.

The sex distributions of MCS and GDMS responders were similar, with approximately 30% female and 70% males in each group. However, the divers with the medical conditions were significantly older than those without, with a difference in the means of 4.7 years. Sixty-three percent of the medical condition group were aged 50 years or older, compared with 45% of the group without the medical conditions. The mean body mass index (BMI) of divers with medical conditions was significantly higher than those without. Sixty-eight percent of the medical condition group were overweight or obese compared to 57% of the GDMS respondents ($P = 0.001$).

The self-reported fitness levels of the two groups were similar with over 90% of each group assessing themselves as moderately fit or fitter. The proportion of the medical condition group who took medications was almost twice that of those without. Although the proportion of smokers was low in both groups, the proportion of smokers in the group without the medical conditions was almost twice that of those with conditions.

Table 3 describes the diving history and characteristics of the
responders to the MCS and the GDMS. The groups did not differ in the numbers of years that they had been diving or their reported total dives. However, more responders without targeted medical conditions were qualified as divemaster or higher (38% vs 29%). The data for decompression dives and technical diving are especially skewed. For example, in the group without conditions, 735 divers reported doing some percentage of decompression dives—some claimed 100% and some only 1%—with many doing no-decompression dives only, giving a median for decompression diving of 1% as shown in Table 3. Similarly, 435 divers reported doing some technical diving but the median percentage for this type of diving was zero.

The groups did not differ in the numbers of dives conducted over the previous year, although the divers without medical conditions reported having dived more recently or in the proportion of dives deeper than 30 metres, decompression dives or technical dives. However, those with medical conditions had done significantly less repetitive diving. Twenty-eight (10%) responders with medical conditions reported having decompression illness (DCI) compared with 62 (4%) of those without ($P < 0.0001$). Twenty-five of the 28 MCS divers who reported DCI were diagnosed with an intra-cardiac right-to-left shunt, predominantly a persistent foramen ovale. The most common diving-related injury reported by those with medical conditions was ear or sinus barotrauma (46, 17%). Two of the cases of ear barotrauma led to significant inner ear damage but both divers continue to dive.

### Discussion

The 70:30 male to female gender distribution between the groups is similar to the 2:1 male:female ratio currently reported by the Professional Association of Diving Instructors (PADI) for its certifications for 2009–2014. The significantly higher age of the responders with medical conditions is consistent with the increased incidence of co-existing disease with age. Although the mean BMI of respondents with conditions was higher, the absolute difference between the groups was small and not clinically significant. However, there was a significantly higher proportion of obese divers in the cohort with medical conditions. This is consistent with data from the general population that indicate an association between the presence of significant health conditions and being overweight or obese. The older age of the respondents with conditions may contribute to the higher proportion of obese divers in this group. The proportions of those with medical conditions who were overweight or obese are very similar to those in a cohort of divers from the United Kingdom (66%). However, the UK cohort (median age 46) were not specifically known to have medical conditions. This could indicate that UK divers are more likely to be overweight or obese than our responders without conditions; or could reflect a reporting bias. Alternatively, the cohort of 346 divers reported in an earlier study had lower BMIs than all of the above-mentioned groups with 46.8% overweight or obese. This was likely due to the substantially lower

<table>
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<td>12 (6, 22)</td>
<td>0.79</td>
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<td>Qualifications $n$ (%)</td>
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<td>OW only</td>
<td>304 (21)</td>
<td>71 (27)</td>
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<td>OW+</td>
<td>420 (29)</td>
<td>89 (33)</td>
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<td>Tech</td>
<td>174 (12)</td>
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<td>DM</td>
<td>237 (17)</td>
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<td>Inst</td>
<td>254 (18)</td>
<td>32 (12)</td>
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<td>Comm</td>
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<td>350 (150, 850)</td>
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<td>30 (20, 50)</td>
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<td>22</td>
<td></td>
</tr>
<tr>
<td>6–12</td>
<td>6</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>&gt; 12</td>
<td>2</td>
<td>7</td>
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</tr>
<tr>
<td>Depth &gt; 30 m (%), median (IQR)</td>
<td>10 (3, 25)</td>
<td>10 (3, 25)</td>
<td>0.77</td>
</tr>
<tr>
<td>Decompression (%), median (IQR)</td>
<td>1 (0, 5)</td>
<td>1 (0, 5)</td>
<td>0.93</td>
</tr>
<tr>
<td>Technical (%), median (IQR)</td>
<td>0 (0, 5)</td>
<td>0 (0, 5)</td>
<td>0.17</td>
</tr>
<tr>
<td>Repetitive (%), median (IQR)</td>
<td>90 (50, 100)</td>
<td>75 (25, 95)</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

Table 3

Diving history and characteristics of survey participants; OW − open water diver; Tech – technical diver; DM – divemaster; Inst – instructor; Comm – commercial diver; > 30 m – dives deeper than 30 metres; * hold commercial qualifications but still dive recreationally
age of the cohort, of which 83% were aged 50 years or less; compared to 40% in the MCS group and 58% of the GDMS group.

Both groups rated their fitness similarly. However, this must be interpreted with caution as self-reported fitness, especially without further questions about specific activities, does not always correlate well with that measured objectively. The higher incidence of medication use among those with medical conditions was expected, given the type of conditions examined, such as hypertension and cardiac disease, whereas in the 2002 study of a younger cohort only 13% reported taking regular medication. The types of medications used will be discussed in a subsequent report that will detail the various conditions. However, given the rarity of testing medications under hyperbaric conditions and the effect of certain medications on circulation and cardiac function, medication usage in divers is an area deserving more scrutiny.

Only 4% of those with conditions were current smokers, compared to 7% of those without. This is consistent with data from UK divers, and lower than the 11.3% reported in 2002. It compares favourably with the percentage of smokers in the general population (approximately 13% in 2013 in both Australia and Singapore, the main bases of DAN AP membership at the time of the surveys). This is likely the result of the increased awareness in recent years of the adverse effects of smoking on cardiovascular and pulmonary health, especially in those with existing health conditions. The smoking rate in the general population in Australia has steadily declined in the past decade and this is likely reflected in the data from the diver surveys.

The groups did not differ in the number of years of diving; 30% of each group had dived for 20 years or more, which is consistent with both the relatively high responder ages and recent PADI data which indicate a median certification age of 29 years. The median number of years of diving is also very similar to the 11 years reported in the previously-mentioned UK survey.

The generally higher level of certifications in the divers without medical conditions suggests that the presence of a medical condition could be a disincentive or barrier to the pursuit of leadership-level diving qualifications. With these qualifications, there is a greater focus on fitness-to-dive issues. The reason why those without medical conditions participated in more repetitive diving is unclear, especially given that there was little difference in the proportions of deeper (>30 metres), technical or decompression diving, or in the reported level of diving activity. Although speculative, this may reflect the older age of those with medical conditions and an acceptance of their potential vulnerability due to the condition and the desire not to push their physical limits.

The presence of a persistent foramen ovale (PFO) is known to increase the risk of neurological, cutaneous and vestibular DCI. The higher incidence of DCI among those with medical conditions is likely due to the relatively high proportion of subjects with a diagnosed septal defect, predominantly PFO. Fatality data from both Australia and the USA point to an increase in the proportion of cardiac-related disabling injuries in divers. Some of the victims were aware of their medical condition and were under treatment at the time. However, in many victims, the condition was undiagnosed and only became apparent at autopsy. There is a need for further research into the medical and diving histories of diving fatality victims for comparison with survivor groups, such as those in this study, in order to better evaluate the risk of diving with such medical conditions.

This study has several limitations:

- DAN AP members are probably not typical of the diving population at large. They are likely older with the associated increased likelihood of co-existing disease, have more available funds, may travel more, and may better understand their potential vulnerability and the need and benefits of having appropriate insurance.
- Some applicants for DAN membership may have been reluctant to declare medical conditions for fear of it affecting their ability to obtain or retain insurance coverage, although it was made clear that failure to declare a relevant condition may nullify coverage. As a result, there were likely to have been more than the 833 members invited to join the MCS who were suffering from the targeted health conditions. This is supported by the fact that around 20% of respondents to the anonymous GDMS reported having such a condition.
- Respondents to both surveys were older than non-respondents and some selection bias may have been introduced. Therefore, some results may not be representative of the entire DAN AP membership.
- The nature of some of the more historical questions may have introduced a recall bias.
- Many responses were excluded in the MCS survey due to missing replies to certain questions. This would have been improved if the survey had been designed requiring responses to certain key questions. Survey Monkey, used for the GMDS, was more user-friendly and reliable and there were consequently fewer lost responses.

**Conclusions**

A large proportion of DAN AP members are diving with potentially significant medical conditions. These members appear to be older, more obese, take more medication and smoke less than other members. There were few major differences in the nature or pattern of diving between divers with and without medical conditions, excepting that those with medical conditions did less repetitive diving. Also, a
greater proportion of divers with a history of intracardiac shunts had suffered DCI. The increased proportion of older divers, the higher likelihood of co-existing disease with age, and the fact that older divers with co-existing health conditions (particularly cardiac conditions) are increasingly represented in diving fatality reports indicate a need for further research into the impact of various medical conditions on divers in order to better determine the level of risk associated with these. Future reports from this project will examine the cohorts with particular conditions and what actions they take, if any, to accommodate these.

References

Acknowledgements

The authors wish to acknowledge the contributions of Scott Jamieson for his assistance with data collection and Michael Lippmann and Adam Lippmann for their assistance in the construction of the surveys.

Conflicts of interest

John Lippmann is the Founder and Chairman of DAN AP. DAN is involved in the collection and reporting of dive accident data and provides evacuation cover and dive injury insurance to recreational divers. This study is funded by DAN AP.

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Accepted: 05 October 2016

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# Authorship Statement

1. **Details of publication and executive author**

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<th>Title of Publication</th>
<th>Publication details</th>
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<td>The demographics and diving behaviour of DAN Asia-Pacific members with and without pre-existing medical conditions</td>
<td>Diving and Hyperb Med. 2016. 46(4):200-6.</td>
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<tr>
<th>Name of executive author</th>
<th>School/Institute/Division if based at Deakin; Organisation and address if non-Deakin</th>
<th>Email or phone</th>
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<tr>
<td>John Lippmann</td>
<td>School of Health &amp; Social Development, Faculty of Health</td>
<td></td>
</tr>
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2. **Inclusion of publication in a thesis**

<table>
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<th>Is it intended to include this publication in a higher degree by research (HDR) thesis?</th>
<th>Yes / No</th>
<th>If Yes, please complete Section 3 If No, go straight to Section 4.</th>
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</table>

3. **HDR thesis author's declaration**

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<th>Name of HDR thesis author if different from above. (If the same, write “as above”)</th>
<th>School/Institute/Division if based at Deakin</th>
<th>Thesis title</th>
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<tbody>
<tr>
<td></td>
<td>School of Health &amp; Social Development</td>
<td>Analysis of Australian Diving-related deaths</td>
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</tbody>
</table>

JL conceived the project, contributed to design of methodology (>50%), collected the data, performed majority of analysis (>80%), drafting and revising the manuscript (>70%)

I declare that the above is an accurate description of my contribution to this paper, and the contributions of other authors are as described below.

| Signature and date | 12/9/17 |

4. **Description of all author contributions**

<table>
<thead>
<tr>
<th>Name and affiliation of author</th>
<th>Contribution(s) (for example, conception of the project, design of methodology or experimental protocol, data collection, analysis, drafting the manuscript, revising it critically for important intellectual content, etc.)</th>
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<tbody>
<tr>
<td>Prof David Taylor</td>
<td>Contributed to design of methodology and contributed to analysis, drafting and revising of manuscript</td>
</tr>
<tr>
<td>A/Prof Chris Stevenson</td>
<td>Contributed to the analysis, drafting and revising of manuscript</td>
</tr>
<tr>
<td>Prof Simon Mitchell</td>
<td>Contributed to design, analysis, drafting and revising of manuscript</td>
</tr>
</tbody>
</table>
5. Author Declarations
I agree to be named as one of the authors of this work, and confirm:

i. that I have met the authorship criteria set out in the Deakin University Research Conduct Policy,
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<td>10/9/17</td>
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<td>Prof Simon Mitchell</td>
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<td>16/10/17</td>
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Signature Redacted by Library

6. Other contributor declarations
I agree to be named as a non-author contributor to this work.

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<th>Name and affiliation of contributor</th>
<th>Contribution</th>
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7. Data storage
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<td>27 May 2016</td>
<td></td>
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</table>

This form must be retained by the executive author, within the school or institute in which they are based.

If the publication is to be included as part of an HDR thesis, a copy of this form must be included in the thesis with the publication.
Chapter 4

Diving with pre-existing medical conditions

As discussed in Chapter 3, DAN AP members with potentially significant and contraindicated medical conditions were identified through self-declaration at the time of joining. These members were later followed up with a survey with targeted questions about their medical conditions, their diving practices and any related problems that occurred prior to, and/or subsequent to, their diagnosis. Detailed questions were posed about the condition itself, interventions received (e.g., surgery or medications), oversight by a diving doctor, modifications made to previous diving practices to accommodate the condition, and related problems experienced while diving. Full details of the study are provided in the following paper. 203

The results of this analysis will be used to address Thesis Aim 1 - “Identify the demographics, diving characteristics and activities of cohorts of active Australian scuba divers”, and Thesis Aim2 “Investigate the prevalence, effects and impacts on diving safety of pre-existing medical conditions”. This in turn will assist in identifying potential “underlying factors associated with scuba diving and snorkelling-related mortality in Australia” (Research Question 1), as well as informing Research Question2 – “What are the implications for preventative strategies”.

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Diving with pre-existing medical conditions

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Key words
Fitness to dive; Scuba divers; Cardiovascular; Diabetes; Respiratory; Asthma; Survey

Abstract


Introduction: This is the second report based on a survey of Divers Alert Network Asia-Pacific (DAN AP) members who dive with cardiovascular and respiratory conditions and diabetes. It examines the medical management of the divers’ conditions, any diving modifications used to mitigate the risk and outcomes.

Methodology: An online cross-sectional survey was sent to 833 divers who had declared a targeted medical condition when applying for DAN AP membership between July 2009 and August 2013.

Results: Two-hundred-and-sixty-eight respondents (32%) provided sufficient information on their conditions to be included in the analyses. These included ischaemic heart disease (31), arrhythmias (20), cardiac septal defects (31), other cardiac conditions (10), hypertension (127), diabetes (25), asthma (40) and pneumothorax (5). Forty-nine per cent had sought specialist diving medical advice about their condition and 23% reported modifying their diving practices to mitigate their risk. The cohort had completed 183,069 career dives, 57,822 of these since being diagnosed with their medical condition. There were 27 individuals who reported having decompression illness (25 of whom were subsequently diagnosed with a persistent foramen ovale), and two individuals who experienced an arrhythmia during diving.

Conclusions: Some DAN AP members are diving with medical conditions which could potentially impact the safety of their diving. A minority modified their diving practices to mitigate the risk of their condition and approximately half sought specialist diving medical advice about their condition. The incidence of diving-related problems precipitated by known and managed pre-existing health conditions seems low but further studies of larger cohorts and incorporating fatality data would be necessary to confirm this. These results are limited by the 32% response rate and potential for bias towards selection of those most careful with their health.

Introduction

Medical conditions such as asthma, diabetes and many cardiac conditions were long considered absolute contraindications to scuba diving.1-3 Some sufferers have ignored such advice and, over time, diving medical organisations have progressively modified their advisories on diving with conditions such as asthma and diabetes to allow candidates meeting certain criteria to dive. As a result, it seems likely that an increasing number of divers with these and other comorbidities, including a variety of cardiovascular conditions, are diving. This has created an increasing need to learn more about the medical conditions of active divers, how these are managed and the impact, if any, that these conditions may have on diving practices and experiences.

This is the second report from a study investigating Divers Alert Network Asia-Pacific (DAN AP) members with declared cardiovascular and respiratory conditions and diabetes (targeted conditions). The first report provided information about the demographics, diving history and activity of members with the targeted conditions and compared these to members without these conditions.4 This article more closely examines the medical management of the divers’ conditions, and how these divers modify their diving practices (if at all) in an attempt to mitigate the risk of a diving incident consequent upon their medical condition.

Methods

Ethics approvals were received from the Human Research Ethics Committees of Austin Health and Deakin University, both in Victoria, Australia. An anonymous, online, cross-sectional medical conditions survey (MCS) was conducted on a cohort of 833 DAN AP adult (> 18 years old) members. The divers had joined DAN AP between 01 July
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2009 and 01 August 2013 and had, at the time of joining, declared that they suffered from hypertension, diabetes, respiratory or cardiac conditions. The cardiac conditions mainly comprised ischaemic heart disease (IHD) (previous myocardial infarction and angina), arrhythmias, and septal defects (i.e., persistent foramen ovale (PFO) and atrial and ventricular septal defects). These self-reported diagnoses were interpreted at face value.

An invitation to participate in the survey was sent to these members in August 2013, a reminder was sent in October 2013 and the survey was closed in December 2013. No inducements to participation were offered. Invitees were assured of their anonymity and that responding or otherwise would have no impact on their insurance status.

The MCS consisted of a two-part questionnaire. The first part sought details of the respondents’ demographics and diving activity. The second part focused on their targeted medical condition and its management. There were also specific questions about any impact these conditions had on the respondents’ diving practices and any adverse incidents that had occurred. The questionnaires are available at <http://www.danap.org/research/med_conditions/>.

All invitees were able to access the first part of the questionnaire, as well as the set of questions relating to their declared condition(s). Participants were invited to enter their responses directly into an online, dedicated, structured query language (MySQL) database (Oracle, Redwood CA).

STATISTICAL ANALYSIS

Responses were downloaded into MS Excel® (Microsoft Corporation, Redmond WA) for collation. Respondents reporting more than one relevant condition (e.g., hypertension and diabetes) were included in the analysis for each relevant condition. A descriptive analysis based on means and standard deviations or median and ranges as appropriate was conducted using SPSS Version 22 (IBM, Armonk, NY; 2013). A conservative minimum required sample size was calculated using the NSS online calculator, assuming a proportion with any specific characteristic of 0.5 and a confidence interval of ± 0.05. The minimum sample size required was calculated to be 263.

Results

Three-hundred-and-forty-three of 833 divers (41.2%) who had reported a targeted medical condition in their DAN membership application responded to the questionnaire. Two hundred and sixty-eight (32.2% of invitees) of the respondents (78.1%) provided sufficient information for inclusion in the study. The mean (SD) age of the invitees was 50 (12) years and 73% were males. By comparison, the mean (SD) age of the respondent cohort was 52.4 (12) years and the proportion of males was 70%. Twenty-one respondents had multiple conditions. Males were in the majority for all diagnostic subgroups except septal defects (10 of 31 male). The mean (SD) age for males was 53.5 (11.8) years, and for females 48.7 (12.4) years (Table 1). The overall mean (SD) body mass index (BMI) was 27 (4) kg.m⁻². Males had a mean (SD) BMI of 28 (4) kg.m⁻² and females 26 (4) kg.m⁻².

The medical conditions of interest were cardiac conditions (92 cases), hypertension (127), diabetes (25) and respiratory conditions, predominantly asthma (45).

Overall, these divers reported a median (interquartile range, IQR) of 350 (150, 800) total dives over a median time of 12 (6, 22) years, with a median of 150 (60, 350) dives done post-diagnosis. Males had dived much more frequently than females (median total dives of 1,000 (388, 2,125) and 400 (225, 1,000) respectively). Details of their diving histories and activities are reported in Table 2. These 268 divers had completed 183,069 career dives including 57,822 since being diagnosed with their medical condition. Other than 27 individuals with decompression illness (DCI) (25 of whom were subsequently diagnosed with a PFO) and two cases of arrhythmias (see later), they reported no other relevant adverse events from diving.

Table 1

<table>
<thead>
<tr>
<th>Medical condition</th>
<th>IHD (n = 31)</th>
<th>Arrhythmia (n = 20)</th>
<th>Septal defect (n = 31)</th>
<th>Cardiac (other, n = 10)</th>
<th>Hypertension (n = 127)</th>
<th>Diabetes (n = 25)</th>
<th>Asthma (n = 40)</th>
<th>Pneumothorax (n = 5)</th>
<th>Total (n = 289)</th>
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<tr>
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<td>Cardiac (other) ((n = 10))</td>
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<tr>
<td>All</td>
<td>165 (80, 337)</td>
<td>221 (100, 500)</td>
<td>58 (10, 145)</td>
<td>nr</td>
<td>151 (76, 400)</td>
<td>200 (89, 400)</td>
<td>220 (115, 344)</td>
<td>60 (20, 103)</td>
<td>150 (60,350)</td>
</tr>
<tr>
<td>Males</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>All</td>
<td>31 (20, 73)</td>
<td>30 (19, 87)</td>
<td>30 (20, 85)</td>
<td>25 (15, 30)</td>
<td>30 (20, 50)</td>
<td>40 (25, 50)</td>
<td>30 (15, 50)</td>
<td>40 (30, 40)</td>
<td>30 (20, 50)</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>30 (28, 58)</td>
</tr>
<tr>
<td>Females</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>35 (20, 50)</td>
</tr>
<tr>
<td><strong>&gt;30 m depth (%)</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>10 (5, 38)</td>
<td>5 (1, 40)</td>
<td>10 (3.5, 40)</td>
<td>3 (1, 18)</td>
<td>9 (5, 24)</td>
<td>5 (5, 15)</td>
<td>10 (2, 30)</td>
<td>18 (5, 30)</td>
<td>10 (3, 25)</td>
</tr>
<tr>
<td>Males</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10 (5, 30)</td>
</tr>
<tr>
<td>Females</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 (2, 20)</td>
</tr>
<tr>
<td><strong>Decompression</strong></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>2 (0, 5)</td>
<td>0 (0, 13)</td>
<td>2.5 (1, 20)</td>
<td>0 (0, 1)</td>
<td>1 (0, 5)</td>
<td>2 (0, 10)</td>
<td>1.5 (0, 5)</td>
<td>2 (1, 20)</td>
<td>1 (0, 5)</td>
</tr>
<tr>
<td>Males</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 (0, 5)</td>
</tr>
<tr>
<td>Females</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 (0, 3)</td>
</tr>
<tr>
<td><strong>Technical</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>0 (0, 3)</td>
<td>0 (0, 18)</td>
<td>2 (0, 30)</td>
<td>0 (0, 0)</td>
<td>0 (0, 5)</td>
<td>0 (0, 2)</td>
<td>0 (0, 0)</td>
<td>1 (1, 20)</td>
<td>0 (0, 5)</td>
</tr>
<tr>
<td>Males</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 (0, 5)</td>
</tr>
<tr>
<td>Females</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>0 (0, 4)</td>
</tr>
<tr>
<td><strong>Repetitive</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>All</td>
<td>70 (30, 90)</td>
<td>60 (50, 90)</td>
<td>40 (25, 90)</td>
<td>70 (9, 94)</td>
<td>70 (22, 90)</td>
<td>80 (24, 100)</td>
<td>90 (60, 100)</td>
<td>81 (70, 94)</td>
<td>75 (25, 95)</td>
</tr>
<tr>
<td>Males</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>75 (25, 90)</td>
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<tr>
<td>Females</td>
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<td></td>
<td></td>
<td></td>
<td>80 (40, 95)</td>
</tr>
</tbody>
</table>
Table 3 shows relevant interventions, where reported, categorized as medication, surgery, changes in diving practice, and diving medical consultation. Specific interventions and activities are discussed by condition in the commentary below.

**ISCHAEMIC HEART DISEASE (IHD)**

These were divers who reported a previous myocardial infarction (MI) (22 divers), angina (10), “coronary stent” (without reference to the indicating symptoms or event) (2), “coronary artery bypass graft” (again, without reference to the indicating symptoms or event) (1), and “partially occluded coronary artery” (without explanation of the indication for an angiogram) (1). Fifteen of the 31 respondents with IHD reported co-morbidities of hypertension, diabetes and/or arrhythmia. Corrective interventions included stenting (13) and coronary artery bypass (6). The median (IQR) time since intervention was 5 (2.5, 8) years. These 19 respondents reported having done a total of 8,622 dives since intervention (including one male instructor and technical diver with 4,000 dives) with a median (IQR) of 100 (60, 250) dives. Relevant medications included statins (18), antihypertensives (14), antiplatelet agents (9), beta blockers (6) and anticoagulants (1). No respondents reported current chest pain or precipitation of cardiac-related symptoms during diving.

**ARRHYTHMIA**

Reported arrhythmias included atrial fibrillation (AF) (9 divers), ventricular tachycardia (3), supraventricular tachycardia (SVT) (3), first degree heart block (1), unspecified heart block (1) and unifocal ventricular ectopics (1). Two conditions were unspecified. One respondent (a male with Advanced and Enriched air certifications) had corrective surgery, an ablation for SVT, and had subsequently done more than 700 incident-free dives. Relevant medications included beta blockers (7), anticoagulants (2) and antiplatelet agents (2). One diver reported taking the antiarrhythmic flecainide.

Two respondents reported having experienced symptoms from their arrhythmia during diving. One of these, diagnosed with SVT, had two SVT-type events while exerting himself on the surface post-diving. The other, diagnosed with AF which was generally well-controlled, went into AF during a dive. On another occasion, this diver had an unrelated episode of “very mild” DCI (symptoms unspecified).

**SEPTAL DEFECTS**

Of the 31 respondents with a septal defect, 27 reported a PFO, three an atrial septal defect (ASD) and one a ventricular septal defect (VSD). The median (IQR) number of dives conducted prior to diagnosis of a septal defect was 438 (252, 763). The relative proportions of technical and decompression diving among respondents with known septal defects was higher than for the remainder of the cohort, albeit still generally low.

The total years’ diving were similar for divers with a PFO or an ASD (10 (7.8, 18) versus 9 (7, 18.5) respectively) . However, divers with a PFO had done more dives than those with an ASD before diagnosis; 400
stroke and decompression illness. Hypertension reported by the divers included cardiac events, but only seven specified the condition (mitral valve prolapse (6) and heart murmur (1)). None of these seven reported taking medications, but one of the others was taking an anti-hypertensive agent.

HYPERTENSION

One-hundred-and-twenty-seven respondents reported having hypertension; the median (IQR) time since diagnosis of hypertension being 7 (4.5, 15) years. The main medication types reported included angiotensin II antagonists (43, 34%), ACE inhibitors (41, 32%), calcium channel blockers (29, 23%) and β blockers (13, 10%). The respondents with declared hypertension were asked to report their last blood pressure measurement, although it was not specified if this was measured by a healthcare professional or themselves. The mean (SD) reported systolic BP was 128 (9) and diastolic 78 (7).

Only one diver reported a general on-going problem associated with hypertension (headache) and none reported problems with diving as a result of their condition. One diver with hypertension also reported having had DCI but did not specify his symptoms. Perceived risks of diving with hypertension reported by the divers included cardiac events, stroke and decompression illness.

DIABETES

Twenty-five respondents reported diabetes. The mean (SD) BMI was 29 (5) kg.m⁻² with four of normal weight, 13 overweight and eight obese. The median (IQR) time since diagnosis was 7.5 (6, 11.5) years and the total number (range) of dives conducted since diagnosis was 9,143 (30 to 3,500) dives. Four divers were insulin-dependent, 19 were controlled by oral medications plus diet and exercise, and two by diet and exercise alone. Medications reported were biguanides (19), sulfonylureas (6), insulin (4), dipeptidyl peptidase-4 inhibitors (4), alpha glucosidase inhibitor (1), meglitinide (1) and thiazolidinedione (1).

Only one respondent reported having ever been admitted to hospital as a result of their diabetes. Seven divers reported having self-managed a hypoglycaemic event (‘hypo’) in any context (none while diving), two of these having done so in the previous year. No respondent required the help of another person to manage their symptoms during the previous year. Of those who reported having a ‘hypo’, the median (IQR) time since the last ‘hypo’ was 2 (1.25, 2) years. Three respondents reported diabetes-related complications. These were cardiac, kidney disease and visual problems. Thirteen of the 25 had undergone an exercise ECG as part of their assessment.

Sixteen of the 25 diabetic respondents (including three of the four who were insulin-dependent) measured their blood glucose level (BGL) before diving, although none practiced strictly in accordance with the relevant guidelines of the South Pacific Underwater Medicine Society (SPUMS) or Undersea and Hyperbaric Medicine Society (UHMS). The frequency of pre-dive measurement varied from one to three times, and the timing from 15 minutes to three hours before diving. The mean (SD) minimum BGL that these respondents reported to be acceptable before diving was 6.1 (1.6) mmol·L⁻¹ with a range of 3.5 to 10 mmol·L⁻¹. Five respondents changed their medication regimen prior to diving – three did not take their oral medications and two insulin-dependent divers reduced their insulin dose. Four respondents reported changing their mealtime to increase carbohydrate and sugar intake before diving. Only one insulin-dependent respondent reported checking his BGL hourly for three hours, while the other five respondents who routinely checked did so at periods of five minutes to several hours after diving.

Sixteen respondents reported being aware of the relevant guidelines and 10 of these indicated that these guidelines had influenced their diving practice. This included BGL monitoring, increased vigilance, greater medical oversight and careful buddy selection. Nine of the 12 respondents who consulted a diving doctor had periodic diving medical
reviews, at intervals of 6–12 months. Perceived risks reported by the diabetics included loss of consciousness in- or underwater, confusion and an increased risk of decompression illness.

ASTHMA

Forty respondents reported asthma. Twenty-eight of 30 who answered the relevant question reported having been diagnosed with asthma before taking up diving. The median (IQR) time since diagnosis of asthma was 19 (13, 30) years. Eleven respondents had been admitted to hospital between one and four times, with the median (IQR) number of admissions being 1 (1, 2). The median (IQR) time since last admission was 16 (15, 23) years. The time since last asthma symptoms ranged from one week to 20 years with a median (IQR) of 2 (0.3, 10) years. Fifteen respondents had symptoms during the previous year including wheeze (13), reduced exercise capacity (9), dyspnoea (5) and stress (1). Thirteen respondents used ‘preventer’ medications, most often daily and 22 used bronchodilators (in all cases salbutamol) either daily (5), monthly (5) or annually (12). There were no reported exacerbations of asthma while diving. The perceived risks from asthma reported by the divers included pulmonary barotrauma, dyspnoea and reduced exercise capacity.

PNEUMOTHORAX AND CHEST SURGERY

Five respondents reported having had a pneumothorax one to five years previously. All were divers at the time of their event. Few condition-specific data were provided by two of the divers so the following is based on the three others. All were left-sided; two were trauma-related and were managed with a chest drain. The other was spontaneous and required no treatment. The two with trauma-related injuries underwent subsequent CT scans (one specifically for informing future diving) while the respondent with the spontaneous event did not. Subsequently the spontaneous pneumothorax victim had conducted 20 dives, whilst the two traumatic pneumothorax victims had completed 30 and 200 dives with no reported problems. Another respondent had a pulmonary lobectomy to remove cancer 11 years prior. He underwent a subsequent CT scan and returned to diving after consultation with a diving doctor. He subsequently had done 750 incident-free dives.

MEDICATIONS

One-hundred-and-fifty-one respondents reported taking a total of 337 medications. The main classes of medications taken are shown in Table 4. The full list of individual drugs is available on request from the corresponding author at <johnl@danap.org>.

Table 4

<table>
<thead>
<tr>
<th>Class</th>
<th>Frequency</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statins</td>
<td>51</td>
<td>(15)</td>
</tr>
<tr>
<td>Angiotensin 2 receptor antagonists</td>
<td>43</td>
<td>(13)</td>
</tr>
<tr>
<td>ACE inhibitors</td>
<td>41</td>
<td>(12)</td>
</tr>
<tr>
<td>Calcium channel blockers</td>
<td>29</td>
<td>(9)</td>
</tr>
<tr>
<td>Bronchodilators</td>
<td>22</td>
<td>(7)</td>
</tr>
<tr>
<td>Biguanides</td>
<td>19</td>
<td>(6)</td>
</tr>
<tr>
<td>Diuretics</td>
<td>17</td>
<td>(5)</td>
</tr>
<tr>
<td>Antiplatelet agents#</td>
<td>16</td>
<td>(5)</td>
</tr>
<tr>
<td>ß blockers</td>
<td>15</td>
<td>(4)</td>
</tr>
<tr>
<td>Inhaled glucocorticoids</td>
<td>13</td>
<td>(4)</td>
</tr>
<tr>
<td>Proton pump inhibitors</td>
<td>12</td>
<td>(4)</td>
</tr>
<tr>
<td>Sulfonylureas</td>
<td>6</td>
<td>(2)</td>
</tr>
<tr>
<td>Insulin replacement</td>
<td>4</td>
<td>(1)</td>
</tr>
<tr>
<td>Dipeptidyl peptidase-4 inhibitor</td>
<td>4</td>
<td>(1)</td>
</tr>
<tr>
<td>Serotonin reuptake inhibitors</td>
<td>3</td>
<td>(1)</td>
</tr>
<tr>
<td>Serotonin-norepinephrine reuptake inhibitors</td>
<td>3</td>
<td>(1)</td>
</tr>
<tr>
<td>Non-steroidal anti-inflammatories</td>
<td>3</td>
<td>(1)</td>
</tr>
<tr>
<td>Anticoagulants</td>
<td>3</td>
<td>(1)</td>
</tr>
<tr>
<td>Thyroxine replacement</td>
<td>3</td>
<td>(1)</td>
</tr>
<tr>
<td>Total</td>
<td>307</td>
<td>(91)</td>
</tr>
</tbody>
</table>

DIVING MODIFICATIONS

Sixty-two (23%) respondents reported having directly modified their diving practice. It is possible that this is an under-estimate as many failed to respond to this question. Reported modifications included:

- exertion avoidance (MI, angina, arrhythmia);
- stress avoidance (MI, angina, asthma);
- reduced depth (MI, angina, septal defect);
- use of nitrox, more conservative dive profiles, padding decompression time or safety stops to be longer than prescribed by tables or computers, longer surface intervals (septal defects);
- less repetitive diving, especially true of the respondents with septal defects who engaged in a much lower proportion of repetitive dives than most of the other groups;
- careful buddy selection and briefing (diabetes, arrhythmia);
- avoidance of cold water (arrhythmia, asthma);
- reduced ascent rate (septal defects, pneumothorax).

In addition to the above actual diving modifications, some respondents also reported:

- increasing vigilance for symptoms before, during and after diving (arrhythmia, diabetes, asthma);
- adjustment of their medication (diabetes, asthma).
**Discussion**

This study identified the characteristics, behaviours and outcomes of active divers with significant medical conditions. Despite our focus on some conditions that are perceived to significantly impact on diver safety, and setting aside the 25 cases of DCI occurring in divers with unrepaired septal defects, our respondents reported only five other significant adverse events in over 183,000 career dives, 57,000 of which occurred post-diagnosis and 13,000 over the year immediately preceding completion of the questionnaire. This is not surprising as, in many cases, the conditions had been or were being appropriately managed (e.g., closure of septal defects, coronary stenting, coronary bypass grafting, effective glucose control in diabetes) and that specific risk mitigation measures had sometimes been introduced to their diving practice. Although our numbers are small and these voluntarily reported data deserve cautious interpretation, our findings are generally supportive of an argument that these diagnoses per se are not necessarily contraindications to diving as they have frequently been considered in the past.

**ASThma**

Traditionally one of the greatest controversies in fitness to dive discussions involved asthma which, for a long time, was regarded as a complete contraindication to diving. Common triggers associated with the diving environment include exercise, cold, the breathing of cold, dry air, anxiety and salt water aspiration. An exacerbation while diving creates the potential for gas trapping and pulmonary barotrauma, as well as the potential for drowning as a result of dyspnoea.

Various surveys of diving cohorts in Australia, the United Kingdom (UK), the United States (USA) and of German-speaking divers have indicated a prevalence of active asthma in approximately 3–9% of respondents. There have been reports of pulmonary barotrauma and arterial gas embolism in asthmatics, but the extent to which asthma materially increases the risk of barotrauma remains unclear. A survey of DAN America members appeared to indicate an increased risk of DCI in those with asthma, while a U.K. report did not. Our respondents diagnosed with ‘asthma’ reported no related problems in 7,613 dives. Given the small numbers it is difficult to categorise this as anything other than ‘reassuring’, but like others, we see no signal of increased risk in our data.

Nevertheless, there are sufficient grounds for believing the risk is more than merely theoretical. A prospective study of 100 UK divers reported that 20 who would have been excluded, based on prevailing selection criteria, had problems during diving including wheezing underwater. Moreover, there are reports of diving fatalities that were directly attributed to asthma. The absence of related problems in ours and other’s data may indicate that the risks of diving, particularly in mild asthmatics, is small or that most divers manage their asthma and diving activities adequately.

In our cohort of 40 divers, 37 had consulted a diving physician about their asthma. This would have allowed both optimisation of their condition and discussion of how best to manage it in relation to diving. Various diving medical guidelines are available (including those of SPUMS) to guide both the physician and the diver in this setting, and all divers with asthma are well-advised to have a diving medical assessment by a doctor with relevant training.

**DIABETes**

Historically, diabetes mellitus, especially in its insulin-dependent form, has been considered an absolute contraindication to diving. The main concern is the consequences of reduced mentation or unconsciousness because of hypoglycaemia during diving. Blood glucose levels (BGLs) do fall with diving and such falls could be substantial and potentially dangerous under demanding conditions. Other concerns include diabetes-related end-organ damage, especially co-existing cardiac disease.

However, in 1991, the UK Sports Diving Medical Committee softened its position and the British Sub-Aqua Club (BSAC) and some other UK-based certification agencies led the way in enabling selected diabetic divers to dive, albeit with some restrictions. Several studies have subsequently been conducted to monitor the habits and blood glucose levels of divers with diabetes before, during and after real or simulated diving exposures. The accumulation of these data, with an associated low incidence of related problems, suggests that people with diabetes can dive safely provided risks are managed effectively by appropriately educated individuals.

As a result, the prohibition on diving with diabetes has eased and more individuals with diabetes are diving, preferably under the general oversight of their endocrinologist as well as a diving physician. In a 2000 survey of 346 experienced Australian divers, only one respondent (0.2%) reported having diabetes. However, in 2014–15, 21/1,119 (1.9%) DAN AP members, 8/350 (2%) PADI members and 9/806 (1%) of PADI-certified divers (most of whom did Open Water Diver courses in the previous four years) who responded to a general diving activity survey reported having diabetes (unpublished DAN AP data). Although survey data are subject to a variety of limitations including response bias, this likely indicates an increase in the number of diabetic divers in Australia.

A 2005 workshop sponsored by the UHMS and DAN led to the development of guidelines for recreational diving with diabetes mellitus. These guidelines describe protocols for diver selection and management of insulin during a day of diving. Although they have been largely endorsed by several diving medical organisations (including SPUMS), there are...
few data describing their uptake and utility. Only 16 of the 25 respondents with diabetes were aware of the UHMS/DAN or SPUMS guidelines and none reported strictly following them. Of concern is the substantially lower mean minimum pre-dive blood glucose level (BGL) of 6.1 mmol.L\(^{-1}\) in this study, versus 8.3 mmol.L\(^{-1}\) recommended by UHMS/DAN, or 9.0 mmol.L\(^{-1}\) recommended by SPUMS. However, this must be interpreted cautiously. Our BGL data are derived from all respondents (including diabetics who do not use insulin) whereas the quoted recommendations apply to insulin-dependent diabetics. In addition, less than half of the respondents had consulted a diving doctor and fewer had periodic diving medical reviews. These findings identify an educational opportunity for improving practice but it is not obvious how diabetic divers or prospective divers can be encouraged to engage with a diving doctor. At the very least, we recommend that those who do so should be provided with the SPUMS or DAN/UHMS guidelines and strongly urged to follow the practice recommendations contained therein.

SEPTAL DEFECTS

There are few available data on diving with most cardiologically-related conditions. One exception to this is PFO which has received considerable attention and has been identified as a risk factor for cutaneous, inner ear, cerebral and spinal DCI. Twenty-five of the 27 respondents who reported having DCI were diagnosed with an intra-cardiac right-to-left shunt, predominantly a PFO. This was the only group with a higher proportion of females, although there appears to be no evidence of a higher incidence of PFO in women. Overall, this group was relatively young and did more decompression and technical diving. It is plausible that these diving activities result in higher venous gas emboli loads, therefore making the diving-related clinical complications of a septal defect more likely, which in turn makes it more likely that the defect will be detected.

Subsequent risk management through surgical intervention and/or changes to diving practice (e.g., our respondents reported less repetitive diving than other cohorts) appear to have been very successful. Similar results were reported in a study of UK divers. Twenty-two of the 28 respondents with a PFO in that study had been diagnosed after an episode of DCI; 20 divers had a surgical closure and 16 returned to diving. Those who continued to dive without closure successfully adopted more conservative diving practices similar to those used by the Australian cohort.

CARDIAC CONDITIONS AND HYPERTENSION

Factors such as central fluid shifts caused by immersion, exercise, cold-induced vasoconstriction, changes in gas density, static lung loads and psychological stress can increase cardiac preload, afterload, heart rate and myocardial work. Based on first principles, this would make a myocardial event more likely in predisposed individuals. A study of 947 recreational scuba diving fatalities indicated that a myocardial event was the likely disabling injury in 26% of the deaths. Not surprisingly, fatality reports suggest that risk increases in older divers and in males. UK fatality data show an increasing incidence of cardiac-related incidents against a background of an ageing diving population.

Recent data suggest that 22% of Australians over 18 years old had one or more cardiovascular diseases with the prevalence being greatest in older age groups. It is inevitable that individuals with various degrees of cardiovascular disease are diving. A survey of Australian divers in 2000 suggested that this applied to 5.7% of respondents. More recent DAN AP survey data indicate that this may have been an underestimation or has subsequently increased, suggesting a prevalence of 9% in recently certified divers and 12–17% in predominantly older, long-time and experienced divers (unpublished DAN data).

It is clear that cardiac disease is prevalent and represents a very real risk in diving and snorkelling, especially if it is poorly-managed. On the basis of witness reports and evidence of cardiac disease or abnormality at autopsy, many diving deaths have been attributed to arrhythmias. However, in the absence of a definitive post-mortem test this remains speculative. These Australian data also reveal that, although some victims were under treatment for cardiac disease at the time of their demise, in many their condition was undiagnosed. Any condition that increases the risk of arrhythmia and/or myocardial ischaemia may compromise safety and needs to be thoroughly investigated, preferably with involvement of a diving medical specialist. In this study, only 21 of 51 divers with ischaemic heart disease or arrhythmia reported having consulted a diving physician. A UK study also reported a low rate of diving medical consultation in those with cardiac disorders.

Arrhythmias

A consensus discussion on cardiac disease during the 2010 DAN Fatality Workshop included a recommendation for automatic exclusion from diving for those with “arrhythmias causing impairment of exercise tolerance or consciousness”. Fitness-to-dive considerations for an individual with arrhythmias should include factors such as the nature of the arrhythmia, the frequency and effect of episodes, the presence and type of causative disease, the treatment used and its success. In addition to considering the likelihood of an episode while diving, it is important to consider the potential adverse effects of medications, including the potential for reduced exercise capacity associated with beta-blockers or the potential for increased bleeding associated with anticoagulants.

Two of this survey’s respondents with arrhythmias (20) reported at least one episode while diving, fortunately
without injury. Most were well-controlled by medication and under diving medical oversight, but about two-thirds reported that they had not modified their diving practices (e.g., by avoiding exertion, cold water, mandatory decompression) in response to their condition.

Ischaemic heart disease

In this survey, 19 of the 31 respondents with IHD had undergone revascularisation although the degree of success is unknown. Complete revascularisation with restored exercise capacity without ischaemia may enable relatively safe diving in low-stress environments. However, only 10 of the 31 divers reported changing their diving behaviour. The divers with IHD were experienced, long-time divers and this might explain a reluctance to change established patterns. Only two of the 10 divers who reported having had angina had sought specific diving medical advice or changed their diving practices.

Hypertension

Given that hypertension was the most frequently managed problem in Australian general practice during 2013–14, it is not surprising that respondents with hypertension represented the largest subgroup in this study. The majority (93 of 127, 73%) of hypertensive respondents were on a blood pressure control regimen. This contrasts with a UK study in which fewer (50%) of the divers with the diagnosis of hypertension took medications, the most common being ACE inhibitors and angiotensin-II antagonists. None of the hypertensive divers in this study reported problems with diving over a total of 32,840 dives. Similarly, despite potential adverse effects of some medications used to manage hypertension, none were reported. The most common antihypertensives used were angiotensin II receptor antagonists. None of the hypertensive divers in this study reported problems with diving over a total of 32,840 dives. Similarly, despite potential adverse effects of some medications used to manage hypertension, none were reported. The most common antihypertensives used were angiotensin II receptor antagonists, which have been suggested as the preferred agents for the treatment of hypertension in divers.

Medical screening

Current diving medical screening guidelines recommend a cardiovascular review for all males at age 45 and females at age 55 years. Active or prospective divers should follow this advice; in any case, consult a diving medical physician in the event that they suffer from any significant chronic or acute medical condition that could be impacted by diving. Overall, only about half of this group had consulted a diving physician about their medical condition. Presumably many of the remainder may have discussed their circumstances with their general practitioner or specialist. However, in the experience of these authors, in the absence of specific diving medical knowledge, it is likely that some of the potential triggers of the diving environment may not have been sufficiently considered.

LIMITATIONS

This study has several limitations:

- The response rate of 32% may have introduced a response bias.
- The results are based on a survivor group of divers and fail to account for diving fatality victims with similar conditions that might have contributed to their demise, as well as divers who may have survived an event and stopped diving as a consequence. Therefore, the study sample may be biased towards milder forms of these conditions.
- DAN AP members are probably not typical of the general diving population. They are likely to be older, have an increased likelihood of co-existing disease, have more available funds, may travel more and may better understand their potential vulnerability and the need for and benefits of having appropriate insurance.
- Some applicants for DAN membership may have been reluctant to declare medical conditions for fear of it affecting their ability to obtain or retain insurance cover, although it is made clear that failure to declare a relevant condition may nullify coverage. As a result, there were likely to have been more than the 833 members invited to join the MCS who were suffering from the targeted health conditions. In addition, although the survey was anonymous, it is possible that there may have been divers reluctant to disclose diving incidents owing to concern that their insurance cover might be affected. If so, this is another potential source of bias.
- The nature of some of the more historical questions may have introduced a recall bias.
- Many responses were excluded from the analysis due to missing replies to certain questions.
- The number of dives performed by divers with particular conditions is relatively small for the purposes of an epidemiological evaluation. Our ability to interpret the associated risks is therefore limited.

Conclusions

These results are limited by the 32% response rate and potential for bias towards selection of those most careful with their health. However, a substantial minority of DAN AP members are diving with medical conditions such as cardiac conditions, hypertension, diabetes and asthma which could potentially impact the safety of their diving. Many of the conditions were controlled by medications, several of which could themselves have adverse effects while diving. Surgical intervention was common for divers diagnosed with a PFO or ischaemic heart disease. Only one quarter of the divers reported modifying their diving practices to accommodate their condition, and only half had sought specialist diving medical advice. Despite the obvious concerns, our respondents with known and largely managed medical problems have dived with very few
incidents associated with their conditions. Conclusions based on survivor populations must be cautious and our numbers remain relatively small, but it does seem that, if these medical conditions are identified and managed appropriately, the risks associated with diving may be acceptable. More research with larger cohorts is needed to better understand the risks in an ageing comorbid diving population.

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The authors wish to acknowledge Scott Jamieson for his assistance with data collection and Michael Lippmann for his assistance in the construction of the survey platform.

Conflicts of interest

John Lippmann is the Founder and Chairman of DAN AP. DAN is involved in the collection and reporting of dive accident data and provides evacuation cover and dive injury insurance to recreational divers.

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<td>John Lippmann</td>
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If there are multiple authors, give a full description of HDR thesis author’s contribution to the publication (for example, how much did you contribute to the conception of the project, the design of methodology or experimental protocol, data collection, analysis, drafting the manuscript, revising it critically for important intellectual content, etc.)

JL conceived the project, contributed to design of methodology (>50%), collected the data, performed majority of analysis (>80%), drafting and revising the manuscript (>60%)

I declare that the above is an accurate description of my contribution to this paper, and the contributions of other authors are as described below.

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<td>Prof Simon Mitchell</td>
<td>Contributed to design of methodology, and analysis, drafting and revising of manuscript</td>
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<td>Divers Alert Network</td>
<td>16 April 2017</td>
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SECTION 3

DIVING ACCIDENT DATA COLLECTION AND ANALYSIS
Chapter 5

The collection and analysis of Australian diving fatality data

Surveillance is an important tool to identify causative and factors associated with morbidity and mortality. Countermeasures can then be developed to improve safety, and these countermeasures should be assessed periodically to determine their effectiveness.\textsuperscript{204}

Some key systemic components of health surveillance require that data collection is appropriate, as complete as possible, on-going, analysed by suitable personnel, stored securely, used within relevant privacy protection guidelines, reported in a timely manner and disseminated to relevant parties.\textsuperscript{205, 206}

The following chapter describes the Australian diving mortality surveillance system and provides some historical diving mortality data. The results of the data analysis will be used to inform Thesis Aim 3 “Estimate the fatality rate of Australian scuba divers, and Research Question 1 “What are the underlying factors associated with scuba diving mortality in Australia”. These data are also the basis for the chain of events analyses reported in chapters 7 and 8.

5.1 The diving mortality surveillance system

The Candidate is currently responsible for the oversight of the diving mortality surveillance system for Australia. The population studied in this system is all recreational scuba divers and snorkellers, as well as divers using surface-supplied breathing apparatus in both a recreational and commercial setting in Australian waters. The events of interest are diving-related deaths in this population.

In many epidemiological studies, the target population ‘denominator’ is available in order to calculate changes in risk and other trends over time.\textsuperscript{207} Unfortunately, this
cannot be determined in most diving populations where there is a dearth of accurate data of participant numbers and activity.\textsuperscript{10, 12} However, there are exceptions, as discussed in Chapter 6.

In the absence of an appropriate denominator, event-based analysis is used.\textsuperscript{208} Although there are relatively few diving mortality events annually, such events can still be important indicators of trends or clusters in place or time.\textsuperscript{205, 209} A strength of this diving surveillance system is the amount of data that have been collected on each individual event. This can help in part to compensate for the small numbers.\textsuperscript{205, 208-210}

Data collection is extensive and complete and is overseen by the Candidate and a co-researcher. The information is stored securely in a purpose-build, password-protected database and relevant privacy requirements are adhered to. The data is analysed and reported regularly.\textsuperscript{211, 212}

Findings from the surveillance, including suggestions for control and prevention of identified problems, are disseminated to divers, diving physicians, instructors, instructional agencies as well as State and Territory coronial offices for consideration. This provides the opportunity for potential countermeasures to be introduced where appropriate and practicable. Continued surveillance will help to determine whether or not such countermeasures have been effective.

5.2 Data collection

The initial data on a diving-related fatality are collected by on-scene investigators such as the police and/or workplace, health and safety officers. Autopsies (including both external and internal examinations) are routinely conducted in diving fatalities except in rare cases (approximately 2%) where there is no familial consent, or if the victim’s body had not been found. This information, together with witness statements, is reviewed by respective coroners and a coroner’s report is produced, with or without an inquest, as determined by the individual coroner.
The fatality data are sought through a variety of sources, which include:

1. Media reports, including weekly scans of key internet sites
2. Contacts through the diving industry
3. Contacts through investigating police
4. Searching the National Coronal Information System (NCIS)\(^2\)\(^{13}\)
5. Liaison with State/Territory Coroners.

The NCIS\(^2\)\(^{13}\) includes all deaths reported to a coroner since 2000. Reportable deaths vary in some jurisdictions but almost always encompass deaths during diving activities. The information available for most cases includes the coroner’s report, a brief summary of the police report and, often, the autopsy report or a summary of it. In order to obtain more complete data, the Candidate liaises with individual State and Territory coroners who provide (under relevant ethics approvals) the complete case files. These files generally include the full police reports, witness statements and, often, medical and diving histories, as well as an equipment report. Key information from these is recorded in the DAN database.

For each year’s fatalities, the data from the various searches are compared and collated to confirm the identities of the victims and to minimise the risk of over- or under-reporting. Periodic comparisons between the NCIS and all other data sources indicate that the current systems for data collection in Australia appear to be exhaustive and comprehensive.
5.3 Annual case series analyses

Historically, Walker, through his “Project Stickybeak” collected data from individual coroners throughout Australia and produced annual reports based on these.\textsuperscript{109-139} Pertinent data from these reports have been integrated into the Divers Alert Network Asia-Pacific (DAN AP) database, overseen by the Candidate, who has been collecting data on diving incidents since 2001 and has been the principal investigator and reporter for annual case series of diving-related fatalities from 2004 to 2013. A structured information-gathering and analysis process devised by the Candidate is followed in the investigation, analysis and reporting of each case in the annual case series.\textsuperscript{155}

A variety of demographic, environmental, equipment-related and dive practice-related factors are extracted from the data, documented and analysed. These include:

- Location
- Dive platform (i.e., shore, boat, jetty)
- Age
- Gender
- Health and medical history
- Relevant training and experience
- Whether an Australian resident or tourist
- Buoyancy management (e.g., floatation aids, weighting)
- Breathing gas supply and its management
- Equipment used and problems detected on examination
- Relevant environmental and dive-related factors
- Witness accounts of the clinical history
- Autopsy findings including histology, toxicology and CT results if available.
The analysis involves the following steps:

1. The Candidate and a co-researcher review the police reports, witness statements and coronial reports and, separately, prepare a summary of each incident identifying all the likely causal events, as well as the sequence in which these events occur.

2. Any discrepancies are investigated and resolved by the Candidate who then prepares initial incident summaries, which are then checked by the assistant.

3. Incident summaries, coronial and autopsy reports are reviewed by a forensic pathologist with extensive experience in diving-related autopsies. The pathologist then prepares the summary of the autopsy reports.

4. The Candidate adds the summaries of the autopsy reports and prepares an extensive initial draft report.

5. The draft report, together with all the background documents are reviewed by one or more diving medicine physicians (and previously for five years, a retired County Court Judge) [the DAN Asia-Pacific Fatality Research Group].

6. A Chain of Events Analysis (see Chapter 7) of each incident is performed by the Candidate.

7. The co-researchers make additions/suggestions/corrections and any differences in the Candidate’s interpretations of the incidents are debated and resolved.

8. The Candidate completes the report with input from the other members of the research team.

This process enables an in-depth exploration of the annual fatalities where each fatality is reviewed by an expert committee and the circumstances of the deaths recorded and reported. The annual reports include a discussion of the various health and safety issues raised therein. The reports from 2004 to 2011 have been published in an international, peer-reviewed diving medical journal 148-155 and the 2012 report been submitted to the journal and is currently under consideration.147
5.4 Annual Deaths, 1965-2013

Following are some trend analyses derived from the surveillance data from 1965 to 2013, inclusive.

5.4.1 Methodology

The most suitable model to examine the trend in annual scuba fatalities was a Poisson regression model with number of deaths as the output variable and year of death as the explanatory variable.\textsuperscript{214} The model was fitted using robust variance estimates to allow for potential overdispersion in the data. Deaths among females as a proportion of total deaths were also investigated using a similar Poisson model with the addition of total deaths as an exposure variable.

Inspection of the scatterplot for scuba diving deaths suggested an initial rise in deaths followed by a plateauing. In this case, the Poisson model was extended to allow the fitting of two simultaneous models using the ‘Joinpoint Method’. This technique fits two Poisson models joined at a ‘joinpoint’, with both the optimal position of the join and the model parameters estimated simultaneously using a sequential permutation test procedure.\textsuperscript{215}

Finally, trends in mean age at death were examined using weighted least squares regression with mean age as the output variable and year of death as the input variable. Each annual mean age value was weighted with the total death count for that year.

The joinpoint Poisson regression was fitted using the joinpoint regression program.\textsuperscript{216} All other analyses were done using the Stata 15 software (StataCorp 2017).\textsuperscript{217}
5.4.2 Results

During this period there were a total of 809 recorded diving-related deaths. These included 393 scuba diving-related deaths (including 13 using rebreathers), 79 divers using surface-supplied breathing apparatus (SSBA), and 337 snorkel and breath-hold divers, as shown in Figure 5.1.

Figure 5.1. Total diving-related deaths in Australia, 1965-2013 (n = 809).

RB = Rebreather; SSBA = Surface-supplied breathing apparatus (these are shown here for completeness but are not addressed in this thesis).

5.4.2.1 Scuba diving deaths

A detailed analysis of the scuba fatality data from 2001 to 2013 for which the Candidate holds the available coronial files is presented in Chapter 8. However, some demographic data and trends revealed from these long-term data are shown in Figures 5.2 to 5.4, and Table 5.1.

Figure 5.2 shows the annual scuba diving death counts with the modelled trend from the joinpoint Poisson regression model.
Figure 5.2. Scuba diving deaths in Australia, 1965-2013 (n = 393).

Correlation coefficient: 0.64, 95% confidence interval 0.28 to 0.70 (1965—1991)
-0.21, 95% confidence interval -0.57 to 0.23 (1991—2013)

The joinpoint regression identified 1991 as the estimated year when the trend in deaths changed. On average scuba diving deaths rose by a factor of 1.44 (95% CI 1.08–1.91) each decade between 1963 and 1991. This means that each decade had, on average, 44% more deaths than the previous decade. After 1991, the number of deaths followed a small, non-statistically significant downward trend, falling by a factor of 0.99 (95% CI 0.70–1.21) each decade between 1991 and 2013.

Figure 5.3 shows the number of female deaths in each year as a proportion of total deaths, along with the trend line fitted by the Poisson model. Overall 18% of the scuba victims were females, with the proportion rising from 0% in 1965 to 27% in 2013. On average, the proportion of female scuba diving deaths rose across this period by a factor of approximately 1.30 (95% CI 1.11–1.53) each decade.
Correlation coefficient: 0.49, 95% confidence interval 0.24 to 0.68.

The mean age for the scuba divers was 33.7 years, with a range of 13 to 72 years.

Table 5.1 shows the age data for the scuba victims as a group, and by gender.

Table 5.1. Age measures of scuba victims, 1965-2013.

<table>
<thead>
<tr>
<th>Measure</th>
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<th>Male (n = 323)</th>
<th>Female (n = 70)</th>
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<tr>
<td>Mean (SD), yrs</td>
<td>37.7 (13.5)</td>
<td>38.1 (13.7)</td>
<td>35.8 (12.6)</td>
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<tr>
<td>Median (IQR), yrs</td>
<td>36.5 (37, 47)</td>
<td>37 (27, 48)</td>
<td>34.5 (24, 46)</td>
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<tr>
<td>Range, yrs</td>
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Figure 5.4 shows the mean age at death in each year, along with the trend line fitted by the weighted least squares regression model for the years 1965 to 2013. The mean age rose by an average of 4.6 years (95%CI 3.4–5.7) for each decade.
Correlation coefficient: 0.79, 95% confidence interval 0.66 to 0.88.

Examination of the data suggests that mean age may have reached a plateau after 2001. Figure 5.5 shows the mean age from 2001 to 2013, which demonstrates almost no rise in mean age across this period. To check this apparent plateauing, a trend break variable was added to the regression line for the period 2001 to 2013. This was not statistically significant (p = 0.189), indicating that the mean ages from 2001 to 2013 are consistent with the estimated increasing trend. This suggests that, while mean age may have reached a plateau after 2001, it is too soon to be definitive about this.
5.4.3 Discussion

The more than 40% increase in scuba-related deaths per decade between 1965 and 1991 likely reflects the growing popularity of the sport during that period. However, there are few available activity data overall, especially during the earlier years, so this is difficult to quantify. Some available participation data, and associated fatality rates, are presented and examined in subsequent chapters of this thesis, and provide a context for the annual fatality data.

The apparent plateauing in annual deaths post 1991 is a likely result of a slowdown in participation, as well as some safety improvements, such as the increasing use of BCDs and improvements in equipment as previously reported by the Candidate and colleagues.⁹

The increase in deaths involving female divers likely reflects a greater involvement of women in the sport, rather than a higher risk. Women victims were, on average, approximately two years younger than the male counterparts in the same calendar year.
The mean age at death rose from 32 years in 1965, to 47 years in 2013. The regression analysis shows that this reflects an underlying trend with an increase of 4.6 years per decade. This increased age of victims may reflect an older cohort of participants, with a higher risk of death. This will be examined later in the thesis.

5.4.4 Conclusions

The trend analysis indicated that the absolute number of scuba deaths rose steadily until 1991 before appearing to plateau. There was a substantial increase in the proportion of female victims, and the age of victims increased steadily during most of the period, reflecting an increased participation in older divers.

In the absence of reliable denominator, it is difficult know the implications of this analysis for an assessment of the risk of diving in Australia. The next chapter attempts to put this in a context by providing estimates of the risk of diving.
Chapter 6

Estimating the risk of a scuba diving fatality in Australia

Questions arise, from time to time, about the safety of recreational diving and the risk of death while participating in the activity. This is a difficult question to answer as there are few reliable data on which to estimate this risk.

In sports such as professional Australian Rules Football, the number of players, the number of games and the duration of these games are all recorded. Hence, it is possible to calculate the actual exposure of players as an accurate denominator for calculating the incidence of injury or death.

However, diving is not conducted in such organised circumstances. Even though many commercial operators may record the number of divers, dives done and duration of their clients’ dives, most do not systematically compile, combine and report these data. Therefore, there is no central database available. Additionally, many divers dive outside commercial settings and may or may not keep personal logs of their dives. As there are hundreds of dive operators and tens of thousands of divers across the country, it is impossible to obtain actual national diving exposure data.

Several attempts have been made to estimate diving activity in various parts of Australia, over short periods, using a variety of methods. These have included diver certifications\textsuperscript{218}, tank fills\textsuperscript{219}, dive operator surveys\textsuperscript{220, 221} and tourism surveys\textsuperscript{222}. However, all these attempts had substantial limitations, including data collection over only one to two years.

The following paper describes the Candidate’s attempt to estimate the fatality rate for Australian divers. Comparative estimates of fatality rates were also calculated.

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for international visitors diving in Queensland, as well as customers of the largest
dive charter operator in Victoria.

The results of this analysis will be used to address Thesis Aim 3 - “Estimate the
fatality rate for Australian scuba divers”. This in turn will inform Research
Question 2 – “What are the implications for preventative strategies”. The study has resulted in the following published paper.223
Estimating the risk of a scuba diving fatality in Australia

John Lippmann, Christopher Stevenson, David McD Taylor and Jo Williams

Abstract

Introduction: There are few data available on which to estimate the risk of death for Australian divers. This report estimates the risk of a scuba diving fatality for Australian residents, international tourists diving in Queensland, and clients of a large Victorian dive operator.

Methodology: Numerators for the estimates were obtained from the Divers Alert Network Asia-Pacific dive fatality database. Denominators were derived from three sources: Participation in Exercise, Recreation and Sport Surveys, 2001–2010 (Australian resident diving activity data); Tourism Research Australia surveys of international visitors to Queensland 2006–2014 and a dive operator in Victoria 2007–2014. Annual fatality rates (AFR) and 95% confidence intervals (95% CI) were calculated using an exact binomial test.

Results: Estimated AFRs were: 0.48 (0.37–0.59) deaths per 100,000 dives, or 8.73 (6.85–10.96) deaths per 100,000 divers for Australian residents; 0.12 (0.05–0.25) deaths per 100,000 dives, or 0.46 (0.20–0.91) deaths per 100,000 divers for international visitors to Queensland; and 1.64 (0.20–5.93) deaths per 100,000 dives for the dive operator in Victoria. On a per diver basis, Australian residents are estimated to be almost twenty times more likely to die whilst scuba diving than are international visitors to Queensland, or to lower than fourfold on a per dive basis. On a per dive basis, divers in Victoria are fourteen times more likely to die than are Queensland international tourists.

Conclusions: Although some of the estimates are based on potentially unreliable denominator data extrapolated from surveys, the diving fatality rates in Australia appear to vary by State, being considerably lower in Queensland than in Victoria. These estimates are similar to or lower than comparable overseas estimates, although reliability of all such measurements varies with study size and accuracy of the data available.

Key words
Deaths; Diving incidents; Recreational diving; Survey; Statistics

Introduction

Scuba diving is an ‘adventure sport’ which many consider to be a dangerous activity. Media publicity about shark attacks and divers being left at sea likely serve to increase this perception. It is important for both the diving industry and the general community to have a reasoned perspective of the level of risk, based on estimated activity and incidents, rather than media perceptions. There are few available data on which to estimate the risk of fatality for Australian divers and much of these data have considerable limitations. Earlier reports explored estimates for Australia (including overseas travellers) but these were based on limited data and were affected by methodological errors, predominantly the combination of activity data from two surveys which used different methods of data collection. In this study, individual estimates are based on single data sources.

To estimate a fatality rate for divers, it is necessary to obtain both an accurate numerator (i.e., the number of deaths over a time period) and denominator (i.e., a measure of diving activity over that same period). In Australia, we can be reasonably confident in the accuracy of the number of dive-related fatalities reported each year because of our effective coronial reporting system and the active involvement of the Divers Alert Network Asia-Pacific (DAN AP) in collection of relevant data and its access to the National Coronial Information System (NCIS). As with most other countries, it is difficult to find a reliable estimate of Australian diving activity. Denominators, the measure of risk exposure, can be based on the number of divers, the number of dives or time at risk. Where reasonably sound activity data are available, the fatality rate per dive is a better measure of actual exposure risk than is a per person death rate, which provides no detail of actual diving exposures. The actual hours of exposure time provides the best denominator to establish an accurate measure of incident risk. However, in the diving population this is rarely reported and, therefore, not available.

In this report, data on the diving activity of Australian-based divers and the associated fatalities are examined to provide ‘best guess’ estimates of the risk of death for Australian divers overall, as well as for subsets of divers in Queensland and Victoria.

Methodology

Numerators were obtained from the DAN AP dive fatality database. DAN AP systematically collects data from all States and Territories through media and diver reports, the National Coronial Information System (NCIS) and coronial offices throughout Australia. Denominator data were sought by: (1) A literature search for suitable Australian activity data; (2) Diving records of a large diving charter operator in Victoria.
Diving activity data for Australia from 1980 to 2015 inclusive were sought through searches of the South Pacific Underwater Medical Society Journal and Diving and Hyperbaric Medicine, other relevant sporting activity reports, liaison with industry bodies and internet searches. Search engines accessed were Google, Google Scholar, Medline, CINAHL, Heath Source (Nursing/Academic Edition), Sportsdiscus, Psychinfo, Global Health, Academic Search Complete, Informit and Embase. Details of the search terms are shown in Table 1. The inclusion criteria for relevant articles were: (1) There was a measure or estimate of diving activity either from survey, recorded dives, tank fills or membership/insurance counts; and (2) data were available for at least five consecutive years.

Three sources of denominator data met the inclusion criteria. These were: (1) The Australia-wide Participation in Exercise, Recreation and Sport (ERASS) Surveys;6–15 (2) Tourism Research Australia Surveys of International visitors to Queensland (Tourism Research Australia, April 2015, with permission);16,17 (3) Victorian dive operator records from 2007 through 2014 (confidential communication, 2015).

ERASS NATIONAL SPORTING PARTICIPATION SURVEYS 2001−2010

The ERASS data were collected via telephone-based surveys conducted on behalf of the Australian Sports Commission (ASC) from 2001 through 2010, inclusive (by AC Neilson Research 2001–2007 and Newspoll Market and Social Research 2008–2010).6−15 The basic questionnaires changed little over the years. The surveys utilised random samples of at least 3,400 Australian residents over 15 years of age, per quarter. Participants were asked about their sporting activities, including scuba diving, during the previous year.

TOURISM RESEARCH AUSTRALIA SURVEYS OF INTERNATIONAL TOURIST ACTIVITY IN QUEENSLAND

Since 2006, Tourism Research Australia has consistently conducted annual surveys of international and national tourists who have visited various Australian States and Territories.16,17 The International Visitor Survey (IVS) samples annually 40,000 departing, short-term international visitors over 15 years of age. It is conducted in the departure lounges of major international airports and utilises computer-assisted personal interviewing. Participants are shown a list of activities which includes scuba diving and snorkelling. The survey results are weighted to data on international visitor numbers over the period, provided by the Department of Immigration and Citizenship, with the assistance of the Australian Bureau of Statistics.

In earlier research, based on the IVS, interviewees who indicated that they had been diving in Queensland in a 12-month period from April 2006 were given a supplementary questionnaire on the number of times they had dived.18 The resulting data were based on interviews with 1,685 scuba divers and indicated an average of 3.7 dives each. It was assumed that a similar number of dives per person could be applied for the years 2006–2014 and these figures were used to estimate the total number of dives conducted for these years and subsequently the per dive fatality rate.

As the IVS contains relatively few diving-related data for most parts of Australia, most were not investigated further due to the increased potential for measurement bias. However, on the advice of Tourism Australia (which oversees the surveys), the international visitor data for Queensland were assumed to be based on sufficiently large samples which ranged between 1,795 and 2,155 diver respondents annually from 2006 through 2014.

DIVE CHARTER OPERATOR

Data were collected from the largest dive charter operator in Victoria which has up to six boats of various sizes and conducts charters for divers, snorkellers and sightseers. It operates an average of four days per week and up to seven days in the summer months. Each dive is logged and scuba activity records from mid-2006 were available.

STATISTICAL ANALYSIS

Estimates were considered to be significantly different if their respective 95% confidence intervals did not overlap. Annual fatality rates (AFR) and 95% confidence intervals (CI) were calculated based on an exact binomial method as implemented in the Binomial Test in the R statistical package.19

Results

Over the 10-year period, the mean annual number of Australian residents who went scuba diving was 84,767 (95% CI 61,767–107,748). Between them, these participants conducted an average of 1,552,728 dives per year (95% CI 1,125,985–1,979,472). In total, there were 129 scuba diving-related fatalities in Australia from 2001–2014. These were both Australian residents and international tourists.
Table 2
ERASS-derived estimates of the number of divers and dives conducted, recorded deaths, and estimated AFRs 2001-10 (95% CI)

<table>
<thead>
<tr>
<th>Year</th>
<th>Sample size</th>
<th>Divers (residents)</th>
<th>Dives/person (Australians)</th>
<th>Dives</th>
<th>Deaths in Australia</th>
<th>Deaths overseas</th>
<th>Deaths total</th>
<th>Deaths/100K divers</th>
<th>Deaths/100K dives</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>13,640</td>
<td>79,379</td>
<td>18.7</td>
<td>1,484,387</td>
<td>11</td>
<td>0</td>
<td>11</td>
<td>13.86</td>
<td>0.74</td>
</tr>
<tr>
<td>2002</td>
<td>13,632</td>
<td>73,331</td>
<td>16.3</td>
<td>1,195,295</td>
<td>8</td>
<td>0</td>
<td>8</td>
<td>10.91</td>
<td>0.67</td>
</tr>
<tr>
<td>2003</td>
<td>13,644</td>
<td>90,592</td>
<td>21.2</td>
<td>1,920,550</td>
<td>6</td>
<td>0</td>
<td>6</td>
<td>6.62</td>
<td>0.31</td>
</tr>
<tr>
<td>2004</td>
<td>13,662</td>
<td>103,337</td>
<td>17.7</td>
<td>1,829,065</td>
<td>7</td>
<td>2</td>
<td>9</td>
<td>8.71</td>
<td>0.38</td>
</tr>
<tr>
<td>2005</td>
<td>13726</td>
<td>86,791</td>
<td>20.7</td>
<td>1,796,574</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>5.76</td>
<td>0.28</td>
</tr>
<tr>
<td>2006</td>
<td>13,710</td>
<td>76,035</td>
<td>12.1</td>
<td>920,024</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>6.58</td>
<td>0.18</td>
</tr>
<tr>
<td>2007</td>
<td>16,400</td>
<td>69,912</td>
<td>24.0</td>
<td>1,677,888</td>
<td>8</td>
<td>1</td>
<td>9</td>
<td>12.87</td>
<td>0.25</td>
</tr>
<tr>
<td>2008</td>
<td>17,293</td>
<td>90,200</td>
<td>17.2</td>
<td>1,551,440</td>
<td>6</td>
<td>1</td>
<td>7</td>
<td>7.76</td>
<td>0.45</td>
</tr>
<tr>
<td>2009</td>
<td>23,031</td>
<td>83,313</td>
<td>20.3</td>
<td>1,682,923</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>6.00</td>
<td>0.30</td>
</tr>
<tr>
<td>2010</td>
<td>21,603</td>
<td>94,783</td>
<td>15.5</td>
<td>1,469,137</td>
<td>7</td>
<td>2</td>
<td>9</td>
<td>9.50</td>
<td>0.28</td>
</tr>
<tr>
<td>Mean</td>
<td>16,034</td>
<td>84,767</td>
<td>18.4</td>
<td>1,552,728</td>
<td>6.8</td>
<td>0.6</td>
<td>7.4</td>
<td>8.73</td>
<td>0.48</td>
</tr>
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</table>

Table 3
Estimated AFRs by gender and age group based on ERASS data and recorded deaths (95% CI)

<table>
<thead>
<tr>
<th>Year</th>
<th>Sample size</th>
<th>Divers/person (Australians)</th>
<th>Dives</th>
<th>Deaths</th>
<th>Deaths/100K divers</th>
<th>AFR/100K dives</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>13,640</td>
<td>79,379</td>
<td>18.7</td>
<td>11</td>
<td>13.86</td>
<td>0.74</td>
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<td>2004</td>
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<td>103,337</td>
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<td>8.71</td>
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<tr>
<td>2005</td>
<td>13726</td>
<td>86,791</td>
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<td>5</td>
<td>5.76</td>
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<td>6.58</td>
<td>0.18</td>
</tr>
<tr>
<td>2007</td>
<td>16,400</td>
<td>69,912</td>
<td>24.0</td>
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<tr>
<td>2008</td>
<td>17,293</td>
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<tr>
<td>2009</td>
<td>23,031</td>
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<tr>
<td>2010</td>
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<td>0.28</td>
</tr>
<tr>
<td>Mean</td>
<td>16,034</td>
<td>84,767</td>
<td>18.4</td>
<td>6.8</td>
<td>8.73</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Table 4
Annual activity and fatality rates for international visitors in Queensland, 2006-13; * data for 2014 not included as fatality numbers for that year are not finalised

<table>
<thead>
<tr>
<th>Year</th>
<th>Divers</th>
<th>Dives</th>
<th>Fatalities</th>
<th>Fatalities/100K divers</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>236,327</td>
<td>874,410</td>
<td>2</td>
<td>0.00 (0.00−0.25)</td>
</tr>
<tr>
<td>2007</td>
<td>228,166</td>
<td>844,214</td>
<td>2</td>
<td>0.00 (0.00−0.25)</td>
</tr>
<tr>
<td>2008</td>
<td>220,836</td>
<td>817,093</td>
<td>0</td>
<td>0.00 (0.00−0.25)</td>
</tr>
<tr>
<td>2009</td>
<td>226,596</td>
<td>838,405</td>
<td>2</td>
<td>0.00 (0.00−0.25)</td>
</tr>
<tr>
<td>2010</td>
<td>222,704</td>
<td>824,005</td>
<td>2</td>
<td>0.00 (0.00−0.25)</td>
</tr>
<tr>
<td>2011</td>
<td>185,543</td>
<td>686,509</td>
<td>0</td>
<td>0.00 (0.00−0.25)</td>
</tr>
<tr>
<td>2012</td>
<td>197,867</td>
<td>732,108</td>
<td>0</td>
<td>0.00 (0.00−0.25)</td>
</tr>
<tr>
<td>2013</td>
<td>213,506</td>
<td>789,972</td>
<td>2</td>
<td>0.00 (0.00−0.25)</td>
</tr>
</tbody>
</table>

Table 5
Annual fatality rates (AFR) for SCUBA divers from the three data sources (95% CI); Qld – Queensland

<table>
<thead>
<tr>
<th>Group</th>
<th>Period (y)</th>
<th>Method</th>
<th>Dives</th>
<th>Divers</th>
<th>AFR per 100,000 dives</th>
<th>AFR per 100,000 divers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australian residents</td>
<td>2001−10</td>
<td>Survey</td>
<td>1,552,728</td>
<td>84,787</td>
<td>0.48 (0.37−0.59)</td>
<td>8.73 (6.85−10.96)</td>
</tr>
<tr>
<td>Qld International tourists</td>
<td>2006−13</td>
<td>Survey</td>
<td>800,840</td>
<td>216,443</td>
<td>0.12 (0.05−0.25)</td>
<td>0.46 (0.20−0.91)</td>
</tr>
<tr>
<td>Victorian operator</td>
<td>2007−14</td>
<td>Measured</td>
<td>15,235</td>
<td>–</td>
<td>1.64 (0.20−5.93)</td>
<td>–</td>
</tr>
</tbody>
</table>

Table 2 includes the ERASS-derived estimates of the number of active divers and the dives conducted from 2001−2010. In addition, it shows the number of Australian residents who died while scuba diving both in Australia and while overseas as recorded on the DAN AP database. The overseas fatalities are included as the ERASS survey did not ask where the diving was conducted and many Australian residents divers do some diving overseas.

According to the ERASS data, 76% of the divers were male, and approximately 30% were aged 45 years or older. By comparison, 59 (80%) of the 74 Australians who died while diving in Australia or overseas from 2001 through 2010 were male and 41 (70%) were aged 45 years or older. These data, along with the associated AFRs are shown in Table 3.

Table 4 shows the annual activity data, annual deaths of international visitors (based on DAN AP fatality data), and
Discussion

The AFRs from these three sources vary more than tenfold. This is likely due to differences in diving conditions and practices, data reliability, and possibly to some differences in diver characteristics. The denominators used as baselines for the AFR estimate calculations vary in reliability. The most accurate denominator was that from the dive operator in Victoria as it was measured rather than extrapolated from surveys. The AFR from this dive operator (1.64 per 100,000 dives) is lower than one based on a one-year Victorian tank fill survey and averaging fatalities over a five-year period (2.5 per 100,000 dives). The difference may indicate that diving with this operator is safer than general diving in Victoria or may reflect the divers who choose to dive with this operator. However, these two estimates lie within each other’s 95% confidence intervals so there may be no significant difference in the underlying risk.

Table 5 provides a summary of the annual fatality rate estimates derived from the three sources.

LIMITATIONS

Comparisons between estimates from different data sources would usually be age/sex-adjusted to reduce possible confounding effects of different age/sex distributions. However, age/sex-specific data were not available from the IVS and the dive operator in Victoria so no age/sex standardisation was possible. Hence comparison of results may be influenced by different age/sex distributions in the populations.

Although commonly utilised by researchers to provide a denominator for a variety of sporting activities in Australia, the ERASS, as with most surveys, has several limitations. These include:

- Based on a relatively small sample, it is subject to sampling error. However, with the national diving data, the mean relative standard error was 14% (range 12–15%) indicating that the annual sample should be sufficiently reliable.
- It is retrospective and subject to recall bias. However, the participants were surveyed about activities in the previous year so the elapsed time was not substantial.
- The response rate in 2010 was 17.6% which may have introduced selection bias.
- Until 2010, the survey only included ‘landlines’ and not mobile phones. This raises the concern of selection bias resulting from mobile-only households being excluded from the previous years’ samples, mainly associated with the likely younger age of the residents.
The proportion of Australian residents living in mobile-only households increased from 5% in 2005 to 13% in 2010. This may have led to under-reporting of the dives conducted by younger divers who tend to only have mobile phones.

- The ERASS surveys did not include divers who were younger than 15 years old. However, these divers likely represented a small proportion of divers (< 1%) and their exclusion should have little effect on the overall results. In addition, there were no deaths of divers younger than 15 years in Australia during that period.

Despite these limitations, the annual ERASS surveys appear to provide the best available national estimates of the scuba diving activity of Australian residents during the period of study.

As with most surveys, the results of the IVS are based on samples, rather than a census of visitors and are therefore subject to sampling error. However, the relative standard error for the number of participants was approximately 3.5%, indicating that sampling error was not a major barrier to their use. Given that most visitors would have stayed in Australia for a relatively short period, recall bias should have been small. Recall bias would have been further reduced given that many of the scuba divers had come specifically to dive. Like the ERASS survey, the Tourism Australia surveys did not include persons younger than 15 years.

Despite accurate denominator data from the operator in Victoria, over the eight-year period there were very few fatalities. This would have reduced the reliability of the estimate, as indicated by the wide confidence intervals. In addition, the results of a single operator may not be representative of the diving fatality rate throughout Victoria.

Conclusions

It is difficult to obtain substantial and reliable data on the diving activity and, therefore, AFRs in Australia. The only measured denominator data currently available comes from a 1994 Victorian tank fill survey and the activity logs of a single dive operator in Victoria from 2007 through 2014. Other denominator data are based on surveys, with their inherent limitations. On the basis of the information currently available, the diving fatality rate in Australia appears to vary by State, with the estimated rate in Queensland being considerably lower than the estimated rate in Victoria or for Australia overall, which may be partly explained by generally more favourable conditions and/or local diving regulations. These rates are similar to or lower than comparable data from overseas, although reliability of all such estimates varies with the size and accuracy of numerator and denominator data. More research is required to further improve diving activity data collection so that risk estimates can be more accurately determined.

References

15 Committee of Australian Sport and Recreation Officials (formerly Standing Committee on Recreation and Sport).


**Acknowledgements**

We are very grateful to the Victorian dive operator for providing its diving data, and to Tourism Research Australia providing data and assistance.

**Conflicts of interest and funding**

John Lippmann is the Founder and Chairman of DAN AP. DAN is involved in the collection and reporting of dive accident data and provides evacuation cover and dive injury insurance to recreational divers. This study was funded by DAN AP.

**Submitted:** 01 August 2016; revised 28 September 2016

**Accepted:** 10 October 2016

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**Address for correspondence:**

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Ashburton, VIC 3147
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johnl@danap.org
# AUTHORSHIP STATEMENT

## 1. Details of publication and executive author

<table>
<thead>
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<th>Title of Publication</th>
<th>Publication details</th>
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<tr>
<td>Name of executive author</td>
<td></td>
</tr>
<tr>
<td>School/Institute/Division if based at Deakin; Organisation and address if non-Deakin</td>
<td>Email or phone</td>
</tr>
<tr>
<td>John Lippmann</td>
<td>School of Health &amp; Social Development, Faculty of Health</td>
</tr>
</tbody>
</table>

## 2. Inclusion of publication in a thesis

<table>
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<th>If Yes, please complete Section 3 If No, go straight to Section 4.</th>
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## 3. HDR thesis author’s declaration

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<th>Name of HDR thesis author if different from above. (If the same, write “as above”)</th>
<th>School/Institute/Division if based at Deakin</th>
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<td></td>
<td>School of Health &amp; Social Development</td>
<td>Analysis of Australian Diving-related deaths</td>
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</table>

If there are multiple authors, give a full description of HDR thesis author’s contribution to the publication (for example, how much did you contribute to the conception of the project, the design of methodology or experimental protocol, data collection, analysis, drafting the manuscript, revising it critically for important intellectual content, etc.)

JL conceived the project, contributed to design of methodology (>80%), collected the data, performed majority of analysis (>75%), drafting and revising the manuscript (>80%)

*I declare that the above is an accurate description of my contribution to this paper, and the contributions of other authors are as described below.*

Signature and date: [Redacted by Library]

## 4. Description of all author contributions

<table>
<thead>
<tr>
<th>Name and affiliation of author</th>
<th>Contribution(s) (for example, conception of the project, design of methodology or experimental protocol, data collection, analysis, drafting the manuscript, revising it critically for important intellectual content, etc.)</th>
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<tbody>
<tr>
<td>A/Prof Chris Stevenson</td>
<td>Contributed to the analysis, drafting and revising of manuscript</td>
</tr>
<tr>
<td>Prof David Taylor</td>
<td>Contributed to the analysis, drafting and revising of manuscript</td>
</tr>
<tr>
<td>A/Prof Jo Williams</td>
<td>Contributed to the drafting and revising of manuscript</td>
</tr>
</tbody>
</table>
5. Author Declarations

I agree to be named as one of the authors of this work, and confirm:

i. that I have met the authorship criteria set out in the Deakin University Research Conduct Policy,

ii. that there are no other authors according to these criteria,

iii. that the description in Section 4 of my contribution(s) to this publication is accurate,

iv. that the data on which these findings are based are stored as set out in Section 7 below.

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v. consent to the incorporation of the publication into the candidate’s HDR thesis submitted to Deakin University and, if the higher degree is awarded, the subsequent publication of the thesis by the
university (subject to relevant Copyright provisions).

<table>
<thead>
<tr>
<th>Name of author</th>
<th>Signature*</th>
<th>Date</th>
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<td>12/09/2017</td>
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<td>A/Prof Jo Williams</td>
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6. Other contributor declarations

I agree to be named as a non-author contributor to this work.

* If an author or contributor is unavailable or otherwise unable to sign the statement of authorship, the Head of Academic Unit may sign on their behalf, noting the reason for their unavailability, provided there is no evidence to suggest that the person would object to being named as author.

7. Data storage

The original data for this project are stored in the following locations. (The locations must be within an appropriate institutional setting. If the executive author is a Deakin staff member and data are stored outside Deakin University, permission for this must be given by the Head of Academic Unit within which the executive author is based.)

<table>
<thead>
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<td>01 August 2016</td>
<td></td>
</tr>
</tbody>
</table>

This form must be retained by the executive author, within the school or institute in which they are based.

If the publication is to be included as part of an HDR thesis, a copy of this form must be included in the thesis with the publication.
The safety of a scuba diver can be influenced by a broad range of factors present before, during, and sometimes after the dive. Such factors can include health and fitness; organisation and planning, communication and supervision; equipment problems; decisional factors; and various environmental factors, among others.

An incident usually involves a trigger which often leads to a cascade of related events, some precipitated by the diver and some circumstantial, and which may lead to morbidity or mortality. Preceding the trigger may be factors which predisposed to such an event.

Several studies of diver fatalities have utilised a ‘chain of events’-type analysis to depict the suspected sequence of events within the accident.\textsuperscript{9, 13, 148-155, 164} This paper is a refinement of previous approaches and enables a more consistent analysis by, and between, investigators.

The results of this analysis will be used to address Thesis Aim 4 - “Create an improved template for the analysis of a scuba diving accident”. This in turn will inform both Research Question 1 – “What are the underlying factors associated with scuba diving-related mortality in Australia?”, and Research Question 2 – “What are the implications for preventative strategies”.

The study has resulted in the following published paper.\textsuperscript{224}
Chain of events analysis for a scuba diving fatality

John Lippmann1,2, Christopher Stevenson2, David McD Taylor3,4, Jo Williams2, Mohammadreza Mohebbi5

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Abstract

Introduction: A scuba diving fatality usually involves a series of related events culminating in death. Several studies have utilised a chain of events-type analysis (CEA) to isolate and better understand the accident sequence in order to facilitate the creation of relevant countermeasures. The aim of this research was to further develop and better define a process for performing a CEA to reduce potential subjectivity and increase consistency between analysts.

Methodology: To develop more comprehensive and better-defined criteria, existing criteria were modified and a template was created and tested using a CEA. Modifications comprised addition of a category for pre-disposing factors, expansion of criteria for the triggers and disabling agents present during the incident, and more specific inclusion criteria to better encompass a dataset of 56 fatalities. Four investigators (raters) used both the previous criteria and this template, in randomly-assigned order, to examine a sample of 13 scuba diver deaths. Individual results were scored against the group consensus for the CEA. Raters’ agreement consistency was compared using the Index of Concordance and intra-class correlation coefficients (ICC).

Results: The template is presented. The index of concordance between the raters increased from 62% (194/312) using the previous criteria to 82% (257/312) with use of this template indicating a substantially higher inter-rater agreement when allocating criteria. The agreement in scoring with and without template use was also quantified by ICC which were generally graded as low, illustrating a substantial change in consistency of scoring before and after template use.

Conclusion: The template for a CEA for a scuba diving fatality improves consistency of interpretation between users and may improve comparability of diving fatality reports.

Introduction
Some accident investigations utilise a root cause analysis (RCA) technique. This follows the ‘domino mechanism’1 whereby an initial causal factor leads to other factors ending in injury or death. However, it can be difficult to determine a single causal factor as the more thoroughly an incident is investigated, the more potential causal factors appear.2

A scuba diving fatality usually involves a series of related events culminating in death. Identification of various contributory factors is hampered by the reality that most diving incident reports are relatively sparse on detail. Given the difficulty in tracking a root cause, such an analysis is more appropriately described and conducted as a ‘chain of events’ or ‘sequential analysis’ where there may be multiple possibilities at some of the stages.

The process of chain of events analysis (CEA) was first applied to diving incidents in the examination of 947 fatalities in the USA.3 The incident sequence was divided into four components: (1) the trigger; (2) the disabling agent; (3) the disabling injury and (4) the cause of death. Later, CEA was applied to a series of 351 Australian compressed-gas diving fatalities.4 Modifications included the re-defining of several subcategories within the four major categories of the CEA to better reflect the available data. Subsequently, others have used similar categories for their analyses.5 However, in the absence of definitive criteria, there is a potential for subjectivity in the categorisation of events.
and classifications can vary substantively from case to case and study to study. A detailed breakdown of predisposing factors, triggers, disabling agents and disabling injuries are presented in Tables 1–4.

To minimise subjectivity and increase consistency between investigators, it is important to carefully define the CEA categories. The aim of this study was to design a template to assist researchers to more objectively categorise the components of a CEA and so facilitate greater compatibility within and between diving incident studies. Where sufficient information is available, the template also provides the opportunity to identify and include some of the human factors which may have influenced events prior to the dive and during some segments of the chain of events. More consistent reporting will help to better inform the diving industry of various contributors to diving injuries and so enable the identification of appropriate countermeasures to help mitigate future deaths.

Table 1
Predisposing factors for a scuba diving fatality

Predisposing factors

Definition: A predisposing factor (as used here) is a relevant factor that was present prior to the dive, and/or prior to the trigger occurring, and which is believed to have predisposed to the incident and/or to key components in the accident chain (e.g., the trigger or disabling agent).

Health-related: May include factors such as a history of cardiovascular disease, epilepsy, diabetes as well as factors such as mental or physical fatigue.

Organisational/training/experience/skills-related: Includes factors that may have impacted a diver’s practical readiness to dive. Factors such as the suitability of training course design and conduct and the overall dive organisation by a dive operator are included as well as the level of skill and/or experience of the diver relevant to the circumstances.

Planning-related: Applies to obviously poor pre-dive planning decisions, whether made well before the dive or immediately prior. This includes factors such as a decision to dive in conditions that were obviously unsuitable, or should have reasonably have been assessed as unsuitable or a decision to dive alone, among others.

Poor communication or coordination: If communication between buddies and/or the dive supervisor (prior to or during the dive) is poor, the opportunity of misunderstandings and unexpected and inappropriate actions is increased.

Absence of appropriate equipment; using obviously faulty equipment: Although this is somewhat planning-related, this particular category is equipment-specific.

Activity-related: Some activities (e.g., spearfishing/seafood collecting, penetration diving) are associated with particular inherent risks. For example, spearfishing is well known to attract sharks and can predispose to an accident triggered by the arrival of an aggressive shark. Penetration diving can predispose to an incident triggered by entrapment.

Unsafe supervision: This can apply to supervision by the divemaster overseeing a dive, an instructor supervising students or to a diver’s interactions with his buddy.

Other: Includes anything that cannot appropriately be allocated to one of the defined categories. This category should be used sparingly and only after a serious attempt to utilise an existing category.

Unknown/none: There is insufficient information on which to make a reasonable suggestion of a possible predisposing factor.

Methods

Access to data for this study was approved by the Justice Human Research Ethics Committee, Department of Justice, Victoria, Australia (No. CF/06/31). The program of research was also approved by the Human Research Ethics Committee at Deakin University, Victoria, Australia (No. 2013-210).

TEMPLATE CREATION

Each of the 54 Australian scuba diving fatalities from 2004 to 2010 was re-examined and a CEA applied, using the previous criteria. A sequence category of ‘pre-disposing factors’ was added, the criteria for the other sequential event categories were expanded, and more specific inclusion criteria were created to better encompass the dataset. As a result, a broader yet better-defined template for the CEA was constructed.
TEMPLATE ASSESSMENT AND ADJUSTMENT

The resulting template was subsequently utilised by four investigators experienced in analysing diving deaths in the examination of 13 of the 14 scuba diving fatalities that occurred in Australia in 2011, for which the usual coronial reports were available at the time. The process involved the following steps:

- Careful scrutiny of the available data on the relevant medical and diving history of the victim and circumstances of each incident;
- consideration of the possible causative factors and chain of events;
- comparison with the categories and subcategories of the available template;
- selection and recording of the preferred categories and subcategories.

For example, in deciding whether there were any potential predisposing factors, the investigator considered the victim’s health, training, experience and skills as well as the planning and supervision of the dive, the equipment used and the nature of the activity. If there was no obvious predisposing factor, it was marked as ‘unknown/none’. If a possible factor was identified which did not align with a defined category, it was allocated to ‘Other’ and noted for further consideration of template modification.

Two investigators were randomly assigned to perform an initial analysis of each incident without using the template (but using the previous criteria). The other two used the template. Subsequently, the roles were reversed and those who initially used the template were asked to conduct a second analysis using the original criteria, while the others used the template. Analyses were conducted two to four weeks apart. All results were collated, discussed and a consensus was reached for the final CEA to be used with this fatality series. The template was further adjusted to reflect feedback received and the final template is presented under results.

The Index of Concordance (IC) between investigators was calculated with and without template use. The IC is defined as the number of inter-rater agreements divided by the number of coding attempts and multiplied by 100 to yield a percentage. The IC between investigators when using the template was calculated and an IC of greater than 70% was taken as indicating agreement. In addition, each rater’s selection was compared to the consensus selections and graded either ‘1’ if in agreement or ‘0’ if not. In this manner, a score of 0–4 (0 = no agreement; 4 = all raters matched consensus) was given for each of the categories for each incident. These scores were summed to create a total incident score.

The Intraclass Correlation Coefficient (ICC(2)) was calculated for each category of the CEA and for the total incident score, comparing these scores with and without use of the template. In a repeated measures ANOVA involving four raters and 13 subjects, ICC(2) assumes both raters and subjects are random effects. Cut-off values of < 0.7, 0.7–0.9 and > 0.9 have been considered as poor, acceptable and good agreement.

Results

TEMPLATE DESCRIPTION

The major sequence categories and their definitions in this CEA were as follows:

- **Predisposing factor:** A relevant factor(s) that was present prior to the dive, and/or prior to the trigger occurring, and which was believed to have predisposed to the incident and/or to key components in the accident chain (e.g., the trigger or disabling agent);
- **Trigger:** The earliest identifiable event that appeared to transform an unremarkable dive into an emergency;
- **Disabling agent:** An action or circumstance (associated with the trigger) that caused injury or illness, e.g., an action of the diver or other persons, function of the equipment, effect of a medical condition or a force of nature;
- **Disabling injury:** Injury or condition directly responsible for death or incapacitation followed by death from drowning;
- **Cause of death:** As specified by the medical examiner, which could be the same as the disabling injury or could be drowning secondary to injury.

Note that, although the disabling injury is often more informative in determining why the diver became incapacitated, the actual cause of death can sometimes provide important information for preventative and emergency management strategies.

Suggested sub-categories for each of the categories are shown in Tables 1−4, whilst Table 5 provides illustrative examples of how these taxonomies may be used. Figure 1 provides a summarised flowchart for a CEA.

TEMPLATE ASSESSMENT

The index of concordance between the raters when using the template was 82% (257/312) compared with 62% (194/312) when not using it. This absolute IC difference of 20% is substantial and clinically significant. Table 6 shows the comparison of the raters’ agreement with and without template use for each scuba-related category and total score.

Table 7 shows the mean and standard deviation (SD) scores with each category of the CEA both with (T) and without (NT) template use, as well as the ICC(2) for each category and for the total scores. As it is illustrated, all post-template mean scores are higher with smaller SDs, indicating a higher agreement and less between-raters heterogeneity. Three out of four categories had poor agreement consistency, with an
Triggers
Definition: A trigger (as used here) is the earliest identifiable event that appeared to transform an unremarkable dive into an emergency.

Environment-related: Relates to the diving environment and may arise from the topography or conditions of the dive site itself or as a result of contact with other users or inhabitants.
• Conditions
  Water – e.g., difficulty in dealing with current, swell, surge, chop, water outflow/inlet; visibility, temperature;
  Weather – e.g., problem arising from rain, wind, lightning;
• Marine animal contact – e.g., aggression from shark;
• Watercraft-related – e.g., boat impact, propeller injury;
• Entrapment – e.g., tangled in line or net, disoriented in cave or wreck;
• Events triggered from the direct effects of immersion, submersion and/or sensory deprivation, e.g., cardiac arrhythmia.

Equipment-related: Includes a problem with any item of the diver’s equipment that precipitates an accident. The list below is not exhaustive and other equipment may trigger an accident and so can be included.
• Regulator, surface-supplied breathing apparatus or rebreather functional problem leading to gas supply reduction or interruption;
• Buoyancy compensator device (BCD) failure – e.g., sticky inflator, dump valve failure but not including its misuse;
• Weights-related – e.g., unintentional release, unable to be released but not including over- or under-weighting from the outset of the dive;
• Mask – e.g., leak, broken strap, broken/displaced lens;
• Fins – e.g., poor fit, broken strap, loss of fin;
• Exposure suit – e.g., tight wetsuit, flooded drysuit but not including drysuit ‘blow-up’;
• Cylinder – e.g., valve-failure, slippage but not including problems from gas content or valve insufficiently opened;
• Faulty depth or contents gauge;
• Hose failure;
• Breathing hose entanglement.

Gas supply-related: Includes any problem relating to the on-going supply, purity and suitability of the breathing gas but not loss of gas supply due to equipment failure.
• Inappropriate breathing gas mixture;
• Contamination;
• Exhaustion of breathing gas supply.

Buoyancy-related: Includes buoyancy problems generally related to poor knowledge or skills but not problems arising from equipment failure. It includes factors such as:
• Overweighted or underweighted;
• Poor skills;
• Drysuit ‘blow-up’;
• Loss of buoyancy control arising from deployment of surface marker buoy.

Exertion-related: Includes problems arising from situations such as carrying equipment, exiting the water post-dive, dragging a heavy object underwater, etc. but not exertion as a result of sea conditions.

Anxiety/stress-related: Anxiety/stress can often be associated with diving, especially in the relatively inexperienced, and can be a trigger for an accident. However, in order for this to be listed as a trigger, it cannot be assumed but must have been observed and reported by a witness.

Primary diver error: Diver error, which is an inherent part of many diving accidents, can be a precursor to or the actual trigger in a sequence. It can be closely associated with another trigger(s) and, in such cases, can be reported in combination.

Other: Includes anything that cannot appropriately be allocated to one of the defined categories. This category should be used sparingly and only after a serious attempt to utilise an existing category.

Unknown: There is insufficient information on which to make a reasonable suggestion of a possible trigger(s).
Disabling agents

Definition: A disabling agent (as used here) is an action or circumstance (associated with the trigger) that caused injury or illness. It may be an action of the diver or other persons, reaction of the equipment, effect of a medical condition or a force of nature.

Gas supply-related: Includes any problem relating to the on-going supply, purity and suitability of the breathing gas but not loss of gas supply due to equipment failure.
- Inappropriate breathing gas mixture;
- Contamination;
- Exhaustion of breathing gas supply.

Ascent-related: Includes any problem that was likely precipitated by or associated with the ascent from a dive. This may include but is not restricted to:
- Breath holding during ascent;
- Gas sharing during ascent;
- Rapid ascent.

Medical-related: Includes any problem that was likely precipitated by or associated with a pre-existing or imminent medical condition (which may or may not be the same as the disabling injury). It may include but is not restricted to:
- Cardiovascular disease;
- Other medical condition.

Buoyancy-related: Includes buoyancy problems related to poor knowledge or skills and secondary to some trigger. It can also include loss of buoyancy control subsequent to equipment failure (e.g., loss of buoyancy subsequent to a faulty BCD).
- Inadequate buoyancy control underwater;
- Lack/loss of buoyancy on surface;
- Drysuit ‘blow-up’ subsequent to equipment failure.

Environment-related: Includes problems where a diver is disabled as a result of environmental circumstances such as:
- Adverse sea conditions;
- Entrapment – this entrapment is secondary to an initial trigger such as narcosis, silting, poor buoyancy or surge. It often leads to exhaustion of the breathing gas (in which case, the disabling agent is recorded as environmental – entrapment, then out of breathing gas.
- Impact with watercraft, rocks, reef;
- Dangerous marine animal contact (e.g., shark attack).

Equipment-related: Includes a consequence of a problem associated with an item of the diver’s equipment, but secondary to some accident trigger.

Other: Includes anything that cannot appropriately be allocated to one of the defined categories. This category should be used sparingly and only after a serious attempt to utilise an existing category.

Unknown: There is insufficient information on which to make a reasonable suggestion of a possible disabling agent.

Discussion

In this study, the use of the template improved consensus in the evaluation of the diving fatalities as indicated by the large increase in IC when using the template. This was supported by the relatively low ICC(2) ratings which indicate a marked difference in scoring (consistency of agreement) with and without template use. An ICC of 0.70–0.90 may be acceptable for use in research purposes but not for policy-making.17

An advantage of using ICC(2) to compare measurement methods is that it can be used when the measurements are given on different scales or metrics, as the ICC(2) is a dimensionless ratio. Because reliability depends on the heterogeneity of the true error-free values in the sampled population, it is essential that reliability
In a study of 1,000 (mainly non-fatal) diving incidents, The Diver Incident Monitoring Survey (DIMS) reported that 87% of the incidents were associated with diver error. Given the inhospitable environment in which diving takes place, in addition to adequate health and fitness, the foundation for safe diving includes ‘human factors’ such as adequate knowledge and skill acquisition and retention and clear, often rapid decision-making. A CEA may provide a useful tool to identify ‘how’ an incident occurred, i.e., the sequence of events in the dive incident itself. However, preceding and/or underlying many of the components in such an analysis is the potential for diver error or inappropriate behaviour from human factors.

Using techniques from research into aviation accidents, a Human Factors Analysis and Classification System (HFACS) was applied to recreational scuba diving incidents in an attempt to determine ‘why’ they occurred. The Diver Incident Monitoring Survey (DIMS) reported that 87% of the incidents were associated with diver error. Given the inhospitable environment in which diving takes place, in addition to adequate health and fitness, the foundation for safe diving includes ‘human factors’ such as adequate knowledge and skill acquisition and retention and clear, often rapid decision-making. A CEA may provide a useful tool to identify ‘how’ an incident occurred, i.e., the sequence of events in the dive incident itself. However, preceding and/or underlying many of the components in such an analysis is the potential for diver error or inappropriate behaviour from human factors.

Although the disabling injury is often more informative in determining why the diver became incapacitated, the actual cause of death can sometimes provide important information for preventative and emergency management strategies.

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<th>Table 4</th>
<th>Disabling injuries and causes of death</th>
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**Disabling injuries**

**Definition:** A disabling injury (as used here) is directly responsible for death or incapacitation followed by death from drowning.

**Asphyxia:** Asphyxia with or without aspiration of water and with no indication of a prior disabling injury

**Cerebral arterial gas embolism:** Gas in the cerebral arteries with or without evidence of lung rupture

**Cardiac:** Acute chest discomfort indicated by the diver, history of cardiac disease, or autopsy findings

**Trauma:** Witnessed trauma, traumatic findings at autopsy

**Other medical:** Stroke, gastrointestinal haemorrhage, carbon monoxide toxicity, etc

**Other:** This includes anything that cannot appropriately be allocated to one of the defined categories. This category should be used sparingly and only after a serious attempt to utilise an existing category.

**Unknown:** Body not recovered; no autopsy available; no indications of disabling injury at autopsy

**Cause of death**

**Definition:** The cause of death is that specified by the medical examiner, which could be the same as the disabling injury or could be drowning secondary to injury.

Although factors such as experience and medical history, where known, are included, the traditional sequential analysis for diving-related injury largely failed to address other human factors often associated with such incidents.

In a study of 1,000 (mainly non-fatal) diving incidents, The Diver Incident Monitoring Survey (DIMS) reported that 87% of the incidents were associated with diver error. Given the inhospitable environment in which diving takes place, in addition to adequate health and fitness, the foundation for safe diving includes ‘human factors’ such as adequate knowledge and skill acquisition and retention and clear, often rapid decision-making. A CEA may provide a useful tool to identify ‘how’ an incident occurred, i.e., the sequence of events in the dive incident itself. However, preceding and/or underlying many of the components in such an analysis is the potential for diver error or inappropriate behaviour from human factors.

Using techniques from research into aviation accidents, a Human Factors Analysis and Classification System (HFACS) was applied to recreational scuba diving incidents in an attempt to determine ‘why’ they occurred. The HFACS comprised two major divisions: ‘active failures’ (unsafe acts) which involved “diver error”, and ‘latent failures’, which included factors that occurred prior to the incident and which influenced the active failure. A “Swiss cheese model” was used to argue that a dive incident does not simply result from diver error alone but is ultimately the result of the alignment of several ‘holes’ in each of the layers of latent and active failures.

This protocol is more readily applicable to non-fatal incidents where greater detail is often available and where the diver
Predisposing Factors

Health-related:
- A diver with significant cardiovascular disease may be predisposed to a cardiac event with immersion and/or exertion.
- A diver who is intoxicated is at an increased risk of making poor decisions.

Organisational/training/skills-related:
- A dive organisation offers services to non-English-speaking (NES) clientele. A NES group booked for a dive and no arrangements were made to translate the dive briefing into the clients’ language. As a result, several divers act contrary to the brief and one subsequently dies.
- A person untrained or poorly trained in the use of a buoyancy compensator device may be more likely to have a buoyancy-related problem, so triggering an accident.

Planning-related:
- A diver went diving alone and without a lookout to retrieve a craypot. He became entangled in a line and was unable to free himself.
- When two divers arrived at their planned dive site, although there were large waves constantly breaking over the entry and exit points from the rocks, they decided to dive there anyway. When trying to enter the water, one diver was swept off the ledge, struck his head on rocks and drowned.

Poor communication or co-ordination:
- One of a buddy pair was aware of a strong current on the other side of a ‘swim-through’, but failed to communicate this to the other, who subsequently swam into the current and was swept away.

Absence of appropriate equipment or using obviously faulty equipment:
- A diver who dives without a BCD may be predisposed to a buoyancy-related problem.
- A diver who dives with air from a faulty or poorly maintained compressor may be predisposed to contaminated air.

Unsafe supervision:
- Poor supervision by the divemaster and/or buddy may result in an inexperienced diver entering the water without all equipment in place and functional and so predispose to an accident.

Triggers

Environment-related:
- A diver got into difficulties while struggling to make headway against a strong current.
  Trigger = Environment-related (current)
- A spearfisherman was confronted by an aggressive shark.
  Predisposing: Activity-related (collecting seafood).
  Trigger = Environment-related (shark)
- A diver breathing air at a depth of 55 metres’ sea water was suffering severe narcosis, misread his contents gauge and ran out of air.
  Predisposing: Activity-related (deep air diving)
  Trigger = Environment-related (narcosis at depth)

Equipment-related:
- A diver’s BCD inflator became stuck open resulting in a buoyant ascent.
  Trigger = Equipment-related (sticky BCD inflator)
- A diver’s regulator failed, causing a loss of air supply.
  Trigger = Equipment-related (regulator failure)

Gas supply-related:
- A technical diver using a rebreather became unconscious at depth due to hypercapnia resulting from overloading of the CO2 scrubber.
  Predisposing = Faulty equipment (CO2 scrubber inadequate)
  Trigger = Gas supply-related (CO2 scrubber exhausted)
- A diver ran out of breathing gas while trying to complete required decompression and was forced to make a rapid ascent.
  Predisposing = Poor planning (unless something unpredictable occurred)
  Trigger = Gas supply-related (out of gas)

Buoyancy-related:
- After deploying his surface marker buoy (SMB), a diver became entangled in its line and was dragged to the surface.
  Trigger = Buoyancy-related (SMB entanglement)
- An inexperienced drysuit user became inverted, was unable to dump air from the suit and had an uncontrolled ascent.
  Predisposing = Experience-related (inexperienced)
  Trigger = Buoyancy-related (drysuit blow-up)

Exertion-related:
- A (healthy) diver collecting abalone became exhausted and distressed while dragging his heavy catch bag and then
struggled to stay afloat on reaching the surface.
  Trigger = Exertion-related (heavy catch bag)

**Anxiety/stress-related:**

- A student on an introductory dive was seen to panic and rush to the surface after encountering a large stingray.
  Predisposing = Experience-related (inexperience)
  Trigger = Anxiety/stress-related (panic from stingray encounter)

**Primary diver error:**

- A rebreather diver on the surface forgot to turn off her bailout valve before removing her mouthpiece. Water entered the scrubber and when she replaced the mouthpiece and breathed from the unit she suffered a ‘caustic cocktail’.
  Trigger = Diver error (equipment-related)

- A diver forgot to open his tank valve before jumping in. Being negatively buoyant, he sank without an available air supply.
  Trigger = Diver error (gas supply-related)

**DISABLING AGENTS**

**Gas supply-related:**

- A diver became entangled in a line inside a wreck, was unable to free herself and ran out of air.
  Predisposing = Activity-related (wreck penetration)
  Trigger = Environmental (entanglement)
  Disabling agent: Gas supply-related (out of gas)

**Ascent-related:**

- A preoccupied underwater photographer failed to check his air, ran out of air, held his breath during ascent and suffered a pulmonary barotrauma.
  Trigger = Gas-supply-related (out of air)
  Disabling agent: Ascent-related (breath-holding)

**Medical-related:**

- Faulty oxygen sensors in a rebreather enabled the PO$_2$ to rise sufficiently to cause a hyperoxic convulsion in the diver.
  Predisposing = Equipment fault (old/poorly-calibrated oxygen sensors)
  Trigger = Gas supply-related (incorrect breathing gas mix from sensor failure)
  Disabling agent: Medical-related (hyperoxic convulsion)

- A diver with a history of epilepsy is seen to become unconscious and have a seizure during a shallow air dive.
  Predisposing = Health-related (epilepsy)
  Trigger = Environmental (sensory effects)
  Disabling agent: Medically-related (seizure)

**Buoyancy-related:**

- A diver surfaced in rough conditions after losing a fin due to a broken fin strap. He was negatively buoyant, failed to replace his regulator, inflate his BCD or ditch weights and was swamped by a wave and sank.
  Trigger = Equipment-related (torn fin strap)
  Disabling agent: Buoyancy-related (lack of buoyancy on surface)

- A drysuit inflator stuck open causing over-inflation and inversion in the water. During the process, the diver aspirated some water and became unconscious.
  Trigger = Equipment-related (drysuit inflator malfunction)
  Disabling agent: Buoyancy-related (inversion underwater)

**Environment-related:**

- A diver lost control of her buoyancy, ascended into and became entangled in the shotline and subsequently ran out of air.
  Trigger = Buoyancy-related (poor buoyancy control)
  Disabling agent: Environment - entrapment (out of air)

- A diver in rough water was thrown against rocks by a large wave, hit his head and became unconscious.
  Trigger = Environmental (rough conditions)
  Disabling agent: Environmental (head impact with rocks)

- An abalone diver was approached and subsequently attacked by a shark.
  Predisposing = Activity-related (collecting seafood)
  Trigger = Environmental (aggressive shark)
  Disabling agent: Environmental – shark attack

**Equipment-related:**

- A rebreather diver on the surface momentarily forgot to turn off her bailout valve before removing her mouthpiece, enabling water ingress. The water entered the scrubber and when she replaced the mouthpiece and breathed from the unit she suffered a ‘caustic cocktail’.
  Trigger = Diver error (equipment-related).
  Disabling agent: Equipment-related (‘caustic cocktail’).
can provide feedback and personal insight into the various human factors involved. However, sometimes witness reports and other background information can indicate where, and which human factors contributed to the cascade of events leading to the death of a diver. So the addition of known or reasonably suspected human factor considerations to a CEA of diving fatalities is valuable in order to obtain a fuller picture of the entire scenario. Such human factors include pre-existing health conditions, inadequate training and skills, inappropriate/poorly-functional equipment; or more deeply-rooted organisational problems that may underpin some of these. An example of an underlying organisational problem is an inadequate training focus and practice in weight-ditching. Given the large number of diving fatality victims whose bodies are found with their weights still in situ,\textsuperscript{5,23} this is an important area to address from training agency level down.

Another important organisational-level consideration is improved education about how certain co-existing conditions can impact on diving safety. Pre-certification diving medical examinations are now uncommon in many countries, with an increasing reliance on a diver to honestly and accurately answer a self-reporting medical questionnaire. This places a greater onus on dive professionals and existing or intending divers to understand the questions and the associated implications, and to take these seriously and act accordingly. This has become increasingly evident with the increasing representation of divers with pre-existing medical conditions (especially cardiac-related) and older divers in dive fatality reports.\textsuperscript{4,13,24}

In reality, multiple factors, discrete or linked, may simultaneously influence an action or circumstance within an incident. It is important for the investigator to logically and systematically consider all possibilities and influences when trying to determine a possible sequence of events. This can be a daunting task, prone to substantial subjectivity and variation between investigators.

When developing this template, one of the main aims was to reduce the variability in categorisation in existing protocols in order to make determinations more uniform between assessors and so increase comparability both within and between studies. This was done by increasing specificity within the categories. In addition, where possible, the categories were designed to be mutually exclusive and as encompassing as practicable to minimise the need to record a component as ‘other’ and so improve the consistency.\textsuperscript{25}

A certain degree of subjectivity is inescapable given the frequent gaps in the information available to diving
incident investigators. However, by creating taxonomies that achieve reasonable consensus between users, subjectivity is reduced. To this end, it remains important to test the consistency between users when allocating events using such taxonomies. There are a variety of suggested methods for determining this but the IC is reportedly the industry standard for use with safety data.26

The study did highlight several minor categorisation problems, which were adjusted in the template presented here. Undoubtedly, more improvements will be identified with further use and the template will need to be modified accordingly. Users are encouraged to send feedback to the corresponding author.

LIMITATIONS

There was likely a net learning effect to both the raters who used the template first and those who did not. Despite the delay between allocations, those who did not use it initially may have been more familiar with the case by the time they re-examined it. Similarly, those who used it first may have recollected some of the categorisation within the template. The template allocations were mixed in an attempt to balance these issues and likely served to narrow the difference between allocations with and without the template. Given the limited information that is often available, and the continued challenges associated with the subjectivity and categorisation of aspects of diving deaths, there will inevitably be variation between reporters.

Conclusions

A CEA can be useful in diving fatality investigations to identify the likely sequences of events that lead to the divers’ demise. However, there is often limited information on which to base such an analysis and this can lead to substantial variation in the interpretation of events by different investigators. An effective template for allocating the components of a chain of events may be useful in reducing the variability between investigators within a study and increase the comparability of different diving fatality studies. Although still imperfect and likely to be modified with future use, this CEA template has been shown to improve consistency of interpretation between users.

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AUTHORSHIP STATEMENT

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<table>
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<tr>
<th>Title of Publication</th>
<th>Publication details</th>
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</thead>
</table>

<table>
<thead>
<tr>
<th>Name of executive author</th>
<th>School/Institute/Division if based at Deakin; Organisation and address if non-Deakin</th>
<th>Email or phone</th>
</tr>
</thead>
<tbody>
<tr>
<td>John Lippmann</td>
<td>School of Health &amp; Social Development, Faculty of Health</td>
<td></td>
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</tbody>
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2. Inclusion of publication in a thesis

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<th>Is it intended to include this publication in a higher degree by research (HDR) thesis?</th>
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<tr>
<td></td>
<td>School of Health &amp; Social Development</td>
<td>Analysis of Australian Diving-related deaths</td>
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If there are multiple authors, give a full description of HDR thesis author’s contribution to the publication (for example, how much did you contribute to the conception of the project, the design of methodology or experimental protocol, data collection, analysis, drafting the manuscript, revising it critically for important intellectual content, etc.)

JL conceived the project, contributed to design of methodology (>80%), collected the data, performed majority of analysis (>75%), drafting and revising the manuscript (>80%)

I declare that the above is an accurate description of my contribution to this paper, and the contributions of other authors are as described below. Signatures and date.

4. Description of all author contributions

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<tr>
<th>Name and affiliation of author</th>
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<td>Contributed to analysis, drafting and revising of manuscript</td>
</tr>
<tr>
<td>A/Prof Chris Stevenson</td>
<td>Contributed to the analysis, drafting and revising of manuscript</td>
</tr>
<tr>
<td>Dr Mohammadreza Mohebbi</td>
<td>Contributed to the analysis, revising of manuscript</td>
</tr>
<tr>
<td>A/Prof Jo Williams</td>
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</tr>
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</tr>
</thead>
<tbody>
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<td>A/Prof Chris Stevenson</td>
<td>Signature Redacted by Library</td>
<td>12/09/2017</td>
</tr>
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<td>Prof David Taylor</td>
<td>Signature Redacted by Library</td>
<td>12/09/17</td>
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<td>Dr Mohammadreza Mohebbi</td>
<td>Signature Redacted by Library</td>
<td>12/09/2017</td>
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<td>A/Prof Jo Williams</td>
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<thead>
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<th>Name and affiliation of contributor</th>
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<th>Signature* and date</th>
</tr>
</thead>
</table>

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<th>Data format</th>
<th>Storage Location</th>
<th>Date lodged</th>
<th>Name of custodian if other than the executive author</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS Word, PDF files</td>
<td>Divers Alert Network</td>
<td>02 December 2016</td>
<td></td>
</tr>
</tbody>
</table>

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Chapter 8

Analysis of scuba diving fatalities in Australian waters from 2001 to 2013 inclusive

To identify and understand the causes of diving fatalities and devise appropriate countermeasures, it is essential to analyse previous accidents and identify common factors and trends in these. This chapter will apply the chain of event template developed in the previous chapter to a series of 126 scuba fatalities. The results will be used to address Thesis Aim 5 – “Describe the characteristics associated with fatal scuba diving-related incidents in Australia from 2001 to 2013, inclusive, in order to examine trends and potentially identify causative factors.” This, in turn, will help identify potential “underlying factors associated with scuba diving and snorkelling-related mortality in Australia” (Research Question 1).

From 1 January 2001 to 31 December 2013 there were 126 recorded scuba diving (and 175 snorkelling-related) fatalities. As this thesis primarily focuses on scuba diving, only the scuba deaths are addressed here. However, an exception to this is the data relating to rescue and resuscitation which covers both diving and snorkelling as the circumstances of these are often similar, especially in the commercial setting where scuba divers and snorkellers may often dive from the same location with the same surface support staff.

Part 1 of this section includes various demographic, diving activity and first aid data analysis. Part 2 includes the results of the Chain of Events Analyses for the scuba divers.
PART 1

8.1.1 Demographics

The victim demographics are presented in Tables 8.1.1.1a and 8.1.1.1b. Most were predominantly ‘middle-aged’ males. More than three quarters were overweight or obese.

Table 8.1.1.1a. Age and gender of victims (n = 126).

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>n = 126</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (SD)</td>
<td>44 (13)</td>
</tr>
<tr>
<td>Median (IQR)</td>
<td>45 (34, 55)</td>
</tr>
<tr>
<td>Range</td>
<td>17 - 72</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Male, n (%)</td>
<td>99 (79)</td>
</tr>
<tr>
<td>Female, n (%)</td>
<td>27 (21)</td>
</tr>
</tbody>
</table>

Table 8.1.1.1b. Body mass index (BMI) of victims, where known (n = 108).

<table>
<thead>
<tr>
<th>BMI, kg/m²</th>
<th>n = 108</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (SD)</td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>28 (6)</td>
</tr>
<tr>
<td>Male</td>
<td>28 (5)</td>
</tr>
<tr>
<td>Female</td>
<td>28 (6)</td>
</tr>
<tr>
<td>Overweight, n (%)</td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>43 (40)</td>
</tr>
<tr>
<td>Male</td>
<td>36 (41)</td>
</tr>
<tr>
<td>Female</td>
<td>7 (33)</td>
</tr>
<tr>
<td>Obese, n (%)</td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>40 (37)</td>
</tr>
<tr>
<td>Male</td>
<td>34 (39)</td>
</tr>
<tr>
<td>Female</td>
<td>6 (29)</td>
</tr>
</tbody>
</table>

Overweight = BMI of 25-29.9 kg.m⁻²; Obese = BMI ≥30 kg.m⁻²

The age distribution for victims is shown in Figure 8.1.1.1. The modal distribution was 40 to 49 years and more than one third were aged 50 years or older.
Figure 8.1.1.1. Distribution of scuba fatalities by age and gender (n = 126).

The mean age of the victims for each year from 2001 to 2013 inclusive are shown in Figure 8.1.1.2. There was little change over this 13-year period.

Figure 8.1.1.2. Mean age of victims from 2001-2013.

The BMIs were available for 108 of the victims. Figure 1.1.3 shows the BMI distribution for these, of whom more than one third were obese (BMI ≥ 30).
Figure 8.1.3. BMI classifications* by gender for scuba victims. Units in kg/m². 
(n = 108).

*<18.5 underweight; 18.5–24.9 normal weight; 25-29.9 overweight; ≥30 obese.

Twelve of the 32 deaths (38%) determined to be cardiac-related were in victims who were obese, with BMIs ranging from 30 to 42 kg/m².

8.1.2 Certifications and experience

The scuba divers’ certification levels were known for 90 victims and are shown in Figure 8.1.2.1.

Figure 8.1.2.1. Certification levels of victims (n = 126).
It is difficult to satisfactorily define diving experience as it is not only dependent on the number of dives, but also on the nature of these dives. Relevant background information was missing in many of the cases, so relatively simple definitions of experience were used, despite their shortcomings.

A “novice” was defined here as having done 30 dives or less, an “experienced diver” had performed more than 30 dives, and a “very experienced” diver had done at least 200 dives. Using these definitions, the victims’ experience is shown in Figure 8.1.2.2. In addition to, or in the absence of a reported number of dives, years of certification/diving and witness statements were also used to help determine the divers’ likely level of experience. Nine of the victims (7%) died on their first dive and 15 (12%) within their first five dives.

Based on 74 cases with information on the period of diving, the median (IQR) was 3 (1, 12) years. The median (IQR) number of dives performed prior to the fatal incident was 20 (5, 100) dives.

*Figure 8.1.2.2. Experience of 126 victims. [Novice = < 30 dives; Experienced = between 30 and 200 dives inclusive; Very experienced > 200 dives]*

Lack of recent diving affects the current competency of a diver and can be contributory to accidents. At least 12 of the scuba victims had not dived for periods ranging from 6 months to 11 years.
8.1.3 Location and setting

8.1.3.1 Location

The distribution of the fatalities is shown in Table 8.1.3.1.1. New South Wales (NSW) and Queensland (QLD) had the highest proportions of deaths with approximately one quarter of deaths each. No scuba-related deaths occurred in the Northern Territory (NT) or Australian Capital Territory (ACT) between 2001 and 2013. (Despite being landlocked, some diving is conducted in pools, lakes and dams in the ACT).

Table 8.1.3.1.1. Distribution of scuba fatalities by State / Territory.

<table>
<thead>
<tr>
<th>Location</th>
<th>Scuba, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSW</td>
<td>32 (25)</td>
</tr>
<tr>
<td>QLD</td>
<td>29 (23)</td>
</tr>
<tr>
<td>VIC</td>
<td>20 (16)</td>
</tr>
<tr>
<td>WA</td>
<td>19 (15)</td>
</tr>
<tr>
<td>SA</td>
<td>17 (13)</td>
</tr>
<tr>
<td>TAS</td>
<td>9 (7)</td>
</tr>
<tr>
<td>NT</td>
<td>0 (0)</td>
</tr>
<tr>
<td>ACT</td>
<td>0 (0)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>126</strong></td>
</tr>
</tbody>
</table>

NSW = New South Wales, QLD = Queensland, VIC = Victoria, WA = Western Australia, SA = South Australia, TAS = Tasmania; NT = Northern Territory, ACT = Australian Capital Territory.

The mean (SD) age of the scuba diving victims varied little between States and Territories as shown in Table 8.1.3.1.2.
Table 8.1.3.1.2. Mean (SD) ages of victims by State / Territory.

<table>
<thead>
<tr>
<th>State / Territory</th>
<th>Scuba Age (yrs) Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSW</td>
<td>47 (13)</td>
</tr>
<tr>
<td>QLD</td>
<td>46 (15)</td>
</tr>
<tr>
<td>WA</td>
<td>41 (14)</td>
</tr>
<tr>
<td>VIC</td>
<td>43 (9)</td>
</tr>
<tr>
<td>SA</td>
<td>41 (12)</td>
</tr>
<tr>
<td>TAS</td>
<td>47 (12)</td>
</tr>
<tr>
<td>NT</td>
<td>na</td>
</tr>
<tr>
<td>ACT</td>
<td>na</td>
</tr>
</tbody>
</table>

8.1.3.2 Setting

Overall, fifty-eight (46%) of the scuba deaths occurred in a commercial setting, either on dive charters or otherwise under the supervision of a dive professional. The large majority of scuba deaths in Queensland occurred in a commercial setting. The relative proportions by State and Territory are shown in Figure 8.1.3.2.1.

Figure 8.1.3.2.1. Proportions of deaths in each State/Territory occurring in a commercial setting.
8.1.4 Origin of victims

Twenty-four (83%) of the 29 scuba victims in Queensland were tourists, one from interstate and the rest from overseas. The proportions of victims who were tourists in the various States are shown in Table 8.1.4.1.

Figure 8.1.4.1. Percentage of each State’s death involving tourists.
(There were no scuba fatalities in the NT or ACT).

8.1.5 Buddy / group situation

Sixty-eight (54%) of the victims had set out diving solo or had separated from their buddy or group, intentionally or unintentionally, prior to the incident. Another 22 separated during the incident. Only 35 victims were with their buddy at the time of their demise. These data are shown in Figure 8.1.5.1.

There was a higher likelihood of separation prior to the incident if the scuba divers were within a group larger than two, rather than within a buddy pair. This occurred with 23 (70%) of victims in groups and 32 (41%) of victims in buddy pairs. (OR = 3.38; 95% CI = 1.42 – 8.05, p = 0.006).
8.1.6  Dive purpose

The activities which the victims were undertaking during the fatal scuba dives are shown in Figure 8.1.6.1. Seafood collection included the collection of abalone (16), crayfish (3), scallops (1) and spearfishing (3). Another diver was collecting cuttlefish eggs for research.

The four divers who died during work-related activities were not commercial divers but were amateurs who died using scuba during activities such as clearing an anchor, un-fouling a propeller or cleaning their boat’s hull. One death occurred in an instructor while leading a deep technical dive using a closed-circuit rebreather (CCR). One diver was undertaking cuttlefish research.
8.1.6.1 Training-related deaths (including introductory scuba)

Seventeen (13%) victims died while undergoing diver training or while being supervised by an instructor on an Introductory Scuba Experience (ISE). One of these occurred while being trained by a friend, who was not a qualified instructor. The others occurred while under the care of certified instructors. The breakdown is shown in Figure 8.1.6.1.1.

Six of these deaths were likely consequent to pre-existing medical conditions, another six were associated with poor supervision in adverse conditions, and at least two involved equipment problems precipitating a rapid ascent and subsequent cerebral arterial gas embolism (CAGE).
8.1.7 Depth of incident

The median (IQR) depth at which the incidents occurred was 12 (6, 21) metres with a range of zero to 125 metres. The depth was unreported in 10 incidents. More than one third of fatal incidents occurred within a depth of 10 m or less, and over 70% in the first 20 m. The depths are indicated in Figure 8.1.7.1.

Figure 8.1.7.1. Incident depth range for 116 scuba fatalities.
8.1.8 Weighting

The weighting circumstances are shown in Figure 8.1.8.1. Of the 99 victims who were known to have been wearing a weight belt or integrated weights at the time of the incident, 64 (65%) were found still wearing the weights.

Figure 8.1.8.1. Weighting circumstances (percent) of 126 dive fatality victims.

The amount of weight carried was known for 63 of the victims. The median (IQR) weight was 9 (6, 12) kg with a range of 2 to 20 kg. The amount of weight (in 5 kg increments) is shown in Figure 8.1.8.2. Almost all of the 40 divers who carried 8 kg or more were diving in temperate waters (i.e., below the Tropic of Capricorn). Only two divers carrying more than 8 kg were in Queensland.

Figure 8.1.8.2. Amount of weight carried (5 kg increments) by 63 victims.
8.1.9 Buoyancy compensators

Data was available about the buoyancy compensator device (BCD) circumstances in 95 of the incidents and are shown in Figure 8.1.9.1. Overall, 45 (36%) victims were found with an uninflated BCD and in only two cases was the BCD later found to be faulty. Of note, 38 of the 45 victims (84%) found with an uninflated BCD were also still wearing their weight belt.

![Figure 8.1.9.1. BCD circumstances for 95 scuba victims (%).](image)

8.1.10 Breathing gas supply

Only six (5%) victims had been breathing a gas other than air. Five of these were using closed-circuit rebreathers (CCRs) and carrying air and oxygen cylinders to provide the ‘bottom mix’. An open-circuit diver who died from fulminating DCS had been breathing air on the bottom and enriched air nitrox during decompression.

As shown in Figure 8.1.10.1, more than one third of the victims had exhausted or near-exhausted their breathing gas supply. Half had sufficient gas to surface safely, with 32% having at least one quarter of their supply remaining.
8.1.11 Equipment faults

There was no mention of any equipment examination in 13 incidents and nothing abnormal reported in 73 cases. Police examiners reported finding faults with the equipment in 40 (32%) incidents although most of the faults were thought not to have been a significant contributor to the fatalities. The pieces of equipment with the identified faults are shown in Figure 8.1.11.1.

Figure 8.1.11.1. Identified equipment faults in 113 scuba deaths (not necessarily contributory).
Faulty (high-reading) cylinder contents gauges were associated with, and likely contributed to, four incidents, all of which involved the victim running out of breathing gas. Most of the regulator faults (n = 7) involved perforated mouthpieces which allowed water aspiration. Most of the identified BCD problems (n = 8) involved malfunctioning inflator/deflator mechanisms. Equipment-related problems were the likely triggers in at least eight of the incidents. These included a detached demand valve, faulty tank valve, faulty inflators on a BCD and a drysuit, and an out-of-date and faulty oxygen sensors on a rebreather.

There were 11 cases where the breathing gas did not meet the relevant Australian Standards. In 10 of these, the water vapour and carbon dioxide levels were high, although not believed to have been contributory. In one case, excess oil in the breathing air was thought likely to have caused nausea and led to a rapid ascent with consequent CAGE.

8.1.12 Rescue and resuscitation (scuba and snorkel combined, n = 301)

In at least three scuba incidents, the sole buddy was unable to lift the victim into the unattended boat so rescue was delayed substantially until help arrived. Similarly, in at least two snorkelling incidents the tender driver was unable to pull the victim on board, again leading to delays in rescue.

In-water rescue breathing (IWRB) was reported to have been performed in 30 (10%) of the incidents (4 scuba and 24 snorkel) with varying degrees of difficulty. In-water cardiopulmonary resuscitation (CPR) was attempted during one rescue of a scuba diver.
8.1.12.1 Soiled airway

In 103 (34%) incidents, which included 51 (40%) of the scuba and 52 (30%) of the snorkelling incidents, airway management was complicated by the presence of regurgitated stomach contents, water, froth, and/or pulmonary oedema fluids. In six cases, rescuers were initially unable to provide rescue breaths because the victim’s jaw was clenched. Soiled airways were generally managed by placing the victim on their side and clearing the airway, although, on many occasions, this had to be done multiple times.

8.1.12.2 On-scene cardiopulmonary resuscitation (CPR)

There was no information about resuscitation attempts in fifteen cases. However, on-scene CPR was attempted in at least 219 (73%) incidents overall. In almost all of the cases where no attempt was made, the victim’s body had not been found or had not been recovered for very extended periods, or was in such a bad state that it was obvious there was no hope of recovery. However, in one case, resuscitation was not attempted after a recovery delay of 10 minutes and, in another, it was abandoned after only three minutes as the companions believed that survival would not be possible. In another incident, CPR was ceased while the only trained rescuer available went to retrieve resuscitation equipment. Information on resuscitation is shown in Table 8.1.12.2.1.

Table 8.1.12.2.1. Cardiopulmonary resuscitation circumstances 126 scuba diving and 175 snorkelling incidents.

<table>
<thead>
<tr>
<th>CPR circumstance</th>
<th>Scuba, n (%)</th>
<th>Snorkel, n (%)</th>
<th>Total, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPR given</td>
<td>95 (75)</td>
<td>124 (71)</td>
<td>219 (73%)</td>
</tr>
<tr>
<td>No CPR</td>
<td>26 (21)</td>
<td>41 (23)</td>
<td>67 (22)</td>
</tr>
<tr>
<td>Unknown</td>
<td>5 (4)</td>
<td>10 (6)</td>
<td>15 (5%)</td>
</tr>
</tbody>
</table>
8.1.12.3 Defibrillation

There were 40 reports (8 scuba and 32 snorkel) which indicated that an automated external defibrillator (AED) was readily available for first aid at the scene and was attached to the victim. In 33 of these, no shock was given. In five cases, one to five shocks were delivered although there was no subsequent recovery. In most cases, there was no clear indication of the likely delay from unconsciousness to the attachment of the AED. In six cases, it appears that the delay might have been less than 10 minutes. In the others, delays in excess of 10 to 20 minutes or sometimes much longer were likely. In one case, an avoidable extended delay occurred as the AED battery was flat and needed to be changed. These data on AED use are shown in Table 8.1.12.3.1.

Table 8.1.12.3.1. On-site first aid AED use in 40 fatal scuba and snorkelling incidents.

<table>
<thead>
<tr>
<th>AED result</th>
<th>Scuba</th>
<th>Snorkel</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No shock given</td>
<td>7</td>
<td>28</td>
<td>35</td>
</tr>
<tr>
<td>Shock(s) given</td>
<td>1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>32</td>
<td>40</td>
</tr>
</tbody>
</table>

8.1.12.4 Supplementary oxygen

There was no indication whether or not supplementary oxygen was administered in 222 (74%) of the incidents, although it appears that it was provided in at least 19% of both the scuba and snorkelling cases. This is shown in Figure 8.1.12.4.1.

In 19 incidents, oxygen-supplemented ventilations were attempted using a bag-valve-mask (BVM) device. However, in four of these, the rescuer abandoned oxygen administration due to problems with the use of the BVM. In another two, the BVM could not be used due to missing parts. Mouth-to-mask rescue breathing
was performed on at least nine occasions, and two rescuers provided oxygen via a manually-triggered resuscitator (MTR).

In one case, oxygen could not be delivered as the only available delivery device was a simple face mask and, in another, the cylinder valve key was missing.

*Figure 8.1.12.4.1. Oxygen supplementation with ventilations.*

### 8.1.13 Post mortem findings

Internal post mortem examinations were available for 123 (98%) of the scuba divers. There was no body found in two cases and only an external examination was performed on the victim in another. It was determined that 32 deaths resulted from a cardiac-related disabling injury (DI). Some cardiac pathology was found in 25 other cases although this was not believed to have been contributory in most of these. However, in six cases, a cardiac event was believed to have been reasonably possible, although the evidence was not sufficiently strong to make a clear determination. Details of cardiac findings believed to have been contributory are shown in Table 8.1.13.1. The data in the table relate to the 38 cases (i.e., the 32 attributed to cardiac causes and other six thought likely).
Table 8.1.13.1. Cardiac findings at autopsy of 38 cardiac-related scuba deaths.
(Multiple abnormalities (e.g., atheroma and ischaemia) were found with many.)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Scuba (n = 38), n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atheroma†</td>
<td>25 (66)</td>
</tr>
<tr>
<td>Ischaemia*</td>
<td>23 (61)</td>
</tr>
<tr>
<td>Cardiomegaly#</td>
<td>18 (47)</td>
</tr>
<tr>
<td>Left ventricular hypertrophy</td>
<td>14 (37)</td>
</tr>
<tr>
<td>Clinical history of undiagnosed cardiac symptoms</td>
<td>6 (16)</td>
</tr>
<tr>
<td>Aortic stenosis</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Left ventricular bridging</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Cardiomyopathy</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Narrow coronary arteries</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Myocardial bridging</td>
<td>0</td>
</tr>
<tr>
<td>Ventricular rupture/tamponade</td>
<td>0</td>
</tr>
<tr>
<td>Left ventricular aneurysm</td>
<td>0</td>
</tr>
</tbody>
</table>

†Significant atheroma usually taken as >70% vessel occlusion.
*includes 2 x myocardial infarction (MI) and two previous MI; #includes 8 MI and 5 previous MI.

Autopsy evidence of left ventricular hypertrophy was found in 24 (20%) of all the victims (both cardiac and non-cardiac) for whom internal post mortem examinations were conducted and pertinent details reported. These are shown in Table 8.1.13.2.
Table 8.1.13.2. Pathological evidence at autopsy of Left Ventricular Hypertrophy in scuba divers with cardiac and non-cardiac disabling agents.

<table>
<thead>
<tr>
<th>Left Ventricular Hypertrophy at autopsy</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cardiac, n (%)</strong></td>
<td>14/38 (37)</td>
</tr>
<tr>
<td><em>Age (yrs) - mean (SD)</em></td>
<td>53 (11)</td>
</tr>
<tr>
<td><strong>Non-cardiac, n (%)</strong></td>
<td>10/81 (12)</td>
</tr>
<tr>
<td><em>Age (yrs) - mean (SD)</em></td>
<td>41 (12)</td>
</tr>
<tr>
<td><strong>Total, n (%)</strong></td>
<td>24/119 (20)</td>
</tr>
<tr>
<td><em>Age (yrs) - mean (SD)</em></td>
<td></td>
</tr>
</tbody>
</table>

Based on 119 of the 123 scuba divers with internal examinations at autopsy.
PART 2 - CHAIN OF EVENTS ANALYSIS

This chain of events analysis for the scuba fatalities above is based on the criteria outlined in Chapter 7. These include the predisposing factors, triggers, disabling agents, disabling injuries and ultimately the causes of death of the scuba diving victims.

8.2.1 Predisposing factors

One hundred and eighty-nine predisposing factors were identified as possible or likely contributors to the 126 deaths. The main factors were related to the victims’ health as well as Organisational/Training/Experience/Skills-related factors prior to diving. The distribution of the overall predisposing factors is shown in Table 8.2.1.1.

8.2.1.1 Pre-existing medical conditions

Forty-six scuba divers were identified as having chronic medical conditions which may have contributed to their incident. Other divers had conditions that were not thought to have played a role in the incidents and in many cases, a medical history was unavailable.

The most common condition was ischaemic heart disease (IHD), which had been diagnosed in 15 of the divers. However, in another eight divers who had not been diagnosed with cardiac disease but who had experienced previous dyspnoea and/or chest pain prior to the incident, significant IHD was evident at autopsy. The disabling injury (DI) in 19 of the 23 divers appears to have been cardiac-related.

Pre-existing cardiac arrhythmias may have contributed to the deaths of two divers. One of these had known atrial fibrillation. The other was a 17 year-old with undiagnosed prolonged QT syndrome. Cardiac dysfunction associated with viral myocarditis was likely to have contributed to the rapid ascent and subsequent CAGE in one diver. Another is believed to have been disabled by an arrhythmia precipitated in part by mitral valve incompetence.
Table 8.2.1.1. Predisposing factors associated with 126 scuba fatalities. Some deaths involved multiple predisposing factors.

<table>
<thead>
<tr>
<th>Category</th>
<th>Subcategory</th>
<th>Mean (SD) Age</th>
<th>Male (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health-related</td>
<td></td>
<td>50 (12)</td>
<td>80%</td>
</tr>
<tr>
<td>Significant medical history</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatigue</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drug medication intake</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obesity per se</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organisational/Training/Experience/Skills-related</td>
<td></td>
<td>39 (13)</td>
<td>70%</td>
</tr>
<tr>
<td>Inexperienced overall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor organisation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of training/skills for the dive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of recent experience</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning-related</td>
<td></td>
<td>40 (12)</td>
<td>83%</td>
</tr>
<tr>
<td>Poor pre-dive choice of conditions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>solo diving in adverse conditions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>location</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absence of appropriate/use of faulty equipment</td>
<td></td>
<td>41 (12)</td>
<td>79%</td>
</tr>
<tr>
<td>Faults in gauge, regulator, BCD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absence of knife, fins, snorkel when needed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor weighting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Pre-existing respiratory conditions likely contributed to the deaths of eight divers. These included asthma (n = 3), chronic obstructive pulmonary disease (COPD, n = 2), pulmonary cyst (n = 1) and pleural adhesions in two divers, one of whom had a prior pneumothorax. Five of these divers were disabled by pulmonary barotrauma (PBT) and/or CAGE.

Twelve divers were being treated for hypertension, two for non-insulin dependent diabetes mellitus (NIDDM) and two had suffered a previous stroke. At least 11 of these divers appear to have had a cardiac event while diving. Three divers had a
history of seizures or epilepsy. The asphyxia-related deaths of two of these three divers were unwitnessed, and it is possible, albeit unproven, that an underwater seizure occurred. Table 8.2.1.1.1 shows 62 pre-existing conditions in 48 divers, their frequency and the associated disabling agents thought to have led to the fatalities.

At least 14 divers who had pre-existing medical conditions that contributed to their deaths had been cleared as fit-to-dive by a medical practitioner within the year prior to their incident. The majority of these doctors were not trained in the assessment of fitness-to-dive. Three of the victims had pulmonary disease (emphysema and pleural adhesions) and the remainder had cardiac conditions. One of these had undergone a cardiac stress test five months prior, with a negative result.

8.2.1.1.1 Medications

The medications taken by 38 of the scuba divers were known, although seven others were reported to have been taking medications, the nature of which were unknown to investigators. It is possible that some others were also taking medications but this information was not gathered. Non-steroidal anti-inflammatory agents (n = 9), ACE inhibitors (n = 7), SSRI agents (n = 7) and antiplatelet agents (n = 6) were the most common medications taken by the scuba victims.

One of the victims, who was believed likely to have been disabled by a cardiac arrhythmia, had been taking both rofecoxib and pseudoephedrine. The former was removed from sale due to concerns about an increased risk of cardiac dysfunction.\(^{226}\) The latter could potentially exacerbate this.\(^{227}\) Known medications are shown in Appendix A2.
Table 8.2.1.1.1. The incidence of 62 pre-existing conditions in 46 scuba divers and the associated disabling injuries in the fatal incidents.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Frequency</th>
<th>Disabling injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Respiratory</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asthma</td>
<td>3</td>
<td>PBT, unknown (cardiac? CAGE?), asphyxia</td>
</tr>
<tr>
<td>Pleural adhesion</td>
<td>2</td>
<td>CAGE (2)</td>
</tr>
<tr>
<td>Lung cyst</td>
<td>1</td>
<td>CAGE</td>
</tr>
<tr>
<td>Emphysema</td>
<td>1</td>
<td>cardiac (also had IHD)</td>
</tr>
<tr>
<td>COPD</td>
<td>1</td>
<td>CAGE</td>
</tr>
<tr>
<td><strong>Cardiac</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IHD (diagnosed)</td>
<td>15</td>
<td>Cardiac (12), unknown (cardiac?/CAGE?, 2), CAGE (1)</td>
</tr>
<tr>
<td>IHD (undiagnosed but symptomatic)</td>
<td>8</td>
<td>cardiac (7), IPO (1)</td>
</tr>
<tr>
<td>Myocarditis</td>
<td>1</td>
<td>CAGE</td>
</tr>
<tr>
<td>MV incompetence</td>
<td>1</td>
<td>cardiac</td>
</tr>
<tr>
<td>Arrhythmia</td>
<td>2</td>
<td>cardiac (2)</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>13</td>
<td>cardiac (7), asphyxia (3), CAGE (1), IPO (1), unknown (CAGE?, 1)</td>
</tr>
<tr>
<td>Diabetes (NIDDM)</td>
<td>2</td>
<td>cardiac (2)</td>
</tr>
<tr>
<td>IPO</td>
<td>1</td>
<td>IPO</td>
</tr>
<tr>
<td>CVA</td>
<td>2</td>
<td>cardiac (2)</td>
</tr>
<tr>
<td>Aneurysm</td>
<td>1</td>
<td>asphyxia</td>
</tr>
<tr>
<td>Epilepsy/seizures</td>
<td>3</td>
<td>CAGE (1), asphyxia (2)</td>
</tr>
<tr>
<td>Bipolar</td>
<td>1</td>
<td>CAGE</td>
</tr>
<tr>
<td>Ankylosing spondylitis</td>
<td>1</td>
<td>cardiac (1)</td>
</tr>
<tr>
<td>Alcohol/drug abuse</td>
<td>2</td>
<td>cardiac (2)</td>
</tr>
<tr>
<td>IgA nephritis</td>
<td>1</td>
<td>cardiac</td>
</tr>
</tbody>
</table>

CAGE = cerebral arterial gas embolism; COPD = chronic obstructive pulmonary disease; CVA = cerebrovascular accident; IHD = ischaemic heart disease; IPO = immersion pulmonary oedema; MV = mitral valve; NIDDM = non-insulin dependent diabetes mellitus; PBT = pulmonary barotrauma.
8.2.1.2 Organisational/Training/Experience/Skills-related

Forty-six incidents involved lack of experience, and/or inadequate training or skills for the fatal dive, or organisational shortcomings. These are shown in Figure 8.2.1.2.1.

*Figure 8.2.1.2.1. Relative frequencies of organisational/ training/experience/skills-related factors (n = 46).*

Inexperience and the relatively poor diving skills associated with these organisational shortcomings were implicated in the highest number of deaths in this category. However, the victims included some experienced divers who had not dived for extended periods. Among the divers with “little relevant experience” were three very experienced divers who died due to a lack of familiarity with new equipment, which included a drysuit, technical rigs and a rebreather.

The organisational shortcomings included a poor internal process in a dive shop for the oversight of the progress and needs of trainees, poor systems for the organising of introductory scuba dives, unqualified staff giving advice to a customer about the relevance and severity of their pre-existing medical condition, and an inadequate system for ensuring the appropriate screening and oversight of inexperienced divers.
8.2.1.3 Planning-related

The planning-related incidents involved poor planning decisions, generally immediately prior to the dive. The majority of these (n = 15) involved a decision to dive in obviously unsuitable conditions, which included rough water and/or surge (n = 8), very poor visibility (n = 4) and strong currents (n = 3).
Six of the divers set out to dive solo in conditions that were obviously unsuitable, especially when alone, and another three intentionally separated in such circumstances. One diver failed to correctly plan his decompression requirements, and another his breathing gas requirements while diving in a cave. Other issues involved poor choice of instructor-student ratios and poor gas supply planning.

8.2.1.4 Absence of appropriate equipment or use of obviously faulty equipment

Predisposing factors related to equipment were contributory to the incidents in 24 cases (19%), some with multiple issues. These included:

- Missing equipment (n = 9): wetsuit (n = 3), fins (n = 2), BCD (n = 2), knife (n = 1), snorkel (n = 1)
- Faulty (n = 9): BCD (n = 2), pressure gauge (n = 2), regulator (n = 1), octopus (n = 1), mouthpiece (n = 1), oxygen sensors (n = 1), tank valve (n = 1)
- Obvious overweighting (n = 4)
- Incorrect configuration or assembly at site (n = 4)
- Poor-fitting wetsuit (n = 2)
- Weights in BCD pockets and unable to be ditched (n = 1)
- Substantial oil in cylinder air (n = 1)
8. 2.1.5 Activity-related

Fourteen victims were undertaking activities that can potentially carry an increased risk of an incident. These included six undertaking penetration dives, three in freshwater caves and two in deep wrecks. In four of these, the victims became separated and ran out of breathing gas. Another involved a dive in a sea cave during which the diver was incapacitated when smashed into the wall by a large surge. One diver died while diving solo in a wreck at night.

Three incidents occurred during deep dives using CCRs. Another three incidents occurred while the victims were collecting seafood, spearfishing or diving near where fishing was being conducted. All of these involved attacks by large sharks.

A solo diver who dived in a very strong current, and without wearing a BCD in an area with multiple mooring ropes, became entangled and subsequently drowned. The final death involved suicide by a diver who had filled his cylinder with pure helium.

8.2.1.6 Poor supervision

In 13 of the 14 of these incidents, poor decisions by the supervisor were made prior to the dive. Five of these involved a formal instructional situation, four with divers with very little, or no, experience. Another involved a diver (a non-instructor) teaching his girlfriend to dive.

One incident involved a divemaster who, in the rush of getting divers into the water, failed to notice that a novice was not wearing his mask, had his regulator out, and his BCD uninflated and unattached to the scuba feed when entering the water. The other incidents involved more experienced divers making poor pre-dive decisions, often about sites or conditions, which affected their inexperienced buddies.

8.2.1.7 Poor communication or co-ordination

Three incidents specifically involved poor pre-dive communication between divers and/or those overseeing them, although several cases in the preceding categories were also associated with communication or co-ordination issues.
One case involved the information passed between instructors and their employer about a student’s poor swimming ability. Another involved a diver intentionally giving misleading information about a dive plan. The other involved confusion between buddies about the exit point for the dive.

### 8.2.2 Triggers

One hundred and thirty-two possible or likely triggers were identified in the 126 fatal scuba diving incidents. The distribution of the various trigger categories are shown in Table 8.2.2.1.

<table>
<thead>
<tr>
<th>Category</th>
<th>Number</th>
<th>Percentage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment-related</td>
<td>68</td>
<td>54%</td>
<td>Conditions (37), Immersion effects (19), Entrapment (5), Marine animal (3), Other (4)</td>
</tr>
<tr>
<td>Equipment-related</td>
<td>10</td>
<td>8%</td>
<td>Mean (SD) age 45 (13), 76% male, Regulators, tank valve, O₂ sensors, Wet and drysuits</td>
</tr>
<tr>
<td>Exertion-related</td>
<td>23</td>
<td>18%</td>
<td>Pre-dive (4), During dive (13), Post-dive (6)</td>
</tr>
<tr>
<td>Anxiety-related</td>
<td>10</td>
<td>8%</td>
<td>Mean (SD) age 39 (15), 63% male, Various</td>
</tr>
<tr>
<td>Buoyancy-related</td>
<td>3</td>
<td>2%</td>
<td>Mean (SD) age 51 (10), 33% male, Lack of familiarity/poor equipment skill</td>
</tr>
<tr>
<td>Gas supply-related</td>
<td>15</td>
<td>12%</td>
<td>Mean (SD) age 42 (9), 87% male, Out of gas (8), Low (3), Incorrect mix (2), Contamination (1), Other (1)</td>
</tr>
<tr>
<td>Primary diver error</td>
<td>3</td>
<td>2%</td>
<td>Mean (SD) age 37 (7), 33% male</td>
</tr>
<tr>
<td>Other</td>
<td>5</td>
<td>4%</td>
<td>Mean (SD) age 43 (15), 71% male</td>
</tr>
<tr>
<td>Unknown</td>
<td>14</td>
<td>11%</td>
<td>Mean (SD) age 45 (15), 71% male</td>
</tr>
</tbody>
</table>
8.2.2.1 Environmental

The main triggers (n = 68) were environment-related, and were implicated in almost half of the fatalities. These were predominantly associated with adverse conditions (n = 37), which included current (n = 14), rough seas (n = 12), poor visibility (n = 8), surge (n = 2) and depth (n = 1). Twenty-three of the 37 (62%) of the divers with a conditions-related trigger were inexperienced, compared with 34/78 (43%) of those with other triggers. This indicates a higher association of conditions-related triggers with inexperienced divers than with 'experienced' divers [OR 2.22, 95% CI 1.00 - 4.94], p = 0.05].

Nineteen fatalities were believed to have been associated with the cardiac-related effects of immersion; seven of these due to immersion per se, and twelve with the combination of immersion and exertion due to conditions. Five incidents involved entrapment due to environmental circumstances. These included entrapment in kelp, in a wreck, entanglement with a line in zero visibility, and with a mooring rope in a strong current. Three of the deaths were associated with the presence of, and subsequent attack by, a shark.

8.2.2.2 Exertion-related

Exertion-related triggers were identified in 23 (18%) incidents and were associated with exertion before, after or during a dive. This exertion was unrelated to adverse sea conditions and was what would normally be expected with swimming or walking around wearing scuba equipment. Seventeen (74%) of these incidents resulted in a cardiac-related DI. Some causes included:

- Exertion before dive, e.g., such as walking to the site wearing the equipment (n = 4)
- Exertion during dive (n = 13), e.g., carrying heavy catch bags (n = 2)
- Exertion post dive (n = 6), e.g., long surface swims (n = 5); boarding boat (n = 1)
8.2.2.3  Gas supply-related

There were 15 (12%) incidents involving gas supply-related triggers. Eleven of these involved low (n = 3) or exhaustion of breathing gas (n = 8) situations. Four of these occurred while hunting seafood, one involved a ‘silt-out’ on a wreck at depth, and one occurred during a cave penetration dive. Three incidents resulted from inappropriate breathing gas - one from contamination by oil and two from incorrect breathing mixes. The final victim entered the water without his regulator in his mouth and, being negatively buoyant, sank and drowned.

8.2.2.4  Equipment-related

The 10 equipment-related triggers included one incident each of:

- Faulty mouthpiece, causing aspiration
- Faulty tank ‘j-valve’, causing loss of reserve air
- Tight wetsuit, causing breathing restriction and subsequent panic
- Tank slippage, causing loss of air supply
- Faulty mask, causing leak and panic
- ‘Octopus’ detachment, causing loss of mask and panic
- Loss of fin, causing mobility problems and panic
- Faulty oxygen sensor, causing hyperoxia
- Faulty drysuit inflator, causing problems at depth and during ascent
- Faulty BCD inflator, causing rapid ascent

8.2.2.5  Anxiety-related

Anxiety is very likely a trigger in a substantial number of diving related deaths. However, it was only included as a factor in the CEA when there were specific witness accounts reporting that the victim displayed signs of anxiety, and this appeared to have led to panic and the subsequent fatality. There were 10 such accounts, all but one involving novice divers.
8.2.2.6 Buoyancy-related

Only three of the incidents appeared to have been triggered by a buoyancy-related problem. One involved a diver who had logged 55 dives but still had not mastered buoyancy control. She sank during ascent (after having a rapid uncontrolled ascent on a dive earlier that day). The other two were in experienced divers, both of who were using relatively unfamiliar equipment – one a CCR and the other a drysuit.

8.2.2.7 Primary diver error

Many incidents involve errors by divers along the accident chain, some prior to the dive and others arising from poor decisions or arising subsequent to a problem. Three of the incidents are likely to have been triggered by primary diver error, in conjunction with other triggers. In one case, the diver failed to heed a repeated warning on his CCR. In another, a substantially over-weighted drysuit diver, relatively inexperienced in the use of her drysuit, re-descended alone with relatively little remaining air and inadvertently inverted in the water while adjusting buoyancy.

In the final incident, an experienced cave diver inadequately accounted for her ability to re-locate and reach an alternative, and necessary, air supply on the other side of a narrow constriction.

8.2.2.8 Other

The other triggers included three medical-related conditions (subdural haemorrhage, expansion and rupture of pulmonary cysts, unexplained chest discomfort), trauma, loss of dentures and inadequate decompression.
8.2.3 Disabling agents

There were 132 likely disabling agents identified in the 126 scuba fatalities. These are shown in Table 8.2.3.1.

Table 8.2.3.1. Disabling agents associated with 126 scuba fatalities.

<table>
<thead>
<tr>
<th>Category</th>
<th>Count (Percentage)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical–related</td>
<td>48 (38%)</td>
<td>- <em>Cardiac disease / dysfunction</em> (38)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>Oxygen seizure</em> (3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>Immersion pulmonary oedema</em> (≥3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Other (4)</td>
</tr>
<tr>
<td></td>
<td>21 (17%)</td>
<td><em>Ascent–related</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>Rapid ascent</em> (9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>Gas trapping</em> (3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>Inadequate decompression</em> (1)</td>
</tr>
<tr>
<td></td>
<td>18 (14%)</td>
<td><em>Buoyancy</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>Failure to gain positive buoyancy at surface</em> (8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Poor control underwater (7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Grossly overweighted (3)</td>
</tr>
<tr>
<td></td>
<td>17 (13%)</td>
<td><em>Gas supply –</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>Out of gas</em> (11)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Loss of regulator access (4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Inappropriate mix (2)</td>
</tr>
<tr>
<td></td>
<td>13 (10%)</td>
<td><em>Environmental –</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Conditions (7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Shark attacks (3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Entrapment (3)</td>
</tr>
<tr>
<td></td>
<td>4 (3%)</td>
<td><em>Equipment –</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- <em>Mean (SD) age 38 (12), 100% male</em></td>
</tr>
<tr>
<td></td>
<td>11 (9%)</td>
<td><em>Unknown</em></td>
</tr>
</tbody>
</table>

8.2.3.1 Medical–related

As shown in Table 8.2.3.1, more than three quarters of the medical-related disabling agents were due to cardiac conditions. The “Other” included two subdural haematomas, and one each from asthma and pulmonary cyst.

8.2.3.2 Ascent–related

The disabling agents in at least 21 (17%) of the incidents were clearly ascent-related, borne out by evidence of pulmonary barotrauma (PBT) or cerebral arterial gas embolism (CAGE). The actual ascent was unwitnessed in eight cases, including three where the diver had run out of breathing gas. There were other incidents in
which the disabling agent may have been due to ascent although these are less clear and were not included.

Nine of the incidents were characterised by a rapid ascent, three of these involving exhaustion of the breathing gas. The incidents in which gas trapping during ascent was likely associated with a pre-existing medical condition involved asthma, COPD and pleural effusion.

8.2.3.3 Buoyancy-related

Eight victims were incapacitated on the surface directly as a consequence of failing to inflate their BCD and/or dump weights. Seven others were disabled while at depth and subsequently drowned due to poor buoyancy control. Two of these were drysuit divers who became inverted while trying to adjust buoyancy. One victim lost control of buoyancy due to narcosis, subsequently became entangled in a line, and drowned.

8.2.3.4 Gas supply-related

The identified events where the disabling agent was related to the supply of breathing gas were:

- Direct exhaustion of breathing gas (n = 8)
- Out of gas post entrapment (n = 3)
- Loss of access to demand valve during dive (n = 3)
- Began dive with inappropriate breathing gas (n = 2, pure helium (1), hypoxic surface mix (1))
- Entered water without demand valve in mouth (n = 1)
8.2.3.5 Environmental

Seven of these deaths involved adverse sea conditions, with six of the victims being disabled after heavy contact with rocks, and one drowning after being swept off the rocks by a large swell. Three were disabled by shark attacks and another three were trapped and subsequently ran out of breathing gas.

8.2.3.6 Equipment

These incidents included:

- Incorrect fitting of demand valve lead to detachment during dive (n = 1)
- Equipment weight and bulk caused incapacitation in rough surface conditions (n = 1)
- Ditched weightbelt became entangled with contents gauge (n = 1)
- Loss of fin and mask subsequent to impact with boat hull (n = 1)

8.2.4 Disabling injuries

The predominant disabling injuries identified were asphyxia, cardiac causes and cerebral arterial gas embolism with or without evidence of pulmonary barotrauma. Others were immersion pulmonary oedema (IPO), trauma, and decompression sickness (DCS). In 21 cases, no clear disabling injury could be identified. The relative occurrence is shown in Table 8.2.4.1.
Table 8.2.4.1. Relative occurrence of disabling injuries in 126 scuba fatalities.

<table>
<thead>
<tr>
<th>Disabling injury</th>
<th>n (%)</th>
<th>Male (%)</th>
<th>Age All (yr) Mean (SD)</th>
<th>Age M (yr) Mean (SD)</th>
<th>Age F (yr) Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphyxia</td>
<td>47 (37)</td>
<td>70</td>
<td>42 (12)</td>
<td>42 (10)</td>
<td>40 (15)</td>
</tr>
<tr>
<td>Cardiac</td>
<td>32 (25)</td>
<td>97</td>
<td>52 (11)</td>
<td>52 (11)</td>
<td>46 (0)</td>
</tr>
<tr>
<td>CAGE/PBT</td>
<td>19 (15)</td>
<td>85</td>
<td>40 (14)</td>
<td>42 (14)</td>
<td>28 (12)</td>
</tr>
<tr>
<td>IPO</td>
<td>3 (2)</td>
<td>0</td>
<td>50 (1)</td>
<td>na</td>
<td>50 (1)</td>
</tr>
<tr>
<td>Trauma</td>
<td>3 (2)</td>
<td>100</td>
<td>29 (6)</td>
<td>29 (6)</td>
<td>na</td>
</tr>
<tr>
<td>DCS</td>
<td>1 (1)</td>
<td>100</td>
<td>45 (0)</td>
<td>45 (0)</td>
<td>na</td>
</tr>
<tr>
<td>Unclear</td>
<td>21 (17)</td>
<td>76</td>
<td>47 (12)</td>
<td>49 (12)</td>
<td>41 (11)</td>
</tr>
</tbody>
</table>

na = not applicable; PBT/CAGE = pulmonary barotrauma/cerebral arterial gas embolism;
IPO = immersion pulmonary oedema; DCS = decompression sickness.

In nine of the cases where the disabling injury was unclear, there were indicators of a possible cardiac-related incident. However, other factors, such as signs of drowning or CAGE, hampered a clear determination.

Thirty-four percent (10/29) of the scuba victims in Queensland were identified with a cardiac-related disabling injury. The proportions for each State where cardiac-related fatalities were identified are shown in Figure 8.2.4.1.

Of the 66 victims aged 45 years or more, 26 (39%) had a cardiac-related disabling injury, compared with 6/60 (10%) of victims younger than 45 years. This indicates a strong association between being at least 45 years old and having a cardiac-related disabling injury \[\text{OR} 5.85, 95\% \text{ CI} 2.20 - 15.55, p = 0.0004\].

Twenty-five of the 32 (78%) deaths attributed to a cardiac disabling injury were associated with exertion, compared with 18/94 (19%) of non-cardiac deaths. This indicates a strong association between the trigger exertion and a cardiac disabling injury. \[\text{OR} 6.31, 95\% \text{ CI} 2.52 - 15.80, p = 0.001\].
Rough conditions were a trigger in 15/47 (32%) deaths attributed to asphyxia as the DI, and 6/79 (8%) of the deaths attributed to other disabling injuries. This indicates a strong association between the trigger of rough conditions and asphyxia as the disabling injury [OR 5.70, 95% CI 2.03 - 16.04, p = 0.001]. There were no other significant associations.

*Figure 8.2.4.1. Proportion of various States’ fatalities which were identified as cardiac-related. (None were identified in the States/Territories not shown).*
8.2.4 Causes of death (COD)

The predominant causes of death identified were drowning, which was reported in half of the incidents, cardiac causes and PBT/CAGE. Others included trauma, IPO and DCS. In 18 cases, no clear cause of death was identified by the pathologists. The relative occurrences are shown in Table 8.2.4.1.

Table 8.2.4.1. Relative occurrence of causes of death in 126 scuba fatalities.

<table>
<thead>
<tr>
<th>Cause of death</th>
<th>n (%)</th>
<th>Male (%)</th>
<th>Age All (yrs) Mean (SD)</th>
<th>Age M (yrs) Mean (SD)</th>
<th>Age F (yrs) Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drowning</td>
<td>64 (51)</td>
<td>73</td>
<td>42 (14)</td>
<td>43 (14)</td>
<td>39 (14)</td>
</tr>
<tr>
<td>Cardiac</td>
<td>23 (18)</td>
<td>96</td>
<td>51 (9)</td>
<td>51 (9)</td>
<td>46 (0)</td>
</tr>
<tr>
<td>PBT/CAGE</td>
<td>14 (11)</td>
<td>86</td>
<td>42 (14)</td>
<td>45 (12)</td>
<td>21 (1)</td>
</tr>
<tr>
<td>Trauma</td>
<td>3 (2)</td>
<td>100</td>
<td>29 (6)</td>
<td>29 (6)</td>
<td>na</td>
</tr>
<tr>
<td>IPO</td>
<td>2 (2)</td>
<td>0</td>
<td>51 (0)</td>
<td>na</td>
<td>51 (0)</td>
</tr>
<tr>
<td>DCS</td>
<td>2 (2)</td>
<td>100</td>
<td>50 (7)</td>
<td>50 (7)</td>
<td>na</td>
</tr>
<tr>
<td>Unclear</td>
<td>18 (14)</td>
<td>72</td>
<td>47 (11)</td>
<td>46 (13)</td>
<td>48 (4)</td>
</tr>
</tbody>
</table>

na = not applicable; PBT/CAGE = pulmonary barotrauma/cerebral arterial gas embolism; IPO = immersion pulmonary oedema; DCS = decompression sickness; PBT/CAGE = pulmonary barotrauma/cerebral arterial gas embolism.

Figure 8.2.4.1 compares the likely disabling injuries as identified by chain of events analysis with the causes of death reported by the pathologists. Drowning has traditionally been (and still is in many places) recorded as the default cause of death when a lifeless diver was recovered from the water and no other obvious cause of death was apparent on autopsy. The difference between the 51% drowning as the cause of death and 37% asphyxia as disabling injury may reflect cases where drowning was secondary to a cardiac arrhythmia or an injury such as CAGE.
Figure 8.2.4.1. Comparison of disabling injuries and causes of death in 126 scuba fatalities.

Disabling Agents and Causes of Deaths

PBT/CAGE = pulmonary barotrauma/cerebral arterial gas embolism;
IPO= immersion pulmonary oedema; DCS = decompression sickness

In support of Aim 5 of this thesis (i.e., “Describe the characteristics associated with fatal scuba diving-related incidents in Australia from 2001 to 2013, inclusive, in order to examine trends and potentially identify causative factors”) the above results provide an overview of the characteristics associated with the 126 fatal scuba diving-related incidents that occurred in Australia from 2001 to 2013 inclusive. They also provide some important data on the impact of pre-existing medical conditions on diving safety (Aim2). In addition, the chapter demonstrates the application of the new chain of events analysis template created in accordance with Aim 4 and presented in chapter 7.

These results will be discussed in context with the other chapters of the thesis in Chapter 9.
SECTION 4

DISCUSSION AND CONCLUSIONS
Chapter 9
Discussion

There were 126 scuba diving-related fatalities in Australian waters from 1 January 2001 to 31 December 2013. Drowning was reported to have been the cause of death in half of these incidents, but was determined to have been the disabling injury in 37%. In the balance of these, asphyxia from water aspiration was secondary to unconsciousness subsequent to a disabling injury, such as a cardiac event or cerebral arterial gas embolism (CAGE), among others. This underlines the importance of diving accident investigators and forensic pathologists striving to identify the disabling injuries, rather than focusing on the causes of death, as mooted by Bayliss in 1969\textsuperscript{108} and clearly elucidated and demonstrated by Denoble and colleagues.\textsuperscript{13}

In chapter 8 it was shown that cardiac events accounted for one quarter of the deaths and these are increasing in prevalence in an ageing diving population.\textsuperscript{9} Many of the victims had one or more significant pre-existing medical conditions that predisposed them to an incident while diving. Cerebral arterial gas embolism was identified as the disabling injury in 15% of incidents which, as expected, mainly involved gas supply or environmental triggers, resulting in rapid or uncontrolled ascents. Environmental factors were the predominant trigger for incidents, although other significant triggers included exertion, gas supply problems, equipment problems, anxiety, buoyancy problems and diver error. The asphyxia-related deaths were strongly associated with the trigger of rough conditions.

Demographic factors

The review of Australian national sporting surveys from 2001 to 2010 (chapter 6) indicated that 76% of Australian scuba divers were males.\textsuperscript{223} This gender distribution was reflected in chapter 2 in the recent survey cohorts of mainly longer-term and active divers.\textsuperscript{201} However, PADI worldwide certification data indicate that 65% of the divers certified by PADI from 2011 to 2016 were males\textsuperscript{228}.
and this was very similar in Australia from 2001 to 2013 (D. Dwyer, CEO PADI Asia-Pacific, personal communication June 2016). PADI data also indicate a high drop-out rate among new divers which, in the USA, has been reported as more than 50% at 4 to 5 years post certification. This implies that, in Australia, the discontinuance rate may be higher in females.

The larger proportion of males in the post-certification diving population is reflected in the genders of scuba diving victims, of whom more than 80% were male. This may also reflect the increased prevalence of chronic medical conditions, especially cardiac and cardiovascular, in the male population.

The national sporting surveys reviewed in chapter 6 also indicated that 30% of Australian scuba divers were aged 45 years or older. Although this proportion was identical to that of the respondents from the survey cohort of mainly relatively inexperienced divers described in chapter 2, respondents to the surveys of more active divers (DAN members and PADI members) were older, with medians in excess of 45 years.

In comparison, the ages of scuba diving victims have increased substantially over the decades (chapter 5) but appear to have plateaued since 2000, with a median age of 45 years (chapter 8). This is very similar to the survey respondent cohort of more active divers (chapter 2).

**Overweight or obesity**

At 77%, the proportion of scuba victims who were overweight or obese was considerably higher than the 63% in the Australian adult population. It was also much higher than the prevalence reported by three cohorts of Australian divers as described in chapter 2, which ranged from 40% in younger, less experienced divers, to 64% in older, active divers.
The prevalence of obesity in the scuba victims (37%) as reported in chapter 8 was also substantially higher than in the general community (28%)\textsuperscript{230} and in the diver survey respondents described in chapter 2.\textsuperscript{201} This suggests that being overweight or obese is a likely risk factor for a scuba diving fatality, which is often cardiac-related. This is consistent with data from the general population that indicate an association between significant health conditions and being overweight or obese\textsuperscript{231-234}, as well was an association between obesity and sudden cardiac death.\textsuperscript{235, 236}

Even if a cardiac event did not underlie the death in some obese divers, obesity \textit{per se} can be a contributory factor to an incident.\textsuperscript{237, 32} The adverse effects of obesity on respiratory mechanics when immersed, the often excessively tight suit or equipment in obese divers, and the need for excessive weights are common in such divers and may act to compromise safety. Undiagnosed obstructive sleep apnoea, diabetes, as well as hypertension and high cholesterol are more common in obese individuals, and are all risk factors for coronary artery disease.

As shown in chapter 3, DAN AP member survey respondents with medical conditions were older and more obese (but smoked less) than those without conditions. However, there were few major differences in the nature or pattern of diving between those with and without medical conditions, other than the divers with medical conditions did less repetitive diving. This may reflect the higher age of those with conditions, and, possibly, an acceptance of their potential vulnerability due to the condition and the desire not to push their physical limits.\textsuperscript{202}

\textbf{Origin of victims, location and setting of diving}

Diving in an unfamiliar setting can introduce additional risks due to the lack of local knowledge about factors such as currents, conditions and underwater topography, differences in diving practices, cultural differences and language difficulty. In the fatality series reported in chapter 8, almost three quarters of the scuba victims were tourists, mainly from overseas. Queensland is a very popular destination for
tourists and many dive or snorkel on the Great Barrier Reef (GBR), mostly in a commercial setting.\textsuperscript{238} As such, it is unsurprising that almost one quarter of the scuba deaths occurred in this State, 80\% of these involving tourists who were predominantly international.

Diving-related tourism is an important income source for Queensland and, in 1992 a regulated Code of Practice for diving activities was introduced and has been periodically updated, the latest version being released in 2018.\textsuperscript{239} However, despite the comparatively high number of deaths, as indicated in chapter 6\textsuperscript{223}, the estimated annual fatality rate for tourist scuba divers in Queensland is considerably lower than the overall rate for Australian residents.\textsuperscript{223} The risk in Queensland may be partly mitigated by what are often more favourable diving conditions and the closer oversight as a result of the existence and enforcement of this Code of Practice.\textsuperscript{239} Although Codes of Practice have been created for Victoria\textsuperscript{240} and WA\textsuperscript{241}, these are voluntary, likely unknown to many operators and are often not followed.

One quarter of the scuba deaths occurred in NSW, most involving NSW residents, and in a non-commercial setting. New South Wales has a relatively large resident diving population, reportedly encompassing 27\% of active Australian divers.\textsuperscript{242} Its long and accessible coastline and variety of dive sites is conducive to independent diving and snorkelling but conditions can often be more challenging than further north.

Diving in the southern States can be more challenging with respect to colder water, rough and variable conditions, poorer visibility and the need for greater thermal insulation with its associated increased weighting requirements. This is reflected in the considerably higher annual scuba fatality rate estimated for Victoria (chapter 6).\textsuperscript{223}
The Chain of Events Analysis

The application of Chain of Events Analysis (CEA) to diving accidents was introduced by Denoble and co-workers in 2008\textsuperscript{13} and has greatly influenced the process of diving accident analysis in some places, including Australia.\textsuperscript{224, 164, 170, 183, 9} It is a dynamic system which has evolved, and will continue to do so, with broader input and experience as discussed in chapter 7.\textsuperscript{224}

The CEA of the cases reported in chapter 8 highlights the value of the addition of the link for Predisposing Factors, as described in chapter 7.\textsuperscript{224} It identified almost 200 factors that were present prior to the dives and which likely, or possibly, contributed to these fatalities.

Human factors can play a part throughout much of the accident chain. These include pre-existing health conditions, poor fitness, lack of experience, organisational shortfalls, poor planning or supervision and inadequate equipment maintenance. In addition, inattention, carelessness, inappropriate attitude and poor decision-making and inappropriate actions, whether prior to or during an incident, can all influence the chain of events and outcome.

Almost one half of the predisposing factors identified were health-related. More than one third were associated with organisational factors, training, experience and skills; and one quarter were planning-related factors.

An increased understanding of the impact of these predisposing factors, in conjunction with other parts of the accident chain, will enhance education about these throughout the diving community. This has a considerable potential to reduce morbidity and mortality in divers.

As shown in chapter 7, the use of a more detailed template to guide researchers when performing a CEA for scuba diving fatalities can be effective in improving
consistency between investigators within a study series, and is, therefore, encouraged to improve comparability between studies.\textsuperscript{224}

\textbf{Health factors}

Pre-existing health-related factors were determined to have played a major role in many of these deaths, the main ones being cardiac-related conditions, such as ischaemic heart disease and cardiac arrhythmias.

Arrhythmias can be precipitated by immersion \textit{per se}, especially in cold water.\textsuperscript{243-247} Immersion counters the effect of gravity and encourages redistribution of venous blood from the limbs into the thorax. As a result, there is a substantial increase in the cardiac workload.\textsuperscript{248, 246, 249, 250} In addition to these central fluid shifts, myocardial work can be further increased during diving from factors such as exercise, anxiety, cold-induced vasoconstriction, respiratory resistance and increased heartrate. The potential for an arrhythmia may also be increased by hyperoxia associated with diving.\textsuperscript{251} Together these increase the likelihood of a cardiac-related event in a predisposed diver.\textsuperscript{28, 252, 253}

As there is no definitive post-mortem test to confirm whether or not an arrhythmia has occurred, such a determination must be based on witness reports, medical history, and surrogate markers such as evidence of cardiac disease or abnormality at autopsy. It is, therefore, somewhat speculative and must be carefully assessed on the basis of the available evidence. Arrhythmias are commonly associated with coronary atherosclerosis.\textsuperscript{254} A critical stenosis believed likely to result in ischaemia is often regarded as being greater than 75\% narrowing of the lumen. However, a substantially smaller stenosis may be significant when associated with other potentially mitigating factors.\textsuperscript{255}

Left ventricular hypertrophy (LVH), generally consequent to hypertension, is a known risk factor for sudden cardiac death and an increased incidence of serious arrhythmias.\textsuperscript{256-261} In a comparative study of matched scuba diving and traffic accident victims, Denoble and colleagues reported that both heart mass and left
ventricular wall thickness were greater in the scuba victims.\textsuperscript{262} In this Australian series described in chapter 8, although the numbers are small and should be interpreted cautiously, 37\% of the 38 divers who were believed likely or possibly to have died as a result of a cardiac-related disabling agent were found to have LVH of varying degrees at autopsy. This is an area that merits further investigation with larger groups of divers and matched with appropriate controls.

The 25\% incidence of cardiac conditions as the disabling injury in this Australian series is consistent with the 26\% incidence reported for divers in the USA.\textsuperscript{13} That at least one quarter of scuba deaths in this era are cardiac-related is undoubtedly a reflection of the increased participation of older divers, as reported elsewhere\textsuperscript{11, 26, 263} and confirmed in this Australian study.

Although potentially limited by low response rates, diver surveys conducted as part of this research, and reported in chapter 2, indicated a prevalence of cardiovascular disease and/or abnormality in the diver respondents ranging from 9 to 16\%.\textsuperscript{201} This was considerably higher than the 5.2\% prevalence reported for the general Australian community\textsuperscript{230}, is consistent with the higher age of the divers, and helps to explain the incidence of cardiac-related deaths in divers.

The higher proportion of cardiac incidents in Queensland is likely reflective of an older cohort of divers, many of whom are tourists from overseas. The five-fold incidence of a cardiac disabling injury in divers aged 45 years or older is further confirmation of this risk in older divers.

There is an obvious need for ‘older’ divers to be medically assessed for fitness-to-dive. Current diving medical screening guidelines recommend a cardio-vascular review for all males at age 45 and females at age 55 years\textsuperscript{264}. However, in the experience of the Candidate, who has dealt with diving health and safety issues on a daily basis for 25 years, these guidelines are often not followed.
Pre-existing respiratory conditions including pulmonary adhesions or cyst, previous pneumothorax, emphysema and chronic obstructive pulmonary disease were, unsurprisingly, mainly associated with CAGE and/or PBT. These conditions, where known, would have rendered the individuals unfit to dive.

There is a considerable number of individuals with asthma who are diving in Australia and elsewhere. Although asthma was a contributing factor in several deaths, asthmatics are not over-represented in this series. As discussed in Chapter 4, some individuals with well-controlled asthma appear to be able to dive relatively safely, especially under appropriate diving medical guidance.

Most of the victims with pre-existing medical conditions were aware of these conditions, although, in others, it was occult. Some divers, both with diagnosed or occult conditions, had prior symptoms which were unrecognised or ignored, sometimes shortly before the fatal dive. This can be particularly problematic in the diving environment where immediate first aid and rapid medical intervention is rarely readily available.

The results from chapter 4 showed that some divers with potentially contraindicated conditions have dived with relatively few adverse incidents, often doing many dives over many years. However, this survivor cohort of divers may not have been representative of the victim cohort as they were typically managed medically and, given that they had taken out diving insurance, might be generally more aware of their health limitations.

**Fitness-to-dive assessment**

Until relatively recently in Australia, diver certification agencies required diver trainees to undergo a fitness-to-dive (FTD) assessment prior to certification. However, this has been progressively abandoned since about 2013, and a FTD
assessment is now only required in limited circumstances, based on responses to a self-reported medical questionnaire.

Although widely-used and supported by some data\textsuperscript{270}, this self-reporting system has limitations.\textsuperscript{271} It relies on the divers or prospective divers, as well as the dive professionals overseeing them, to fully understand the questions, the rationale underpinning them and the potential implications of failing to declare a relevant health condition. In any event, even if a FTD dive medical assessment was required initially, there is generally no requirement for further assessments, with the exception of some higher-level training. This means that much of the diving population have aged without having undergone another diving medical check.

There are several on-going issues with FTD assessments. Many are conducted by doctors who have no specific training or knowledge of diving medicine and, therefore, have little or no appreciation of the physiological effects and demands of diving. This can lead to a poor assessment of a candidate’s suitability.\textsuperscript{190} Only half of the survey cohort of DAN AP members with known medical conditions had discussed their condition with a diving doctor.\textsuperscript{203} All divers with potentially contraindicated conditions should be encouraged to consult with a diving medical specialist in conjunction with their treating doctor.

Some individuals intentionally withhold information for fear that they will be prevented from participating. An honest and complete medical history needs to be provided in order to facilitate a more accurate assessment.

Even when conducted by appropriately-trained doctors, FTD assessments are fallible and have some inherent limitations.\textsuperscript{272} Relatively few tests are routinely performed and appropriate tests will not always reveal underlying problems. Fitness-to-dive examiners are faced with the difficulty of selecting which diver candidates to investigate further, and what are the most appropriate tests to conduct. Such investigations have a cost, an associated risk, and are prone to both false positive and false negative results.
In the case series discussed in chapter 8, despite having been assessed as FTD within the previous year, at least 14 divers died as a consequence of their pre-existing health conditions. Well-considered guidance is available to FTD examiners and much of the experienced diving medical community readily avail themselves to medical colleagues to discuss and advise on diving medical issues.\textsuperscript{273-275}

Although most divers who undergo diving medicals are assessed to be ‘low risk’, a dive medical, especially one performed by a doctor with appropriate training, will sometimes determine that an individual has an unacceptable risk of a diving accident. This risk assessment is usually carefully explained to, and discussed with, the individual. However, some undeterred and determined individuals resort to ‘doctor shopping’ to obtain a diving medical clearance. In fact, in this series, a diver with a history of significant emphysema sent a friend as a substitute for another assessment. His subsequent death was a result of a pulmonary barotrauma and cerebral arterial gas embolism while diving.

\textbf{Medications}

At least 30\% of the scuba victims were taking identified medications. One, who was determined to have been disabled by a cardiac arrhythmia, had been taking a combination of medications that would have predisposed him to such an event.

Relatively little is known about the effects of immersion and hyperbaric pressure on most medications, especially various combinations of these. What is known is well summarised elsewhere.\textsuperscript{276}

Some medications (e.g., angiotensin-converting-enzyme (ACE) inhibitors, phosphodiesterase enzyme (PDE) inhibitors) affect fluid balance and vascular tone and may compound the cardiac effects of immersion. Others (e.g., beta-blockers) reduce exercise tolerance and may limit a diver’s ability to deal with exertional requirements during a dive. Some may cause drowsiness and increase the
likelihood of narcosis (e.g., antihistamines), some may lower the seizure threshold, (e.g. tramadol, certain tricyclic antidepressants and selective serotonin reuptake inhibitors) while others increase the risk and severity of haemorrhage (e.g., anticoagulants).

Although respondents to a survey conducted as part of this research and presented as chapter 4 reported no significant problems associated with their medication use, this was a relatively small survivor cohort. Further research involving larger groups of divers is required in order to better understand this important area of potential risk. Sometimes it is difficult to determine if it is the drugs themselves or the underlying condition that precipitates the death.

As part of a future study, the candidate and appropriately qualified co-researchers are planning to review the medications used by both the scuba and snorkelling victims during the 2001-2013 period. In addition, another study involving the collection of medical history, including medications, and subsequent real-time cardiac monitoring of snorkellers is planned.

**Scuba Diver’s / Immersion Pulmonary Oedema**

Three of the deaths in this series were attributed to immersion pulmonary oedema in scuba divers (scuba divers pulmonary oedema - SDPE). However, it might have been a contributing factor or the disabling injury in another five incidents.

Immersion pulmonary oedema (IPO – which includes SDPE) has been reported in swimmers (especially involving significant exertion), snorkel and breath-hold divers, and those using scuba, including rebreathers. Diving victims are usually ‘older’. As yet unpublished data relating to 31 cases of IPO (including nine fatalities) in the Oceania/Indo-Pacific region reveals a mean (SD) age of 53 (12) years with 58% being females. (Lippmann J, Edmonds C, Fock A. Immersion pulmonary oedema – Case reports, and Edmonds C, Lippmann J, Bove A. Immersion pulmonary oedema in Oceania – A review. Manuscripts under consideration)
Increased pulmonary artery pressure and wedge pressure have been identified as risk factors for IPO.\textsuperscript{279} Precipitants include the increase of hydrostatic pressures from immersion, exertion, stress, cold, negative pressure breathing water aspiration and over-hydration prior to diving.\textsuperscript{277} Immersion pulmonary oedema has also been associated with the use of certain medications such as beta-blockers.\textsuperscript{280} There have been an increasing number of reported cases in divers, both fatal and otherwise but it is probable that IPO is substantially under-reported.\textsuperscript{279, 281-286} (Edmonds/Lippmann, manuscript in preparation)

Although prompt investigations such as blood gases, chest X-ray or CT, blood tests and echocardiography can confirm a diagnosis of IPO in survivors, and may help explain the aetiology, this is far more difficult post mortem. Autopsy findings of pulmonary oedema in the airways and lungs can readily be attributed to drowning or cardiac disease. Indeed pulmonary oedema often results from cardiac dysfunction with or without immersion, so the role of immersion is not always clear.\textsuperscript{287} To further complicate the diagnosis, IPO can also be associated with other aspiration syndromes, pulmonary decompression sickness, pulmonary barotrauma, oxygen toxicity and irukandji envenomation. Hence, these potential causes need to be eliminated when trying to determine the differential diagnosis. However, despite, and because of, these potential confounders, it is likely that SDPE is under-reported.

A clinical history of diving-related dyspnoea is an important diagnostic factor which was reported in most of the incidents determined to be SDPE, or where SDPE was believed to have been a possibility. Witness reports of dyspnoea, especially with associated coughing and sputum and without apparent aspiration, raises suspicions and/or support for such a diagnosis and was present in the majority of confirmed or suspected cases. The sputum was usually described as blood-stained, or brownish and frothy.

Pre-existing medical conditions, especially cardiovascular disease or dysfunction, are common\textsuperscript{278, 279} (Edmonds/Lippmann, manuscript in preparation). Therefore,
when investigating a diving death when SDPE is suspected, investigators need to carefully review the victim’s medical history, especially any cardiac investigations where available. However, in some cases, the event appears to have been idiopathic. Stress cardiomyopathies such as Takotsubo and other reversible cardiomyopathies have explained some of these. Contraction band necrosis of the myocardium has been associated with reversible myocardial dysfunction and may provide supporting evidence at autopsy, although these can also occur from resuscitation so interpretation requires caution.

The presence of sand or other sediment in the airways, lungs and other gas spaces may sometimes help to distinguish drowning from IPO. However, this can also be misleading as descent while unconscious can draw fluid and debris into these gas spaces as they contract.

Organisational/training/experience/skills factors

Other important factors that predisposed divers to incidents included organisational, training, experience and skills-related shortcomings.

An important organisational-level consideration that is evident from the preceding discussion is the need for improved education of the diving community and medical community on fitness-to-dive considerations, and how certain health conditions can impact diving safety. Another organisational issue that was apparent in several incidents was the need for dive operations to have clear guidelines on staff responsibilities as well as hand-over protocols (e.g., for students between instructors, divers between the shop/booking agent and the boat skipper/dive masters) to ensure appropriate communication between staff about a customer in their care. However, the most predominant factor in this category grouping was inexperience.
Certification and experience

Of the 90 scuba victims whose certification level had been recorded, 91% were known to have been certified or were undergoing training at the time of their demise. This proportion was considerably higher than the 77% reported for scuba victims from 1972 to 1993, and suggests an improved delivery of the message for the need for training and certification. Although, it is generally accepted that training reduces the likelihood of a mishap, there appears to be little published data specifically supporting this. However, there are studies which have indicated that diving fatality victims had often broken one or more of the general diving safety rules, so learning, and adhering to, such rules should provide a safety buffer.

Swimming competency is assessed prior to diver certification, although the requirements are basic and some certified divers have relatively poor aquatic skills. These do not hold them in good stead if challenged by difficult surface conditions, as reflected by some incidents in this series.

Given the varying definitions of experience used in previous fatality reports from Australia, and beyond, it is impossible to confidently measure and compare any change in the level of experience of the victims over time. However, from 2001 to 2013, at least 46% of the scuba victims had done a minimum of 30 dives, so experience per se is not necessarily protective.

Factors such as recency and relevance of experience are important. Diving in different environments may require specific skills for which specialised training is required. On other occasions, appropriate supervision may suffice or a thorough briefing and orientation may be adequate. In any event, relevant factors need to be carefully considered, a risk assessment conducted and appropriate action taken.

A recurring theme in diving accident reports and reflected in this series is ‘experienced’ scuba divers getting into difficulties after an extended absence from
diving. Unless practiced, diving skills will deteriorate over time and re-
familiarisation under controlled conditions is well-advised. Any potential change in
an individual’s fitness to dive needs to be carefully considered and acted upon.
Equipment requires proper inspection and servicing, especially after not being used
for an extended period, as corrosion and deterioration can occur.

**Deaths during diver training or introductory experience**

It is concerning that 16 of the 126 (13%) scuba-related deaths in this series involved
divers, 11 of these 16 being novices, while participating in sanctioned training or an
introductory scuba experience (ISE). Pre-existing medical conditions are likely to
have contributed to the deaths of six of these divers. However, poor planning and
inadequate supervision, often in adverse conditions, was identified as major
contributors to the others.

Some deaths during training are to be expected. Individuals who are predominantly
inexperienced and of unknown compatibility with the demands of diving (physically
and psychologically), are pitted against, and learning to adapt to, the potentially
hostile environment. A trainee can come to harm as a result of unforeseen
problems arising from the environment, human error, ignorance, medical factors,
carelessness and negligence. An analysis of PADI training data from 1999 to 2008
indicated a fatality rate of 1.66 deaths per 100,000 trainees, or 0.47 deaths per
100,000 training dives.\textsuperscript{188}

By way of comparison, the death rate in diving-certified Australian residents was
estimated to be 8.73 deaths per 100,000 divers, or 0.48 deaths per 100,000
dives.\textsuperscript{223} This implies that the risk per dive is similar, suggesting that trainee divers
are at no greater risk than certified divers. This is likely due to the higher level of
supervision, comparatively non-provocative nature of the dives and the generally
younger age of the trainees. However, certified divers have performed more dives
and are generally older so that their overall risk is higher.
Training agency standards include maximum instructor-to-student ratios. Such ratios need to be reduced if conditions are less than ideal. However, there is sometimes a reluctance to do so, or to cancel dives, whether for loss of revenue or to avoid disruption of the plans of various parties involved. This was apparent where obviously adverse conditions (i.e., very poor visibility, strong current, rough conditions) were instrumental in the demise of four rank novices.

The Candidate has previously suggested that: “From a safety perspective, with an introductory dive it may be more sensible for an instructor (and their employer, if relevant) to consider a ratio starting point of one or two students, and work upwards if the conditions are considered suitable, rather than starting from the maximum and working down. The mindset is subtly different and might help to err on the side of safety. However, this suggestion is likely to be unpopular commercially.”

Another common factor in several cases was that the instructors led the groups from the front, turning around periodically to check on the students. It is often preferable for the students to swim closely abreast on each side of the instructor. Alternatively, the students can swim closely abreast of each other with the instructor close in front, facing them and swimming backwards. The crux of the matter is that instructors must remain very close to the divers at all times, so that they can intervene without delay when necessary. They should also have a low threshold for aborting a dive if visibility or other conditions deteriorate substantially.

In at least two training-related deaths in this series, the student appears to have been substantially over-weighted. Divers are usually taught to adjust their weights so that they are ‘neutrally buoyant’ on the surface (or at their safety stop). However, it is quite common for instructors to make their trainees negatively buoyant. The reason for this is to reduce the likelihood of the trainee floating away without the instructor’s knowledge. Although this is far from ideal, it can be effective as it keeps the trainee on the bottom. However, it can alter a diver’s
posture in the water, increases swimming resistance and therefore fatigue, and stirs up sand or sediment on the bottom which may visibility. Most importantly, if a diver is over-weighted it can be more difficult to ascend to, and remain on, the surface unless they sufficiently inflate their BCD and/or ditch their weight belt.

Two of the four victims who died during their introductory scuba dives, and three of the four Open Water Diver training victims were found on the bottom without their BCDs inflated, and with their weight belts in place. They were unable to reach, and/or remain at, the surface and underwater searches were required to recover their bodies.

Every new diver needs to be orientated to, and demonstrate, weight belt removal and BCD inflation, and should be required to show competency in these skills prior to certification. However, data from this study has highlighted that an important underlying organisational problem is an inadequate training focus and on-going practice in the skill of weight belt ditching and gaining positive buoyancy when required in an emergency.

**Becoming positively buoyant in an emergency**

Delay to resuscitation adversely affects the outcome, and precious time is lost if it is necessary to locate and recover a victim underwater. Therefore, it is far better for an unconscious diver to be at the surface, rather than having to be searched for and recovered from underwater. It follows that, if a diver is in danger of becoming unconscious, whether underwater or on the surface, it is important to attain positive buoyancy. This can be achieved by inflating the BCD, ditching weights, or both. The exception to this is during a penetration dive where the surface is not directly accessible.

In an earlier review of Australian compressed gas diving-related fatalities, almost three quarters of the victims were found wearing their weights. By comparison, in the series analysed in this thesis, more than two-thirds of the scuba divers still had
their weights in situ (whether on a weight belt or integrated in their BCDs) at the
time of attempted rescue or recovery. This highlights an on-going problem of divers
being reluctant, or unable, to act effectively in gaining positive buoyancy in an
emergency. In this series, more than one third of the victims had not inflated their
BCDs or ditched their weights. In many cases it is probable that, by the time the
divers recognised the need to do so, in the mind-numbing inertia of the situation
they were too incapacitated to act effectively.

Just as learning and practicing the deployment of the reserve parachute is essential
in skydiving, ditching the weight belt is an important training drill for scuba divers,
and needs to be practiced, embedded and periodically re-visited.

Planning-related factors

One quarter of the incidents involved poor planning decisions such as diving in
patently adverse conditions, and/or diving solo or with an obviously ineffective
buddy system. Dive planning should always allow for adverse events (‘Murphy’s
Law’) – a history of trouble-free practice of a procedure is no guarantee of lack of
future problems. Past poor practice where there have been no obvious
repercussions can lead to “normalisation of deviance”\(^{298}\) whereby it becomes
acceptable not to follow best practice and so narrows the margin of safety.

Buddy system

The absence, or breakdown, of the ‘Buddy System’ is another recurring theme in
dive fatality reports.\(^{88, 9, 11, 171, 16, 21}\) In this series, only approximately one quarter of
the scuba victims were with a buddy at the time of their demise. Although this is
higher than the 18% reported in an earlier Australian series\(^{9}\), it indicates an on-
going problem that needs to be further addressed.
The Buddy System is taught to trainees as an important part of diving safety in a
hostile environment where a diver might need assistance with equipment,
entanglement, breathing gas supply, managing sea conditions and a variety of
other potential problems. Training in self-sufficiency and the carrying of redundant equipment is a valuable safety measure. However, as previously argued by the Candidate, “a well-trained and vigilant buddy can be an important asset in an emergency. The time saved in searching for and recovering a missing diver or snorkeller, or in quickly recognising that a diver or snorkeller is in distress, may well prove an important factor in increasing their likelihood of survival, depending on the mechanism of their problem.”

The ‘same ocean’ buddy system (a term used to describe the situation where divers may enter the water together but do not specifically stay close to one another) is common practice amongst technical divers and those hunting seafood. Unless there is a proper, close buddy system, there is, in reality, no buddy system at all.

Diving in buddy groups larger than two introduces additional challenges in monitoring and maintaining contact. This was quantified in this series where victims were more than three times more likely to have separated if they were diving in a buddy group larger than two.

**Environmental factors**

Various environmental factors appear to have been the triggers in almost one half of the incidents. The majority of these were associated with adverse sea conditions including, singularly or in combination, strong currents, poor visibility, rough surface conditions and underwater surge.

Inexperienced divers, especially those with poor aquatic skills and lack of comfort in the aquatic environment, can comparatively easily underestimate, and be overcome by, what might be mild to moderate sea conditions. Even diving veterans can become over-confident and complacent about what they believe to be manageable conditions. This can trigger a cascade of events leading to their demise. In this series, inexperienced divers were twice as likely to have had a conditions-related trigger, than those who had done more than 30 previous dives.
Sea conditions are dynamic, and appropriate local knowledge, planning and consideration is important to minimise the potential for such problems.

Depth did not appear to have played a large role in incidents in this series, with only 11% occurring deeper than 30 msw. This is consistent with the reported median proportion of 10% of dives over 30 msw reported by some cohorts of survey respondents who were predominantly experienced divers.201

Exertion

Exertion was the trigger, or a co-trigger, in over a quarter of these fatal incidents. Dependent on the wearing of weighty equipment, diving inherently involves some level of exertion, which can be multiplied manyfold by the presence of a current and rough conditions. Given the potential cardiac demands associated with diving, as discussed earlier, it is unsurprising that an incident triggered by exertion was six times more likely to result in a cardiac-related disabling agent.

Equipment-related problems

Although post-incident equipment examination, when conducted, revealed faults in the equipment of one third of the victims, these appear to have been directly contributory as a trigger in a relatively small percentage (8%) of the deaths. This is considerably lower than the 18% previously reported for Australia (1972 – 2005)9, 15% for the USA (1992 – 2003)13, and 20% in the UK (1998 – 2009).11

The apparent reduction in equipment triggers may be due in part to improvements in the equipment or in its use over time, as well as regional differences in equipment use. A recent report from a survey of European divers indicated an overall incidence of equipment malfunction in 2.7% of 39,099 dives.299 However, in the UK fatality series11, over half of the equipment-related deaths involved the use of rebreathers which are more commonly used in the UK than in Australia and many other countries. The likely over-representation of rebreathers in ‘near-misses’ reported in some Australian divers201 is testament to the greater
complexity of these devices, and the increased need for training, maintenance and vigilance.\textsuperscript{300-302} Many fatal incidents involving rebreather divers appear to result from human error. However, a considerable number have also been attributed to design faults in the devices, something that is being progressively identified and addressed.\textsuperscript{300, 303, 304}

All of the equipment-related deaths in this series were preventable. For example, one inexperienced diver assembled his own ‘octopus’ and failed to secure it, enabling it to detach during a cave dive. If asked, the dive operator could have easily secured the fitting and the death would not have occurred. Other problems arose from lack of maintenance. Buoyancy compensator inflator/deflator mechanisms have historically been a common cause of mishaps\textsuperscript{305}, and continue to be. Faulty submersible pressure gauges should have been identified well before the planned dive and repaired or replaced.

The use of pre-dive checklists can be invaluable in the prevention of a variety of diving mishaps, including those related to equipment, and should be strongly encouraged throughout the diving community, but especially among those using more complicated equipment, such as rebreathers.\textsuperscript{306-308}

**Gas supply problems**

Gas supply-related issues comprised 12% of triggers and 14% of the disabling agents in this series, usually resulting in CAGE or asphyxia. Despite the ubiquitousness and relatively low cost of good quality submersible pressure gauges, breathing gas depletion remains a problem. This is usually a result of inexperience, inattention, poor planning or faulty equipment. All of these are preventable with appropriate equipment maintenance, careful gas supply planning and greater situational awareness prior to, and while, diving.

Technical divers need to be very careful about their choice of breathing gases to avoid using an inappropriate mixture during any part of a dive. Several deaths in this series were associated with the use of unsuitable breathing mixtures.
Although breathing gas contamination was not identified as the direct cause of any death in a scuba diver in Australia between 2001 and 2013 as reported in chapter 8, it has subsequently. However, cylinder air contaminated by oil was a likely contributor to one death in this series, in which the diver appeared to have become nauseated, made a rapid ascent and suffered a CAGE. Deficiencies in the required purity of the breathing air were found in over 8% of cases, so this is an area requiring vigilance. Correct compressor placement, maintenance, and appropriate oversight by knowledgeable personnel is important, and the addition of carbon monoxide monitoring is highly desirable.

**Resuscitation-related issues**

The resuscitation-related issues from the scuba and snorkel incidents were combined as the supervisory circumstances under which the activities are conducted are often similar, as is surface management of the victim. The combination enabled analysis of a larger dataset.
Rescue, in-water rescue breathing and /or chest compressions

Removal of the victim from the water

There were at least five incidents (three scuba and two snorkel) in which the rescuer was unable to lift the unconscious victim onto the boat or tender. This is often a difficult task, especially with a large victims, and is something that needs to be considered well in advance. In some situations, pre-prepared ropes or harnesses can be used to facilitate the task. However, whatever technique is planned, it needs to be practiced and streamlined. This is especially important with technical diving, where the victim is likely to be laden with bulky equipment which is often more difficult and time-consuming to remove.

In-water Rescue Breathing (IWRB)

At least 30 of the rescuers (four scuba and 24 snorkel) attempted in-water rescue breathing (IWRB). Although none of these were ultimately successful, there is some evidence from lifesavers in Brazil that this can increase the chances of survival of a victim of drowning.310

In-water rescue breathing is commonly taught to lifesavers, and also to Rescue Divers, and there is evidence that it can be performed effectively on a manikin by well-trained persons.311 However, unless learned and practiced, this skill can be poorly-performed and can delay proper assessment, airway management and further resuscitation on a dry, solid platform. Therefore, it is important for a rescuer to carefully assess the particular circumstances, and make a decision on whether or not to perform IWRB based on the likely period of apnoea of the victim, the distance to the boat, shore or platform, the conditions and the rescuer’s competence. The International Life Saving Federation has published recommendations to IWRB312, 313 and these were modified to provide guidance for the rescuers of scuba divers.314
In several cases, it was reported that the rescuers used a diving demand valve to try to ventilate the victim. The flow rate from a modern demand valve when purged is very high, often well in excess of 200 L/min. Despite the difficulty in obtaining an effective seal when using a demand valve with mouthpiece on an unconscious victim, and the presence of exhaust valves, such high flow rates are hard to control and can easily cause stomach distension and consequent regurgitation, as well as the potential for pulmonary barotrauma. In one incident, the demand valve was used on an apnoeic victim during ascent, further complicating the circumstances with water ingress and the expansion of air in the lungs during ascent. For these reasons, this technique is not recommended.

Some individuals equate the use of diving regulators with positive pressure oxygen resuscitators. However, the flowrate in oxygen resuscitators is limited to 40–60 L/min and they are fitted with one or more pressure relief valves to prevent pulmonary barotrauma.

**In-water Chest Compressions**

One of the rescuers of a scuba diver in this series attempted in-water chest compressions. Despite some historical manikin studies indicating that, in theory, in-water compressions might achievable on a manikin\(^ {315, 316} \), it would be very unlikely that a rescuer could deliver adequate coronary and cerebral perfusion to an unconscious person in the water, especially at the compression depths and rates now recommended. Therefore, attempts at in-water compressions should be discouraged, and priority given to removing the victim from the water as soon as possible.

**Airway management**

Airway management complications from vomiting, regurgitation or frothy sputum are very common occurrences in the resuscitation and aftercare of victims rescued from the water. An Australian study of reports from lifesavers reported
regurgitation in two thirds of 262 immersion victims who received IWRB, and 86% of those who required cardiopulmonary resuscitation (CPR). At present, there are no substantial published data on the incidence in divers.

Airway management complications were gleaned from witness reports in one third of the scuba and snorkelling victims (40% of the scuba and 30% of the snorkel victims), but may have been unreported in other incidents as on-scene investigators rarely seek such information. Potential rescuers need to be aware of the likelihood of the presence of regurgitated stomach contents, water, froth and pulmonary oedema fluids and be prepared to deal with them. This is generally managed by rolling the victim onto their side to drain and clear the airway of any fluids or solid matter, before commencing, or recommencing, resuscitation. This manoeuvre may need to be done multiple times. Access to a resuscitation mask may reduce concerns about providing ventilations in such circumstances, although this did not appear to deter the rescuers in most cases in this series.

**On-scene cardiopulmonary resuscitation (CPR)**

Basic life support (BLS) is a very important factor in increasing the chances of survival of a victim of cardiac arrest from a variety of causes. However, internationally, only a minority of victims receive CPR from bystanders. The average rate in Victoria has previously been reported to be 62.4%, and from 24.5 to 41% in Perth. However, a very recent report of Australian and New Zealand ambulance data indicated an overall rate of 41%, rising to 67% when witnessed by a bystander.

Some information about resuscitation was available in 95% of incidents in this series. Based on these, bystander CPR was performed on almost all victims where their body was available; 73% overall.

The higher rate of BLS in diving-related scenarios is a likely due in part to the requirement that dive professionals, as well as those involved in the supervision
and conduct of commercial snorkel activities in Queensland, are trained and certified in BLS. In addition, those offering charter services or instruction to divers and snorkellers owe a duty of care to their customers, placing an additional onus on the need for preparedness to perform such skills. There are no data to indicate whether or not there is a higher rate of BLS training in divers, than the general community, although this is possible. Additionally, resuscitation is often performed by other divers or snorkellers who knew the victim and so have a greater motivation to do so.

Unfortunately, despite the application of BLS, these victims failed to recover, often due to the delay to implementation of BLS and subsequent Advanced Life Support (ALS), which was sometimes considerable. It has been reported that early BLS can double or triple survival from ventricular fibrillation cardiac arrest.\textsuperscript{324} However, unlike a witnessed cardiac arrest in the street or at home where BLS may begin within a minute or two, a typical delay to commencement of BLS in diving-related scenarios is 10 to 15 minutes, due to the initial recognition of a problem and subsequent recovery of the victim to a place where BLS could be implemented. Diving activities are often conducted in relatively remote locations so the arrival of paramedics is often delayed, typically being in excess of 30 minutes, and sometimes over an hour. This heightens the need for those conducting diving activities to have access to the skills and equipment required to increase the chances of survival of a diving accident victim. Such skills include competency in BLS, first aid and oxygen administration and the use of an automated external defibrillator (AED).

**Premature cessation of resuscitation**

There were several incidents where it was reported that BLS efforts were abandoned after a very short time, or not performed at all, on the basis that the (layperson) rescuers believed that there was no hope of success. The cessation of, or decision not to perform, resuscitation is an important decision which, where possible, should be guided by an appropriate medical professional.
“The rescuer should continue cardiopulmonary resuscitation until any of the following conditions have been met:

- the person or begins breathing normally
- it is impossible to continue (e.g., exhaustion)
- a healthcare professional takes over CPR
- a healthcare professional directs that CPR be ceased.”

In most cases, resuscitation attempts extended beyond 30-40 minutes and were ceased on the advice of arriving paramedics or doctors, or after telephone instruction from a doctor.

**Automated external defibrillator (AED) use**

The availability of AEDs has increased exponentially in the general community, and their prevalence in the diving community appears to be increasing, albeit relatively slowly. In response to a series of cardiac-related deaths in snorkellers and divers, in 2005, the Northern Coroner in Queensland recommended that “Persons undertaking recreational diving or snorkelling (to include employers, self-employed persons, employer organisations and recreational dive training agencies) shall ensure an automatic external defibrillator (AED) is immediately available at each dive and snorkelling site”. This is reflected in the recently updated Queensland Code of Practice for Recreational Diving.

Early defibrillation can increase the survival rate for out-of-hospital cardiac arrest. It has been reported that, every minute of delay to defibrillation leads to a 10% reduction in the survival if the cardiac arrest was from ventricular fibrillation (VF). However, VF is not as commonly detected in drowning victims which would include approximately 40% of both the scuba diving and snorkelling cohorts. This low incidence of detectable VF may be at least in part due to delays in recovery and electrocardiogram analysis. Therefore, defibrillation might not be so inherently effective in such cases, which are not primarily cardiac in origin.
Key predictors in the survival of drowning victims are the emergency medical response time and being found in a shockable rhythm.  

In 40 cases, AEDs were available at, or near, the site of the incident but, in almost 90% of these, when the AEDs were attached, there was no shockable cardiac rhythm. As previously mentioned, in diving scenarios there are often delays in the recognition and rescue of victims, compounded by the fact that these activities are often conducted distant from medical care. However, given the increasing number of diving fatalities that are due to primary cardiac causes, if recognition and rescue are swift and the opportunity for subsequent drowning minimised, prompt defibrillation may be more effective.

AEDs do require regular checking and pads and batteries need to be replaced when required. In one case in this series, when the AED was attached, the battery was flat and precious minutes were lost in accessing and replacing the battery.

**Oxygen first aid**

The provision of high concentration oxygen to victims of a scuba diving incident is an industry Standard of Care as it is very effective in the management of decompression illness, pulmonary barotrauma and drowning, among various other illnesses and injuries. Certified dive professionals from divemaster level and higher are required to undergo training in oxygen first aid.

Despite the potential benefits of oxygen first aid and the ease of access to suitable equipment, oxygen-supplemented ventilations were reported to have been provided to only 24/128 (19%) of the scuba diving victims (and 19% of the snorkelling victims). However, once again, it is likely that many cases of oxygen administration went unreported as it was not a standard investigation question in most jurisdictions.
The delivery of near-100% oxygen to a person who is breathing spontaneously is not difficult, although it does require appropriate training and equipment. Suitable and commonly used delivery modes to conscious scuba divers are via a demand valve with oronasal mask, or by non-rebreather mask. However, the delivery of near-100% oxygen to an unconscious, apnoeic person can be challenging and a variety of additional problems can arise, depending largely on the equipment used and the operator’s familiarity with this equipment. Bag-valve-masks (BVM), preferably with an oxygen reservoir, are often used for this. Such devices are valuable in trained, skilled and well-practiced hands, but can be ineffective and potentially harmful in the hands of occasional users.\textsuperscript{339, 340} In this series, in six of the 19 (32%) reported incidents where BVMs were available, oxygen administration was abandoned or not commenced due to problems with the use of the BVM.

Manually-triggered oxygen-powered resuscitators (MTR) can more easily deliver 100% oxygen to the apnoeic victim. However, they still require appropriate training and regular practice, as well as on-going maintenance, especially when used in an aquatic environment.\textsuperscript{334, 341} It is recommended that two-operators are used when using a BVM or MTR - one to manage the airway and mask seal, and the other to ventilate with the device.\textsuperscript{342, 341, 339}

The recreational dive industry and its regulators have been pragmatic about the difficulties for lay first aiders using BVMs ad MTVs. Recreational dive professionals are usually trained to ventilate a non-breathing diver using a resuscitation mask with oxygen-supplemented expired breath, as this skill is far easier to perform, especially by those with minimal training.\textsuperscript{339, 343, 340} It has been reported that this technique can deliver an inspired oxygen concentration in excess of 40-50% with an oxygen flowrate of 15 lpm.\textsuperscript{344, 345} The rationale is that it is better to deliver around 50% inspired oxygen effectively using a resuscitation mask, than to be unable to use more sophisticated devices effectively, despite their potential to provide higher oxygen concentrations.
The incidents where oxygen equipment was unusable due to missing, or faulty, parts highlight the need for on-going maintenance and regular checking of both the equipment itself and the cylinder contents. Potential oxygen providers and first aiders need regular practice to maintain their skills, so that these are well-honed in the event of an emergency.

Overall, these data indicate that divers and providers of diving-related activities have much room for improvement in the provision of supplemental oxygen to their dive buddies, or divers under their care. BVMs should be avoided unless the users are well-trained and practiced in their use.

**Autopsy issues**

The determination of the disabling injury and cause of death at the autopsy of the victim of a scuba diving incident can be challenging. The old adage “If he’s wet and dead; he drowned” has been shown to be very limiting and it is important that an autopsy on a diver is conducted by a pathologist with an appreciation of the issues involved and/or in consultation with a diving medical specialist.\(^{346, 347}\) The absence of a definitive post mortem test for cardiac arrhythmia has already been discussed, as have the problems associated with the consideration of immersion pulmonary oedema as a factor.

Vitreous fluid is relatively isolated from blood and other body fluids that are affected by postmortem changes such as redistribution and haemoconcentration, and can be used for post mortem chemical analysis. The measurement of post mortem vitreous sodium and chloride (PMVSC) has been proposed as a diagnostic tool for salt water drowning. A PVMSC of 259 mmol/L or higher reportedly indicates salt water drowning as long as the body has not been immersed for longer than one hour.\(^{348}\) This suggestion has been applied with varying success to the analysis of some Australian diving and snorkelling deaths in this series where PMVSC levels in ocular fluid were reported\(^ {147, 148}\), although the relevant tests were either not performed or reported in most of the autopsies.
A continuing conundrum in the investigation of scuba diving fatalities is the detection and interpretation of extraneous post mortem gas in the body. Such gas can arise from a variety of sources including putrefaction, post mortem decompression artefact, decompression sickness, pulmonary barotrauma, arterial gas embolism, resuscitation and drowning. Investigators need to have a clear understanding of where gas from the different sources accumulates and the associated volumes in order to facilitate a more accurate interpretation and allocation. Guidance for this is available.\textsuperscript{346, 347, 349-351} In many cases, there is a delay of several days between death and autopsy. Such a delay can make diagnosis more difficult, mainly due to the gas associated with decomposition as well as the redistribution of fluid from the lungs.\textsuperscript{287} Early computed tomography (CT) scan examination can help to minimise the effects of such a delay and has become more widespread in Australia. However, although highly recommended, this is not yet universal. A full body CT can provide a clear picture of existing gas prior to surgical intervention from the pathologist, which can introduce gas. However, the CT is far less useful the longer it is delayed.

Sometimes delays are inevitable due to the remoteness of the dive site. It has been recommended that a CT be done within eight hours of death to minimise gases from putrefaction, but the sooner it is done, the better (ideally within three hours).\textsuperscript{351} Gas from resuscitation and post mortem decompression artefact may still be present but one source is reduced. Intracadaveric gas sampling and compositional analysis conducted in conjunction with CT can help to identify the source of the gas and help to confirm or refute a diagnosis of AGE.\textsuperscript{352} However, when considering the possibility of AGE it is very important to seek and consider information about the dive itself, including any history of gas supply depletion, breath-holding, rapid ascent and rapid loss of consciousness at or near the surface. A history of pulmonary disease can also be enlightening. The ability to download the dive profile from a victim’s dive computer can be an invaluable tool in obtaining important information about the profile. This needs to be done with knowledge
and consideration of the sampling frequency of the device and limitations of the
data provided.\textsuperscript{353}

In this series, 18\% of the 105 deaths where a disabling injury was clearly identified
were attributed to CAGE, compared to 25\% of 311 deaths from 1972-2005.\textsuperscript{9}
Although this substantial reduction may be coincidental, it could be due in part to a
greater reluctance of forensic pathologists to attribute post mortem gas to arterial
gas embolism. There were an additional 14 cases where CAGE was considered but
no confident diagnosis was made.

The presence of an intracardiac shunt can increase the likelihood of AGE\textsuperscript{354-356} and,
despite the recommendation that probe patency of the foramen ovale be routinely
tested during the autopsy of a scuba diver\textsuperscript{351}, this is not commonly mentioned in
autopsy reports.

**Scuba diving safety in Australia**

Diving is generally regarded as an “adventure sport” and perceived to be a
dangerous activity.\textsuperscript{357} The question is often posed about how the associated risks
compare with other sporting activities. Denoble reported that overall death rates
during recreational (scuba) diving are similar to that of motor vehicle accidents and
jogging.\textsuperscript{12}

Unfortunately, there are no available national data with which to compare scuba
diving mortality with that associated with other recreational activities throughout
Australia, or providing a national fatality rate for sporting activities. A report from
New South Wales estimated the death rate during sport or recreation in that state
to be 0.85 deaths per 100,000 persons.\textsuperscript{358} However, this was based on the general
population of NSW rather than actual participation and would therefore be an
underestimate of the rate in actual participants. A study of sport and recreation-
related injury and death in Victoria from 2001 to 2007 estimated an overall death
rate of 1.10 (95\%CI 1.03, 1.19) per 100,000 participants per year.\textsuperscript{359} The fatality
rates for the sports reported ranged from 0.5 deaths per 100,000 participants for ice/snow activities, to 10.1 deaths per 100,000 participants for off-road motor sport. The estimated fatality rate of 8.73 deaths per 100,000 Australian resident divers was comparable to that reported for fishing in the Victorian study, which was 9.5 deaths per 100,000 participants.

The Candidate has sometimes heard claims that diving in Australia has become "safer" over time; this claim being made on the basis of a presumed increase in the level of activity without a consistent increase in the absolute number of annual fatalities. The trend analysis shown in chapter 5 indicates an increase in annual death counts for each decade from 1965 to 1991 followed by a subsequent general plateau to 2013. Although, there was undoubtedly a substantial growth in diving activity during parts of that period and the annual deaths counts would reflect this to some extent, there are no reliable activity data on which to calculate a risk estimate for most of that period. However, the Exercise, Recreation and Sport Surveys (ERASS) data for 2001 to 2010 described in chapter 6 do not indicate a steady increase in diving activity or the number of active Australian divers. There was also no consistent reduction in the estimated annual fatality rate during the corresponding period.

Although not a direct measure of diving activity or total active divers, one important indicator of the health of the diving industry is the annual number of entry-level certifications. Many training agencies do not publish figures on certifications. However, international certification data from the Professional Association of Diving Instructors (PADI) (the predominant diver training agency worldwide) and the British Sub Aqua Club (BSAC) membership data have shown a lack of growth, or reduction, in annual certifications or memberships during the period of this study.

The first national study of the Australian scuba diving industry, published in 1989, reported that there were 50,550 new scuba divers certified in 1988. By 1991, this figure had reportedly risen to 54,153. However, in 2007, it had dropped to
around 48,000 (personal communications from the PADI, SSI, NAUI, SDI dive training agencies, 2008.). Entry-level certifications continued to drop and reached approximately 28,000 by 2013 (personal communications with PADI, SSI and NAUI, 2014). Coupled with the reduced certifications is the substantially high drop-out rate in new divers, reported to rise beyond 50% at 4-5 years post certification.229

The reduction in diver certification numbers, especially over the later years supports some anecdotal reports of a perceived contraction in the Australian scuba diving industry since the activity heights of the late 1980’s and early 1990’s. This may be due in part to a lower level of interest in diving, which has to compete with a broad range of other ‘adventure activities’. The marketing of scuba diving can be made more difficult in the presence of adverse media reports of, for example, shark attacks or divers being left at sea.364-366 However, it will also be influenced by more Australians becoming certified while visiting overseas destinations. Diving has become increasingly popular in various resort destinations in Asia and this has attracted both Australians and other international travellers and provided strong competition to the industry in Australia.

In any event, although the overall risk of a diving fatality is low, there appears to be no evidence of a reduction in the scuba diving fatality rate in Australia and claims of improved diving safety using this criteria appear to have no basis. However, on a more positive note, there was a reduction of almost 40% in the number of divers treated annually for decompression illness from 2001 to 2013367,368, indicating that, from that perspective, diving has become safer. This is the subject of separate research.
Chapter 10

Strengths and Limitations

The strengths and limitations specific to a paper published as part of this thesis are presented within the paper, as indicated in chapters 2, 3, 4 6 and 7. This section focuses on the more general strengths and limitations associated with the overall thesis.

**Strengths**

A key strength of this study is that it is based on a strong, virtually complete diving mortality surveillance system which is superior to known diving mortality data systems internationally. It is based on detailed searches of all recorded diving-related coronial cases and thorough and expert analyses of the associated coronial data.

A structured information-gathering and analysis process was followed in the investigation, analysis and reporting of each diving-related fatality in the reported case series. The process enabled an in-depth exploration where each fatality was reviewed by an expert committee, and the circumstances of the deaths recorded and reported. The data collection is appropriate, as complete as possible, analysed by suitable personnel, stored securely, used within relevant privacy protection guidelines, reported and disseminated to relevant parties.

Despite some potential for bias (discussed below) strengths of the surveys include the relatively large and varied number of participants, and the breadth and depth of information provided.

**Limitations**

A major limitation of the diving fatality surveillance system is the general lack of denominator data to calculate changes in risk and other trends over time.
However, event-based analysis can be used to identify potential risks to the diving community.

Although there are relatively few diving-related deaths annually, such events are an important indicator of trends or clusters in place or time, particularly when monitored in a systematic way over a long time period, and can provide important information about the preventability of similar events and evaluate the effectiveness of interventions. The amount of data that have been collected on each event can help in part to compensate for the small numbers.

In addition, the study has some specific limitations associated with the data and its collection as outlined below:

**Limitations with the collection and analysis of fatality data**

The fatality data has been compiled over an extensive period and is usually based on all of the information that was made available to the investigating coroners; including police reports, equipment reports, medical records and autopsy reports. However, as with any uncontrolled case series, the collection and analysis of the fatality data are subject to inevitable limitations and uncertainties associated with the investigations. These include:

1. **Incomplete case data:** Deaths were sometimes unwitnessed and, therefore, potentially important observational information was missing for these. Reports provided by witnesses varied in their likely reliability. Police reports varied in their content, often related to the expertise of the investigators. This may lead to incomplete or inaccurate chain of events analyses for these.

2. **Autopsy reports:** These can sometimes be unreliable. This may result from the difficulty in determining the presence of arterial gas embolism in the absence of relatively prompt post-mortem CT scans; as well as the inability to detect direct evidence of cardiac arrhythmias; among other factors. Care must be taken to critically examine the available evidence in light of its limitations. Otherwise, inaccurate allocation of the disabling injury may result, and important
information about less obvious disabling injuries may be missed.

(3) Classification of cases into chain of events: Even with the use of a template, classification of cases into a sequence of five events (predisposing factors, trigger, disabling agent, disabling injury, cause of death) using chain of events analysis is imperfect and remains vulnerable to some subjectivity. Multiple factors may be contributory at various levels and need to be taken into account in order to prevent misallocation of categories and incorrect conclusions about the sequence of, ultimately, fatal events.

The above limitations were taken into account by the Candidate and co-investigators when assessing and analysing available data, and allocations were not made in the absence of reasonable information. Therefore these limitations will not materially impact the conclusions drawn.

**Limitations with the collection of survey data**

The surveys included in this study employed a detailed questionnaire about demographics, health, diving behaviour and associated problems. These were sent to DAN AP members, PADI members and a cohort of PADI divers. In addition, a targeted health questionnaire was sent to DAN AP members who had declared a significant medical condition.

The low and sometimes differing response rates to some of the surveys may have introduced various selection biases, so creating the potential for the data not to accurately reflect the groups surveyed. Also, the nature of some of the more historical questions in some surveys may have introduced a recall bias.

DAN AP members are probably not typical of the general diving population. They are likely to be older with the associated increased likelihood of co-existing disease, have more available funds, so may travel more, and may better understand their potential vulnerability and the need for and benefits of having appropriate
insurance. In addition, some applicants for DAN membership may have been reluctant to declare medical conditions for fear of it affecting their ability to obtain or retain insurance coverage. This may have led to underreporting of the prevalence of such conditions.

Self-reporting on medical conditions, diving activities and events in the surveys may have been a source of various reporting biases such as poor recall, incomplete understanding of the conditions, and incomplete understanding of the question. In addition, the results of the surveys of divers with medical conditions are based on a survivor group of divers and fail to account for diving fatality victims with similar conditions that might have contributed to their demise, as well as divers who may have survived an event and stopped diving as a consequence. Therefore, the study sample may be biased towards milder forms of these conditions.

The numbers of dives performed by divers with particular health conditions were relatively small for the purposes of an epidemiological evaluation. Therefore, the ability to interpret the associated risks is limited.

Whilst many Australian divers will fall into one of the population groups surveyed in various parts of this research, they will not be representative of the entire Australian diving population. Finally, in the absence of the ability to standardise for age/sex distribution, comparisons between estimates from different data sources may be influenced by different age/sex distributions in the populations.

Conclusions have been made about the demographics and diving practices of Australian divers based on the best available data. However, these should be interpreted cautiously as none of the diving cohorts examined could be considered to be truly representative of the general Australian diving population.
Chapter 11
Conclusions and recommendations

The aims of this thesis were to:

1. Identify the demographics, diving characteristics and activities of cohorts of active Australian scuba divers.
2. Investigate the prevalence, effects and impacts on diving safety of pre-existing medical conditions.
3. Estimate the fatality rate for Australian scuba divers.
5. Describe the characteristics associated with fatal scuba diving-related incidents in Australia from 2001 to 2013, inclusive, in order to examine trends and potentially identify causative factors.
6. Determine appropriate prevention strategies based on the information collected from mortality data.

The specific research questions to be answered are:

1. What are the underlying factors associated with scuba diving-related mortality in Australia?
2. What are the implications for preventative strategies?

These aims have been addressed through a variety of methods, which include the design and conduct of surveys of various cohorts of divers, analysis of previous research and available data, and collection and analysis of new Australian diving fatality data. The conclusions are discussed below.
Aim 1: Demographics, diving characteristics and activities of cohorts of active Australian scuba divers

This aim was addressed in chapter 2 where survey data of the demographics and diving activities of three cohorts of Australian divers were described. It provides some background about the health of the divers, the type of diving undertaken and problems encountered, and provides some insight into potential causes of mortality. However, these data must be interpreted cautiously as no single cohort was truly representative of Australian divers in general.

Certification data indicate that two thirds of certified divers are male. However, surveys of continuing divers, in and beyond, this study suggest that approximately three quarters of these are male. Hence, there appears to be a higher attrition rate among females. The more active Australian divers appear to be generally older (median age of 45 years), whereas two thirds of less active, relatively inexperienced divers were younger than 45 years.

In this study, the proportion of more experienced and active divers who were either overweight or obese was similar to that of the general Australian adult population. However, the obesity rate in divers in this study was lower than in the general population, which may reflect a greater level of physical activity in the divers.

Unsurprisingly, less experienced divers were unlikely to perform dives deeper than 30 metres, technical or decompression dives. However, the levels of these activities were relatively low in each of the cohorts surveyed, including amongst the most highly active divers. On the other hand, repetitive diving is very commonly performed by divers of all experience levels, albeit less so by divers with known medical conditions.

Although limited by low and differing response rates and likely response bias, surveys in this study have indicated that there are clear differences in the age,
health-related conditions and diving activity and experiences in various cohorts of Australian scuba divers. Therefore, a survey of any single diver group may not be representative of the general recreational diving population. This bias needs to be clearly understood and any survey findings interpreted accordingly.

**Aim 2: Prevalence, effects and impacts on diving safety of pre-existing medical conditions**

This aim was addressed in chapters 2, 3, 4 and 8 in which health conditions of cohorts of active divers and also fatality victims were identified and examined. These data revealed important information on potential sources of health-related diving mortality and of possible countermeasures.

Chronic health-related factors were determined to have played a major role in almost 40% of the scuba-related deaths studied. The main factors identified were cardiac-related conditions such as ischaemic heart disease and cardiac arrhythmias. In fact, one quarter of the deaths in this series were attributed to a cardiac disabling injury, and there were possibly more.

Some surveys conducted as part of this research suggested that the prevalence of cardiovascular disease and/or abnormality in the diver respondents was considerably higher than in the general Australian community. This is consistent with the higher age of many divers, and helps to explain the incidence of cardiac-related deaths. The prevalence of obesity in the scuba victims was substantially higher than reported in the general population, and in the respondents to the diver surveys, and suggests that obesity may be a risk factor for a cardiac-related diving fatality.

Various studies have shown that arrhythmias can be precipitated by immersion *per se* in scuba divers and other swimmers. The likelihood of an arrhythmia can be increased by a variety of factors commonly associated with diving. Many of the cardiac-related deaths were attributed to arrhythmia and, although there is no
specific test for this at autopsy, there was reasonable support for such
determinations. Although based on relatively small numbers, the high prevalence
of left ventricular hypertrophy (LVH) identified in these diving victims supports the
suspicion that the presence of LVH could increase the risk of an arrhythmia and
sudden cardiac death in divers. However, more research is necessary to confirm or
refute this.

Most of the studies of arrhythmias during diving and other in-water aquatic
activities have been conducted on relatively young subjects. It is important to learn
more about the incidence of arrhythmias in older participants, especially those on
various medications during such activities. The candidate is currently seeking
funding to conduct such a study.

Immersion pulmonary oedema is being increasingly identified as a cause of
morbidity and mortality in scuba divers. Many divers with this condition have been
identified as having a pre-existing cardiovascular condition or abnormality that
likely predisposed them to such an incident while diving. This is an important area
for further research, especially after non-fatal incidents where prompt and
appropriate medical investigations and interviews can provide important insights
that could better identify those most at risk. The Candidate is actively involved in
one such study.

Respiratory conditions such as asthma, chronic obstructive pulmonary disease
(COPD) and other abnormalities were also well-represented. Although emphysema,
COPD, pulmonary adhesions and, usually, a history of pneumothorax are often
clear contraindications for diving, this study and others have shown that there are
a considerable number of individuals with asthma who are diving. Although asthma
was a contributing factor in several deaths, asthmatics were not over-represented
in this series.

Research conducted as part of this thesis showed that some divers with potentially
contraindicated conditions, including ischaemic heart disease, certain arrhythmias
and asthma have dived with relatively few adverse incidents, often doing many dives over many years. However, this survivor cohort of divers may not have been representative of the victim cohort as they were typically managed medically and, given that they had taken out diving insurance, might be generally more aware of their health limitations.

Fitness-to-dive (FTD) assessments have limitations and relatively recent FTD assessments failed to prevent some health-related deaths in this series. The high incidence of cardiac-related deaths indicates an obvious need for ‘older’ divers to be medically assessed for FTD. A cardiovascular review is highly advised for all males at age 45 and females at age 55 years, in line with current recommendations. Because of the specific physical, physiological and medical challenges that can be associated with diving, it is important than any FTD assessment is conducted by a doctor who has a thorough understanding of these challenges.

With what appears to be an ageing diver population, it has become increasingly important to educate divers, dive industry professionals, the diving media and medical professionals about the very real potential problems associated with the interaction between certain health-related conditions, especially cardiovascular conditions, and diving. Although some efforts have been made, this education needs to be expanded and driven more forcefully by the diver certification agencies to their instructors and operators, and, in turn, by the instructors to their customers. Dive professionals should not give medical advice. In the event of any revelations or indications of the presence of a potentially contraindicated condition, they should have a low threshold for referring divers, or potential divers, to a doctor trained in FTD assessment.

Diving medical and safety organisations should expand their outreach in this area to strengthen this very important countermeasure to health-related diving fatalities. The Candidate, in his role with DAN Asia-Pacific, is currently planning to expand and re-launch a campaign to better inform divers of the risks of diving with inadequately managed cardiovascular conditions.
Aim 3: Estimation of the fatality rate for Australian scuba divers

This aim was addressed in chapter 6. This examined scuba diving fatality rates for different cohorts of divers in Australia in order to gain an appreciation of the extent of the problem.

While historical DAN AP fatality data include accurate annual death counts for scuba divers, an acceptably reliable denominator with which to estimate the annual fatality rate has been elusive. However, as part of this study, data from annual sporting participation surveys through the Australian Sports Commission were used to provide the best available estimates of the number of divers and annual dives for each year for the decade from 2001.

Although based on extrapolated survey data with inherent limitations, the annual scuba diving fatality rate for Australian residents was estimated to be 0.48 deaths (0.37-0.59) per 100,000 dives, or 8.73 deaths (6.85-10.96) per 100,000 divers. Fatality rates appear to vary by State, being considerably lower in Queensland than in Victoria, a likely result of more favourable diving conditions and, possibly, closer scrutiny of commercial operations. These estimates are similar to or lower than comparable overseas estimates, although reliability of all such measurements varies with study size and accuracy of the data available.

Due to the nature of the conduct of recreational diving in Australia, it is not possible to obtain an actual nationwide count of annual dives. National sporting surveys remain the only potential source of denominator estimates for the foreseeable future. The relevant government agencies are encouraged to increase efforts to collect these data. The collection of more localised diving participation data is more achievable and dive industry participants should be encouraged to collect this through the accurate logging of tank fills, charter dive participants and trainees. However, even if localised activity data is collected, risk estimation can remain problematic due to the small number of deaths and the relative unlikelihood of such events occurring over a limited period.
Aim 4: Creation of an improved template for the analysis of a scuba diving accident

This aim was addressed in chapter 7. It facilitates a more systematic and comprehensive identification of both causes of mortality and potential countermeasures.

A scuba diving fatality usually involves a series of related events, culminating in death. A Chain of Events Analysis (CEA) can be useful in diving fatality investigations to identify the likely sequence of events that lead to the diver’s demise. A CEA has been utilised in a variety of studies. However, an important category that was not highlighted in previous CEA formats was that of factors that preceded the triggers and which predisposed a diver to the incident. This study highlights the important benefits of the addition of this category in identifying predisposing factors for which appropriate countermeasures can be considered, introduced or strengthened.

Additionally, the often limited information about a fatality on which to base parts of a CEA can lead to substantial variation in the interpretation of events by different investigators. Therefore, an effective template for allocating the components of a chain of events can provide valuable guidance. The template created and utilised within this study was shown to significantly reduce the variability in incident interpretation between the investigators. Broader use of this template could potentially increase the comparability of different diving fatality studies. It is already being utilised by some investigators, including coroners and workplace investigators in and beyond Australia. However, the template remains imperfect and will continue to evolve and improve with greater usage and feedback.

The utilisation of a similar template for the analysis of snorkelling fatalities would enhance such investigations. The Candidate has created such a template which is in the process of being validated.
Aim 5: Characteristics associated with fatal scuba diving-related incidents in Australia from 2001 to 2013 inclusive

This aim was addressed in chapter 8 which provides a detailed examination of contributors to all of the 126 scuba diving fatalities that occurred during the defined period. Identification of these mortality causes helped to pinpoint areas where relevant countermeasures are indicated. Numerous risk factors for scuba diving fatalities were identified by the chain of events analysis and include personal factors, as well as factors directly related to the dive itself and the equipment used.

This study highlighted the substantial role that human factors can play throughout the chain of events leading to a diving fatality. These factors include pre-existing health conditions, poor fitness, lack of experience, organisational shortfalls, poor planning or supervision, inadequate equipment maintenance, inattention, carelessness, inappropriate attitude and poor decision-making. Each factor can predispose a diver to an incident, or exacerbate a problem once adverse circumstances develop.

Health-related predisposing factors likely contributed to the demise of almost half of the victims; organisational factors, training, experience and skills factors were associated with more than one third of deaths; and one quarter involved planning-related factors.

The main health-related factors were cardiac-related conditions such as ischaemic heart disease and cardiac arrhythmias. In this series, there was a six-fold incidence of a cardiac disabling injury in divers aged 45 years or older. This highlights this risk in older divers, who now comprise a large proportion of active divers in Australia.

Another major factor that predisposed divers to death was lack of experience and the consequent skills-related shortcomings. More than one half of the victims had performed fewer than 30 dives over their diving career. In many cases, the diver had not dived for several years prior to the fatal dive. Experience plays an
important part in a diver’s ability to make appropriate judgements and take
suitable actions to prevent, or deal with, an incident. Frequent exposure helps to
maintain a diver’s skills and comfort. However, even highly experienced divers
sometimes come to harm after making errors, exceeding their abilities, or their
equipment or health capabilities. Novices, in particular, need to ensure that they
dive within the limits of their training and experience and have a low threshold for
abandoning a planned dive in adverse circumstances.

The incidence of deaths during training is concerning, especially those involving
planning and supervision deficiencies of raw novices. This issue needs to be
appropriately addressed by training agencies and instructors. Improved medical
screening, careful selection of dive sites and assessment of the suitability of
conditions, appropriate reduction of instructor-student ratios, improved instruction
on BCD inflation and weight belt ditching, correct weighting and better in-water
instructor and student positioning might all help to reduce this risk of a trainee
coming to harm. Results from this research have already informed and influenced
recent changes to the Queensland recreational diving Code of Practice.239

Factors related to environmental conditions were implicated as major contributors
in almost one half of incidents. Inexperienced divers can easily underestimate and
be overcome by sea conditions, although this can and does also occur with
experienced divers. All divers should diligently assess the prevailing conditions prior
to, during, and after surfacing from the dive and carefully evaluate the appropriate
course of action.

Fatalities associated with the depletion of breathing gas remain common. These
usually result from inexperience, inattention, poor planning or faulty equipment.
Each of these factors is preventable with appropriate equipment maintenance,
careful gas supply planning, discipline and greater situational awareness prior to,
and during, the diving.
As the time to rescue and resuscitation is usually far shorter if an underwater search is not required, a diver who is likely to become unconscious should strive to become positively buoyant. This study highlights an on-going problem of divers being reluctant, or unable, to act effectively to attain positive buoyancy in an emergency. Ditching of the weight belt is an important training drill for scuba divers and needs to be learned, embedded and regularly practiced. It is important that this message is more clearly and strongly conveyed to all divers to minimise complacency.

One quarter of the incidents involved poor planning decisions such as diving in challenging conditions, or diving alone or with an obviously ineffective buddy system. If a diver becomes entrapped, unconscious or otherwise incapacitated, the presence of a nearby and vigilant buddy can be lifesaving. Three quarters of the victims in this series were alone at the time of their incident and this often created delays in locating and recovering them. While training in self-sufficiency and equipment redundancy is laudable, the importance of a reliable and effective buddy system should be continually emphasised to avoid complacency. As evidenced in this study, diving in buddy groups larger than two increases the likelihood of separation and should be avoided. However, it remains preferable to solo diving.

Most of the contributing factors identified are unsurprising and have been reported previously. However, the influence of predisposing factors is often not appreciated and is under-reported. The reinforcement and an increased understanding of the impact of such contributing factors prior to, and throughout, the accident chain, will enhance education about these within the diving community. This has a considerable potential to reduce morbidity and mortality in divers.
Policy and practice recommendations

Recommendations for changes in diving practice to reduce diving-related morbidity and mortality

1. Improved education about potential predisposing factors

The analysis in chapter 8 demonstrates the importance of potential predisposing factors for a scuba diving death. This suggests a role for improved education and communication about the range and identification of potential predisposing factors for a fatality, and the appropriate countermeasures for these. Such countermeasures include FTD assessments, regular and thorough equipment maintenance, assessment of suitability of dive site and conditions, the need for thorough pre-dive planning and communication between involved parties, as well as thorough and regular organisational reviews to reassess the appropriateness and effectiveness of training, dive support and conduct.

2. Improved education about diving with health-related conditions

The data in chapter 4 and the analysis in chapter 8 suggest the need for improved education of the diving and medical community about the potential problems associated with diving with certain health-related conditions. This applies especially to cardiovascular conditions, and highlights the need for, and benefits of, consultation with a doctor with diving medical training.

3. Routine medical assessment for older divers

The survey data from chapters 2, 3 and 4 and analysis in chapter 8 indicates the importance of strengthening the education of the diving and general medical community about the need for ‘older divers’ to be routinely assessed for FTD. There should be a particular focus on cardiovascular health. Where possible, a FTD assessment should be conducted by a doctor with relevant training in the assessment of fitness to dive.
4. **Diving within limits and capability**

The analysis in chapter 8 suggests that the reinforcement of advice to divers, particularly novices, of the need to ensure that they dive within the limits of their training and experience. They should have a low threshold for abandoning a planned dive in adverse circumstances.

5. **Improved oversight during training/introductory diving**

The analysis in chapter 8 suggests the need for improved oversight of introductory scuba and trainee divers. This should be especially focused on the suitability of conditions, the reduction of trainer/trainee ratios and in-water oversight.

6. **Gaining positive buoyancy in an emergency**

The analyses in chapters 8 and 9 demonstrates the need for an increased educational and training focus on the benefit of attaining positive buoyancy in an emergency through the ditching of weight belts and BCD inflation. The message to divers, that weight belt ditching needs to be practiced periodically in order to refresh and embed the skill, needs to be reinforced.

7. **Equipment checks**

The analysis in chapter 8 demonstrates the need for reinforcement of the importance of thorough equipment checking and maintenance.

8. **Gas supply planning and monitoring**

The analysis in chapter 8 demonstrates the need for reinforcement of the importance of careful gas supply planning and monitoring.

9. **Reliable buddy system**

The analyses in chapters 8 and 9 demonstrate the need for the reinforcement of the importance of a reliable and effective buddy system, preferably as a buddy-pair. However, this should not discourage training in self-reliance and the use of equipment redundancy.
10. Availability and use of oxygen unit

The analyses in chapters 8 and 9 suggest the need to encourage dive operators and private divers to ensure that suitable and functional oxygen equipment is available at all dive sites. In addition, there is an identified need for improvement of the education, training and skills of dive professionals, other support staff and divers generally, in the provision of oxygen, especially oxygen-supplemented ventilations to an apnoeic victim.

Improving the collection and analysis of scuba diving fatality data

Scuba diving fatalities are not common events. For this reason, it is necessary to collect as much information about each incident in order to better understand the causes and prevention. It is, therefore, important for divers and dive professionals to readily share details of known incidents for appropriate research. It is also crucial for the relevant government agencies to be diligent in the investigation and reporting of these incidents. Factors that would improve the collection and analysis of scuba diving accident data include:

1. Improved reporting from the diving community

Better educating the diving community of the benefit of reporting diving-related accidents that they have witnessed, or heard about, may increase data capture and facilitate the accuracy of reporting.

2. Thorough and consistent data collection and reporting from government investigators

Increasing the depth, and improving the focus and consistency of information collected by police and other on-scene investigators after a diving accident. Appendix A3 includes a protocol which was progressively developed by the Candidate as a tool for exhaustive data collection on diving fatalities, and used to inform the Australian dive fatality reports.
3. **Prompt CT scanning**

Encouraging the practice of performing a full body CT scan on all scuba diving victims as soon as possible after death, and preferably within 3-8 hours.

4. **Recording of potentially relevant information at autopsy**

Encouraging forensic pathologists to record the heart weight, left ventricular wall thickness and whether the foramen ovale is patent or sealed with all diving-related cases.

5. **Enlisting expert advice**

Encouraging coroners and forensic pathologists to seek expert advice when investigating and reporting on a scuba diving death.

6. **Indication on Coroner’s Findings that deaths occurred during diving-related activities.**

Encouraging coroners to indicate whether the victim was scuba diving (or snorkelling, or using surface-supplied breathing apparatus) in their summary so that such incidents can be more effectively identified in the National Coronial Information System (NCIS).

The purpose of dive fatality reporting is to identify, examine and learn from the misfortunes of the victims and so minimise the likelihood that other divers will experience a similar incident. However, such reports are valuable only if they are readily accessible, and carefully read and absorbed by divers, dive professionals and medical professionals, and the insights gained are used to change practice. Sadly, it is clear that many of the same mistakes are repeated and communication efforts need to be improved and increased.
Recommendations for Future Research

This study has identified some further gaps in knowledge and a number of areas deserving future research. Some of this research should be extended to include snorkellers who are exposed to many of the same potential problems as scuba divers and, so, provide another relevant source of data. These areas for further research include, but are not limited to:

1. **Confirmation of the demographics of Australian divers (Aim 1)**
   There is a need for larger targeted surveys of a variety of diver cohorts to compare the findings of this thesis relating to Australian diver demographics.

2. **The effect of comorbidities on diving safety (Aim 2)**
   More research with larger cohorts is required to better understand the risks in an ageing, comorbid diving population. This would involve a cohort study where hundreds of divers with various conditions were identified, enlisted and followed-up annually over an extended period.

3. **The incidence of arrhythmias in scuba divers and snorkellers (Aim 2 & 5)**
   There is a need for further field investigations to determine the incidence of arrhythmias in older scuba diving and snorkelling participants, especially those on various medications during such activities. This information may inform the development of better screening questionnaires.

4. **Comparison of features of fatalities between various States and Territories. (Aim 5)**
   Further investigation and reporting of scuba diving and snorkelling fatalities in the various States and Territories would be useful to better identify any local differences.
5. **Left ventricular hypertrophy (Aims 2 & 5)**

There is a need for further investigations of larger cohorts of diving and snorkelling victims to determine the comparative prevalence of LVH and its relationship with diving-related mortality.

6. **Immersion pulmonary oedema (Aims 2 & 5)**

Further research of the incidence of immersion pulmonary oedema scuba diving and snorkelling morbidity and mortality is needed to identify the extent of this problem.

7. **Snorkelling fatalities**

An extended case series analysis of snorkelling-related fatalities in Australia, including comparisons and contrasts with scuba deaths, would provide further data on the effects of immersion on individuals of varying demographic characteristics (Aims 2 & 5).

8. **Template for CEA of snorkelling fatalities (Aim 4)**

The creation, validation and application of a chain of events analysis template for snorkelling fatalities would facilitate the investigation of snorkelling incidents.
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SECTION 4

APPENDICES
Appendix A1
Search Strategy and results

Search strategies in EBSCO Host
(Medline Complete, CINAHL Complete, Health Source (Nursing/Academic Edition), SPORTDiscus with Full Text, and PsychINFO)

Search 1
1. scuba
2. “compressed air”
3. “compressed gas”
4. div*
5. death*
6. fatalit*
7. mortalit*
8. 1 or 2 or 3
9. 5 or 6 or 7
10. 4 and 8 and 9

Search 2
1. “scuba div*”
2. cardi *
3. heart
4. diabetes
5. asthma
6. hypertension
7. arrhythmia*
8. dysrhythmia*
9. pneumo *
10. emphysema
11. epilepsy
12. pulmonary
13. edema
14. oedema
15. medication*
16. autops*
17. 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16
18. 1 and 17
Records identified through database searching (n = 1397)

Additional records identified through other sources (n = 273)

Records after duplicates removed (n = 1341)

Records screened (n = 912)

Records excluded (n = 340)

Full-text articles assessed for eligibility (n = 572)

Full-text articles excluded (n = 150)

Studies included in qualitative synthesis (n = 422)

Appendix A2

Known medications used by 38 scuba diving fatality victims

<table>
<thead>
<tr>
<th>Drug</th>
<th>Frequency</th>
<th>Class</th>
</tr>
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<tbody>
<tr>
<td>alprazolam</td>
<td>1</td>
<td>Benzodiazepine</td>
</tr>
<tr>
<td>amiloride</td>
<td>1</td>
<td>Antikaliuretic-diuretic agent</td>
</tr>
<tr>
<td>amlodipine</td>
<td>2</td>
<td>Calcium channel bloker</td>
</tr>
<tr>
<td>aspirin</td>
<td>3</td>
<td>Antiplatelet agent</td>
</tr>
<tr>
<td>atorvastatin</td>
<td>2</td>
<td>Statin</td>
</tr>
<tr>
<td>beclomethazone</td>
<td>1</td>
<td>corticosteroid</td>
</tr>
<tr>
<td>bupropion</td>
<td>1</td>
<td>Aminoketone antidepressant</td>
</tr>
<tr>
<td>candesartan</td>
<td>1</td>
<td>Angiotensin receptor blocker</td>
</tr>
<tr>
<td>carbamazepine</td>
<td>1</td>
<td>Anticonvulsant</td>
</tr>
<tr>
<td>cetirizine</td>
<td>2</td>
<td>Antihistamine</td>
</tr>
<tr>
<td>chlorpheniramine</td>
<td>1</td>
<td>Antihistamine</td>
</tr>
<tr>
<td>cilostazol</td>
<td>1</td>
<td>Antiplatelet agent</td>
</tr>
<tr>
<td>citalopram</td>
<td>3</td>
<td>SSRI</td>
</tr>
<tr>
<td>celecoxib</td>
<td>1</td>
<td>Non-steroidal anti-inflammatories</td>
</tr>
<tr>
<td>clopidogrel</td>
<td>2</td>
<td>Antiplatelet agent</td>
</tr>
<tr>
<td>dexamphetamine</td>
<td>1</td>
<td>CNS stimulant</td>
</tr>
<tr>
<td>dextropropyphene</td>
<td>1</td>
<td>Analgesic</td>
</tr>
<tr>
<td>diazepam</td>
<td>1</td>
<td>Benzodiazepine</td>
</tr>
<tr>
<td>diclofenac</td>
<td>2</td>
<td>Non-steroidal anti-inflammatories</td>
</tr>
<tr>
<td>digoxin</td>
<td>1</td>
<td>ACE inhibitor</td>
</tr>
<tr>
<td>diphenhydramine</td>
<td>1</td>
<td>Antihistamine</td>
</tr>
<tr>
<td>dothieprin</td>
<td>1</td>
<td>Tricylclic antidepressant</td>
</tr>
<tr>
<td>doxazosin</td>
<td>1</td>
<td>Alpha-1 adrenergic blockers</td>
</tr>
<tr>
<td>duloxetine</td>
<td>1</td>
<td>SNRI</td>
</tr>
<tr>
<td>enalapril</td>
<td>2</td>
<td>ACE inhibitor</td>
</tr>
<tr>
<td>escitalopram</td>
<td>1</td>
<td>SSRI</td>
</tr>
<tr>
<td>esomeprazole</td>
<td>3</td>
<td>Proton pump inhibitor</td>
</tr>
<tr>
<td>ezetimibe</td>
<td>1</td>
<td>Cholesterol-absorption inhibitor</td>
</tr>
<tr>
<td>finasteride</td>
<td>2</td>
<td>Type II 5a-reductase inhibitor</td>
</tr>
<tr>
<td>fluoxetine</td>
<td>1</td>
<td>SSRI</td>
</tr>
<tr>
<td>glipizide</td>
<td>1</td>
<td>Sulphonylurea</td>
</tr>
<tr>
<td>glycerol trinitrate</td>
<td>1</td>
<td>Vasodilating agent</td>
</tr>
<tr>
<td>ibuprofen</td>
<td>2</td>
<td>Non-steroidal anti-inflammatories</td>
</tr>
<tr>
<td>levonorgestrel</td>
<td>1</td>
<td>Progestin</td>
</tr>
<tr>
<td>lithium</td>
<td>1</td>
<td>antimanic agent</td>
</tr>
<tr>
<td>magnesium</td>
<td>1</td>
<td>Magnesium</td>
</tr>
<tr>
<td>metformin</td>
<td>1</td>
<td>Biguanide</td>
</tr>
<tr>
<td>Drug</td>
<td>Frequency</td>
<td>Class</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------</td>
<td>--------------------------------------</td>
</tr>
<tr>
<td>mirtrazapine</td>
<td>1</td>
<td>Tetracyclic antidepressant</td>
</tr>
<tr>
<td>montelukast</td>
<td>1</td>
<td>Leukotriene receptor antagonist</td>
</tr>
<tr>
<td>naproxen</td>
<td>3</td>
<td>Non-steroidal anti-inflammatories</td>
</tr>
<tr>
<td>olanzapine</td>
<td>1</td>
<td>Atypical antipsychotic</td>
</tr>
<tr>
<td>oxycodone</td>
<td>1</td>
<td>Opioid analgesic</td>
</tr>
<tr>
<td>montelukast</td>
<td>1</td>
<td>Leukotriene receptor antagonist</td>
</tr>
<tr>
<td>paracetamol/codene</td>
<td>2</td>
<td>Analgesic/antipyretic</td>
</tr>
<tr>
<td>paroxetine</td>
<td>2</td>
<td>SSRI</td>
</tr>
<tr>
<td>perindopril</td>
<td>4</td>
<td>ACE inhibitor</td>
</tr>
<tr>
<td>phenytoin</td>
<td>1</td>
<td>Anticonvulsant</td>
</tr>
<tr>
<td>pizotifen</td>
<td>1</td>
<td>Benzocycloheptene</td>
</tr>
<tr>
<td>pravastatin</td>
<td>1</td>
<td>Statin</td>
</tr>
<tr>
<td>pseudoephedrine</td>
<td>4</td>
<td>Amphetamine</td>
</tr>
<tr>
<td>rabeprazole</td>
<td>1</td>
<td>Proton pump inhibitor</td>
</tr>
<tr>
<td>rofecoxib</td>
<td>1</td>
<td>Non-steroidal anti-inflammatories</td>
</tr>
<tr>
<td>salbutamol</td>
<td>4</td>
<td>Bronchodilator</td>
</tr>
<tr>
<td>simvastatin</td>
<td>1</td>
<td>Statin</td>
</tr>
<tr>
<td>tadalafil</td>
<td>1</td>
<td>PDE5 inhibitor</td>
</tr>
<tr>
<td>telmisartan</td>
<td>1</td>
<td>Angiotensin receptor blocker</td>
</tr>
<tr>
<td>tiotropium</td>
<td>1</td>
<td>Anticholinergic bronchodilator</td>
</tr>
<tr>
<td>valproate</td>
<td>1</td>
<td>Anticonvulsant</td>
</tr>
<tr>
<td>valsartan</td>
<td>1</td>
<td>Angiotensin receptor blocker</td>
</tr>
<tr>
<td>vardenafil</td>
<td>1</td>
<td>PDE inhibitor</td>
</tr>
<tr>
<td>verapamil</td>
<td>1</td>
<td>Calcium channel blocker</td>
</tr>
</tbody>
</table>
### Appendix A3

#### Diving fatalities – Preliminary information sought

<table>
<thead>
<tr>
<th>Feature</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Organisation</td>
<td>1. How arranged (e.g. commercial / private)</td>
</tr>
<tr>
<td></td>
<td>2. Planning and preparation (Plan made? Weather &amp; likely conditions considered?)</td>
</tr>
<tr>
<td>B. Location</td>
<td>1. Location of dive site</td>
</tr>
<tr>
<td></td>
<td>2. Physical description of dive site (e.g. depth, topography (e.g. wall, reef), other features)</td>
</tr>
<tr>
<td>C. Weather</td>
<td>1. Forecast</td>
</tr>
<tr>
<td></td>
<td>2. Before/During/After dive</td>
</tr>
<tr>
<td></td>
<td>3. Air temperature</td>
</tr>
<tr>
<td></td>
<td>4. Wind (e.g. direction and strength)</td>
</tr>
<tr>
<td>D. Water Conditions</td>
<td>1. Visibility underwater</td>
</tr>
<tr>
<td></td>
<td>2. Current (Any? Strength and direction)</td>
</tr>
<tr>
<td></td>
<td>3. Tide (incoming/outgoing, level)</td>
</tr>
<tr>
<td></td>
<td>4. Surface conditions (e.g. chop, swell - height)</td>
</tr>
<tr>
<td></td>
<td>5. Surge?</td>
</tr>
<tr>
<td></td>
<td>6. Water temperature</td>
</tr>
<tr>
<td>E. Victim - Health</td>
<td>1. Age</td>
</tr>
<tr>
<td></td>
<td>2. Gender</td>
</tr>
<tr>
<td></td>
<td>3. Height &amp; weight</td>
</tr>
<tr>
<td></td>
<td>4. General health and fitness</td>
</tr>
<tr>
<td></td>
<td>5. Medical history (e.g. prescribed medications, medical conditions, previous significant surgery)</td>
</tr>
<tr>
<td></td>
<td>6. Details of any medical clearance to dive or snorkel</td>
</tr>
</tbody>
</table>
| F. Victim – Diving qualifications & experience | 1. Swimming ability  
2. Type of diving qualification (e.g. Open Water, Advanced etc)  
3. Where, when obtained  
   - Experience:  
     - How many logged dives?  
     - Training/experience in similar circumstances  
4. Recent experience? When and what? |
| --- | --- |
| G. Medical history | 1. Victim’s medical history (from usual doctor)  
2. Medications taken  
3. Date of last medical examination  
4. Details of any diving medical examination (including any relevant comments about fitness to dive)  
5. Doctor’s Qualifications & experience in assessing fitness to dive |
| H. Buddy/companion(s) | 1. How many?  
2. Qualifications  
3. Experience  
4. Proximity to victim during accident  
5. Buddy rescue actions |
| I. Witness(es) and Incident | 1. Description of incident  
2. Where occurred – surface/depth  
3. What was victim doing/last seen to be doing  
4. If breath-hold diving, was the victim seen to hyperventilate, and/or were they known to routinely hyperventilate prior to breath-hold diving?  
5. Any warnings to/by victim  
6. Equipment malfunction?  
7. Equipment lacking?  
8. Breathing gas shortage?  
9. Intervention of elements? (e.g. caught in strong current)  
10. Other intervention? (e.g. marine animal, boat impact)  
11. Witness rescue attempt? |
| J. First aid and Resuscitation | 1. What? (Rescue breathing / CPR / Oxygen / AED / ALS)  
2. When? How long after likely unconsciousness?  
3. Where? (In-water / on boat / on shore)  
4. Sequence  
5. Equipment  
- type of oxygen equipment (e.g. resus. mask with constant oxygen flow, bag-valve-mask)  
- AED available at site? Defibrillation attempted?  
  - likely delay to defibrillation  
  - shock advised? Shock(s) given  
6. Victim response to resuscitation  
7. Complications with resuscitation (e.g. regurgitation or other airway problems)  
8. Any required equipment missing? (e.g. oxygen equipment) |
| K. Diving equipment | 1. Mask                  |
|                    | 2. Snorkel               |
|                    | 3. Fins                  |
|                    | 4. Exposure suit (type, thickness, coverage) |
|                    | 5. Weights:              |
|                    | - weightbelt? (on or off when found) |
|                    | - integrated weights? (in situ or released) |
|                    | - amount of weight worn at outset |
|                    | 6. Buoyancy compensator |
|                    | - worn?                  |
|                    | - type (jacket? Wings?)  |
|                    | - inflated? Deflated?    |
|                    | - functional?            |
|                    | 7. Regulator(s)          |
|                    | - manufacturer and model |
|                    | - service/maintenance history |
|                    | - functional state       |
|                    | - defects                |
|                    | 8. Cylinder(s)           |
|                    | - manufacturer           |
|                    | - capacity               |
|                    | - pressure when found    |
|                    | - likely starting pressure |
|                    | - condition              |
|                    | - valve position when victim found |
|                    | (e.g. on (how many turns), off |
|                    | - valve functional state |
|                    | - last hydrostatic test date |
|                    | - fluid inside?          |
|                    | - breathing gas analysis |
|                    | 9. Dive computer         |
|                    | - manufacturer & model   |
|                    | - functional?            |
|                    | - details of last dive(s) (download profile for analysis) |
|                    | 10. Submersible pressure gauge |
|                    | - functional? Accurate?  |
|                    | 11. Rebreather           |
|                    | - manufacturer & model   |
|                    | - Refer to relevant guidelines & specific expertise |

<p>| L. Commercial charter / Club | 1. Nature of operation (e.g. instruction, charter, guidance) |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
</table>
|   | 2. License / Qualification / Experience for conducting activity  
|   | 3. Training of supervisors, if any  
|   | 4. Applicable rules/regulations (e.g. WHS)  
|   | 5. Protocols of operator (suitable procedures in place?)  
|   | 6. Emergency procedures (suitable procedures, trained staff and equipment in place? utilised? – see J5) |
| M. Training Incident | 1. Level of training undertaken  
|   | 2. Pre-activity briefing  
|   | 3. Supervision  
|   | 4. Instructor/student ratio  
|   | 5. Instructor first awareness of problem  
|   | 6. Emergency procedures (suitable procedures, trained staff and equipment in place? utilised? – see J5) |
| N. Unaccompanied activity | 1. Any plan advised beforehand & to whom  
|   | 2. When/where last seen  
|   | 3. Equipment taken  
|   | 4. Where entered water  
|   | 5. Where found  
|   | 6. Equipment located with/nearby person  
|   | 7. Purpose of activity |
| O. Autopsy | 1. Pre-autopsy CT scan ideally within 8 hrs (best < 3 hrs)  
|   | 2. Internal examination if possible  
|   | 3. Report should specifically include:  
|   | - heart weight  
|   | - degree of coronary artery narrowing  
|   | - left ventricular wall thickness  
|   | - whether foramen ovale is patent or closed  
|   | - lung weights |