



A N N U A L  
**DIVING**  
R E P O R T

2018 EDITION

2016 Diving Fatalities, Injuries and Incidents



# DAN ANNUAL DIVING REPORT

2018 EDITION

A REPORT ON 2016 DIVING FATALITIES, INJURIES, AND INCIDENTS

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DIVERS ALERT NETWORK  
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# FOREWORD

Risk is inherent to diving, whether the diver breathes compressed gas or holds their breath. The diving environment is unforgiving. Fortunately for divers, most incidents can be avoided entirely with safe practices, but incidents still occur. Prior to 1980, divers involved in incidents were largely on their own, but that changed with the establishment of the Divers Alert Network® (DAN®).

DAN® is the only organization of its kind. Any diver can contact DAN for expert medical advice from our in-house physicians and medical professionals, and we follow up on and continually monitor diving incidents from around the world. DAN Research works year-round to collect and analyze dive incident, injury and fatality data, and we publish the findings here in the *DAN Annual Diving Report*.

In this 2018 edition of the *Annual Diving Report*, our goal remains unchanged: to raise awareness of the risks and hazards associated with diving and to promote safer diving practices. Promoting dive safety and injury prevention is essential to cultivating a safe diving community, and with the help of a growing global network of contributors, the *DAN Annual Diving Report* has become the most widely applicable report to date. This report not only highlights our expanded efforts to monitor and prevent injuries internationally but also provides vital insights for divers, dive professionals, dive businesses and even chamber operators seeking to mitigate risks and prevent injuries.

The first step in reducing injuries is to identify them, and the next step is to understand them. In this report, DAN identifies the most critical risks divers face and uses easily interpreted figures, intriguing case studies and informative passages to help divers comprehend those risks. This content is relevant to divers at all levels, shedding new light on diving incidents and allowing divers to learn from the experiences of others without incurring the risks themselves. We encourage you to share this report with your peers, colleagues, superiors and anyone else you know who wishes to learn more about safe diving.

Giving divers the knowledge they need to make safe decisions above and below the surface is at the core of DAN's mission. Understanding how and why injuries occur allows the community to benefit from individual lessons learned. With the support of all the DAN offices and our contributors worldwide, we are committed to providing resources that we hope will resonate with divers everywhere.

William M. Ziefle, JD, MBA  
President and CEO  
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# SECTION 1. DIVING FATALITIES

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## 1.1 INTRODUCTION

The 2018 *Annual Diving Report* presents an analysis of recreational diving fatalities that occurred in the US or Canada or that involved US or Canadian residents. While the recent years have seen a decline in the number of fatalities, we are saddened to report that 2016 saw an above-average number of recreational diving fatalities. Many of the circumstances and risks associated with these fatalities could have been avoided, or at least reduced. By describing what is known about diving fatalities each year, DAN hopes that every diver will consider their diving decisions carefully and will take greater care in the water. Our sport is relatively safe when undertaken responsibly, but we can do more, and we must, if we are to strive for all dives to be injury- and fatality-free. (Note that fatalities associated with scuba diving are covered in Section 1 of this report, and that injuries and fatalities associated with breath-hold diving are covered in Section 4.)

### THE DATA COLLECTION PROCESS

The data collection process at DAN begins when a diving death is identified through internet alerts, news stories, forums, or reports from affiliated organizations, such as county coroners, fish and wildlife officers, county medical examiners, local law enforcement agencies, or members of the public. Each death is classified as to whether it should be followed up on or not. All recreational

diving fatalities that occur in the US or Canada are tagged as follow-up cases, and all deaths of US or Canadian citizens, no matter where they occur, are also marked for follow-up. Any fatalities that occur outside the US or Canada and that involve citizens of other countries, as well as any fatalities that occur during non-recreational dives (e.g., military dives) are classed as no-follow-up.

Online news media outlets are monitored for keywords involving diving and scuba deaths. Other sources for notifications regarding fatalities include families of DAN members and friends and acquaintances of decedents who are aware of DAN's fatality data collection efforts. The DAN Medical Services Call Center (MSCC) is also a valuable resource, since the DAN Medical Services Department assists with the management of any diving incident that is called in, whether the victim is a DAN member or not.

### INVESTIGATOR AND MEDICAL EXAMINER REPORTS

Diving-related deaths in the US are frequently investigated by local law enforcement agencies or the US Coast Guard (USCG) and a proportion of them are subject to autopsies. These investigative and autopsy reports are integral to DAN's research into the causes of diving-related

fatalities. Without access to these reports, it would be virtually impossible to compile enough data for analysis.

Each state in the US has its own set of regulations regarding the release of personal health information, on top of the federally mandated HIPAA (Health Insurance Portability and Accountability Act of 1996) Privacy Rule. Some states consider investigative and medical examiner reports to be public information and release such documents readily, while others have more stringent privacy laws. In addition, within a given state, the regulations (and, hence, ease of procuring reports) can sometimes vary from county to county. As described in Section 1.2, the majority of diving deaths in the US occur in Florida and California, and these two states have relatively straightforward protocols for requesting and obtaining copies of reports.

Local investigative agencies (sheriff's and police departments) follow privacy laws similar to those of medical examiners. However, since their reports typically do not contain private medical information, those entities are often able to release reports upon requests made under the Freedom of Information Act (FOIA). Reports on cases that have been investigated by the USCG can now be requested centrally, from Washington, D.C. However, it may take up to two years after an incident occurs before the case is closed and the report is released. The USCG follows FOIA protocols and will not release personal health information contained in their reports. A redacted copy, with all personal and identifying information removed, is usually requested. When they're available, downloaded dive-computer profiles are also included in USCG case files, along with any available gas-analysis or equipment-testing results.

#### REPORTS FROM WITNESSES AND NEXT OF KIN

DAN uses its own Fatality Reporting Form to collect data from witnesses and family members. The form may be downloaded from the DAN website (<http://www.diversalertnetwork.org/files/FATform.pdf>) or requested from the DAN Research or Medical Services departments. When necessary, a family member of the decedent may be contacted to assist in the

data-collection process. Family members may complete the Fatality Reporting Form and/or provide authorization for the release of the decedent's autopsy report. The incident reporting form on the DAN website (<https://www.diversalertnetwork.org/research/incidentReport/>) can also be used by family members and/or witnesses to report diving fatalities or to provide additional details regarding already reported fatalities.

#### DATA ENTRY AND ANALYSIS

DAN Research maintains the diving fatality data on a secure server. Once all pertinent information has been gathered and entered into the database, the results are analyzed and published in the *DAN Annual Diving Report*.

### 1.2 GEOGRAPHIC AND SEASONAL DISTRIBUTION OF FATALITIES

Worldwide, DAN received notification of 169 deaths involving recreational scuba diving during 2016 — a 33% increase over the 2015 figure. A breakdown of this total is shown in Table 1.2-1. Only 94 of the 169 fatalities occurred in the US or Canada or involved US or Canadian citizens and thus were actively investigated by DAN. Reports were received about 75 recreational scuba deaths that occurred in other countries and that did not involve US or Canadian citizens, but, due to geographical limitations, these cases could not be investigated. (DAN also received word of 12 scuba-related fatalities that did not involve recreational divers. And fatalities associated with breath-hold diving are covered in Section 4.)

Table 1.2-2 shows the geographic distribution of the 2016 fatalities that occurred in the US and Canada, broken down by state and province (n=64). An additional 30 cases involved US or Canadian citizens who died while scuba diving overseas. Again in 2016, Florida had the largest number of fatalities reported to DAN, followed by California, then Hawaii.

Figure 1.2-1 shows the distribution of fatalities in 2016 by month, in cases where that information is known (n=92). Not much can be inferred from a single year of data, but looking at the

Region	Country	n	Region	Country	n
North America			72		
	United States	59		United Kingdom	5
	Mexico	8		Italy	3
	Canada	5		France	3
Oceania			23		
	Australia	14		Malta	3
	New Zealand	6		Switzerland	3
	Fiji	2		Ireland	2
	Micronesia	1		Scotland	2
Caribbean			19		
	Cayman Islands	4		Spain	1
	Bahamas	4		Bulgaria	1
	Turks and Caicos	4		Iceland	1
	Netherland Antilles	3		Norway	1
	Virgin Islands	1		Poland	1
	Antigua and Barbuda	1		Sweden	1
	Dominican Republic	1	Asia		
	Jamaica	1	18		
South America			4		
	Colombia	2		Indonesia	5
	Brazil	1		Philippines	3
	Argentina	1		Thailand	3
Northern Africa			1		
	Egypt	1		Sri Lanka	2
Southern Africa			1		
	South Africa	1		China	1
Middle East			1		
	Israel	1		Singapore	1
				Vietnam	1
				Taiwan	1
				Maldives	1
			Central America		
			1		
				Belize	1
			Unknown		
			2		
<b>TOTAL</b>					<b>169</b>

Table 1.2-1. Distribution by region and country of diving fatalities reported to DAN in 2016 (n=169)

patterns over a longer period of time, it is evident that the number of fatalities reported to DAN usually increases as summer approaches, peaks around July, and then declines as winter approaches.

### 1.3 AGE AND HEALTH OF DECEDENTS

Autopsies were available for 21 of the 94 US and Canadian cases (22%). Figure 1.3-1 shows the distribution by age and sex of the 84 cases for which that information is known. In 78% of the 94 cases, the victims were male (n=73), and in 12% of cases the victims were female (n=11). Either the age or the sex of the

State/Province	Count
Florida	20
California	7
Hawaii	6
Washington	4
Massachusetts	3
Michigan	3
Texas	3
British Columbia	2
North Carolina	2
Nevada	2
South Carolina	2
Arkansas	1
New Jersey	1
New Mexico	1
New York	1
Ohio	1
Ontario	1
Pennsylvania	1
Saskatchewan	1
Tennessee	1
Unknown	1
<b>Total</b>	<b>64</b>

Table I.2-2. Distribution by state or province of scuba fatalities in the US and Canada in 2016 (n=64)

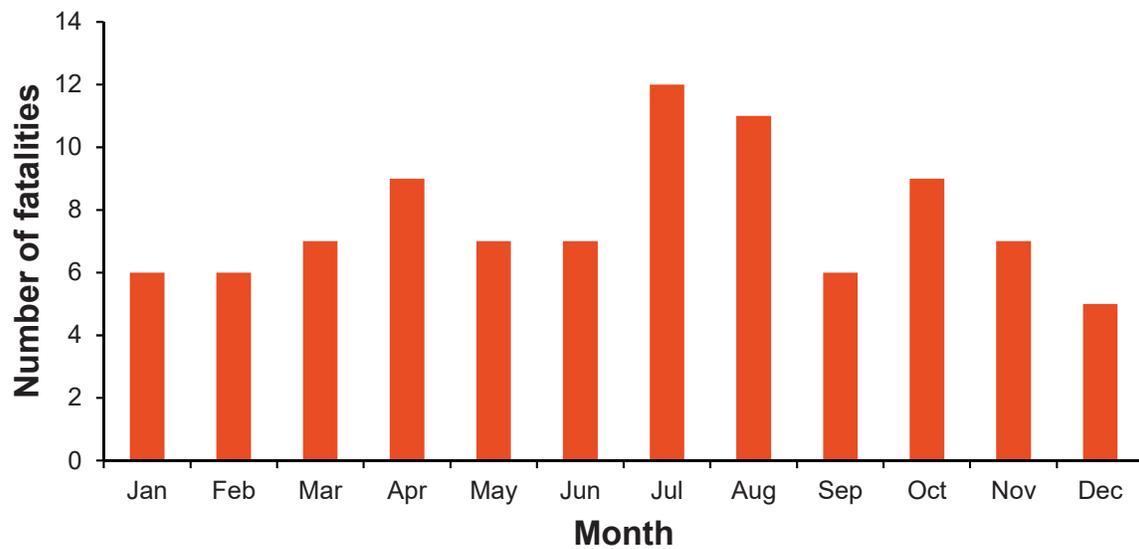


Figure I.2-1. Distribution by month of US and Canadian scuba fatalities in 2016 (n=92)

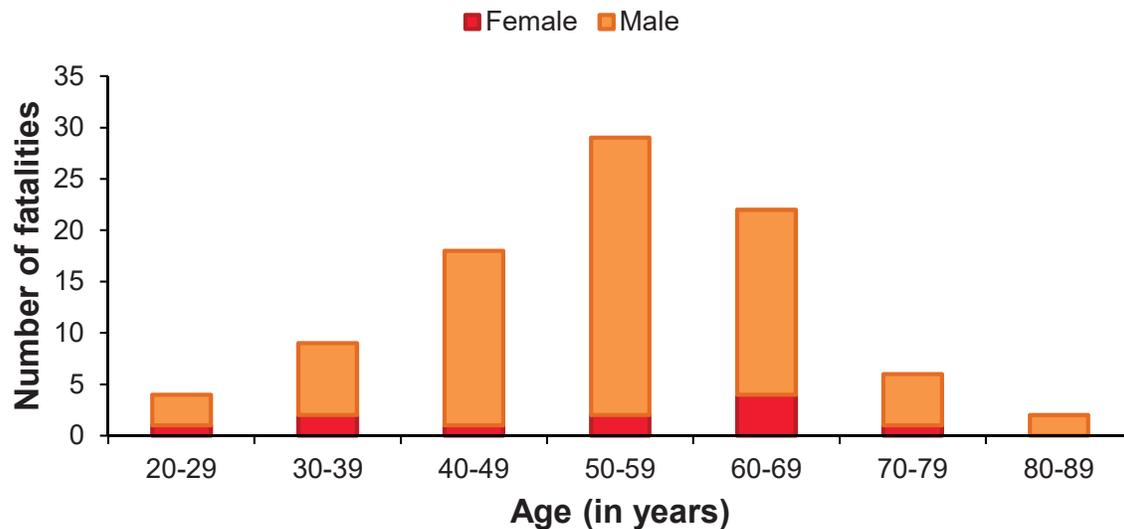


Figure 1.3-1. Distribution by age and sex of US and Canadian scuba fatalities in 2016 (n=84)

decedent was unknown in 4 cases. About two-thirds of the 84 decedents whose age and sex are known were 50 years of age or older; 86% (n=63) of the males and 73% (n=8) of the females were 40 years or older.

**Medical history:** The decedents' medical history was, in most cases, incomplete or unknown. In 5 cases, it was explicitly reported that the victim had no known medical conditions. Any known pre-existing medical conditions are listed in Table 1.3-1, but autopsy findings discovered many more.

Condition	Count
Hypertension	3
Diabetes	2
Flu/cold	1
Back Pain	1
Ear/sinus	1
None	5

Table 1.3-1. Known medical history of victims of US and Canadian diving fatalities in 2016

The true prevalence of high blood pressure and cardiovascular disease among victims is not known. Table 1.3-1 represents only the cases in which the decedent's medical condition was known. In addition to the fact

that a medical history was not available for the majority of cases, some of those who were reportedly healthy may have had undiagnosed hypertension, heart disease, or diabetes, as is often the case in the general population. For examples, see cases 1-5, 1-6, 1-8, 1-12, 1-15, 1-18, 1-20, and 1-21 in Section 1.9.

**Body mass index (BMI):** The decedents' BMI was available in 23 cases (24%) — 20 males and 3 females. According to the classification of the US Centers for Disease Control and Prevention (CDC)<sup>1</sup>, 26% of known BMIs were classified as normal weight (18.5-24.9 kg/m<sup>2</sup>), 30% as overweight (25.0-29.9 kg/m<sup>2</sup>) and 43% as obese (30.0-39.9 kg/m<sup>2</sup>). Two divers were classed as morbidly obese (BMI≥40.0). Comprehensive BMI data is not available for the overall scuba diving population, so we cannot know if obesity is more common in divers than in the population at large and/or if obesity is associated with an increased risk of dying while scuba diving. What we do know, however, is that a recent paper used the above CDC classifications of BMI and described 48% of active US divers as overweight.<sup>2</sup> This may have been a contributing factor in some of the cases in this report. For examples, see cases 1-6, 1-7, 1-9, 1-24, 1-18, and 1-20 in Section 1.9.

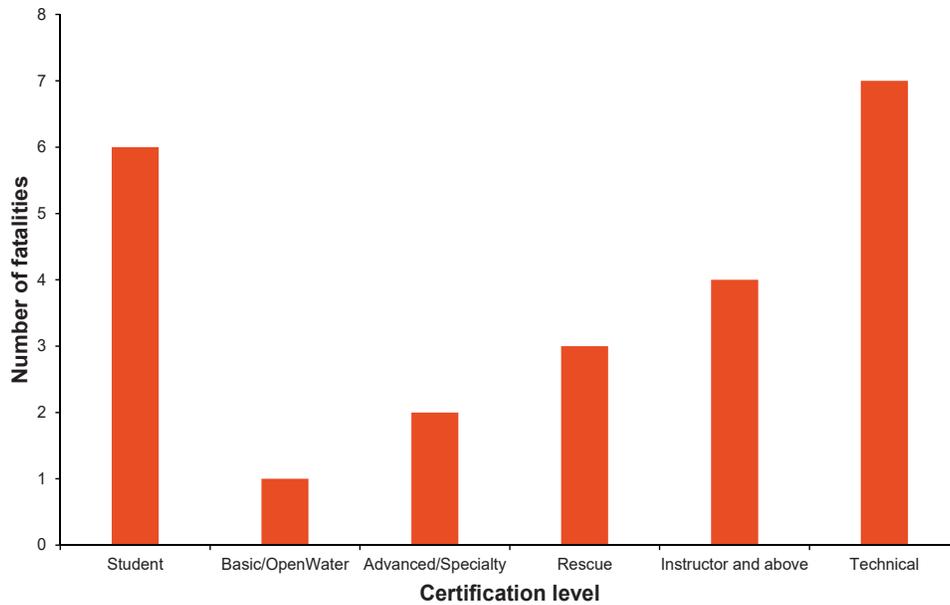


Figure 1.4-1. Distribution by dive certification level for US and Canadian scuba fatalities in 2016 (n=23)

## 1.4 DIVING CERTIFICATION AND EXPERIENCE

Information about decedents' diving certification level was available in 23 of the 94 cases (24%), as shown in Figure 1.4-1. Decedents' years of diving experience since their initial certification was known in only 4 cases.

## 1.5 CHARACTERISTICS OF DIVES

Figure 1.5-1 shows the type of diving activity undertaken during the fatal dive. Information was available for 35 of the 94 cases (37%). At least 20 cases (21%) involved pleasure or sightseeing, 8 (9%) were training dives (not necessarily involving a student, however), and 7 (7%) involved spearfishing, hunting, or collecting game. For examples, see cases 1-2, 1-4, 1-5, 1-14, 1-15, and 1-24 in Section 1.9.

Figure 1.5-2 shows the platforms from which fatal dives began. That information was known in 42 of the 94 cases (45%). In 19 of those 42 cases, the dive began from a charter boat or a private vessel (45% of known cases), and in 18 cases it began from a beach or pier (43% of known cases).

**Environment:** The majority of fatal dives occurred in an ocean/sea environment (n=70, 74%), with the rest occurring in stationary fresh water (n=11, 12%) or in rivers or springs (n=9, 10%); 4 cases, including a double fatality, occurred in caves. In 4 cases (4%), a description of the environment was missing. For examples, see cases 1-7, 1-10, 1-16, and 1-17 in Section 1.9.

**Visibility:** Only 5 cases (5%) included information on visibility, highlighting the challenges of gathering complete data on diving fatalities.

**Sea conditions:** Of the 94 cases, 12 (13%) included a report on sea conditions. Calm seas were noted in 4 cases (4%), moderate seas in 5 (5%), and rough seas in 3 cases (3%). For examples, see cases 1-14 and 1-18 in Section 1.9.

**Current:** The current was described in 10 of the 94 cases (11%). Currents were strong in 5 cases (5%), slight in 4 cases (4%), and none in one case (1%).

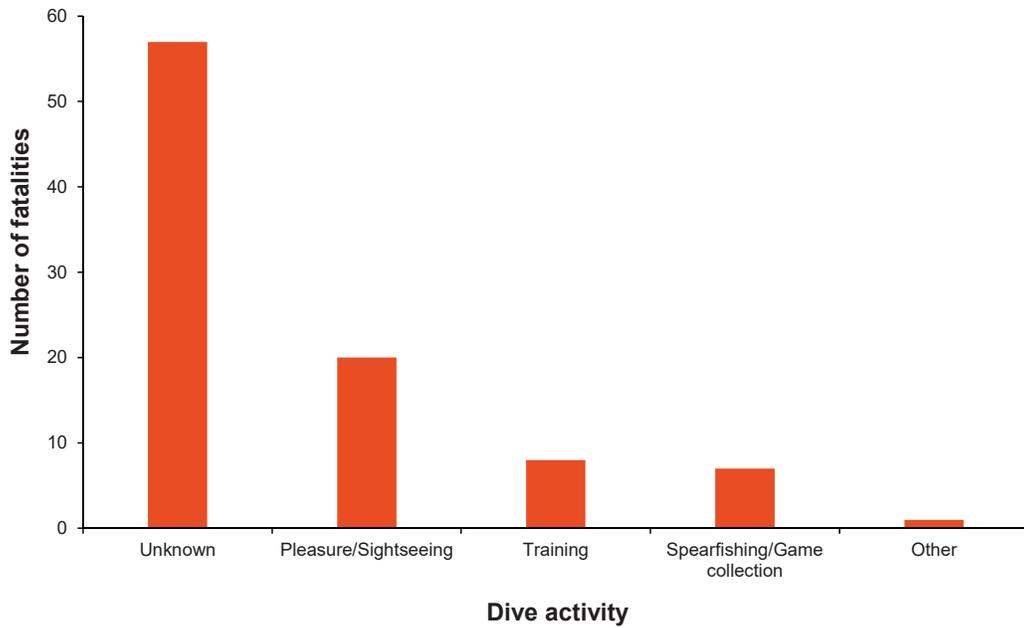


Figure 1.5-1. Primary dive activity during US and Canadian scuba fatalities in 2016 (n=94)

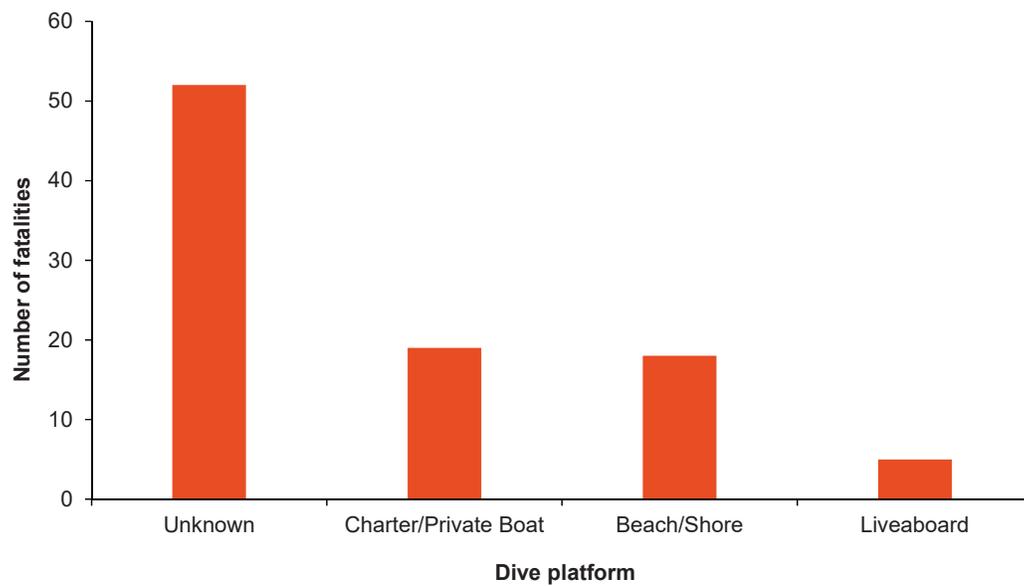


Figure 1.5-2. Dive platform for US and Canadian scuba fatalities in 2016 (n=94)

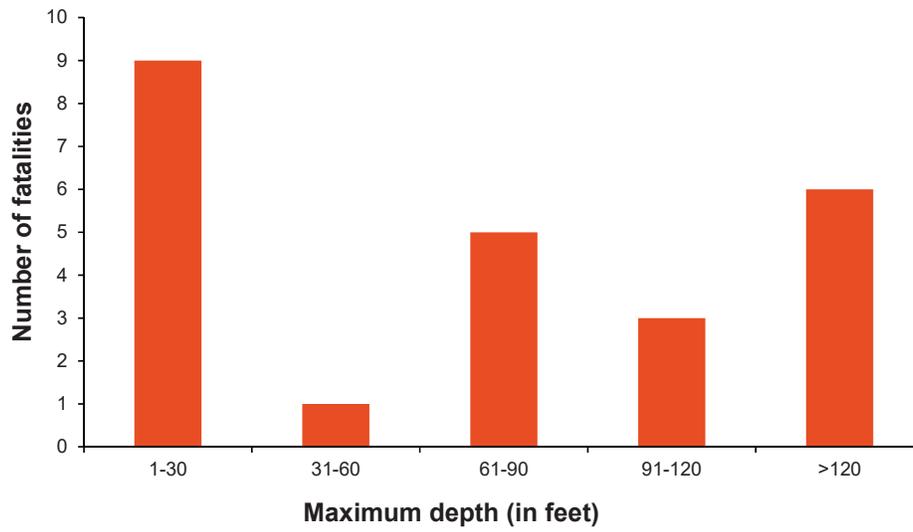


Figure 1.5-3. Maximum depth of the fatal dive in US and Canadian scuba fatalities in 2016 (n=24)

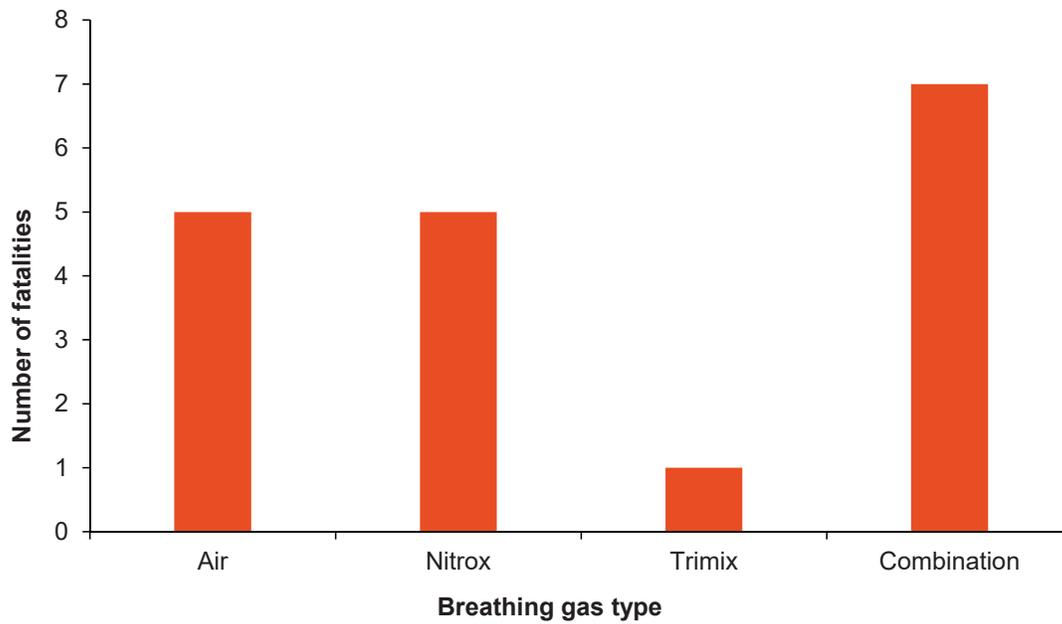


Figure 1.5-4. Type of gas used during US and Canadian scuba fatalities in 2016 (n=18)

**Time of Day:** The timing of the fatality was known in 30 of the 94 cases; 28 of those (93%) occurred during the day, and 2 (7%) occurred at night. The time of day was unknown for the remainder of the 2016 cases.

**Protective suits:** Whether the decedent was wearing a protective suit was known in just 12 of the 94 cases (13%). Of these 12 victims, 9 wore wetsuits and 3 wore drysuits.

**Maximum depth:** Figure 1.5-3 shows the reported maximum depth of the fatal dive for the 24 cases (26%) in which that information is known. Of those 24, 9 (10%) occurred in water up to 30 feet deep, 1 (1%) in water from 31 to 60 feet, 5 (5%) in water from 61 to 90 feet, 3 (3%) in water from 91 to 120 feet, and 6 (6%) in water deeper than 120 feet. Depth information was not available for 70 cases (74%).

**Type of gas:** The type of breathing gas being used by the victims is shown in Figure 1.5-4. The type of gas was unknown in 76 cases.

**Breathing apparatus:** Open-circuit scuba equipment was used in 26 of the 94 cases (28%), and rebreathers in 11 (12%). The breathing unit used in the remaining 57 cases was unknown.

**Buddy status:** At least 8 (9%) of the 94 fatal dives were intended as solo dives, but most of 2016’s dive victims started with a dive buddy. Adherence to buddy system diving is difficult to establish retrospectively, however.

When survivors notice that a buddy is missing, it does not necessarily mean that the buddy broke away intentionally; it may, rather, mean that nobody noticed the diver having the problems that eventually led to their death. Either circumstance may indicate a failure of the buddy system. Figure 1.5-6 shows the distribution by buddy status of fatal dives during 2016.

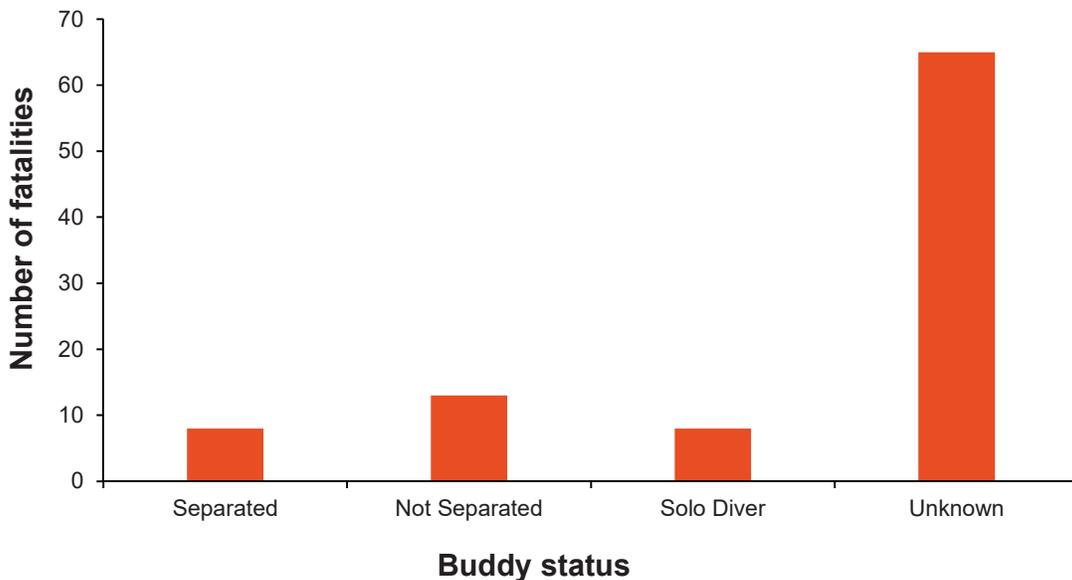


Figure 1.5-6. Buddy status during US and Canadian scuba fatalities in 2016 (n=94)

## 1.6 ANALYSIS OF SITUATIONS AND HAZARDS

We examined each case to identify the phase of the dive during which the incident occurred and the chronological chain of events that ended in death.

### 1.6.1 FATALITIES BY DIVE PHASE

We use the following dive-phase categories: a) on the surface before diving, b) underwater, c) on the surface after diving, and d) exiting the water. Dive-phase information was available in 28 of the 94 cases (30%) and was not available in the remaining 66 cases (70%). Figure 1.6.1-1 shows the distribution of this information. In the majority of the 28 cases where the information was known, the diver lost consciousness either underwater (n=11) or on the surface following the dive (n=9).

### 1.6.2 CAUSES OF INJURIES AND DEATHS

DAN's determination of the causes of the reported fatalities was based on the following sources of information: a) the autopsy findings and/or the underlying cause of death as reported by the medical examiner; b) the victim's dive profile; c) the sequence of events as reported by witnesses; d) the findings from analyzing the victim's equipment and gas supply; and e) the expert opinions of DAN reviewers. This process is described in further detail in a published paper.<sup>5</sup>

Root causes, mechanisms of injury, and causes of death could not be established in 62 of the 94 cases (66%), usually because of missing information and/or inconclusive investigative results. Based on the 32 cases for which such information was available, the most common triggers were an underlying health problem (15%) or equipment malfunctions or problems (15%). See Table 1.6.2-1 for more details.

The most commonly identified harmful events, or actual mechanisms of injury, were insufficient breathing gas (12%), panic (9%), and rapid ascent (9%). See Table 1.6.2-2 for more details.

The cause of death as established by medical examiners, in most cases, was drowning. However, according to DAN's expert reviewers, once again the data indicated that a leading cause of disabling injuries was either a loss of consciousness or an acute cardiac event. Tables 1.6.2-3 and 1.6.2-4 list the disabling injuries and causes of death, respectively, and Figure 1.6.2-1 compares disabling injuries and causes of death side by side. Once again, in 2016 the leading cause of death was drowning, and the leading disabling injury that led to death was cardiovascular-related problems.

For examples, see cases 1-1, 1-3, 1-5, 1-6, 1-8, 1-11, 1-12, 1-18, and 1-20 in Section 1.9.

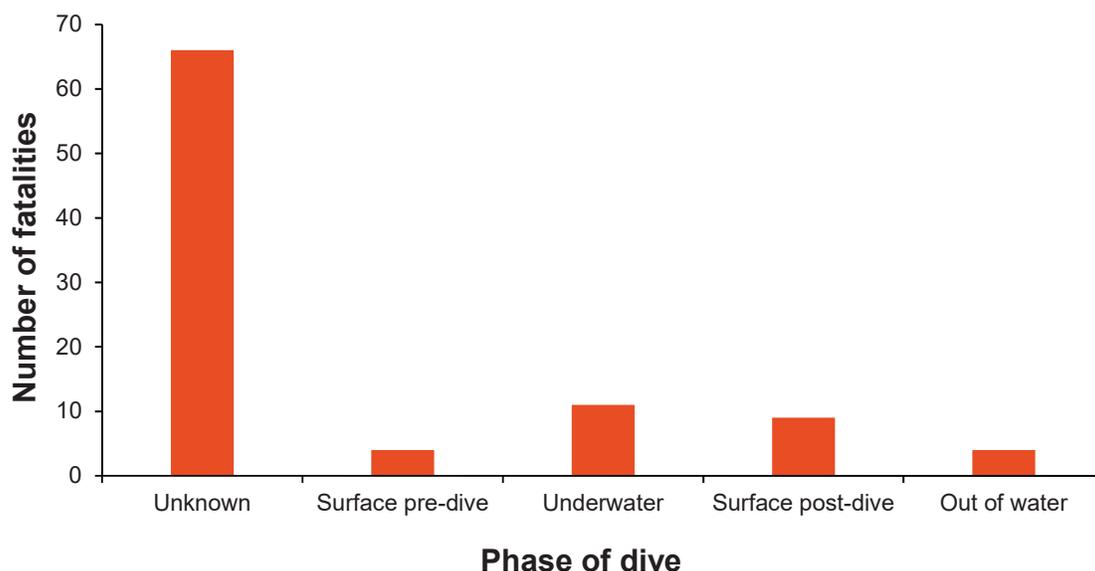


Figure 1.6.1-1. Distribution of fatalities by the phase of the dive when the deceased lost consciousness during US and Canadian scuba fatalities in 2016 (n=94)

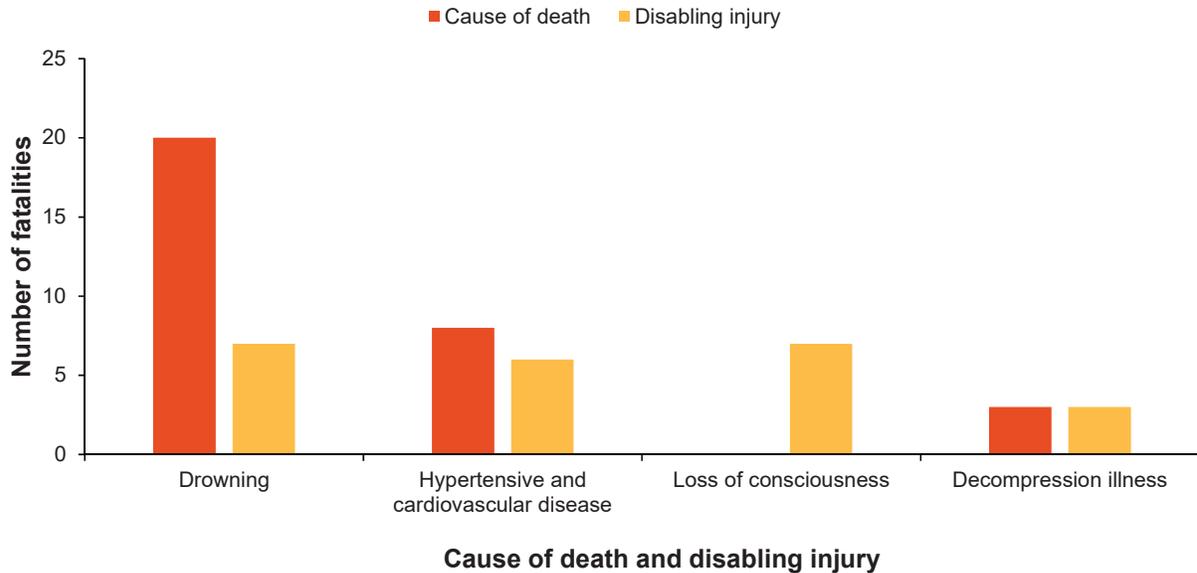


Figure 1.6.2-1. Most common causes of death (n=32) and of disabling injuries (n=23) in US and Canadian scuba fatalities in 2016

Trigger	Count
Equipment malfunction/problem	6
Cardiac condition	5
Entrapment	2
Hit by a large wave	2
Alcohol	1
Buoyancy problem	1
Current in a cave	1
Difficulty breathing	1
Exhaustion	1
Low on air	1
Panic	1
Rough seas	1
Other	2
Unknown	7
<b>Total</b>	<b>32</b>

Table 1.6.2-1. Triggers for US and Canadian fatalities in 2016 (n=32)

Mechanism	Count
Insufficient breathing gas	4
Panic	3
Rapid ascent	3
Exhaustion	2
Hypoxia on rebreather	2
Natural disease	2
Intoxication	1
Striking an object	1
Other	7
Unknown	7
<b>Total</b>	<b>32</b>

Table 1.6.2-2. Mechanisms of injury for US and Canadian scuba fatalities in 2016 (n=32)

Disabling injury	Count
Drowning	7
Loss of consciousness	7
Heart problem	6
Decompression illness	3
Dyspnea	1
Other	1
Unknown	7
<b>Total</b>	<b>32</b>

Table 1.6.2-3. Disabling injuries in US and Canadian scuba fatalities in 2016 (n=32)

Cause of death	Count
Drowning	20
Hypertensive and cardiovascular disease	8
Decompression illness	3
Immersion pulmonary edema	1
<b>Total</b>	<b>32</b>

Table 1.6.2-4. Causes of death in US and Canadian scuba fatalities in 2016 (n=32)

## 1.7 REBREATHER FATALITIES

DAN is aware of 11 recreational diving rebreather fatalities in 2016 that occurred in the US or that involved a US citizen whose body was repatriated to the US. Four of those cases are described below.

### Case 1-7: Double fatality in a cave

Cause of death: Drowning  
 Disabling injury: Loss of consciousness  
 Mechanism: Insufficient breathing gas  
 Trigger: Equipment problem  
 53-year-old diver's BMI = 23.1 kg/m<sup>2</sup>  
 38-year-old diver's BMI = 36.5 kg/m<sup>2</sup>

A 53-year-old male, and a 38-year-old, both experienced divers. Both were on rebreathers in a cave system and did not surface as scheduled. Their bodies were recovered at 260 ffw (80 msw) and 1200 feet (366 meters) into the cave. The recovery team indicated that stage bottles were positioned appropriately; there were 16 tanks total and only 3 were empty. It is presumed the divers ran out of air during their attempt to exit the cave, lost consciousness, and drowned.

### Case 1-10: Death due to CCR failure in a cave dive

Cause of death: Drowning  
 Disabling injury: Loss of consciousness  
 Mechanism: Hypoxia  
 Trigger: Equipment problem  
 BMI = 20.5 kg/m<sup>2</sup>

An experienced male cave diver who had been diving with a closed circuit rebreather (CCR) for over a year began to act erratically during a cave dive with a buddy. According to the buddy, the

victim was not able to continue using his scooter, his trim was off, his fine motor control was off, and his buoyancy was off. He was seen starting to swim in circles and bounce off the ceiling and the floor of the cave, so other divers started assisting him out of the cave. At some point, he lost consciousness and no longer had his regulator in his mouth. The other divers clipped him to the cave line and started a body recovery procedure after surfacing and calling local emergency services. The initial finding was that he had suffered a heart attack and that all his gear was functioning properly. A later examination found that water in his unit may have led to water-blocked oxygen cells and thus a hypoxic mix. The witnesses' description of the diver's behavior suggests a loss of consciousness due to hypoxia rather than a heart-related cause of death.

### Case 1-16: A death during a risky drill

Cause of death: Drowning  
 Disabling injury: Loss of consciousness due to hypoxia  
 Mechanism: Oxygen bottle turned off  
 Trigger: Blackout drill  
 BMI = 36.5 kg/m<sup>2</sup>

A 41-year-old male diver, a rebreather student, died during a training dive in the cavern portion of a cave. The information on this case is contradictory; however, as best as can be determined from various reports, the victim died during a blackout drill and was found floating while the instructor was possibly still at depth. According to one account, the victim's was blocked by a neoprene cover and his oxygen bottle was turned off. By another account, at 35 fsw (11 msw), while ascending,

the lead instructor saw the victim take his regulator out of his mouth and started moving his mouth in different directions. She asked him, using hand signals, if he was OK, and he signaled back yes and put the regulator back in his mouth. After a few seconds, she saw that his regulator was out of his mouth again and that his safety equipment was blinking red. She then saw him fall two feet to a ledge. She inflated his wing to get him to the surface. Another team assisted when the victim floated up and got stuck at the top of the cavern. They got him to the surface where cardiopulmonary resuscitation (CPR) was commenced, but he could not be resuscitated and was pronounced dead in the emergency room.

#### Case 1-17: VGE following a long dive

Cause of death: Decompression sickness  
Disabling injury: Decompression sickness  
Mechanism: Rapid ascent  
Trigger: Current in cave  
BMI = 35.6 kg/m<sup>2</sup>

A 46-year-old male, an experienced CCR instructor, complained of chest pain and shortness of breath immediately after surfacing from a 4.5 hour solo cave dive. He started coughing intensively and he was transported to a local hospital where he later died. Vascular gas emboli (VGE) were found in the mesenteric and portal venous system, in the inferior vena cava, and in his pulmonary artery. The coroner ruled the cause of death to be Type 2 decompression sickness (DCS).

## 1.8 DISCUSSION

About half of all 2016 recreational diving fatalities reported to DAN occurred in the US or Canada. Table 1.2-1 highlights the fact that diving fatalities are a global hazard, occurring in tropical seas and colder waters alike. In the US, the two states with the highest number of fatalities in 2016 were, as in previous years, Florida and California — states whose diving milieus likewise range from tropical conditions to colder waters requiring drysuits. As a result, many of the issues discussed in this section will apply to divers all around the world.

In 2016, 4 out of 5 decedents were male. While this ratio cannot be compared with the diving population at large, because it is unknown exactly how many divers there are or how many

dives any given diver makes, this proportion is similar to that reported in previous years. Once again, BMI data are a cause for concern, especially in light of both pre-existing medical conditions and the high proportion of known causes of death associated with cardiovascular health. Overweight individuals with known heart conditions need to consider carefully if diving is the sport for them. If they decide it is, then they should get in shape for the exertion they will inevitably encounter while diving.

Rebreathers continue to increase in popularity on dive boats and in their prevalence in DAN's annual fatality reports. Concurrent with this increase has been an increase in fatalities at depths greater than 130 fsw (40 msw). This apparent growth in recreational "technical" diving continues unabated, and DAN has been actively engaging the technical diving community through magazine articles and presentations at dive shows and workshops. We encourage all recreational divers to be vigilant when it comes to safety, and we encourage the technical diving community to be hypervigilant. If you see something unsafe, say something about it. You just might save a life.

Two of DAN's important 2018 research findings<sup>2,3</sup> should be emphasized in light of the results reported here. First, diving has an excellent safety record when it is undertaken with safety in mind. We have found that there are probably fewer than two deaths per million recreational scuba dives.<sup>4</sup> That should serve as a pat on the back for all the dive professionals who make safety their highest priority and for the millions of divers who safely make adventurous dives. But, collectively, we make millions of dives each year, and, as these annual reports show, dozens and dozens of recreational divers die every year. The second important 2018 DAN paper highlights why this is such a tragedy. Of the most active divers in our community — those who make perhaps a couple of dives per week and who dive most weekends — about half are married and about 30% have children.<sup>2</sup> Nearly 100 US and Canadian divers died in 2016, and exactly half were between 40 and 59 years old. This represents a terrible toll on our extended diving family. DAN urges every diver to pay close attention to safety before, during, and after every dive. Together, let us

all work toward further improving our already impressive safety record by eliminating unsafe diving practices and maintaining our fitness for diving.

## 1.9 DIVE FATALITY CASE REPORTS

### Case 1-1: Distress at depth

Cause of death: Arterial gas embolism (AGE)  
 Disabling injury: AGE  
 Mechanism: Rapid ascent  
 Trigger: Acute health problem, low on air  
 BMI = Unknown

A 41-year-old male, diving off a private boat, was on his second dive of the day. He and his son were sharing one tank with two secondary regulators. They had been at 65 fsw (20 msw) for about 25 minutes when they started running low on air. According to the son, the victim became distressed at depth, so they quickly ascended to the surface. The son called for help, and they were both pulled onto the boat; the victim was barely breathing. He soon stopped breathing, and friends administered CPR while the boat headed to shore. The victim was transported to the hospital, where he was pronounced dead. The official cause of death was reportedly “barotrauma due to acute decompression.” That diagnosis is possible, but according to DAN’s experts, considering that the decedent went into distress at depth and that toxicology studies reportedly found amphetamines, it is also possible that the disabling condition was an acute health issue.

### Case 1-2: Distress during a lobster hunt

Cause of death: Acute heart condition  
 Disabling injury: Atherosclerotic cardiovascular disease with significant narrowing of the coronary arteries  
 Trigger: Strenuous exercise  
 BMI = Unknown

A 60-year-old male, an experienced diver, was diving solo from a boat in 8–12 fsw (2–4 msw) for lobster. On his first dive of the day, witnesses on the boat said he surfaced in distress after 45 minutes and was assisted back on board, where CPR was immediately started. He was transported to the hospital, where he was pronounced dead. The official cause of death was atherosclerotic cardiovascular disease, with significant narrowing of the coronary arteries.

### Case 1-3: Equipment malfunction and panic

Cause of death: Drowning  
 Disabling injury: Panic  
 Mechanism: Loss of buoyancy; out of air  
 Trigger: Equipment malfunction  
 BMI = Unknown

A 67-year-old male was diving with his wife as a buddy. On their fourth dive of the day, they went to a depth of 50 fsw (15 msw). Upon surfacing, the victim had trouble inflating his buoyancy control device (BCD) due to a dump valve actuator entanglement. His buddy tried to help to fix the problem with the tangled equipment. But the victim started to panic and grabbed at the buddy, knocking off her mask and regulator. The buddy recovered her regulator and had put it back in her mouth before they started to sink. Soon they were back on the bottom. She tried to drop the victim’s weights and pull him to the surface, but she was unable to do so. She dropped her equipment at the bottom and made an emergency ascent to the surface to get help. The divemaster went down and brought the victim to the surface within minutes. However, he was not breathing and had no pulse, and a physician and nurse who were among the boat’s other passengers immediately started CPR. After an hour of unsuccessful CPR, the victim was pronounced dead.

### Case 1-4: Loss of a student diver

Cause of death: Drowning  
 Disabling injury: Unknown  
 Mechanism: Unknown  
 Trigger: Unknown  
 BMI = Unknown

A 52-year-old male student diver was on his first dive. He initially had trouble with his fins, but the issue was resolved, according to the instructor. The victim then became separated from his group, but his companions did not realize he was missing until they surfaced; there were reportedly three divers in the party. His body was recovered 30 minutes later and he was pronounced dead at the scene. According to his wife, he had no known medical problems and was not taking any medications. An autopsy identified drowning stigmata with cerebral edema and moderate coronary artery disease.

### Case 1-5: Myocardial infarction on a solo dive

Cause of death: Sudden cardiac death  
Disabling injury: Atherosclerotic cardiovascular disease  
Trigger: Exertion  
BMI = Unknown

A 79-year-old male, an experienced diver, was diving solo, collecting lobster. He was found floating next to his boat, unresponsive. His dive computer showed that his maximum depth had been 74 fsw (23 msw) and his dive time had been 20 minutes. The water temperature was 58°F (14°C). His cause of death was listed as sudden cardiac dysfunction due to extensive cardiovascular atherosclerosis and a recent myocardial infarction (MI) – which was judged to have occurred between 12 hours and several days, or perhaps as much as a month, before his death. He also had a family history of fatal myocardial infarction. His left anterior artery was 80% to 90% occluded, and his right coronary artery was 40% occluded. He was diagnosed posthumously with hypertensive cardiovascular disease, including mild left ventricular hypertrophy and moderate bilateral nephrosclerosis. It appears that he had finished his dive, placed his catch in the boat, and was in the process of removing his gear when he suffered a heart attack. He had been diving his whole life, three to four times a week.

### Case 1-6: A death before descent

Cause of death: Sudden cardiac death  
Disabling injury: Dysrhythmia/immersion pulmonary edema (IPE)  
Trigger: Immersion  
Other contributing factors: Obesity  
BMI = 30.1 kg/m<sup>2</sup>

A 49-year-old male diver with intermediate experience was on a solo dive. He never descended, according to his computer, and was found floating. An autopsy found mild coronary artery disease, cardiomegaly, pulmonary edema, an atrial septal defect, and hypertensive changes of the kidneys

### Case 1-8: Young diver with cardiomegaly

Cause of death: Cardiac arrest  
Disabling injury: Hypertensive and atherosclerotic cardiovascular disease  
Mechanism: Natural disease process  
Trigger: Unknown  
BMI = 27.7 kg/m<sup>2</sup>

A 30-year-old male was making his first dive in 10 years. He was diving with nitrox to 30 fsw (9 msw) off a boat. He reportedly surfaced and signaled that he was OK but then collapsed on the ladder. CPR was performed, but resuscitation was unsuccessful. An autopsy found cardiomegaly with left ventricular hypertrophy (LVH), moderate calcific coronary artery disease, and myocardial scarring. An inspection of his equipment found that his buoyancy compensator (BC) was not working properly but that it did hold air. The coroner concluded that the cause of death was hypertensive arteriosclerotic cardiovascular disease (HASCVD) and that the manner of death was natural. The facts of the case imply a strong likelihood of an AGE, but the pathologist did a thorough exam and excluded that possibility.

### Case 1-9: A morbidly obese diver in rough waters

Cause of death: Drowning  
Disabling injury: Cardiac disorder  
Mechanism: Panic  
Trigger: Immersion  
Other contributing factors: Morbid obesity, seasickness  
BMI = 57.2 kg/m<sup>2</sup>

A morbidly obese 27-year-old male was seasick, vomiting, and sweating profusely during the ride out to the dive site. The seas were rough, and the victim had trouble putting on his gear and had to be assisted in that effort. At the dive site, upon entering the water, the victim started flailing and appeared to panic. He pulled off his mask and dropped his regulator out of his mouth. Another diver swam over to help, but the victim latched on to him and pulled both of them underwater. The rescuing diver managed to inflate his BCD and brought them back to the surface. They went under twice before the rescuer calmed the victim down and got him to float on his back. A divemaster instructed the victim to return the regulator to his mouth and assisted him back toward the side of the boat.

The victim lost consciousness at the ladder. Due to his size, the crew was unable to haul him back aboard. An inflatable boat was used to take the victim to shore. He was transported to the hospital, where he was pronounced dead. An autopsy found cardiomegaly with LVH. The official cause of death was listed as drowning, secondary to morbid obesity.

#### Case 1-11: A severe decompression accident

Cause of death: DCS  
 Disabling injury: DCS  
 Mechanism: Rapid ascent, omitted decompression stops  
 Trigger: Equipment malfunction  
 BMI = 27.1 kg/m<sup>2</sup>

A 50-year-old male, an experienced diver, was on a deep dive to a wreck in 210 fsw (64 msw), using mixed gas. During ascent, the victim suddenly ascended rapidly, missing his decompression stop and safety stop and leaving his companions. His buddy lost sight of the victim and figured that he had over-ascended and would come back down to decompress. However, when the victim did not rejoin him, the buddy decided to cut his decompression time short and follow the victim to the surface. The buddy found the victim on the boat, unconscious, but with a heartbeat and still breathing. The buddy put the victim on oxygen and helped their third companion aboard, and they sailed back to shore. By that time, the victim was conscious and semicoherent. He was transported to the hospital, then to the nearest hyperbaric chamber, which was some distance away.

#### Case 1-13: A cocaine-related death

Cause of death: Drowning  
 Disabling injury: Sudden cardiac death  
 Mechanism: Dysrhythmia related to cocaine\*  
 Trigger: Exertion  
 BMI = 22.9 kg/m<sup>2</sup>

A 33-year-old male lost consciousness while he was swimming out from the shore. He was rescued by his companions and brought to the hospital, where he died. The cause of death was ruled to be asphyxiation due to drowning. A toxicology test was positive for parent cocaine and its metabolites.

*“Cocaine is a potent stimulant which affects cardiovascular system severely. The mechanism of cardiac toxicity depends on multiple factors. Cocaine increases sympathetic stimulation and causes excess catecholamine secretion. Besides, its indirect sympathomimetic effect also directly exerts cardiotoxic effect by different cellular, molecular, and ionic mechanisms, resulting in acute or chronic cardiovascular impairment. Cardiac arrhythmia and acute myocardial ischemia or infarction is the most common cause of cocaine-induced sudden cardiac death.”<sup>5</sup>*

#### Case 1-12: Solo diver with diabetes

Cause of death: Drowning  
 Disabling injury: Atherosclerotic cardiovascular disease  
 Trigger: Unknown  
 BMI = 25.1 kg/m<sup>2</sup>

A 57-year-old male was seen going into the water for a solo scuba dive. He told a witness that he was experienced and had been diving for 10 years. Sometime later, the witness saw the diver floating facedown in the water and swam out to him. The victim was unconscious, so the witness towed him back to shore. The witness said the regulator was still in the victim’s mouth, and he could hear the victim breathing. Once the victim was on shore, CPR was performed. He was pronounced dead on the beach. He had 1100 psi (76 bar) remaining in his tank. The victim had a history of diabetes mellitus and hyperlipidemia. The autopsy found evidence of hypertensive and ischemic cardiac disease.

#### Case 1-14: Hunting lobsters in heavy seas

Cause of death: Drowning  
 Disabling injury: Drowning  
 Mechanism: Exhaustion  
 Trigger: Rough seas  
 Other contributing factors: Atherosclerotic cardiovascular disease  
 BMI = Unknown

A 38-year-old male was diving for lobster with a buddy in about 20 fsw (6 msw) when he signaled his buddy to ascend. At the surface, they faced strong currents and strong seas. They tried to swim back to shore but soon became exhausted. The victim sank, and the buddy retrieved him. The buddy was able to flag down a boat and had to tread water while holding onto the victim for about

30 minutes. The harbormaster came and took the pair out of the water. CPR was administered to the victim, and both the victim and his buddy were transported to the hospital. The victim was pronounced dead. The cause of death was judged to be drowning (there was lots of water in his lungs), and the manner of death was declared to be an accident. Atherosclerotic cardiovascular disease was judged to be a contributing factor.

#### Case 1-15: Diver with cardiac risk factors

Cause of death: Drowning  
Disabling injury: Likely heart problem  
Trigger: Exertion  
BMI = Unknown

A 55-year-old male was diving alone for lobster. A kayaker noticed that the diver's surface marker had not moved for 30 minutes. He paddled out to the buoy and observed the diver face up in the water, about two feet below the surface, without a mask on his face or a regulator in his mouth; the water depth at that point was about 5 feet (1.5 meters). The victim's body was already in a state of rigor mortis; it was recovered and brought to shore by USCG personnel who happened to be patrolling nearby. The victim had three lobsters in his catch bag, and there was still air left in his scuba tank. He was a smoker and had a history of hypertension, increasing the likelihood that he experienced cardiac issues due to the exertion of the lobster hunt.

#### Case 1-18: Diver with coronary disease

Cause of death: Cardiac condition  
Disabling injury: Ischemia  
Mechanism: Unknown  
Trigger: Exertion  
Other contributing factors: Obesity, cardiomegaly with LVH and focally severe coronary atherosclerosis  
BMI = 36.0 kg/m<sup>2</sup>

A 52-year-old male, an experienced diver, was making a shore entry with a group when a strong current separated the divers. A few minutes later, the victim called for help and said he couldn't breathe. Two of his buddies were able to reach him, but he lost consciousness before they could get him to shore. CPR was started and he was taken to the hospital, where he was declared dead. The decedent had a history of hypertension and ischemic heart

disease and had a coronary artery stent. An autopsy disclosed cardiomegaly with LVH and focally severe coronary artery disease.

#### Case 1-19: A rapid ascent

Cause of death: Drowning  
Disabling injury: AGE  
Mechanism: Rapid ascent  
Trigger: Rapid ascent  
BMI = 27.2 kg/m<sup>2</sup>

A 56-year-old male was completing his fourth instructional dive. The victim and his instructor were touring and doing a navigational dive on a reef in about 30 fsw (9 msw), when the victim suddenly turned off and went over the backside of the reef down to 80 fsw (24 msw), in a strong current. The instructor caught up to him and asked if he was OK. The victim signaled back to her that he was OK. The instructor showed him how deep they were and motioned to start ascending. After ascending about 10 feet (3 meters), the victim bolted to the surface. The instructor tried to grab the victim's fin but was unable to hold on and surfaced shortly after the victim. The instructor told him to inflate his BCD; he started to do so orally, at which point the instructor told him to use his power inflator and to use his snorkel to swim back to the boat. During the swim to the boat, the victim stopped because he was getting tired; the instructor told him to just hold on to the line, and the crew would pull them back in. He put his snorkel back in his mouth and started kicking. At some point he stopped kicking, and the instructor could not get a response from him. She purged the victim's regulator and put it back in his mouth. A rescue team got to them within a minute or two and took over; the instructor let go of the line and was picked up by another dive boat. When she got back to the boat, they were performing CPR on the victim and giving him oxygen. He was transported to the nearest hyperbaric oxygen (HBO) chamber, where he died. On autopsy, there was no evidence of heart disease, AGE, or pulmonary barotrauma. The resuscitation efforts, and possibly even the HBO, may have erased signs of AGE. The victim's rapid ascent, followed by his loss of consciousness soon after surfacing, points to his having suffered an AGE, despite his brief interval of lucidity.

**Case 1-20: Diver with neglected hypertension**

Cause of death: Drowning  
 Disabling injury: Heart problem  
 Mechanism: Unknown  
 Trigger: Cardiac event  
 Other contributing factors: Obesity, cardiomegaly with LVH  
 BMI = 34.6 kg/m<sup>2</sup>

A 42-year-old inexperienced male was diving with a buddy and a divemaster. They completed their buoyancy checks and started to swim out to the dive site. The buddy looked back at one point and saw the victim go under but assumed that he had started his dive. They became separated during the dive, and the buddy did not realize that the victim had not returned after the dive. Two other divers found the victim 6 to 7 minutes later in 12 fsw (4 msw), unresponsive. He was brought to the surface, CPR was started, and he was transported to the hospital, where he was pronounced dead. His medical history included hypertension. An autopsy disclosed cardiomegaly and LVH. The medical examiner considered barotrauma but did not report any evidence of such injury, and it was left off the death certificate. The cause of death was judged to be drowning due to cardiac problems.

**Case 1-21: Sudden death after surfacing**

Cause of death: Hypertensive Heart Disease  
 Disabling injury: Heart problem  
 Mechanism: Unknown  
 Trigger: Unknown  
 BMI = 31.4 kg/m<sup>2</sup>

A 75-year-old female reported feeling unwell after diving and lost consciousness on the boat. It is not clear if she felt ill only after or also during the dive and what caused her to surface. She was airlifted to the hospital and was in and out of cardiac arrest multiple times and was defibrillated more than once in the helicopter on the way to the hospital. In the emergency department, she was hypotensive and was placed on multiple medications to maintain her blood pressure. Her pupils were fixed and dilated and her muscles were limp. Brain death was confirmed. She did not receive HBO therapy because she was too unstable and it was not known if she had suffered an AGE or a cardiac event. She was taken off life support a few days later and passed away.

**1-22: Possible medication interactions**

Cause of death: Drowning  
 Disabling injury: Loss of consciousness  
 Mechanism: Possible pharmacological effects of a multidrug cocktail she used  
 Trigger: Unknown  
 BMI = 28.5 kg/m<sup>2</sup>

A female diver in her late 50s, an experienced diver, dived to 92 fsw (28 msw) for 31 minutes on her first dive of the day, on the first day of a dive trip. She was with a group until her ascent. The dive leader watched her ascend to 30 fsw (9 msw), deploy her safety sausage, and give the OK signal. The captain of the boat saw her for a moment upright in the water as he was picking up two other divers. When he went over to her, she was on her back, unconscious, with her head under water. She was brought on board and given CPR, then brought to shore and to the hospital, where she was pronounced dead. She tested positive for multiple, redundant medications, both psychotropics and antihistamines, some of them above therapeutic levels. Her death was ruled to be an accidental drowning.

The following medications were detected:

- Nordiazepam 0.132 mg/L (within therapeutic range)
- Lorazepam <.025 mg/L (below therapeutic range)
- Diphenhydramine (Benadryl) 0.505 mg/L (within therapeutic range)
- Bupropion (Wellbutrin) 488 ng/mL (above therapeutic range [50-100 ng/mL])
- Dextro/levomethorphan (Robitussin) 250 ng/mL (above therapeutic range)
- Doxylamine (Unisom) 110 ng/mL (within therapeutic range)
- Zolpidem (Ambien) 5.7 ng/mL (within therapeutic range)

### Case 1-24: Lobster diver runs out of air inside a powerplant pipe

Cause of death: Drowning

Disabling Injury: Loss of consciousness

Mechanism: Insufficient breathing gas

Trigger: Entrapment in a drainage pipe

BMI = 34.7 kg/m<sup>2</sup>

A 47-year-old male was diving alone for lobster off the coast and did not return to his boat. He was later found dead inside a power plant pipe and was pronounced dead. The official cause of death was judged to be drowning. The decedent apparently ran out of air in an overhead environment. His equipment was tested and found to be working properly.

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## SECTION 2. DIVING INJURIES

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### 2.1 VOLUME OF CALLS TO THE MSCC AND TREATMENT NUMBERS REPORTED BY HYPERBARIC CHAMBERS

The two main sources of information about diving injuries for this section are the DAN Medical Services Call Center (MSCC) and data regarding treatment of injured divers in the annual survey of hyperbaric chambers. (Note that information collected by DAN on fatalities associated with scuba diving is covered in Section 1 of this report and on injuries and fatalities associated with breath-hold diving in Section 4.)

Table 2.1-1 shows the volume of calls to DAN's MSCC over a period of three years. In 2016, there were 10,320 calls or emails requesting assistance, information, or consultation. The medical staff answered 3,593 calls requiring

assistance (referred to here as cases) and 6,727 calls or emails requesting medical information (referred to here as inquiries). These numbers include 43 calls about fatalities.

The first step in managing a case is to establish if it was dive related. In 2016, 59% of cases were dive related and 41% were not, which is a breakdown similar to that of previous years. Table 2.1-2 shows the geographic origin of cases.

Figure 2.1-1 shows the volume and percentage of overall calls by month. The highest volume is in the summer months in the northern hemisphere, but the seasonal variation is rather small.

Year	Cases	Inquiries	Totals
2014	3,169	6,361	9,530
2015	3,485	6,635	10,120
2016	3,593	6,727	10,320
<b>Totals</b>	<b>10,247 (34%)</b>	<b>19,723 (66%)</b>	<b>29,970</b>

Table 2.1-1. Volume of MSCC calls by year

DAN Region	Calls
United States	1,329
Caribbean Basin	552
Missing	426
Mexico	379
Southeast Asia	265
Central America	170
Pacifica	111
Canada	78
South America	68
Europe	58
Australia	48
Africa	37
Far East	33
Middle East	21
Polar	2
<b>Totals</b>	<b>3,577</b>

Table 2.1-2. Geographic distribution of MSCC cases in 2016

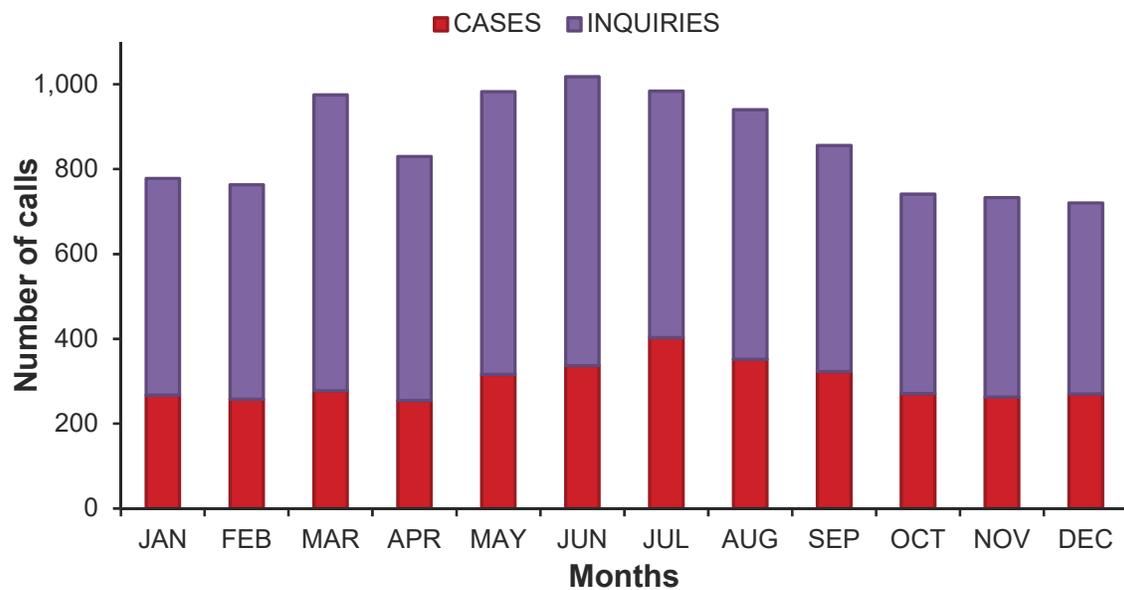


Figure 2.1-1. Distribution of MSCC calls by month in 2016

Category	Cases		Inquiries		Totals
	#	%	#	%	
Barotrauma	1,071	47%	105	59%	1,176
Decompression sickness	694	31%	32	18%	726
Marine envenomation	229	10%	19	11%	248
Fatality	48	2%	1	1%	49
Arterial gas embolism (AGE)	47	2%	1	1%	48
Immersion pulmonary edema (IPE)	45	2%	3	2%	48
Gas contamination	32	1%	3	2%	35
Nonfatal drowning	24	1%	0	0%	24
Motion sickness	17	1%	6	3%	23
Mask squeeze	17	1%	4	2%	21
Finfoot	16	1%	1	1%	17
Loss of consciousness	14	1%	1	1%	15
Cardiac arrhythmia	12	1%	1	1%	13
Nitrogen narcosis	2	0%	2	1%	4
<b>Totals</b>	<b>2,268</b>	<b>—</b>	<b>179</b>	<b>—</b>	<b>2,447</b>

Table 2.1-3. Distribution of MSCC calls by dive-related health issues in 2016

The distribution of dive-related health issues, based on classification at the time of the call, is listed in Table 2.1-3. Most calls originated from the United States, followed by the Caribbean Basin and Mexico.

Once a diver with an acute health issue has reached a facility where appropriate care can be provided, the case management phase for the MSCC has concluded and follow-up begins. The follow-up process focuses on decompression sickness (DCS), immersion pulmonary edema (IPE), unconsciousness, and severe nondive-related issues like chest pain. In some instances, calls concerned issues related to recent injuries that had already been addressed without MSCC involvement.

## 2.2 BAROTRAUMA

As usual, barotrauma was the most commonly reported dive-related health issue in 2016. Figure 2.2-1 shows the distribution of various types of suspected barotrauma.

It has previously been established that ear and sinus barotrauma are the most common health issues reported by divers.

Ear and sinus issues represent 4 out of 5 barotrauma-related calls to DAN. We have written about this quite extensively in previous editions of the *Annual Diving Report*. In this edition, we will focus on the lung injury commonly referred to as pulmonary barotrauma, an issue that seems to be occurring less than had been feared.

### 2.2.1 PULMONARY BAROTRAUMA

Divers can incur pressure-related lung injuries from exposing their lungs either to excessive positive differential pressure, which results in a condition called pulmonary overinflation syndrome (POIS), or to relative differential negative pressures, which results in a condition called squeeze. Relatively small pressure differentials can cause considerable injury to lung tissue. The capillaries and alveoli in the lungs have very thin walls, to enable a rapid exchange of gas between the air in the alveoli and the blood in the capillaries. It doesn't take much pressure to damage these delicate structures.

Barotrauma	Cases		Inquiries		Totals
	#	%	#	%	
Ear and sinus	881	80%	95	90%	976
Pulmonary	165	15%	5	5%	170
Mask squeeze	24	2%	3	3%	27
Dental	13	1%	2	2%	15
Gastrointestinal	8	1%	0	0%	8
Suit squeeze	6	1%	0	0%	6
<b>Total</b>	<b>1,097</b>	<b>—</b>	<b>105</b>	<b>—</b>	<b>1,202</b>

Table 2.2-1. Number of barotrauma cases by type in 2016

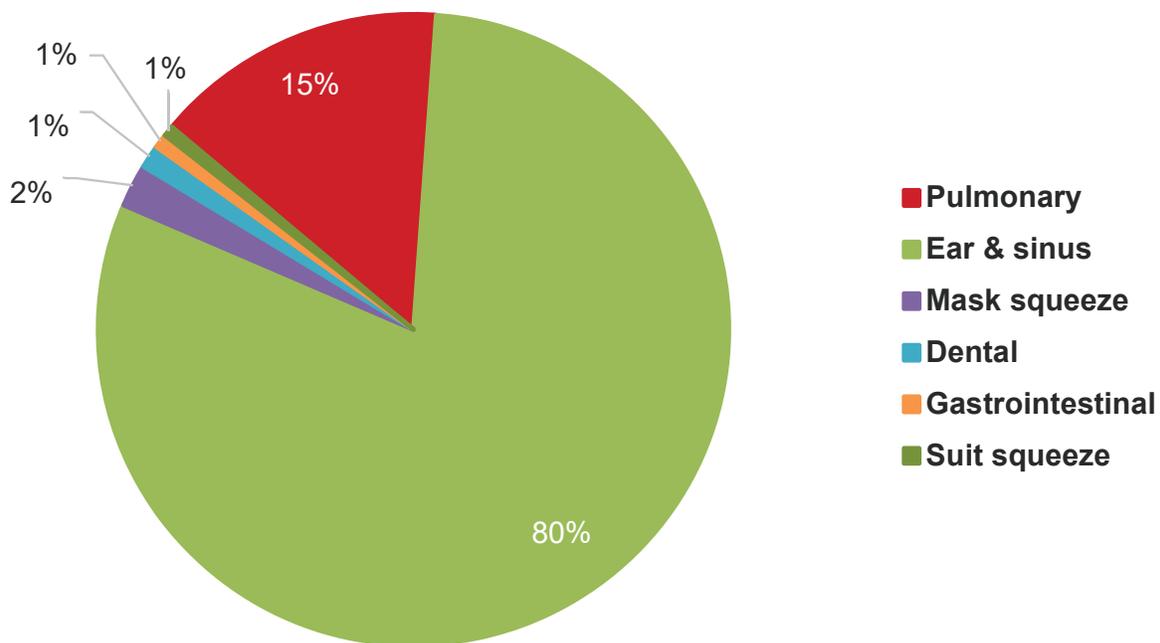


Figure 2.2-1. Proportions of barotrauma by type in 2016

### 2.2.1.1 LUNG SQUEEZE (NEGATIVE PRESSURE)

Relative negative pressure in the lungs can occur during extremely deep breath-hold diving and can result in serious injury. It causes vascular engorgement, leakage of fluids into the alveoli, and even bleeding. Symptoms include coughing; wheezing; frothy, blood-tinged sputum or coughing up of blood; shortness of breath; dizziness; and general weakness and fatigue. The following is an illustrative case.

#### Case 2-01: Breath-hold diver with chest pain and cough

A 42-year-old male breath-hold diver without formal dive training called to complain of chest pain after a series of successive dives beyond 100 fsw (31 msw). He had a history of postdive cough and, occasionally, some blood-tinged sputum. Evaluation by his physician team, several days after the most recent episode, was negative. This was a relatively mild case of lung squeeze, in that the victim was not coughing up blood and his condition resolved quickly and spontaneously. While lung squeeze was the most likely diagnosis in this case, mild IPE cannot be ruled out.

### 2.2.1.2 PULMONARY OVERINFLATION SYNDROME

Pulmonary overinflation is a concern when divers breathe compressed gas at depths greater than 3–4 fsw (1 msw). It occurs during ascent if divers are holding their breath or if a blockage in any part of their airway impedes exhalation. Buoyancy problems, panic, and out-of-air situations often set the stage for a rapid ascent and a subsequent POIS injury. Underwater distractions — such as photography, work, reduced visibility, new gear, etc. — can be contributing factors. Breath-hold divers cannot develop overinflation unless they unwittingly breathe from a compressed-air source during their dive (such as from a scuba diver, a spare air source, a trapped air pocket at depth, or extreme lung packing).

Overinflation of the lungs can result in air escaping from the lungs into surrounding tissues, can cause pneumomediastinum (air in the mediastinum), pneumopericardium (air in the sac surrounding the heart), subcutaneous emphysema (air trapped under the skin), or pneumothorax (air between the lung and the chest wall). These conditions do not require recompression in a hyperbaric chamber. In rare cases — when recompression is needed for a coincident decompression illness — a pneumothorax may worsen and even become life-threatening, especially on ascent, if it is not first addressed properly; this is because when the trapped gas expands, it can compress the lungs, the heart, and/or the large central blood vessels, resulting in collapse. Divers are usually taken to an ER before being taken to a chamber — not only to evaluate their injuries and prepare them for the recompression chamber, but also to detect whether they've suffered a pneumothorax and to treat it before they undergo recompression.

#### Case 2-02: Likely mediastinal emphysema

A 37-year-old male compressed-gas diver was harvesting marine life at 20 fsw (6 msw), with frequent ascents and descents. After his second dive, he noticed chest pain upon each deep breath, a voice change, and neck fullness. By the time he got to a hospital, his evaluation was negative, including a normal chest X-ray and normal neurological findings. He was placed on oxygen, observed without

event, and discharged. A voice change and neck fullness after a dive are quite reliable signs of mediastinal emphysema. A chest X-ray will readily reveal any air that is still present, but it is not unusual for trapped gas to resolve before victims can get to an emergency room, especially if they have been breathing oxygen. Subcutaneous and interstitial gas usually reabsorbs slowly, however. In this case, due to the victim's delay in seeking medical evaluation, all evident signs of his condition may have resolved by the time of his arrival at the ER.

#### Case 2-03: Diagnosed mediastinal emphysema with voice change and skin crackling

A 32-year-old male noticed shortness of breath, a neck ache, and a voice change following a dive. When he was seen at the ER, subcutaneous air was still evident, and his skin had a crackly feeling (subcutaneous crepitation). A chest X-ray demonstrated mediastinal emphysema without pneumothorax. His neurologic exam was normal. He was given oxygen to breathe during observation. His voice change resolved, and his neck pain had lessened before he was discharged.

#### Case 2-04: Mediastinal emphysema and AGE

A 51-year-old male made a rapid ascent from a 52 fsw (16 msw) dive. He noticed neck fullness and a crackling sensation when he rubbed his upper shoulder and neck. He was placed on oxygen and transported to an emergency facility. Most of his symptoms had resolved by the time he reached the hospital. A chest X-ray was normal and showed no evidence of a pneumothorax. However, a neurological exam revealed mild mental confusion, so hyperbaric treatment for an AGE was performed and full resolution of his symptoms was attained.

#### Case 2-05: Probable overinflation during a shallow dive

A 13-year-old girl's first experience breathing compressed gas was during a vacation with her parent. After a brief orientation, she was attached to a SNUBA (surface nexus underwater breathing apparatus) system prior to diving. Her parent insisted that she be allowed to also try photography (i.e., a distraction) while at the resort. The guide repeatedly asked the girl to stop holding her

breath as she operated in 10–15 fsw (3–5 msw). After the dive, she developed severe chest pain, which lasted into the night. She did not receive any medical attention until she returned home, by which time her chest pain had improved but not resolved completely. A chest X-ray reportedly was normal. There was no report of subcutaneous emphysema, and she exhibited no neurological deficits on examination. Diving in a distracted state on compressed gas at 10–15 fsw (3–5 msw), where the greatest pressure/volume changes occur, may cause pulmonary barotrauma even if diver only briefly holds her breath. In fact, it sometimes takes only 4 feet (1.2 meters) of overpressure to rupture the lungs.

*Comment: This case illustrates several important points, including the mistaken belief that shallow dives are without risk — when, in fact, the greatest pressure/volume changes occur at shallow depths. Also, proper dive training should never be sidestepped because of time constraints or inconvenience. If children demonstrate an inability to acquire a skill or repeatedly violate safe diving procedures, it may be best to try again when they are older. And lastly, incorporating new and complex tasks or distractions into a dive can result in injury for any diver, especially a new one.*

### 2.2.2 ARTERIAL GAS EMOLISM

An AGE occurs when air escapes from the alveoli into the pulmonary vasculature and the arterial system, where it blocks circulation. Any organ can be affected by circulatory congestion, but among the most vulnerable are the brain and the heart. Symptoms of AGE usually occur shortly after reaching the surface. A rapid onset of symptoms can result in loss of consciousness or paralysis. If these dramatic events occur while the diver is still in the water, drowning may ensue if a prompt rescue is not mounted. This is the only consequence of POIS that requires recompression, even if the symptoms resolve spontaneously, either with or without supplemental oxygen, since relapse is possible.

#### Case 2-06: Breath-hold during rapid ascent

A 36-year-old male scuba diver accidentally overinflated his buoyancy compensator (BC) at his 15-foot (5-meter) safety stop. As a result,

he made a rapid, buoyant ascent while holding his breath. His companions reached him quickly once he surfaced, but he was not moving and was unresponsive. Chest compressions were conducted for less than a minute, and he soon became responsive. The rest of his symptoms resolved as well, except for right arm paralysis, which gradually resolved with oxygen. He was quickly transported to shore and the hospital, where a chest X-ray was normal; a pneumothorax was thus ruled out. Despite being asymptomatic by that time, he was recompressed to prevent relapse. He recovered fully.

#### Case 2-07: DCS or AGE?

A 41-year-old female completed one dive to 80 fsw (24 msw) for 35 minutes and then made a quick ascent directly to the surface. Upon surfacing and boarding the boat, she experienced an acute onset of confusion and left-side weakness. She was placed on surface oxygen, which relieved her mental confusion. By the time she arrived at a recompression chamber, all her symptoms had resolved, so she opted to leave without treatment and before a neurological examination could be conducted — despite the physician's advice to the contrary. About 2 hours later, she experienced two seizures and returned for a series of hyperbaric treatments. Unfortunately, although most of her symptoms resolved, she was left with intermittent periods of confusion and difficulty expressing herself verbally. The diver reported that she had also experienced neurological symptoms and skin discoloration after previous dives and did not seek attention in those instances as well.

*Comment: This case clearly illustrates why a complete examination (including a detailed neurological examination) is needed whenever a diver falls ill after a dive, even if the symptoms resolve spontaneously. It also vindicates the value of recompression treatment of acute postdive neurological symptoms, even if they have resolved. While this diver's dive profile could have produced bubbles that led to neurological DCS, this case was most likely an AGE. However, given her repeated neurological deficits and skin rashes following previous dives, the possibility of a patent foramen ovale (PFO) as a contributing factor was discussed with the patient, and she was advised to get tested for a PFO.*

**Case 2-08: Failure of a homemade scuba rig**

A 26-year-old man without dive training made his own scuba rig, and on his test dive he experienced second-stage regulator failure and subsequent exposure to high-pressure air when he reportedly released the regulator from his mouth and made a rapid ascent to the surface. He lost and never regained consciousness. In this case, the victim may have developed an overinflation injury while he was still at depth due to exposure to high gas pressures as a result of the failure of his second-stage regulator. Either an additional or possibly the primary injury may have occurred during this untrained diver's rapid ascent without exhalation, due to the fact that he may have had little to no understanding of the impact of the gas laws on pulmonary physiology.

**Case 2-09: Use of scuba by a freediver**

A 43-year-old man was freediving to 40 fsw (12 msw) when he took three breaths from a friend's regulator at depth. Upon ascent, he lost consciousness and was brought to the boat by his diving buddy. His vitals were stable, but he showed a marked decrease in his level of consciousness. He was taken to the ER, where a chest X-ray was normal, and then was transported to a chamber and recompressed. He recovered after a treatment to 60 fsw (18 msw), though he remained drowsy. A second treatment the following day resulted in full resolution of his symptoms.

**2.3 DECOMPRESSION SICKNESS**

Decompression sickness was the second most common dive-related reason for calls to the MSCC in 2016.

Of all calls related to DCS, most (52%) were concerned with possible neurological decompression sickness. Cutaneous DCS was the leading concern in 24% of calls, and osteoarticular manifestations in 23% of calls. Possible cardiopulmonary manifestations were of concern in 2% of calls.

**2.3.1 NEUROLOGICAL DCS**

The most common form of DCS in recreational divers manifests with neurological symptoms. There are various patterns of such symptoms, including cerebral, spinal, and vestibular. The diagnosis is not always straightforward, but the theoretical probability of DCS is high when acute neurological symptoms develop shortly after a dive. One of the symptoms that usually indicates a severe spinal form of DCS is the inability to void. According to the treatment reports from recompression chambers that we used to receive before the passage of HIPAA (the US Health Insurance Portability and Accountability Act of 1996), this symptom occurs in about 5% of neurological DCS cases. However, an analysis of more recent emergency calls to the MSCC shows the symptom to be underreported, as we could find only a few cases mentioning it. This is a reminder to physicians that they should always check the bladder function of divers with postdive neurological symptoms. The following cases are illustrative of bladder dysfunction.

Type of DCS	Cases		Inquiries		Totals
	#	%	#	%	
DCS Type 2	338	51%	6	38%	344
Cutaneous DCS	163	24%	8	50%	171
DCS Type 1	152	23%	2	13%	154
Pulmonary DCS (chokes)	13	2%	0	0%	13
<b>Total</b>	<b>666</b>	<b>—</b>	<b>16</b>	<b>—</b>	<b>682</b>

Table 2.3-1. Distribution by type of DCS-related calls to the MSCC

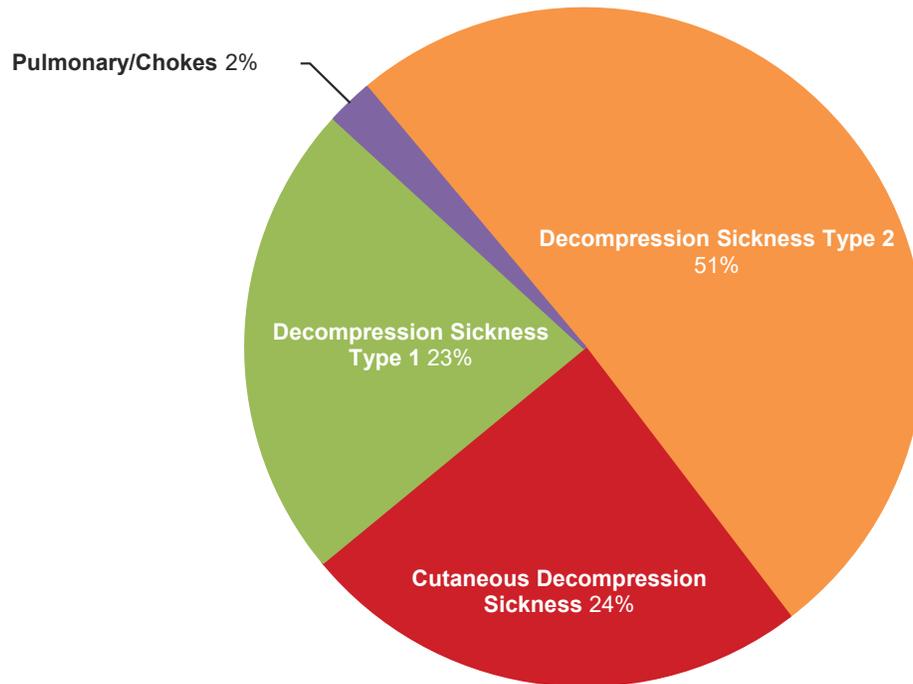


Fig 2.3-1. Proportions of suspected types of DCS cases in 2016

#### Case 2-10: Urine retention, low back pain, and foot numbness

A 75-year-old male stated that he had developed low back pain shortly after diving and then urinary retention late that night. He said he had paresthesia in his feet but could still walk. At the time of his call, he was still experiencing urinary retention and some weakness in his legs, and the paresthesia had moved into his calves. He wanted to know what hospital he should go to. Paralysis of the bladder is rarely seen with only minor paresthesia of the feet, but, regardless, the caller was given advice about the most suitable location where he could be evaluated and treated if that proved necessary.

The follow-up call was answered by the patient's wife. Both the patient and his wife were physicians. She affirmed her husband's initial report and said he was having lots of trouble walking. She thought at first he was just stiff. She said that he had a history of benign prostatic hyperplasia (BPH), for which he had had a prostate resection, and that a long time previously he was thought to have had an L5-S1 herniation.

The patient received normobaric oxygen for an hour but showed no improvement. He was recompressed using USN TT6 and this time did improve. After three more hyperbaric oxygen (HBO) sessions (using USN TT6 extended and USN TT5), he was able to void and his numbness was relieved, but some loss of vibration sensation remained.

Ten days later, his wife called again from their hometown and asked for a referral to a nearby chamber. They had just been at the doctor's office, and the doctor had recommended an MRI and a neurological workup. But after leaving the doctor's office, the wife realized that her husband was confused and was exhibiting an altered mental status. She thought immediately of bubbles and DCS. She was advised to take her husband to an ER and told that DCS was not likely 10 days postdive, after four HBO sessions. At that point she became angry and dropped the call.

### Case 2-11: Sepsis, not DCS

A rebreather diver on a liveaboard, 7 hours offshore, developed a dark, mottled rash on his stomach, sides, and back; a deep pain that he described as an “ache” in his back, thigh, and groin; and a tingling in his right bicep. He was reportedly unable to urinate. The boat headed to port with the patient on 100% oxygen by non-rebreather mask. He also received 800 mg of ibuprofen. Upon arrival ashore, after traveling all night, the patient still was not able to pass urine and he could walk only with assistance. His skin mottling seemed to be resolving, however.

An update came in on the emergency line from the patient’s wife. She said the patient had become septic and had been admitted to the ICU. An HBO physician had evaluated him and found him too unstable to receive treatment in the facility’s offsite chamber. The wife was told that her husband had two pockets of air — one in his chest and the other in his abdomen. She said he had been evaluated for a possible bowel perforation but one had not been found. The patient had a high white blood cell count and an abnormal hematocrit. He was receiving two different antibiotics. The mottling and redness on his right arm and leg were intensive, and both limbs were swollen, with a noticeably increased circumference compared to his left arm and leg. He was also hypotensive.

Five days later, the patient called to report that he had been discharged the previous day and felt much better and had gotten some rest. His right arm was still sore and his chest muscles were still tender. His stamina was also not what it normally had been. He denied any continued urinary retention and said he was urinating about every 4 hours and even had woken up during the night to urinate. He also said that he was walking without problems and reported normal function of his extremities. The patient said that the cause of his infection had not been found but that his doctors thought maybe he had a perforated diverticulum which had allowed air to enter his abdomen.

He subsequently did a single day of diving, with three rebreather dives to 110–113 fsw (34–35 msw); the set point on his rebreather was 1.2 atmospheres absolute (ATA). He denied missing any decompression obligations. He

got out of the water about 5:30 p.m. local time, and his first symptom was right arm pain an hour later. When he looked in the mirror, he saw a “black and white” rash on his right arm, shoulder, side, and leg. When he was subsequently questioned about the color of the rash, he said calling it black and white was inaccurate; rather, he said, it was mottled and blotchy, with dark and white areas.

What appeared at first to be DCS turned out to be something else. Except for the patient’s inability to void, no other neurological symptoms characteristic of DCS developed during his more than 8-hour trip to the hospital. Mottling on one side of the body is also not typical of cutaneous DCS, which usually presents symmetrically. Luckily, the patient’s development of hypotension and septic shock did not catch his physicians off guard, and their proper response saved the life of this diver.

Endothelial injuries and fluid leakage are quite common in DCS. In extreme cases, the fluid leakage may be enormous, and a lot of intravenous fluids may be required to maintain sufficient volume of circulating blood.

### Case 2-12: Severe DCS with vascular fluid leakage

A 52-year-old tech diver made a dive to 140 fsw (43 msw) for 80 minutes, enjoyed an uneventful dive, and completed all his required decompression stops. Upon exiting the water, he immediately experienced weakness and double vision and lay down on the deck. He was placed on oxygen and transported to the nearest ER. He required multiple liters of IV fluids secondary to hypotension on initial presentation. Minimal urine output was noted initially, despite the placement of a Foley catheter, but this symptom improved as he was resuscitated. He gained almost 20 pounds due to the leakage of the resuscitation fluids into his tissues. His symptoms improved over time but required recompression using USN TT6. He made a full recovery.

### Case 2-13: Slowly progressing spinal DCS

A female visitor to a remote island was diving from a liveaboard vessel. Over the course of 12 days, she completed 40 dives. Her maximum depth during this period was 127 fsw (39 msw).

By noon on the day of the call, she had made two dives. At about 2:40 p.m., after her last dive, she discovered a rash on her back that was warm to the touch. Five minutes later, both her feet felt numb, and the numbness started to move up her legs. She had difficulty breathing, and she felt some pain on inhalation (about 4 on a 1-to-10 scale). She said it felt a little bit like asthma, which she had experienced as a child. Around 15 minutes after the onset of her symptoms, the crew of the liveboard placed her on oxygen from a DAN oxygen first aid kit with a demand regulator system. By this time, both her feet and half of her lower legs were numb. She started at the same time to drink water dosed with rehydration salts, and over the next 2 hours she consumed 2 liters of this rehydration solution. Her symptoms started to improve after about 20 minutes on oxygen. She did take a short break from the oxygen to talk by phone with a doctor, and during this time her symptoms temporarily worsened. She remained on surface oxygen until the boat arrived in port, 5 hours after the onset of her symptoms; at that point, she was transported to a hyperbaric chamber. There, she received a neurological exam and was recompressed using USN TT6. At the end her second oxygen period at 60 feet, a repeat neurological exam was normal, as was a third exam at the end of her first period at 30 feet. The USN TT6 was completed, and she was discharged the next day.

#### Case 2-14: A rapid emergency ascent

A 64-year-old male made a dive to 145 fsw (44 msw) to remove debris from a wreck. He had planned a brief bounce dive but became fouled at depth. Although he was diving with a buddy, due to their experience level they often separated while underwater; they did so in this case, so the buddy was unable to assist in the victim's extrication. By the time he untangled himself, he had already been at depth twice as long as he'd planned, so he ran out of air and had to make a rapid ascent. After he surfaced, he quickly began to have mild bilateral motor weakness and so was put back in the water on air in an attempt to treat his symptoms. The lack of an emergency action plan (EAP) and of immediate administration of therapeutic oxygen resulted in a delay in the victim receiving definitive care. His symptoms worsened, so he was subsequently taken to a

hyperbaric chamber for a long series of HBO treatments. Even so, he experienced significant long-term deficits.

This case highlights the importance of buddy diving, of the existence of an EAP, of the availability of emergency oxygen, and of advanced divers planning and training for in-water recompression.

#### 2.3.2 CUTANEOUS DCS

Cutaneous manifestations of DCS are being reported more often in recent years, cutaneous DCS was a leading concern in 24% calls involving suspected DCS, and it may have been a secondary factor in additional cases involving other leading concerns. This increase is most likely due to increased awareness. We dedicated an entire chapter to cutaneous DCS in the *DAN Annual Diving Report, Edition 2016*; illustrative cases are available in that document.

#### 2.3.3 OSTEOARTICULAR DCS

Osteoarticular DCS was a concern in 23% of calls. When divers' pain is severe, it usually prompts them to seek help, while mild pain may be unrecognized or ignored. Pain seems to be less common in recreational than in commercial and military divers, but that may just be due to heightened awareness, more available treatment options, and greater readiness to report.

#### 2.3.4 VERTIGO

Vertigo was the initial concern of callers in 181 cases, but only 80 cases turned out to involve true vertigo, while most of the rest involved dizziness. Inner-ear DCS was eventually suspected in about two-thirds of the cases of true vertigo, and the rest of these likely were inner-ear barotrauma. A diagnosis of vestibular DCS was more probable in the presence of other DCS symptoms. In three cases, vertigo and skin mottling were present at the same time.

#### Case 2-15: Vertigo and skin mottling resolved on prompt recompression

A 62-year-old female was brought to the clinic at a dive resort after complaining of severe vertigo, nausea, vomiting, and pain in her right thigh. She was admitted about 45 minutes after

surfacing from her last dive. She also had a mottled skin rash on her abdomen and thighs. She had made three dives that day, each to 60 fsw (18 msw) on air, with her final dive lasting 35 minutes. She was treated with HBO using USN TT6. All her symptoms resolved except a slight dizziness, which subsided after two more follow-up treatments over the next two days.

#### Case 2-16: DCS misdiagnosed as positional vertigo and thus

A liveaboard crew called in behalf of a 76-year-old diver who had developed acute onset vertigo and nausea within 5 to 10 minutes of exiting the water. Within another 10 minutes, he had developed a mottled rash over his back and flanks. An internal medicine specialist who was a passenger on the liveaboard did a neurological evaluation. He noted a rapid nystagmus in the victim's left eye. The patient was able to speak fluently and exhibited no obvious peripheral neurological deficits. His gait could not be checked due to his extreme vertigo.

The patient denied any ear symptoms or any problems equalizing. He had done 17 dives during the previous week. On the last day, his dives were to 60 and 80 fsw (18 and 24 msw) for 35 to 40 minutes. He was administered 100% oxygen via a non-rebreather mask and was transported to a hospital on a nearby island. He arrived at the hospital about 40 minutes after his final dive, breathing oxygen for the last 25 minutes of that period. There was no hyperbaric facility on the island, and physicians at the hospital were reluctant to evacuate him.

In the meantime, he was improving but the vertigo was still present. A CT scan later that evening did not reveal any abnormalities, and a physician decided that he did not have DCS. Two days later, a neurologist diagnosed him with positional vertigo and released him to fly. Four days later, the patient was back home, continuously improving, but still experiencing mild vertigo. DAN advised the diver to see a dive medicine specialist. Further contact with the victim was lost.

*Comment: Acute onset of severe and persistent vertigo and skin mottling shortly after a dive are nearly exclusive to DCS. On the other hand, benign paroxysmal positional vertigo (BPPV)*

*can be provoked by head movement and lasts for several seconds to less than a minute. In this case, it seems clear that a diagnosis of inner-ear DCS was missed and the proper treatment was not provided. Fortunately, inner-ear DCS may improve spontaneously, and even in the case of permanent injury to the vestibular organ, symptoms can subside as compensatory mechanisms evolve.*

#### Case 2-17: Neurological DCS

A diver stated that after surfacing from his last dive, he started feeling tingling in his lower extremities, as well as abdominal pain, vertigo, and nausea. He was put on oxygen and transported to a hyperbaric chamber. By the time he was admitted, he was unable to walk due to vertigo and weakness of his lower extremities. The skin on his abdomen and back was mottled and his blood pressure was 100/90 mm Hg. After his last dive on the previous day, he had felt a burning sensation and pain in his abdomen, but he did not report it. After resting, his symptoms had resolved and he had dived again. In this case, a diagnosis of DCS was established and the patient was treated using USN TT6. He improved significantly and continued to improve over the next two days until his symptoms were fully resolved.

#### Case 2-18: Vertigo in a breath-hold diver

A caller identified himself as an MD on an island. He had in his care a male patient who had been snorkeling earlier in the day. The patient had had a sinus infection prior to his vacation but had thought it was resolved. The patient reported that while he was snorkeling, he had forcefully equalized during descent. He did not experience any severe symptoms at that time. However, approximately 1.5 hours later, he had a sudden onset of vertigo, nausea, and vomiting. The MD reported that upon admission, the patient exhibited no observable nystagmus or true hearing loss, though any head movement caused him mild nausea and vertigo. It was decided that the patient should be seen by an ENT but that there was no need for an emergency evacuation.

In most cases of vertigo, the diagnosis is either inner-ear DCS or barotrauma. This patient's history of equalization issues and signs of middle-ear barotrauma support a diagnosis of inner-ear barotrauma.

Alternobaric vertigo is also not uncommon. There were at least eight calls during 2016 pertaining to transitory vertigo during a dive that fits the description of alternobaric vertigo. In most cases, the affected divers experienced problems equalizing.

In rare instances, postdive vertigo may not be related to diving. A coincidental neurological illness may not always be easy to distinguish from DCS, but in some cases of very shallow exposure and an uneventful dive without any signs of ear barotrauma, a cause unrelated to diving should be considered. Even so, there are some cases when a local physician rushes to recompress a diver despite low probability of DCS. Here is one such case.

#### Case 2-19: Unnecessary treatment, no DCS

A caller stated that her 45-year-old husband was being treated in a hyperbaric facility at a dive resort for inner-ear DCS and had already had two full treatments using USN TT6 and one 2-hour treatment (presumably using TT9). He was not improving, and the treating physicians decided the patient needed to return to the US for continuation of HBO treatments. The caller said that her husband had been doing open water certification and that none of his dives had been deeper than 40 fsw (12 msw). His last dive had been 15 fsw (5 msw), and he had developed vertigo the next morning.

Another case of vertigo that was obviously not inner-ear DCS was noticed by the diver the next morning, 11 hours after an uneventful dive in an aquarium not deeper than 20 feet (6 meters). While this diver did not have inner-ear DCS, and likely did not have inner-ear barotrauma, he was advised to seek neurological and ENT evaluation.

### 2.3.5 PULMONARY DCS (“CHOKES”)

This class of serious decompression sickness can be fatal. It is often associated with dives involving considerable decompression stress. Deep, long, extensive decompression dives often precede this problem. Triggering events include aborted decompression stops or blow-ups (uncontrolled ascents). Venous gas emboli develop after most dives but are cleared in the lungs with little consequence. But when the bubble load becomes severe, the pulmonary filter is overwhelmed and

a life-threatening cardiopulmonary collapse can quickly follow, even if the diver receives prompt attention and immediate recompression. Primarily because of the high inert gas bubble load and secondarily because intravascular bubbles may impede off-gassing, other manifestations of DCS may develop, and a thorough examination should be conducted once the patient is stabilized. Milder cases can be confused with nonfatal drownings, pulmonary edema, or other underlying lung conditions.

#### Case 2-20: Chokes after a deep dive

A 52-year-old male was engaged in a week of technical diving — to depths of 190 fsw (58 msw) and with bottom times of more than 30 minutes, thus requiring almost 80 minutes of decompression. On his third dive during his fifth consecutive day of diving, he surfaced and quickly developed an uncontrollable cough with copious frothy sputum. He became light-headed and marbling was evident on the skin over most of his abdomen. He was laid supine, with his head elevated, and given 100% oxygen. His respiratory symptoms improved, and he was taken to an emergency room. His blood pressure was low and his oxygen saturation remained in the mid-90s. A cardiac workup and neurological exam were both negative. His blood pressure was supported with intravenously administered medication and 5 liters of crystalloid solution. As he was being resuscitated, he was transported to a recompression chamber, where he received a USN TT6 treatment, after which his symptoms completely resolved.

#### Case 2-21: Deep, repetitive deco dives

A 23-year-old fit male technical diver made six dives deeper than 180 fsw (55 msw) over the course of three days, completing more than 400 minutes of in-water decompression. On his final dive of the series, he was diaphoretic and initially coughed uncontrollably, then began producing copious frothy sputum. Therapeutic oxygen was not available. Eventually he was transported to a hyperbaric chamber for recompression. During this interval, he developed a dramatic marbled rash over his abdomen. He fortunately responded well to the HBO treatment. Four liters of crystalloid solution were required during the acute resuscitation of this diver. He was fortunate

that his cardiopulmonary system was capable of perfusing and oxygenating his critical organs during this significant episode of DCS. Despite his claim and proof that he was following the recommendations of his dive computer, this case illustrates the fact that diving to the limits of a dive computer's algorithms and testing their validity at the extremes may not be advisable. In this case, not having adequate oxygen or a rehearsed EAP could also have proven disastrous.

#### Case 2-22: An obese, diabetic diver

A 64-year-old male was trying to do four or five dives a day on a remote liveaboard. On his second day, despite feeling poorly, he continued with this plan. As he reached the surface after his fourth dive of the day, he had trouble breathing and began coughing up pink, frothy sputum. He became confused, developed left shoulder pain, and briefly lost consciousness. He was promptly given surface oxygen and regained consciousness. The captain recalled all divers and began the trip back to port. The victim's breathing remained labored and his chest pain continued. He then mentioned that in addition to being obese, he had diabetes and hypertension and had been diagnosed with coronary artery disease before this trip. As a result, he was taking a beta-blocker, in addition to nitrates for exercise-induced chest pain so he could proceed with his planned liveaboard vacation. He perceived diving to be very low-stress exercise. His condition worsened, and his cardiogenic shock was heroically managed by the local hospital until his evacuation could be arranged to a facility that emergently performed cardiac bypass surgery to save his life. He was fortunate in that he lived, but he did sustain considerable permanent injury to his heart.

*Comment: Unlike the previous case, this diver did not have adequate cardiopulmonary fitness due to his underlying cardiac condition. As a result, his situation spiraled into a life-threatening emergency secondary to the cascade of events, likely triggered by his repeated dives and his refusal to acknowledge his serious symptoms prior to his last, fateful dive.*

#### Case 2-23: Associated constitutional symptoms

A 41-year-old technical diver had done several days of trimix diving to over 190 fsw (58 msw). On his last dive, he experienced light-headedness and shortness of breath. He was placed on surface oxygen and showed some subjective improvement; however, he still felt dizzy and extremely fatigued but obtained some relief upon lying down. He had periods of coughing, but little sputum production, and episodes of low blood pressure (according to a manual cuff). He was somewhat confused and could not answer most of even simple questions posed to him. After considerable transport time, he was taken to a local emergency department, where he received 2–3 liters of crystalloid solution and remained on oxygen. He continued to improve rapidly, and his neurological exam was normal that evening. His symptoms appear to have been related in part to a perfusion impairment due to a large quantity of venous gas emboli; such emboli are not uncommon, and in this case they responded to IV hydration and surface oxygen. Fortunately, the victim did not exhibit any additional neurological deficits.

## 2.4 IMMERSION PULMONARY EDEMA

Episodes of IPE continue to affect divers, and we have seen increasing reports of the condition in recent years. This may be due to heightened awareness of its symptoms (dyspnea, cough, frothy sputum production, hemoptysis, etc.) by both dive professionals and medical personnel. A second possible reason for the apparent increase in its incidence is the fact that divers are continuing to dive — and even beginning to dive — well into their retirement years.

Many medical conditions can result in pulmonary edema. Even changes in the oncotic pressure of the blood (most often due to blood dilution) warrant consideration as a cause of IPE. Ideally, divers are aware of these chronic conditions and consult a dive medicine specialist before diving. Pulmonary edema can have grave consequences and can lead to drowning if it is not quickly addressed once symptoms start.

The basic mechanism behind IPE is an increased pressure difference across the alveolar-capillary wall, due to an increase in divers' central pulmonary pressures or to a decrease in the pressure in their alveoli, either of which causes leakage of fluid from the capillaries into the alveoli and can even cause bleeding. This prevents normal gas exchange, meaning the victim becomes hypoxic. A number of additional factors can facilitate the leakage of fluid from the pulmonary capillaries into the alveolar space. Unfortunately, immersion in water exposes relatively healthy divers to many of these factors. Dyspnea, hypoxia, panic, rapid ascent, loss of consciousness, and even drowning may ensue if the dive is not successfully aborted. Even when divers recover spontaneously, they should abstain from diving until they receive a comprehensive medical evaluation. Here are some cases in which contributing factors may have played a role in the development of IPE.

#### Case 2-24: IPE due to immersion alone

A 53-year-old female on a 40 fsw (12 msw) checkout dive, shortly before reaching the bottom, experienced shortness of breath (SOB) that worsened over time. She signaled to her dive instructor and made a controlled ascent. On the surface, she continued to experience SOB and also coughed up a moderate amount of white, frothy sputum. The boat turned back to port, where she was handed over to EMS personnel. She was conscious and coherent but still short of breath and exhibiting low oxygen saturation levels, despite receiving supplemental oxygen. She continued to worsen, and concern about her ability to maintain her airway arose. Before starting the trip to the hospital, she was intubated and ventilated mechanically. At the emergency room, she improved within hours and was extubated without difficulty. She had no neurological deficits and her cardiac workup was normal.

*Comment: The victim's immersion was the only obvious factor in this case. Hydrostatic forces can rapidly infuse almost a liter of fluid from the periphery of the body to the central circulation. This increases the burden on the heart, so in this case the victim's cardiovascular system may have been unable to cope with*

*the challenge, causing the hydrostatic pressure in her lung capillaries to increase, resulting in leakage of fluid into her alveoli.*

#### Case 2-25: IPE due to overhydration.

A 52-year-old obese, experienced female was diving from a liveaboard in a remote location. She consumed several liters of water before her first dive to 73 fsw (22 msw) for 25 minutes. A moderate current caused her to surface about 100 yards from the boat, and she experienced panic and shortness of breath as she tried to swim back to the boat with her snorkel. She began to struggle and stopped swimming. The crew and her dive partner retrieved her. She remained SOB and was "coughing up blood" (blood-tinged sputum). She was placed on oxygen. All the divers were recalled and the boat returned to port. She was doing well by the time she was seen at the hospital, 14 hours later. All clinical tests were reportedly normal, with the exception of evidence of mild pulmonary edema on her chest X-ray.

*Comment: Everyone has gotten the word that it's important to be well hydrated. But drinking too much fluid can overload the circulation and elevate the pressure in the central circulation enough to lead to the development of IPE.*

#### Case 2-26: IPE due to increased breathing resistance and overhydration

A 56-year-old female had dived to 55 fsw (17 msw) and began to experience shortness of breath and a cough within 15 minutes of surfacing. A dive guide assisted her back to the boat, where she coughed up a moderate amount of pink, frothy sputum. She started breathing oxygen, and her symptoms improved. The crew conducted a field neurological exam and found no neurological deficits. While she was transported to the ER, she remained on oxygen and kept progressively improving. Her cardiac workup at the ER was normal, but her troponin levels were slightly elevated, indicating that her heart muscle had been affected. In retrospect, she remembered that she had forced herself to drink several liters of water prior to her dive. In addition, from the beginning of the dive, she had felt that inhalation was difficult through her rental regulator.

*Comment: If a regulator has not been adequately serviced, it may require higher inspiratory effort, causing negative pressure in the alveoli. Similar conditions may occur due to increased breathing resistance at depth, due to the use of some rebreathers, or due to breathing through a long or narrow snorkel. A combination of negative pressure and overhydration may have contributed to the development of IPE in this case.*

#### Case 2-27: IPE due to exertion and anxiety

A 51-year-old female was diving in cold water with low visibility. She was extremely anxious because of repeated separations from her dive partners during multiple ascents and descents and also because she was struggling against a current during the dive. She aborted the dive and was assisted back to the boat, where she complained of shortness of breath. She continued to feel dizzy and appeared cyanotic. She was started on oxygen and slowly began to improve. After a 6-hour evacuation, she was evaluated in an emergency room and had a normal cardiac workup, chest X-ray, and neurological exam.

*Comment: Overexertion can increase one's cardiac output as the heart struggles to meet an individual's increased energy consumption; this can in turn lead to elevated central pressures. Vigorous swimming or finning, such as against a current, are examples of overexertion. Excessive release of catecholamine (adrenaline) into the circulatory system due to stress can also contribute to IPE.*

#### Case 2-28: IPE precipitated by cold

A 61-year-old male had a history of a cough, mild sputum production, and hoarseness starting at depth on most of his dives. On his last dive in cold water and a moderate current, he experienced dyspnea and eventually lost consciousness but retained his regulator in his mouth. His alert, well-trained dive buddy rescued him and helped bring him aboard the vessel, where he spontaneously regained consciousness while lying down and breathing supplemental oxygen. His respiratory complaints resolved over the next 4-5 hours. He was taken to the ER, where his cardiac workup was negative.

*Comment: This diver seemed to have mild symptoms indicative of IPE on each dive. His exposure to cold during his last dive likely caused vasoconstriction (narrowing of the blood vessels), contributing to elevated central pressures, which is a risk factor for severe IPE.*

#### Case 2-29: History of previous IPE

A 40-year-old female got in trouble in a remote location during a checkout/skills assessment dive. Shortly after descending to 40 fsw (12 msw), she became dyspneic and felt an urge to cough. She ascended and bolted for the ladder. The onboard physician who listened to her breathing with a stethoscope noted bilateral crackles. The patient denied having aspirated water. She was given albuterol, and with time her symptoms resolved. She pushed her divemaster to let her dive the following day and developed more pronounced symptoms. The symptoms cleared again, though slowly, while she was on oxygen. The dive boat recalled all divers and commenced the daylong journey to the nearest medical facility, where she was diagnosed with IPE. She later stated that the same thing had happened on previous dives. She said she was in great physical shape and engaged in a balance of physical activities and exercise. No other contributing factors were identified.

*Comment: Some individuals seem more susceptible to IPE than others. A history of IPE is ominous, and continuation of diving in such a case may result in severe IPE with a fatal outcome. If a medical evaluation of a diver with a history of IPE finds no plausible causes that can be actively and reliably mitigated, the individual should reconsider diving as a sport.*

#### Case 2-30: IPE in a diver with hypertension

A 71-year-old female had just returned to diving after a 10-year hiatus. She had experienced shortness of breath and a cough with each dive over the previous several weeks. A recent cardiac workup had been normal, except for a mild decrease in cardiac function.

*Comment: In some people, their cardiac function (their heart's ability to efficiently pump out all the blood that comes into the organ) may be normal at rest but failing slightly*

*during exercise. In combination with immersion and other factors possibly present during diving, such a situation may tip the balance and cause IPE.*

#### Case 2-31: IPE in a breath-hold diver

A 53-year-old male breath-hold diver had a history of hypertension and left ventricular hypertrophy. He consumed almost two liters of water prior to a 75-foot dive. Upon surfacing, he felt SOB and coughed up blood-tinged sputum. He also reported feeling mild chest pain when he was at depth. He proceeded to the ER, where a chest X-ray reportedly revealed fluid — more in his right chest than his left chest. A cardiac workup was negative. He recovered uneventfully while under observation and was discharged.

*Comment: Contributing factors in this case include the victim's pre-existing medical conditions, overhydration, and the possibility of mild lung squeeze.*

### PRE-EXISTING MEDICAL CONDITIONS

Cardiac arrhythmias, asthma, stress-induced cardiomyopathy, the use of beta-blockers, aspiration, and elevated CO<sub>2</sub> levels can all be factors in diving injuries.

#### Case 2-32: IPE due to pre-existing conditions

A 46-year-old female had a history of atrial fibrillation and mitral valve prolapse and was taking metoprolol (a beta-blocker) regularly. In the process of gaining her initial dive certification, after she surfaced from each dive she experienced dyspnea and shortness of breath. She also said she had a dry cough and felt like she had bronchitis for an hour after each dive.

*Comment: This diver should give up diving and seek a thorough medical evaluation.*

#### Case 2-33: IPE and coincidental cutaneous DCS

A 57-year-old female made three repetitive dives to about 100 fsw (30 msw). On her last dive, while at depth, she began to experience increasing shortness of breath (SOB) and chest pain. She made an emergent ascent and successfully made it back to the boat, where

her SOB continued, along with a cough. She also noted skin mottling on her right abdomen. She breathed 100% oxygen during the boat ride back to shore, which significantly eased her symptoms. By the time she reached the ER several hours later, her rash had resolved and her SOB was nearly gone. A cardiac workup was normal. She was observed until the next morning, when she was discharged.

## 2.5 LOSS OF CONSCIOUSNESS

One can think of several factors that could cause loss of consciousness (LOC) while diving. However, in most cases of LOC, the cause remains unknown. The following cases are among those reported through the DAN emergency line in 2016. The most striking common characteristic of these cases is the age of the divers.

#### Case 2-34: Unknown cause

A 69-year-old female unexpectedly lost conscious while underwater, within a few minutes after reaching 67 fsw (20 msw). Her buddy brought her to the surface, where CPR was started. EMS personnel arrived soon after and successfully restored her circulation and intubated her. She did not regain consciousness, however. She was taken to the ICU, and she subsequently died during transit to receive hyperbaric therapy. No cardiovascular disease or brain lesion was noted on autopsy. Her cause of death remains unknown.

#### Case 2-35: Seizure

A 61-year-old male was diving to 60 fsw (18 msw) on air when he was observed having a grand mal seizure. His dive buddy brought him to the surface and onto the boat. Once he was aboard, CPR and AED were used to restore his circulation. He was placed on oxygen through a mask and was transported to a hospital, where he arrested and was resuscitated once again. He never regained consciousness and died three weeks later.

#### Case 2-36: Likely cardiac-related drowning

A 65-year-old male was snorkeling when he lost consciousness as he struggled against a current while trying to return to the beach. He was rescued but continued to be SOB and then

dyspneic and cyanotic. He was subsequently intubated and then was extubated several days later. One day after being extubated, he arrested and again was successfully resuscitated. Five days later he was discharged home.

#### Case 2-37: Unfit diver

A 63-year-old, obese, unfit male lost consciousness at depth after his first dive under relatively good conditions. While underwater, he lost consciousness while he appeared to his buddy to struggle to keep up with the group. His buddy stopped to check on him and noticed he was breathing fast and then lost consciousness. He was brought to the surface with his regulator still in his mouth. The crew was able to bring him aboard promptly, despite his size, and quickly placed him on oxygen. He had a pulse but was still breathing rapidly. He was transported to a local hospital and was observed overnight in the ICU. He was discharged the next day. He fortunately did not aspirate any water, due to the prompt actions of the crew. No etiology was determined.

#### Case 2-38: Atrial fibrillation

A 65-year-old female had a history of symptomatic atrial fibrillation. She had previously discontinued diving due to these symptoms. Prior to the dive trip in question, she had sought medical attention and had been admitted for cardioversion, which was successful. Several weeks later, she embarked on a previously planned dive trip, reportedly “feeling well.” She lost consciousness during a dive and was recovered by the boat crew; once aboard, she was found to be pulseless and CPR was initiated promptly. A waiting ambulance on the pier determined that her pulse was restored, but she remained unconscious. She was intubated, but after a period of aggressive ICU care she expired.

#### Case 2-39: Recent myocardial infarction

A 55-year-old female was seen by her dive buddy to be diving in an uncharacteristically careless manner — eventually bouncing off the bottom without purpose. The buddy looked closely and saw that she had almost lost her mouthpiece and was unresponsive.

While holding the victim’s regulator in her mouth, the buddy made a controlled ascent to the surface, where the victim was promptly brought aboard the boat and CPR was started. She was transported by ambulance to an ICU, where she was found to have had a recent myocardial infarction. She later died. Beginning three days prior to her dive, she had disregarded the onset of apparent indigestion and of significant lack of energy and had not sought medical attention.

## 2.6 MARINE LIFE INJURIES

### 2.6.1 LIONFISH ENVENOMATION

Although not the most common cause of marine envenomations, lionfish stings are on the rise. In 2016, there were 17 cases reported to DAN. As noted in previous years, such injuries have shifted from aquarium lionfish stinging their keepers to stings from lionfish encountered randomly in the wild or during intended capture. The influx of this invasive species and their presence in locations frequented by divers has been an important factor in this increase. Equally important have been operations by divers to search for and destroy these prolific invaders, which have few other natural enemies. The process of capturing or transporting lionfish or of preparing them for consumption has given rise to the increasing number of people being punctured by their venomous spines. Following are some illustrative cases.

#### Case: No apparent infection

A 29-year-old male engaged in a hunt was stung by a lionfish on his left thumb. His pain was minimal but blisters later developed at the site of the bite. There was no evidence of infection. The DAN physician advised him to keep the area clean, keep the blisters intact, and cleanse the area should any blisters break. There appeared to be no reason to start antibiotics.

Marine envenomation	Cases		Inquiries	
	#	%	#	%
Other	116	35%	5	26%
Bites/stings (unknown)	94	29%	4	21%
Coral	45	14%	5	26%
Jelly fish	23	7%	1	5%
Lionfish	23	7%	2	11%
Seabather's eruption/sea lice	19	6%	0	0%
Stingray	6	2%	2	11%
Ciguatera	2	1%	0	0%
<b>Totals</b>	<b>328</b>	<b>—</b>	<b>19</b>	<b>—</b>

Table 2.6-1. Causes of marine life injuries reported to the MSCC in 2016

**Case: Persistent mild pain**

A 58-year-old male was stung accidentally on his lower leg. Two days later, mild pain radiating to his ankle persisted. Localized erythema was noted at the site of the original puncture. The victim denied experiencing any fever, chills, advancing erythema, or lymph node enlargement. He was advised to continue symptom management, as his pain was well controlled with over-the-counter Motrin (ibuprofen).

**Case: Swelling and redness**

A 52-year-old male was stung on his left thigh while harvesting lionfish. His pain was initially moderate but decreased over the course of a week and was well controlled with Motrin. Initially, an erythematous, swollen mass could be palpated at the puncture site. It responded to warm compresses. When the victim was evaluated a week later, there was no infection or foreign body detected.

**Case: Intense pain**

A 55-year-old male who was handling a lionfish harvest on deck was struck in both his hand and his leg. Intense pain ensued; it did not respond to Tylenol, warm water, or narcotic pain medications, remaining at a 10/10 level for most of the day. The victim's pain gradually resolved over the next five days, however, and he showed no signs of infection.

**Case: Relief with hot water**

A 46-year-old female was stung by a lionfish and experienced a quick onset of intense pain that did not respond to Motrin. Once ashore, she soaked her injured index finger in hot water and felt what she described as near-immediate relief of her intense pain.

**Case: Pain for three weeks**

A 37-year-old male was stung as he reached over a ledge while harvesting lobster. He experienced intense pain, but it was relieved by immersion in hot water. He continued to feel pain for almost three weeks; it was mild when he was at rest but increased with activity such as driving, with radiation from the initial site of the injury in his hand up to his elbow.

## SECTION 3. DIVING INCIDENT REPORTING SYSTEM

PETER BUZZACOTT, CASLYN BENNETT

The Diving Incident Reporting System (DIRS), which started in late 2012, collects diving incident reports lodged through the DAN website. Divers are encouraged to report any unanticipated incidents that occur during recreational compressed-gas diving. Reports of fatalities are forwarded to DAN's diving fatality investigation team.

In 2016, the 102 reported incidents comprised 91 open circuit incidents (89%), 5 rebreather incidents (5%), and 6 breath-hold incidents

(6%). The 6 breath-hold incidents are discussed in Section 4 of this report. The remainder of this chapter describes the other 96 incidents; of those, 62 (65%) involved males, 28 (29%) involved females, and 6 (6%) involved individuals of unreported sex. The monthly distribution of reports for 2016 is shown in Figure 3-1.

The vast majority of the reports (n=93, 97%) were made in English, and 3 (3%) were made in Portuguese. The victim of the incident in question

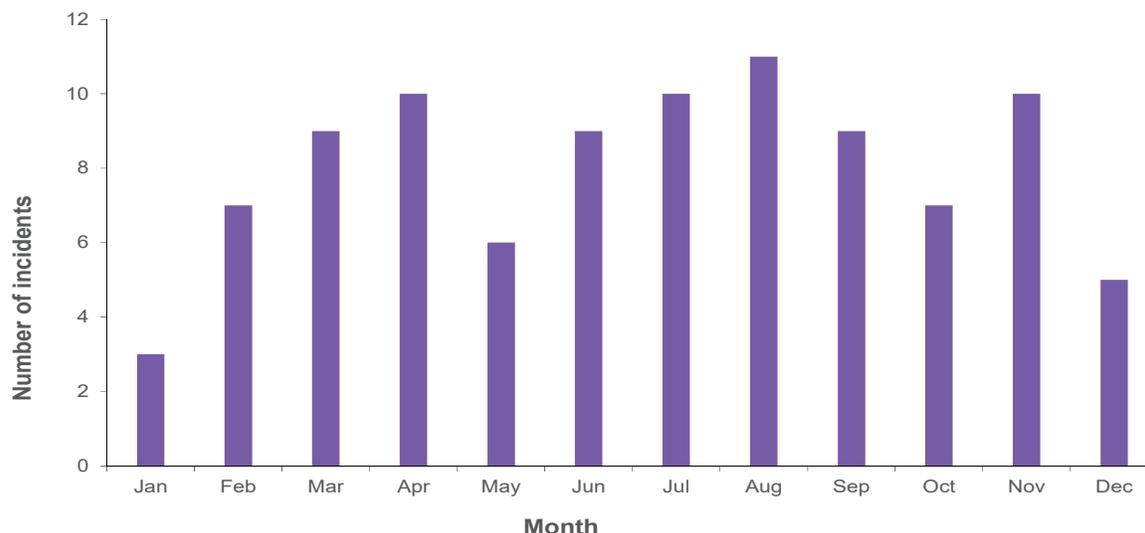


Figure 3-1. Monthly distribution of compressed-gas diving incident reports in 2016 (n=96)

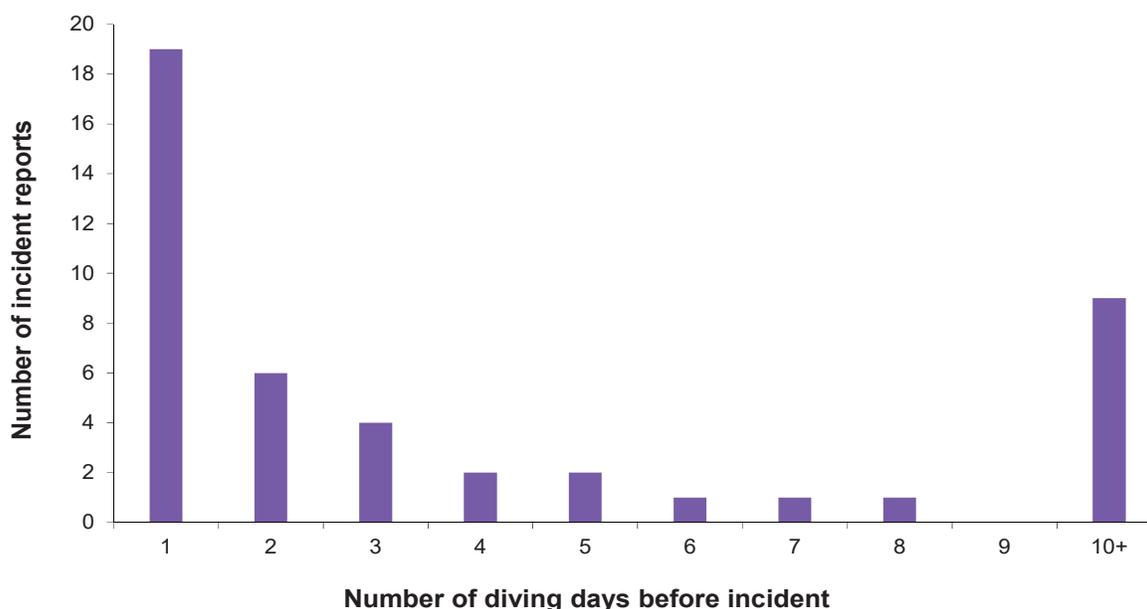


Figure 3-2. Number of days in the diving series before the incident occurred in 2016 (n=44)

made the report firsthand in 69 cases (72%), and reports made by third parties accounted for the remaining 27 cases (28%).

Of the 96 compressed-gas reports made in 2016, 83 (86%) occurred during 2016, 9 (9%) occurred during 2015, and 4 (4%) occurred in 2013 or before. The majority of incidents happened on the first day of a diving series, as shown in Figure 3-2.

The diver's degree of familiarity with the dive site where the incident occurred was specified in 75 reports (78%); 32 of these incidents (43%) occurred during the diver's first time at the site, while 43 (57%) occurred during a return visit to the dive site. The incident in question took place during the only dive of the day in 25% of the 96 cases, during a double-dive day in 14% of cases, and during a three-or-more-dive day in 5% of cases; how many dives were made on the day of the incident was not specified in 45% of reports.

Inexperience featured prominently in the reported incidents, with 30 reports (31%) involving divers with less than two years of diving experience since they were first certified. Of the 82 divers who reported their training status, 6 (7%) reported having received no

formal training. Figure 3-3 shows divers' self-reported experience level in the activity they were engaged in at the time the incident occurred.

Three divers reported having made 2,000 or more lifetime dives. The median number of lifetime dives by the 68 other divers who reported their experience level was 100 dives, with a range from 1 to 1,500. The number of dives made within the previous year was mentioned in 81 reports; the median for these cases was 30 dives, with a range from 1 to 350. The year in which the diver was first trained was mentioned in 55 reports, and in 47 of these cases the victim's initial training occurred no earlier than 2010; this information is shown in Figure 3-4.

Demographic characteristics of the divers involved in reported incidents are shown in Table 3-1.

The depth at which the incident occurred was not reported in 38 incidents (40%); the mean depth reported for the other 58 incidents (60%) was 57 fsw (17 msw). The mean maximum depth previously reached by the affected diver during the incident dive was 71 fsw (22 msw), with 73 reports (76%) including this information.

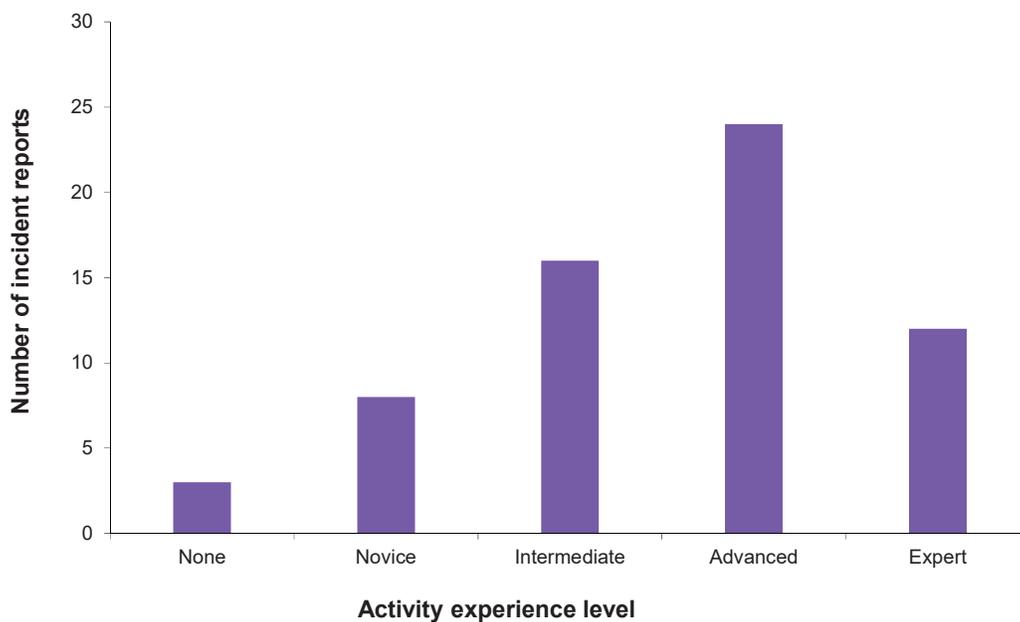


Figure 3-3. Self-reported experience level in the activity during which incidents occurred in 2016 (n=63)

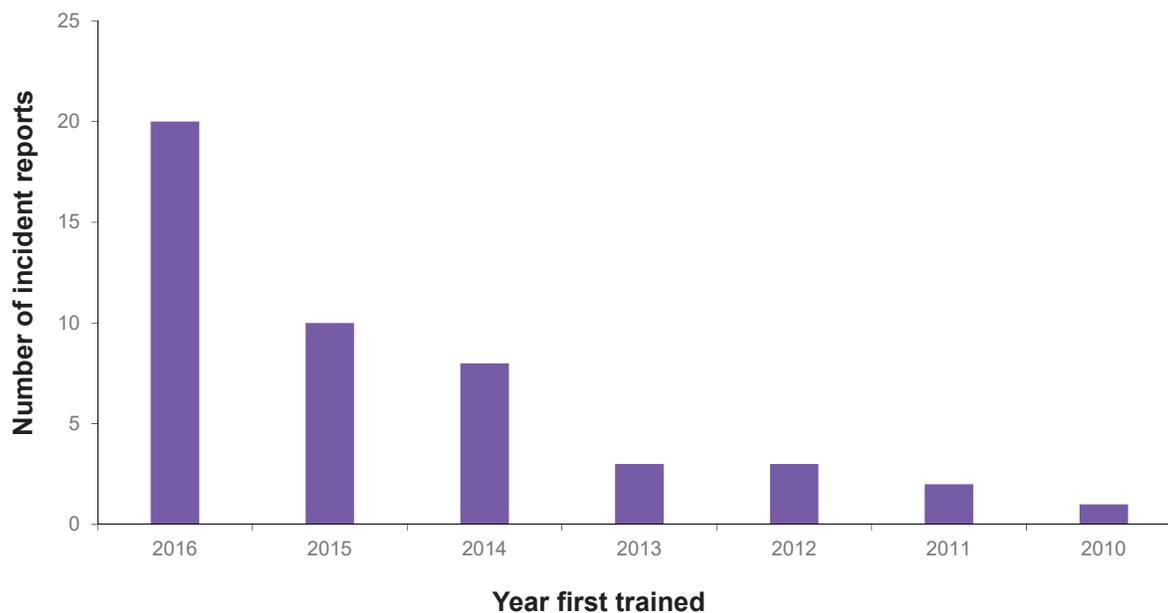


Figure 3-4. Year of first dive training by divers who reported incidents in 2016 (n=47)

	Males	Females	Overall
Age (years)	Mean=37, range=20-58	Mean=42, range=16-60	Mean=40, range=16-60
Body Mass Index (cms.kg <sup>-2</sup> )	Mean=28, range=21-39	Mean=26, range=20-39	Mean=27, range=20-39

Table 3-1. Age, body mass index, and sex of divers involved in reported incidents in 2016

Surface support type	n (%)
Underwater	26 (27)
Dive partner (direct supervision throughout dive)	23 (24)
Dive partner (limited supervision)	22 (23)
Not reported	21 (22)
Group	3 (3)
Surface supplied scuba	1 (1)

Table 3-2. Type of support during reported incidents in 2016 (n=96)

Temp °C	<4	4-9	10-15	16-20	21-26	27-32	>32	Unknown
Temp °F	<39	39-48	50-59	60-68	69-79	80-90	>90	Unknown
<b>n (%)</b>	<b>1 (1)</b>	<b>5 (5)</b>	<b>7 (7)</b>	<b>9 (9)</b>	<b>18 (19)</b>	<b>37 (39)</b>	<b>1 (1)</b>	<b>18 (19)</b>

Table 3-3. Water temperature during reported incidents in 2016 (n=96)

The type of support during each incident dive is shown in Table 3-2. The water temperature during reported incidents tended to be warmer, as shown in Table 3-3.

The time of day when reported incidents occurred was noted in 80 cases; of these, 70 (88%) were during the day, 1 (1%) was at night, (4%) were at dawn, and 5 (5%) were at dusk. The majority of reported dives (58, or 60%) were in the ocean/sea, 11 (11%) were in open freshwater, 6 (6%) were in springs or caves, and 1 (1%) occurred in a pool; 20 reports (21%) did not specify the dive environment.

Visibility was reported for 79 (82%) incident dives; of those, visibility was poor (<10 feet [ $<3$  meters]) in 14 cases (18%), moderate (10–50 feet [ $3$ – $15$  meters]) in 28 cases (35%), and excellent (>50 feet [ $>15$  meters]) in 37 cases (47%).

The altitude of the incident dive site was reported in 77 cases (80%). It was between 0 and 1,000 feet (0–305 meters) in 74 cases (77%), between 1,000 and 3,280 feet (305–1,000 meters) in 2 cases (2%), and over 3,280 feet (>1000 meters) in 1 case (1%).

The dive platforms for the incident dives are shown in Table 3-4.

The severity of the outcome was declared in 91 (95%) of the 96 DIRS reports logged in 2016. Given multiple-choice options of “death,” “injury,” or “no injury,” 7 reporters (7%) checked death, 45 (47%) checked injury, and 39 (41%) checked no injury; the remaining 5 reporters did not select any of those options.

The free-text portion of the 2016 DIRS reports described incidents that occurred around wrecks (n=4, 4%), while underwater hunting (n=6, 6%),

Platform	n (%)
Day boat	41 (43)
Beach/shore	20 (21)
Liveaboard	8 (8)
Pier	3 (3)
Other	5 (5)
Not declared	19 (20)

Table 3-4. Dive platform for incident dives in 2016 (n=96)

Type of equipment failure
BCD inflator stuck open/closed (n=4)
Second stage regulator detached from hose (n=3)
DIN valve dust cap exploded when valve opened (n=2)
Regulator stopped delivering air (n=2)
Scuba tank exploded (n=2)
Inhaled water through second stage regulator (n=1)
Back plate disconnected from wing (n=1)
DIN valve dust cap string extruded when valve opened (n=1)
Regulator mouthpiece detached from second stage
Weight belt buckle released belt (n=1)
Caustic cocktail in a rebreather (n=1)

Table 3-5. Types of equipment malfunction reported in 2016 (n=19)

on training dives (n=9, 9%), during rapid ascents (n=13, 14%), and/ or due to loss of buoyancy control (n=3, 3%); 2 incidents (2%) involved a diver running out of gas, and 3 (3%) involved a diver starting a dive with a tank valve not fully open, a situation that often becomes apparent only at depth when the diver finds it hard to breathe.

Gas contamination may have been associated with 4 incidents (4%). An equipment malfunction was a factor in 19 incidents (20%), as detailed in Table 3-5. Of these 19 incidents involving a reported equipment failure, 7 (37%) involved an air-supply problem, 5 (26%) a buoyancy-control problem, and 5 (26%) an explosive release of gas.

The free-text incident summaries also offered more nuanced insights than the multiple-choice injury-severity question into whether the reported events had resulted in injury. These in-your-own-words incident descriptions resulted in 73 cases (76% of the 96 reports) being classified by a DAN expert as involving a nonfatal injury (compared with only 45 classified that way by the incident reporters, in response to the multiple-choice injury-severity question). Table 3-6 shows the distribution of injuries identified by the DAN expert in those 73 cases.

While statistics can certainly help identify possible targets for preventive interventions, case vignettes are richer in detail and can often provide useful learning points.

Following is a selection of lightly edited case reports. These are actual reports from divers, received through DIRS. Units of measurement have been added so they are given in both imperial and metric formats; abbreviations and slang have been clarified; and the names of people, dive boats, dive businesses, and specific locations have been removed. Other than those few changes, the original tone of each report has been retained in the hope that readers will get an authentic feel for the experiences being reported. DAN thanks everyone who supplied incident reports in 2016.

## EQUIPMENT-FAILURE INCIDENTS

### Case 3-461: Middive buoyancy wing inflation

After getting my first technical diving certification, I bought myself some new gear. One of my new purchases was a new double- bladder (and double-inflator) wing. I dive in warm water, so I often use a wetsuit and need two sources of buoyancy for redundancy.

My setup for the dive was a 12l twin set with isolating manifold on a backplate and harness, long hose to my primary regulator, a necklace for the second regulator, the new wing, and redundant computer, tools, etc. I was also carrying a stage bottle with an oxygen-rich mix for decompression.

I noticed while running through the checklist that my usual securing point for the backup inflator (a rubber band around the bottom part of a tank) couldn't be reached — the inflators on the new

Type of injury	Cases	%
Abdomen itch	1	1
Caustic cocktail from rebreather	1	1
Chest pain	3	4
Carbon dioxide (hypercapnia) in rebreather	1	1
Costochondritis	1	1
Coughing	1	1
Decompression sickness	13	18
Difficulty breathing	2	3
Dizziness	3	4
Ear barotrauma/infection	3	4
Explosive trauma	2	3
Fatality	5	7
Hazardous marine life (stingray, alligator, coral, etc. )	3	4
Heart attack	2	3
Immersion pulmonary edema	5	7
Inhaled water	1	1
Loss of consciousness	10	14
Lung overexpansion	1	1
Memory loss	1	1
Near drowning	1	1
Numbness	2	3
Paralysis	2	3
Pulmonary thromboembolism	1	1
Shoulder pain	2	3
Sinus barotrauma	2	3
Spinal Injury	1	1
Tooth squeeze	1	1
Vomiting	2	3

Table 3-6. Diving injuries based on analysis of incident summaries in 2016 (n=73)

wing were not what I was used to. So I secured the backup power inflator to the side of my plate with a bungee. I tested it to make sure it stayed in place and out of the way and checked that it was easy to reach if I needed it during the dive.

We ran through the checklist with the rest of the team and proceeded into the water. I have a rule (which is probably what turned a potentially dangerous situation into just an irritant): I never go on a deep or demanding dive with new equipment. So keeping with that rule, we had a nice relaxing dive, staying well within no-decompression limits and above -20 msw (-65 fsw).

On the way back, I started feeling very light. I knew immediately something was off, but I couldn't place it. I purged my wing and things got a bit better, but the more I ascended, the more pronounced the problem became. I was pretty confident with respect to my weighting, so I immediately suspected the new wing. I was convinced something had happened and it wasn't letting all the air out.

At ~8 msw (~26 fsw) depth, I grabbed hold of a rock to prevent an unwanted ascent and tried to roll this way and that to make sure all the air had gone out of my wing. My buddies helped however they could, examining the

wing, checking the inflator, etc. In the end, not finding anything wrong with the wing and being absolutely sure that its bladder was empty, we gave up. My buddies contributed what weights they could and we moved on, me staying close to the rocks, making sure handholds were available to keep me from ascending. We halted for our safety stop and I grabbed a large piece of rock and waited for the minutes to tick by.

After the safety stop, I dropped the rock and again used handholds to give myself as smooth an ascent as possible. Safely on the surface, we swam toward the shore. As we reached shallow water, we started unclipping stage bottles and discussing what could have possibly gone wrong. One of the team, the most experienced diver among us, had an epiphany. He asked me to take hold of my backup inflator and try to purge air from the backup bladder. Sure enough, the backup bladder let out a good amount of air. Although I had secured the backup inflator in a way that it stayed out of the way and was easily reachable, it was also in a position where the button on the inflator could conceivably get pushed between the plate and my back, thus resulting in the button being depressed inadvertently.

During the dive, this must have happened a couple of times at depth, letting in air. I must have unconsciously compensated by purging air from my primary bladder, not realizing that the secondary — which in my mind was my backup, ergo not used — had been partially inflated. As I ascended, the air expanded, creating a serious buoyancy problem. Ever since this dive, I've taken special care to stow my backup inflator properly, to avoid accidental inflation.

*Comment: Some technical divers do not connect the redundant inflation hose to the inflator. Instead they secure it in place with an elastic bungee, ready to be connected if needed.*

#### Case 3-413: Plastic DIN valve dust-cap explodes

I hate to admit it, but this could have easily injured my young son. I had set a pair of double 95s down on the floor in the corner of my dining room. My son was around 2 or 3 years

old at the time, and I should have known better than to leave the tanks unattended.

He cracked the valve open, and the DIN valve dust cap blew apart. It was a molded, six-sided black cap with an O-ring and a vent hole on the side. Fortunately, the cap did not hit him in the face. It blew with enough force to embed itself in the 8-foot-high ceiling. I felt pretty bad about the whole thing and will never leave my tanks unattended again.

I actually still have that busted cap sitting in my dive box. It's sort of a reminder for me to respect high-pressure gas.

#### Case 3-493: Second-stage regulator detaches

I was completing one of probably over 100 dives at this site and was approaching my safety stop depth. Part of my dive plan was to practice inflating a surface signal (a safety sausage) while at or below ~20 fsw (~6 msw) while I was neutrally buoyant and off the bottom, since I was heading for drift diving the following week (where we typically surface over ~30 fsw [-10 msw] depth). I got the safety sausage ready and in place, removed the regulator from my mouth, and had positioned it to inflate the safety sausage when, suddenly, the regulator became disconnected from the low-pressure hose. Knowing that the about 1,000 psi (69 bar) I had left in my tank would become depleted very rapidly, and knowing that I was diving with my small pony tank, I reached for my pony tank regulator, purged the water from it, and began breathing from it.

By the time I got my pony regulator in my mouth, I had come up in the water column far enough that I began an uncontrolled but not very rapid ascent from about ~25 fsw (~8 msw). I reached the surface just as my main tank emptied. My dive profile was very conservative, and I handled the situation calmly. I was very fortunate to have been diving with a completely redundant gas supply (standard for my buddies and me in the murky, cold waters where we live).

This incident could have ended very badly had it occurred at depth and had I not had a pony bottle. The cause: The regulators had just been serviced, and the second stage was screwed

on only within a half turn of the end of the threads. This connection is now a standard part of my pre-dive checks. Interestingly, I posted my experience to my dive club website, and only about a month later a dive buddy stated that he checked this connection just before diving and after having his regulator serviced and also noted that the connection was loose.

## MEDICAL EVENTS

### Case 3-427: A mid-dive heart attack

While conducting a search in a pond for a weapon, I started to experience chest discomfort. At the end of my first bank-to-bank sweep, I surfaced and rested for a few minutes. Still experiencing the discomfort, I searched back to the other bank where I had entered the water and aborted my dive. I cleaned up my gear and started heading home. My dive chief said that I looked unwell and made the decision to take me to the emergency department. Within minutes, they determined I was having a heart attack, and I had a stent placed in my left anterior descending artery.

### Case 3-471: Likely Type 2 DCS

I came up from the my fifth dive of the weekend, and felt fine, but shortly after, while breaking down my gear and loading it into the car, I began to feel like I was limping. I couldn't put my full weight on my right leg. I also felt a little dull ache in my right shoulder. I decided to have my wife, who was also my dive buddy and divemaster for the day, drive us back to the scuba shop. I let her know that something didn't feel right, and that if we got to the shop and I still wasn't feeling well, I'd probably want to go get checked out. We'd only been driving for a couple of minutes when I noticed my right arm start to feel cold. I was still wearing a damp, long-sleeved rash guard, and thought that maybe it was just the cold AC blowing on the sleeve. As I continued to feel around on my arm, I realized that the cold had turned to numbness, with a light feeling of pins and needles, but mostly just numb.

I immediately had my wife pull over and set up the DAN O<sub>2</sub> kit that we were carrying with us. I chose the demand valve mask initially but had her hook up the non-rebreather out

of concern that I might lose consciousness. After she got me onto oxygen, she called DAN. DAN got some information from us and advised us of the nearest ER, and we headed that way. Before we reached the hospital, my symptoms had all but subsided. I no longer had trouble walking, and complete feeling had returned to my arm. Nevertheless, I spent a few hours in the ER, while the ER doctor had conversations with DAN, who referred her to several hyperbaric specialists in the area. Several tests were ordered, and everything came back clean. Transport to recompression was not recommended unless my symptoms returned, which they did not.

The diagnosis was that I possibly suffered Type 2 DCS of the central nervous system. From my understanding, I was extraordinarily lucky, as most of these types of cases don't clear up with oxygen treatment alone. I believe that having an immediate supply of oxygen available, along with people trained in how and when to use it, as well as the cool head of my dive buddy, made the outcome much more positive than it potentially could have been. From my perspective, there is no substitute for early recognition of potential symptoms, immediate oxygen therapy, immediate contact with DAN, and immediate professional medical attention. DAN helped the emergency department staff get the helpful advice they needed to treat me.

*Comment: This diver did everything by the book, and his complete recovery was a great result.*

### Case 3-481: Recognizing symptoms of IPE

This was a mid-morning shore dive. The visibility was poor and the water temperature was 53° F (12° C). We swam out about 50 yards and descended on a line to about 50 fsw (16 msw) and continued out to a max depth of 83 fsw (27 msw).

The dive was uneventful until my buddy started struggling with something. He had lost sight of something and was trying to find it on his drysuit. I swam around him looking for whatever he was looking for and shining my flash light on him to assist. He found what he wanted and we continued on.

After about 20 minutes, we headed back toward shore and completed a safety stop at the line we had descended on. At the safety stop I started to breathe hard. I also noted at that time that I had left my regulator on the pre-dive setting.

I had experienced immersion pulmonary edema (IPE) a year before so I recognized the symptoms — and was sure when I took the regulator second-stage out of my mouth at the surface and could hear the rattles. I told my buddy, and he helped me get to shore and called for help. Another diver at the site had oxygen, and that was administered right away. When the ambulance came, I told them my IPE had been treated with Lasix the last time and they got permission to administer it on the way in to the emergency department. I was released from the hospital the same day.

#### Case 3-491: Aggravating a pre-existing injury

It was the first dive of the day on a one-day charter. I completed a 35-minute dive at 70 fsw (21 msw) and performed a safety stop at 15 fsw (5 msw) after a 60-feet/minute (18 meters/minute) ascent. So it was an unremarkable, relaxed dive with a controlled ascent.

At the surface, I removed my own fins, which were firmly stuck onto my drysuit boots; my movements were somewhat restricted by the drysuit, backplate, and heavy (130-cubic-foot) tank and pony bottle I had secured alongside the main tank. I ascended the ladder to the boat and then, as I moved to my dive station, I began to feel a spasm in my neck, chest, and arms that became increasingly intense over a three-minute period. I asked for and received assistance taking off my dive gear and further received assistance getting the drysuit off my upper body, indicating to my dive buddies that I didn't feel quite right. Both my arms became numb; while they were not paralyzed, it was difficult to raise them with any strength above my shoulders.

I self-administered oxygen through a demand-valve regulator. I also began to drink bottled water a little bit at a time while remaining seated. Over the next 15 minutes (so about 20 minutes since the end of the dive) I noticed that my right foot began to feel numb, and that the numbness slowly moved up my lower leg during the next 45 minutes as we returned to

port. My right foot also began to feel numb. On the bright side, the muscle spasm in my neck and the weakness/numbness in my arms basically went away. Psychologically, I was pretty frightened.

Upon returning to the dock, I was able to call DAN and described the incident. Significantly, I had experienced severe spasms in my neck in the past that were virtually identical to the spasms and symptoms on the boat post-dive. Additionally, sometimes after a dive my feet will feel a little numb — it feels like maybe my feet got wet in my drysuit — but I had chalked this mild symptom up to reduced circulation and diving in cold water.

About 8 hours after the dive, my feet began to feel numb following a 2-hour stint in a chair working at my computer. The next morning, about 24 hours after the dive, I noticed tingling and numbness in my left arm and progressive numbness in both legs, extending to my right hip and left knee. At this point I called DAN, and they advised me to go to the local medical center, where there is a recompression chamber available.

At the emergency department, blood tests, an EKG, and a simple neurological examination ruled out a coronary event or a stroke but did confirm cervical radicular neuropathy and paresthesia in my feet/lower legs. After consulting with the hyperbaric treatment facility, it was decided that I should undergo a trial recompression to see if my symptoms abated. After a 60-minute compression to 60 fsw (18 msw) there was no change in my symptoms, and the treatment was concluded with decompression sickness ruled out as a cause.

In the weeks following, further examinations and treatment have resulted in the conclusion that I injured my lumbar spine (a soft tissue injury and muscle strain) while removing my fins, and then while rapidly climbing the ladder with a heavy rig I aggravated a pre-existing neck injury that impinges upon several nerves that serve my arms.

I have not been on a dive trip since the incident, as I want to give my back and neck a chance to heal more fully.

## WEIGHT AND BUOYANCY PROBLEMS

### Case 3-416: An insufficient weight belt

It was the first dive of the first day. The dive leader insisted that all divers use weight belts, but there was a shortage of belts so the crew also distributed the restraint harnesses from the rescue board and “trouser belts and zip ties.” I was given a worn belt. At a depth of 86 fsw (26 msw), and at an approximate bottom time of 9 minutes, my belt fell off. I jettisoned to the surface in a 7mm wetsuit and, once there, signaled the panga driver. My dive buddy and I got into the panga. I asked for oxygen but the panga driver ignored me. I returned to the liveboard dive boat, and there was a complete absence of interest in my early return. After our divemaster returned, I inquired as to whether I should have oxygen or dive the next dive. He said to go ahead and dive because I was not down that long. At no point did anyone on the crew make any further inquiries as to my condition, and our divemaster did not even inquire as to why I was not on the return ride from the first dive.

### Case 3-402: A power inflator malfunction

My buoyancy control device (BCD) inflator and octopus combination had been serviced by my local dive shop just before a dive trip. I did not test their work before my first dive in deep water, as I probably should have. At 11 minutes into the first dive, I tapped the inflator button at 91 fsw (28 msw) to correct a slight negative buoyancy issue. The guts of the inflator blew out into my hand and my BCD instantly became positively buoyant. I started to rise rapidly, so I went inverted (fins up) and kicked to try to control my ascent rate. This also made me breathe deeply and rapidly, and I pulled on my bottom dump valve (now upward due to my inversion) to try to control my ascent rate. Nonetheless, my fins soon breached the surface. In hindsight, I should have simply unplugged the air-supply line, grabbed my nearby buddy/wife/best friend, and headed slowly to the surface where a safety stop could have been done (on her octopus if necessary). The divemaster — who did not see the spectacle, as he was working with some new divers on the other side of a pinnacle — soon appeared on the surface and asked what was going on. I explained what

had happened, and he signaled for the boat to come pick me up. I assured him I was fine and sent him down so the group could finish the dive. At my request, my rig was set up with a different regulator set during the surface interval.

### Case 3-411: An octopus mishap

I was attending an open spearfishing tournament. My first dive of the day started great, but toward the end of the dive, at 130 fsw (40 msw), my buddy swam up to me and showed me his air pressure gauge; it was showing less than 100 psi (7 bar), so he started buddy-breathing off my octopus and we started our ascent to the surface. The closer we got to the surface, the faster we started to ascend. I noticed that we were going up way too fast, but I couldn't get the air out of my BCD because I had a panicking diver on my hands and also because I have an alternate air source which is integrated into my BCD power inflator. During the process of trying to get my dive buddy off my inflator/octopus we ascended so fast that I couldn't control our rate, and I dropped my expensive spear gun, with my video camera attached to it. That caused me to drop back down, even though I knew I was probably hurt — but I didn't know how bad until the next day. The tournament causes me to dive recklessly. Following those two dives, I continued diving and did about four more dives, not realizing how hurt I was from my first dive. The next day, during the open awards, was when I realized how hurt I was; that realization caused me to go to the hyperbaric chamber. I had suffered a lung overexpansion injury, and my right arm was full of bubbles.

## REBREATHING INCIDENTS

### Case 3-462: A caustic cocktail

During a photography dive, my rebreather gave me a caustic cocktail. I was on a <90-minute dive (full runtime) at ~120 ffw (~37 mfw) maximum depth. Toward the end of the dive (on a slow and controlled ascent), I began to notice an off taste in the gas I was breathing. I continued to breathe from the loop even though it seemed off, then after about 2-3 minutes of this I experienced what seemed to me to be a large ingestion of caustic material.

At this point I bailed out (off the loop) and went to open-circuit air. I completed my deco (an added 12 minutes in 3°C water, on air). Upon inspection of the rebreather, it was noted that there was a very small tear on the underside of the mouthpiece of the diver's supply valve. A complete operational checklist had been performed prior to the dive; however, the tear was on the diver's side of the breathing loop and not the rebreather side. The tear was less than 1 cm in size.

## AIR SUPPLY INCIDENTS

### Case 3-409: A regulator detachment

The dive was shallow, at about 35 fsw (11 msw). We had two dive instructors, one with two new divers and one with me. We reached depth, and the dive instructor with me started showing there were bubbles escaping from the hose joint near her regulator. I moved in her direction immediately, and then her regulator completely separated from the hose, resulting in a free flow of air from the hose but no air for her. By that time, I was close enough to make my alternate regulator available, which she used while I reached around to close off the tank valve. Once all was calm, we ascended to the boat, where she was able to switch gear, and we rejoined the others for the remainder of the dive.

The other instructor had stayed below with the other divers. We remarked after the event that training really works - we had no moments of panic or uncertainty.

*Comment: This is a classic case of two buddies competently handling a potentially catastrophic gear failure.*

### Case 3-410: A valve not fully open, or fully closed

I went on a guided dive trip for my first dive after receiving my open water certification two months previously. I rented a complete set of gear for the dive. We got on the boat, and I put on the wetsuit and started to put together the BCD and regulators.

I was having a hard time listening to the captain talk while I was trying to remember everything I was supposed to do. The captain

saw I was slow to put everything together, so when we arrived at the dive site, he came over and put the gear together for me. He checked the alternate regulator for airflow, and I pushed both buttons on the BCD, and the air flow was fine. He told me to wait and be the last person off the boat so he could recheck everything before I got in the water.

As I lined up at the bow, I took a breath and exhaled from the regulator. It felt strange so I said to the captain, "It feels tight, is that OK?" He said it was fine. I got in the water and joined the group. A fellow diver saw that one of the shoulder straps on my BCD was twisted, so she unclipped it, untwisted it, then checked the other clips on my BCD. I thanked her for the help. Then we all descended. My descent was easy and without incident, but when I got to the bottom, I couldn't get a good breath. I didn't understand what I was doing wrong, and just focused on staying relaxed and breathing slowly and evenly. It was difficult to breathe. The air seemed to be "stuttering" in my regulator. I took the regulator out of my mouth, then put it back in and cleared it, and continued to focus and to try to regulate my breathing. I was concentrating on moving slowly and evenly and breathing regularly. But none of it was working. I was still struggling to breathe and bouncing (mostly sinking).

All this time, I had been following fins to stay with the group but then realized I was alone. I did a 360° turn and didn't see any fins, so I decided to ascend. I quickly reviewed in my mind what to do and started to ascend, still having trouble breathing.

When I surfaced, I gave the distress signal to the boat. The captain swam out and towed me to the boat. On the boat, the captain told me the air valve was completely shut off. I didn't understand fully what he was saying at first. He didn't know how that could have happened and called it an equipment malfunction.

After resting, I continued the dive as a snorkeler. The captain had been the last person to touch my valve before I got in the water, and no one touched it while I was in the water. The captain said he turned it fully on and a quarter turn back. Since I know the valve was open before

I put on the BCD, the only explanation for the closed valve, and the breathing difficulties I had underwater, is that the captain must have shut off the valve and turned it a quarter turn back on by mistake.

*Comment: The days when divers would turn valves all the way on and back a quarter turn are long behind us. Today there is no need for the quarter turn; it is safer to open dive tank valves all the way.*

#### Case 3-419: A cave diver used newly serviced regulator during exploration

The incident occurred in a cave I have been diving in once every 2 to 4 weeks for 12 months as part of an ongoing exploration project. On this dive, I had returned with freshly serviced regulators and was to transport a bag of ropes through to a climb in a dry chamber further into the cave. A short way into the dive, there is a single person restriction/flattener at <100 ffw (30 mfw) depth. I had noted that the water on entry was low, so in the base of this restriction I turned my head to view the depth on my computer to note for later. At this stage, I had pushed the caving bag of gear ahead of me with difficulty. I then went to take in a large breath to push ahead with my legs and inhaled water instead. I groped for my other regulator, which took some time due to the restricted movement in the tight passage (rock pressing above and below me) and zero visibility. I got this regulator in my mouth upside down and gasped, trying hard to suppress the urge to cough. I pushed ahead (not possible to double back) and entered the top of a large underwater void where the diver is around midwater. I decided to continue to an air chamber — a long distance but with clearer visibility, no more restrictions, and no risk of coming face to face with my support diver (15 minutes behind me) in the tight silt-out section.

I noticed that the mouthpieces had come off both regulators. They had been returned cable-tied on, and then tightened again by me with pliers before diving. I believe they were levered off when I turned my head to the side (to read my computer), as the clips I use to fix them to a chest D-ring were higher than normal after servicing.

As I swam across the void, I was being dragged down by the weight of the pack and the lack

of air in my BCD (dumped intentionally before the restriction to reduce my profile). I had been manually inflating, as the hose on the newly serviced regulators did not connect to my BCD and I had not bothered to change it. With effort, I ditched the bag of equipment and held the line to avoid sinking further. I tried to orally inflate my BCD but was unable to given my breathing pattern, which was one large, quick breath in followed by a rapid, fast exhalation out. At this time, I noticed my other regulator free-flowing, and manipulating it did not stop the free-flow. I turned the cylinder valve off, only to be faced with no air delivery from the regulator I was using. By the time I turned that cylinder back on and turned the other one off, the gauge was reading zero.

While ascending, I struggled to breathe, as the urge to cough (to cough up water from my lungs) was almost impossible to suppress and I felt very dizzy. I was not panicking but was very worried that if I began to cough I would inhale more water due to my lack of mouthpieces. I also worried that the dizziness was an injury and that I could lose consciousness. I was careful to ascend at a normal speed, but I could not bring my breathing under control so was still taking large, rapid inhales. Upon surfacing, I coughed up a lot of water with a small amount of vomit. I had to do some short but intense exercise to leave the water (a difficult rope climb up a near-vertical mud wall) before I could rest and check/remove my gear. At this time I noticed chest pain, which was worse with activity. It took approximately 3 hours to exit the cave (slower than normal due to pain) then another 3 hours to drive down from the mountains. After 24 hours of unresolved pain, I presented to emergency, where tests revealed a slight bruising to the heart lining tissue (probably from the initial shunt of inhalation at depth) as well as aspiration bronchitis.

*Comment: "Sump diving" such as this diver described is a highly specialized type of cave diving and should not be attempted without adequate training, followed by mentorship within the caving community. Generally speaking, it is common for sump divers to avoid taking new dive equipment, or recently serviced regulators, into caves. Instead, such equipment is used to dive in an open water environment first, to be sure it is fully functional.*

## TRAINING DIVES

### Case 3-444: Training dive in an aquarium

A 33-year-old female presented to the emergency department after sustaining a diving injury during a training session at the local aquarium. She was diving at 10 fsw (3 msw) for 4 minutes with her hands and feet bound, when she was hit in the chest with a weight and had a rapid, uncontrolled ascent from 10 feet (3 meters). She reported coughing during the ascent. On arrival at the surface, the diver was hyperventilating and had immediate pain in her left shoulder. Within 2 to 3 minutes of surfacing, she had numbness bilaterally in her upper and lower extremities — her left arm more than her right arm and her right leg more than her left leg. She was immediately placed on oxygen via a nasal cannula; after some improvement of her symptoms, she was transported to the emergency department, where she was further treated with oxygen. Her tingling resolved, except in her left arm.

*Comment: Apparently the diver's hands and feet were tied during this exercise to simulate a disabled diver.*

### Case 3-447: Pulmonary edema during a dive class

We had completed our certification skills and were simply swimming around. I had just come out of some rather cold water and was about 15 feet (5 meters) down when I suddenly couldn't take a deep breath. I thought it was a panic attack, although I'd never had one, so I tried to reassure myself and calm down and force myself to breathe normally, but I couldn't. I checked my gauges and had plenty of air, but it was getting harder and harder to breathe, so I surfaced, slowly and in control as instructed. One of our divemasters surfaced with me and asked if I was OK. I said I couldn't breathe, and he towed me the ~50 yards (~50 meters) to shore. While being towed, I felt my lungs filling with fluid. As a former paramedic, I recognized pulmonary edema (PE) immediately but didn't understand why it was happening. My dive school gave me oxygen and called for an ambulance as my condition worsened. I was transported to the hospital, where I spent two days being treated for pulmonary edema.

## MISCELLANEOUS REPORTS

### Case 3-482: A dental reverse block

While ascending from a 100 fsw (30 msw) dive to a wreck, I thought I was suffering a reverse block with vertigo, so I slowed my ascent and stayed on the line. The pain persisted, and I realized later that night that two of my fillings had popped out, possibly due to the pressure.

### Case 3-463: An alligator encounter

I was diving with my buddy, searching for fossils in approximately 10 ffw (3 mfw). Visibility was only a few inches, even with a light. I have made about 300 dives in the river (nearly 900 total logged dives), am an instructor, and work full-time at the local dive center. We did not observe any signs of alligator nesting or trails in the area. The water temperature was unusually warm at 70oF (21oC). We stayed in the center of the river, away from the sides. About 45 minutes into the dive, I sensed a rapid movement in front of me, and immediately my head was inside the mouth of a large alligator, facing the back of the gator's throat (it's very white in there!!). The alligator bit straight down, pushing my face down into the lower inside of its mouth. Two teeth punctured the underside of my lower jaw, and there were five tooth lacerations on top of my head, in line with my ears.

My face was inside the alligator's mouth, and I understood my situation immediately. In less than a second, the gator fully released my head, and when I knew I was clear I inflated my BCD and rose to the surface. My buddy surfaced a few seconds later and yelled that he had been bumped by an alligator. I told him I had been bitten; by this time my nose was bleeding profusely (it wasn't broken but was very "impacted") and I was bleeding from the two punctures to my lower jaw. We retreated to a shallower area and removed my hood and mask. We ascertained that my injuries were not life-threatening and left the area by boat.

Within the hour, we went to an urgent care center and were advised to go to a full hospital (nearby) for a CAT scan, due to the possibility of brain injury. I was seen at the hospital quickly, and no brain injury was found (however, a small fatty brain tumor was detected, which I am having checked out — so this may have been

a fortunate event). The wounds from the bite were cleaned, and I received three stitches in my lower jaw, along with five staples in the top/sides of my skull. I was also given an antibiotic.



*Comment: This diver is lucky to be alive. The fact that he did not panic during ascent also prevented the outcome from being much worse. In fact, the diver later reported that he was diving again after three weeks' convalescence (though not in the river).*

#### Case 3-437: Chest pains underwater

On the first dive of a two-week dive trip, I experienced significant chest pain during the last 20 minutes of the dive. The level of pain was 7 or 8 out of 10, was worse on exhalation, and was focused at the level of my left nipple but close to the sternum.

I am 70 years old and in good shape and have never experienced chest pain while working out or swimming long distance. Needless to say, because of the level of persistent pain, my age, and the fact that I was underwater, I felt a level of concern. I was wearing a 5mm wetsuit at the time. I did not terminate the dive because we had just ascended to 25–30 feet (8–9 meters) and were getting close to the end of the dive. I did not panic or become overly concerned because I could elicit pain at a focal point at the costochondral junction on my left side. I completed the slow ascent and 3-minute safety stop with my buddy and dive group.

When I was on the boat, the pain did not let up, so I did not join the second dive. After I removed my wetsuit, the pain was less but still

present. After an hour, the pain was decreased and was no longer associated with exhalation. I felt comfortable at this time that I had costochondritis, exacerbated by the wetsuit and the pressure of the water. I also thought there was some mild pain or discomfort where the affected rib articulated with the thoracic vertebra.

Fortunately, the next two days of diving were canceled due to bad weather. My treatment consisted of lying on my back over a folded pillow every few hours and taking Meloxicam. To this point, this incident's surmised cause was purely self-diagnosis. I have had costochondritis in the past but not underwater and not this severe. A physician staying at the hotel looked at me and concluded that it was indeed costochondritis. Over the next two days, the pain subsided completely except on deep palpation. I dove three days later and continued to dive for two further weeks without incident. The physician who looked at me said that 25% of patients presenting to the emergency department with chest pain have costochondritis. During the dive, I spent most of the time going through differentials in my mind (i.e., coronary disease, pneumothorax, etc.), but the fact that I could reproduce the pain by digital pressure put my mind at ease and cemented my decision not to ascend prematurely to the surface. My medical background certainly helped (I am a veterinarian).

#### Case 3-423: An agonizing decision at depth

My wife, myself, and a friend had planned a short 190 ffw (58 mfw) trimix dive in a quarry using 20/24 as a bottom gas (20% oxygen and 24% helium, and the remaining 56% nitrogen) with 32% and 70% nitrox as decompression gases. We descended to 195 ffw (59 mfw) down a shotline, settled ourselves, exchanged OK signals, and set off for a short swim, gently ascending as we went. The plan was to release delayed marker buoys at 12 minutes and begin our ascent to the first stop at 15 minutes.

At 12 minutes, we were at approximately 150 ffw (46 mfw). I checked that the other two divers were close by and inflated and released my buoy, then looked at my wife, expecting her to do the same. However, she just looked at me and shrugged. Thinking she maybe was

suffering a little vertigo (the water was very clear below us), I moved closer to her and gestured toward her delayed surface marker buoy (DSMB), to which she made ineffectual movements. As I got closer, she reached out with her right hand and grabbed my left hand, in which I had my reel. I looked straight into her eyes and could see she was in trouble, as there was no understanding or recognition there. I then had to control her buoyancy as well as my own, a task I found to be nigh onto impossible.

We had drifted toward the wall of the quarry, and the third diver (who was trying to help by lifting my wife's manifold) gestured toward the wall, pointing out to my wife that there was a visual reference to help. My wife just looked at her, then me, and shrugged. Her mask was half full of water but she was making no effort to clear it. We had ascended and descended a number of times at this point and were well over our bottom time. My wife had made no effort to control her buoyancy at all, but she suddenly dumped all the air from her wing, and we sank from approximately 140 ffw (43 mfw) to 225 ffw (69 mfw). The other diver released us and conducted a safe ascent.

I managed to stop my wife's and my descent at 225 ffw (69 mfw), at which point my wife looked at me, indicated "I can't breathe," and died, releasing my hand and sinking away from me! I realized very quickly (unbelievably quickly) that I had three choices: a) leave her, ascend, and do as much deco as I could, b) inflate her wing and let her go, even though I didn't know if she would be seen at the surface, or c) grab her and do a buoyant lift, hoping she could be helped on the surface and I would survive to get to a chamber.

I went with c, ascending at approximately 160 feet (49 meters) per minute. She didn't survive, and I ended up with a vestibular and spinal bend that put me in the hospital for two weeks, with 16 hyperbaric treatments.

#### Case 3-449: Rough seas

It seemed like a beautiful day for a beach dive. It was my first beach dive since I'd gotten my open water certification in Cancun. I'd bought a brand new 7mm suit and an aluminum 80 tank. My buddy and I entered the water and

realized we were both underweighted when we couldn't descend easily. It was low tide, and the swell was strong, with big waves and a sweeping surge. We decided it was too far to go to get weights from the car, and if we swam down deep enough we should still be able to achieve neutral buoyancy. We swam out with the reef to our right, and my buddy, who knew the site, eventually guided us into a gap in the reef. Once we were in the gap, the swell picked up and became a white-out of bubbles. We lost sight of each other and were tossed around in the white-out. After a few minutes of struggling, my flipper hit the surface and I realized I was in the rocks, about to take on some big waves. I managed to crawl onto the rocks and yell for help from the lifeguard. A wave then came and knocked me off the rock and took my fin, my spare air, and regulator with it. I struggled underwater to find my second stage but eventually went to my octopus. I kicked back to shore with the guidance of the lifeguard and made it back to shore exhausted. The lifeguard then helped my buddy, who had managed to crawl into the rocks and ditch his gear.

*Comment: Anyone who learns to dive while on holiday should consult their local dive shop when they return home regarding local conditions. These divers were lucky not to suffer any injuries, or worse.*

## IN CONCLUSION

Now in its sixth full year, the Diving Incident Reporting System is steadily receiving around 100 incident reports a year, mostly from divers involved in the incidents and usually within a few weeks of the incident happening, while memories of the event are fresh. As with previous years' DIRS reports, the incidents reported in 2016 often happened when a diver was visiting a dive site for the first time and/or on the first dive of the day, and/or on the first day of a dive series. Divers are reminded to pay extra attention to safe diving practices at such times, in particular to pre-dive checks and to staying within reach of a buddy. Most incidents occurred when diving in the sea, from a boat, in warm water, during daylight — probably because this is likely the most common type of recreational diving.

Equipment problems were not common but when they did occur usually involved either the BCD inflator or regulators, both of which should be rinsed after diving in the sea, serviced regularly, and checked carefully after they're serviced. As in previous years, the severity of injuries in the 2016 reports ranged from mild to very serious, even fatal. And yet, while reading the incidents, it is hard not to imagine ways in which many of them could have been avoided. A recent analysis that DAN and the Professional Association of Diving Instructors collaborated on showed that violating safe diving practices likely increases the risk of death during recreational diving. The full paper is freely available online; in essence, it convincingly shows that divers who died from a medical cause had made far fewer violations of safe diving practices.<sup>1</sup> The implications of this research are that all of us can reduce the likelihood of dying while scuba diving if we simply follow the rules of safe diving, such as making a pre-dive check and staying within reach of a buddy, including when a diver signals they intend to exit the water.

Scuba diving is a relatively safe type of recreation, and we can all take a step toward making it even safer if we simply embrace the habits we know are safe.

DAN Research thanks all the divers who reported incidents to the DIRS in 2016.

## REFERENCES

1. Shreeves K, Buzzacott P, Hornsby A, Caney M. Violations of safe diving practices among 122 diver fatalities. *Int Marit Health*. 2018;69(2):94-98. Available from: [https://journals.viamedica.pl/international\\_maritime\\_health/article/view/58319](https://journals.viamedica.pl/international_maritime_health/article/view/58319)

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## SECTION 4. BREATH-HOLD DIVE INCIDENTS

PETAR J. DENOBLE, ASIENNE J. MOORE

### 4.1 INTRODUCTION

Breath-hold diving is a natural method of submersion performed during various aquatic activities, including spontaneous child's play at a swimming pool or at the beach; some ad hoc tasks conducted by untrained people, like freeing an anchor; casual snorkeling; spearfishing or the harvesting of marine life; and competitive sports involving freediving. While all breath-hold activities expose participants to the same environmental and physiological effects, their magnitude is usually different, as is the preparedness of divers and their ability to adapt to the stress of diving. While some snorkelers may not intend to submerge at all, they are still exposed to the stress of immersion, which may endanger individuals with pre-existing medical conditions.

Uninitiated divers can rarely extend their breath-hold time beyond one minute, and the average depth of their dives is usually limited by the pain in their ears. If they ever learn how to equalize the pressure in their ears and become more enthusiastic about breath-hold diving, they could theoretically reach a depth where their lungs are squeezed to their residual volume; usually such divers will not exceed 99 feet (30 meters). At that point, they are exposed to additional risks, but the urge to

breathe usually prompts them to surface before they get in serious trouble. However, divers engaged in fishing, harvesting, or other tasks may push past this threshold and experience a blackout underwater.

On the far end of the breath-hold diving spectrum are freediving activities that involve special training and goals to exceed the limits that untrained divers encounter. Table 4.1-1 shows the categories of freediving diving activities currently recognized by AIDA (l'Association Internationale pour le Développement de l'Apnée, the organization that sets worldwide freediving standards and certifies record performances).

### 4.2 CASES IN 2016

While breath-hold diving is very common, the breath-hold activities with the most participants (such as snorkeling, spontaneous breath-hold diving, or recreational spearfishing) are not regulated, and there is not a formal reporting system for related incidents and injuries. Since 2005, DAN has collected and reported breath-hold diving incidents and injuries. Our sources of information are the public media; calls to the DAN emergency line, including voluntary reports from witnesses or divers experiencing problems; and DAN's online Diving Incident

Discipline	Description	Record	
		Male	Female
Static apnea (STA)	Resting, immersed breath-hold in controlled water (usually a shallow swimming pool)	11:35 Mins	9:02 Mins
Dynamic apnea, with fins (DYN)	Horizontal swim in controlled water	990 ft (300 m)	802 ft (243 m)
Dynamic apnea, no fins (DNF)	Horizontal swim in controlled water	805 ft (244 m)	630 ft (191 m)
Constant weight, with fins (CWT)	Vertical self-propelled swimming to a maximum depth and back to surface; no line assistance allowed	429 ft (130 m)	353 ft (107 m)
Constant weight, no fins (CNT)	Vertical self-propelled swimming to a maximum depth and back to surface; no line assistance allowed	337 ft (102 m)	240 ft (73 m)
Free immersion (FIM)	Vertical excursion propelled by pulling on a rope during descent and ascent; no fins	413 ft (125 m)	320 ft (97 m)
Variable weight/ ballast (VWT)	Vertical descent to a maximum depth on a weighted sled; ascent by pulling up a line and/or kicking	482 ft (146 m)	429 ft (130 m)
No limits (NLT)	Vertical descent to a maximum depth on a weighted sled; ascent with a lift bag deployed by the diver	706 ft (214 m)	528 ft (160 m)

Table 4.1-1. AIDA-Recognized Competitive Freediving Disciplines and Record Performances, current as of November 2018

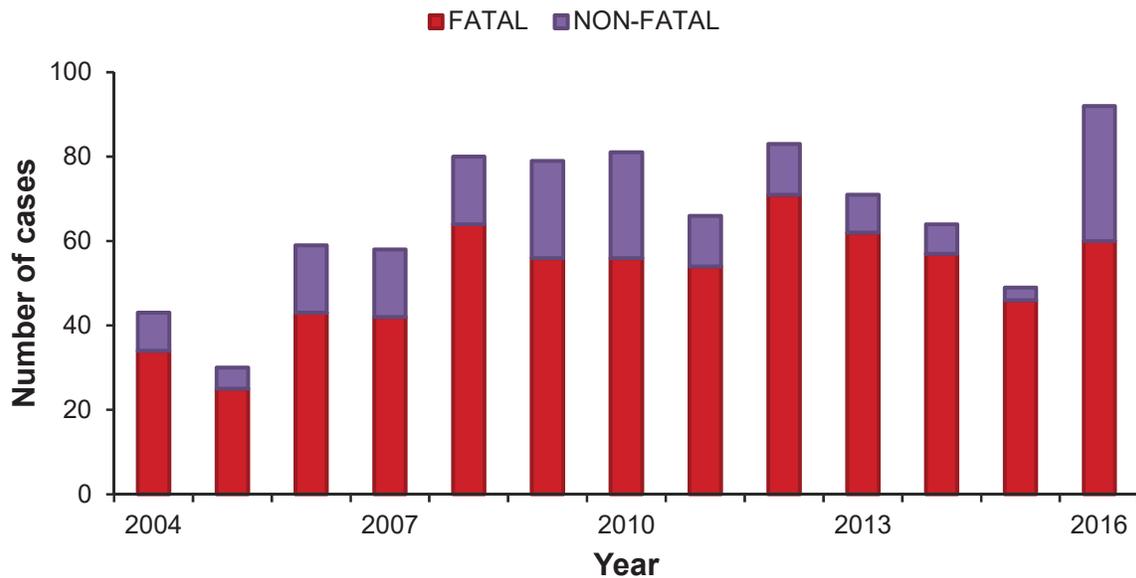


Figure 4.2-1. Breath-hold incidents between 2004 and 2016 (n=855, 78% fatal)

Report System (DIRS). The amount of data we capture is only a fraction of what happens in the field, but we collect increasingly more data every year. Figure 4.2-1 shows data captured annually since 2004.

In 2016, we captured information on 92 breath-hold incidents — 60 fatalities and 32 injuries or incidents without injury. The proportion of fatalities to overall incidents does not reflect a high mortality from breath-hold incidents but, rather, the availability of data. In the past,

our data on nonfatal incidents came mainly through direct contact with various breath-hold dive groups or individual breath-hold divers. In 2016, the number of incidents increased and most reports of nonfatal cases came through the emergency line at DAN's

Medical Services Call Center. Breath-hold diving incidents can also be reported through DAN's online DIRS process (see <http://DAN.org/incidentreport>).

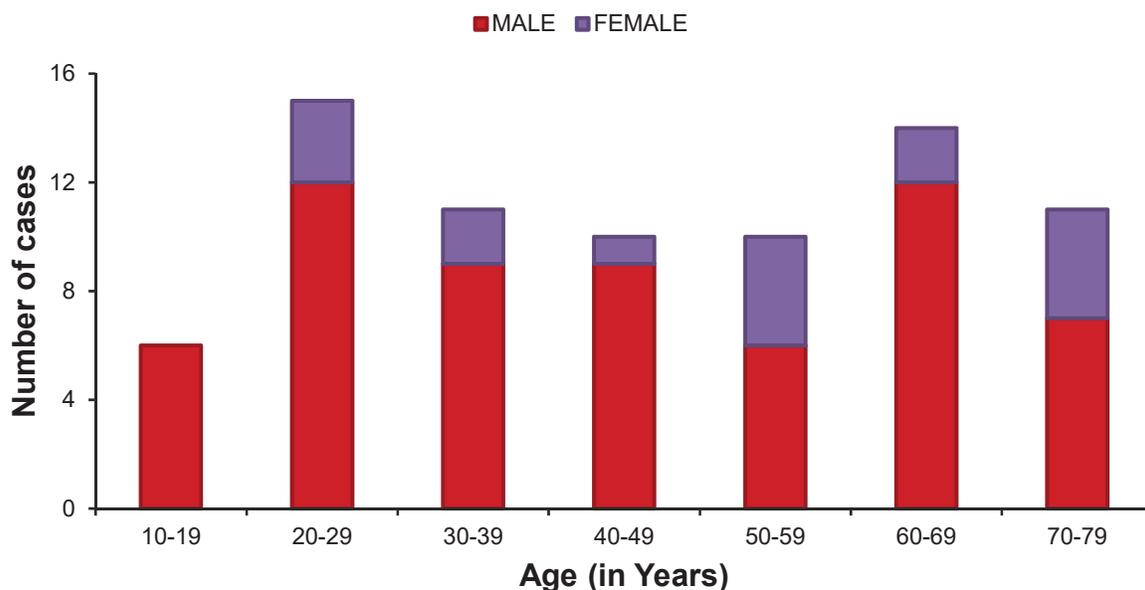


Figure 4.2-2. Distribution by age of fatal and nonfatal breath-hold incident victims in 2016 (n=77)

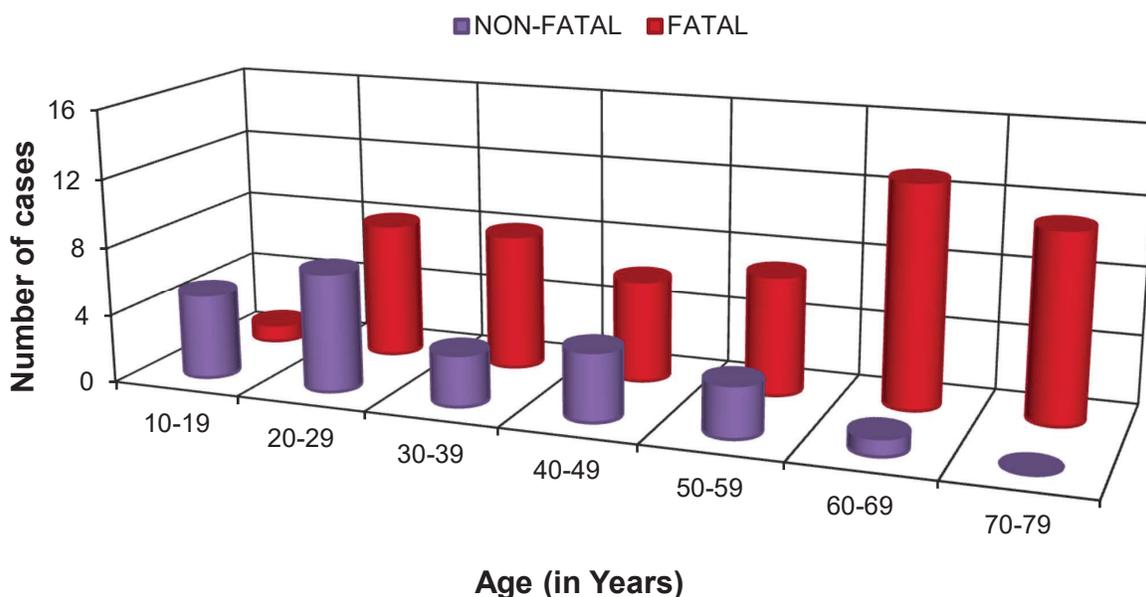


Figure 4.2-3. Distribution by age of fatal and nonfatal breath-hold incident victims in 2016 (n=77)

The age of breath-hold divers in our dataset for 2016 is shown in Figure 4.2-2. The mean age was 52 years for fatalities and 34 years for nonfatal incidents.

The age and sex of the individuals involved in reported breath-hold incidents was known in 77 of the 92 cases reported in 2016; that distribution is shown in Figure 4.2-2. The age distribution in those 77 cases, separated by fatal and nonfatal cases, is shown in Figure 4.2-3. Breath-hold fatalities peak in divers age 60 and older. In all age groups, male victims exceed the number of female victims, but we do not know how that distribution compares to the actual population participating in breath-hold diving.

### 4.3 ACTIVITIES DURING INCIDENTS

The activities in which divers were engaged when the incident or injury happened are shown in Table 4.3-1.

As in previous years, most fatal incidents occurred during snorkeling and spearfishing, while most nonfatal incidents occurred while freediving. The differences in representation of various activities in our numbers probably reflect the level of organization in various activities and the health status of participants, rather than the level of stress involved. The mean age for victims involved in the various activities is shown in Figure 4.3-1.

Snorkelers on average were the oldest victims, even though that activity is practiced by divers of all ages. The older age of these victims most likely

Activity	Fatal	Non-fatal	Totals
Unknown	14	2	16
Miscellaneous Tasks	2	0	2
Spearfishing	15	1	16
Snorkeling	24	0	24
Free diving	5	29	34
<b>Total</b>	<b>60</b>	<b>32</b>	<b>92</b>

Table 4.3-1. Breath-hold activities preceding reported incidents in 2016

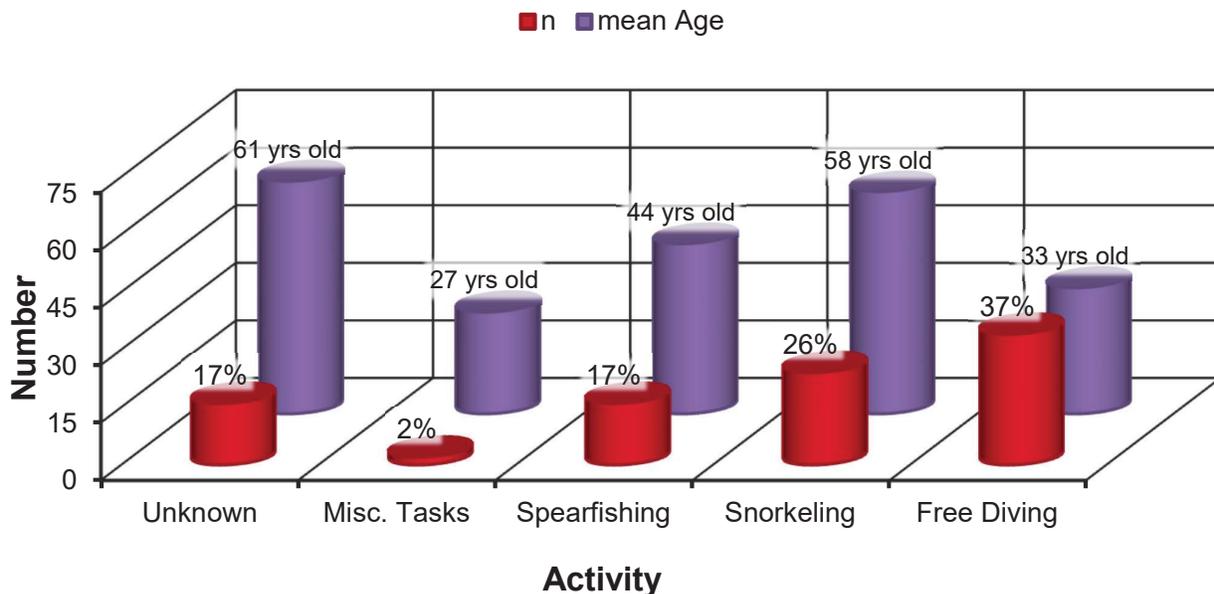


Figure 4.3-1. Mean age of victims involved in breath-hold activity at time of incident in 2016 (n=77)

indicates that health-related factors play a role in snorkeling injuries and fatalities. Spearfishing and harvesting, on the other hand, are vigorous activities typically practiced by somewhat younger divers — a fact that is reflected in the younger age of these victims. Spearfishing is often an individual activity, so when accidents happen nobody may be there to help. Many of those who take up spearfishing are self-taught and may be missing a proper understanding of their risks. Freedivers are even younger, on average, and so are presumably fit. While they may incur injuries, fatalities among freedivers are rare due to adherence to safety measures mandated by most freediving organizations.

#### 4.4 BREATH-HOLD INCIDENTS AND FATALITIES

##### Case: Blackout while freediving

The DAN Emergency Line was contacted by the husband of a 58-year-old female freediver, who lost consciousness while practicing at a freediving competition. According to witnesses, she was unconscious for several minutes and spent approximately a minute of that time in the water. About 1.5 hours prior to the call, she'd already been admitted to a local clinic, where she was diagnosed with "drowning and shallow-water blackout." The diver was coherent and recalled everything prior to her syncopal episode.

*Comment: Blackouts during breath-hold practice sessions are unfortunately quite common. Good organization and close monitoring of divers is of utmost importance for their safety. In this case, the unconscious diver was without help during the one minute that may lead to a drowning which is otherwise preventable. Fortunately, this victim recovered completely.*

##### Case 4-01: Fire coral sting in an open wound

An email was received from a 22-year-old male freediver, who wrote:

"So, a few months back, maybe three to four months, a couple of buddies and I dove down south. We're experienced divers. I am an EMT and a Certified Level 1 Freediver. At the time, I had an open wound on my knee, about 1.25 in (3.18 cm) long and 0.5 in (1.27 cm) wide. It was in the process of healing but still open for the most part. Anyway, on

one of my last dives, while looking for some bugs, I got stuck directly in my open wound by fire coral. ... I immediately ascended to the top, because my leg felt as if it was on fire — but not like it normally does when you get stuck by that coral, for this wasn't my first encounter with it. My leg literally felt like it was burning on the inside. I checked the wound on the boat, and the wound on my knee that was previously healing now looked like a golf ball. It hurt 10 times worse than it did originally, when I first got the wound climbing a ladder. So I guess my main question for you guys is whether or not there could still be a shard of fire coral residing in my leg, if that's even possible, and if so what should I do about it? To this day, it doesn't hurt to walk around and/or look at it, but when I even tap it, such as on a chair as I'm walking by, my right leg lights up like it's burning. The burning doesn't run all the way up to my groin area, but I would say to about mid-quadrant. Thank you for reading my novel that I just wrote you guys. I would love to hear back if you have the time!"

*Comment: Swimming with an open wound is not a good idea in the first place. Regardless of where you swim, the water is not a sterile environment, and secondary infections of wounds — such as *Mycobacterium marinum* infections, cutaneous sporotrichosis, and many others — are always a risk. The advice for such situations is to make an appointment with a primary care physician to have the wound looked at. Fire coral is not actually a coral but a hydrozoan, making it more closely related to the Portuguese man-of-war and other stinging hydroids that we see all around us in the water while diving, like tiny feathers. Hydrozoans have a pesky toxin that can cause symptoms for some time (though not necessarily months). Among their toxic effects are dermonecrotic activity, which is tissue death, and hemolytic activity, which is the breakdown of red blood cells. Dermonecrotic activity becomes especially important if the envenomation also results in a skin abrasion or laceration. In this case, because the envenomation was introduced through an open wound, it could cause more extensive tissue damage.*

#### Case 4-02 Possible pulmonary barotrauma

A 58-year-old male freediver consulted with a DAN medic after he felt what he called a “hiccup” during descent. He’d participated in multiple dives, the last one five days prior to his call, when he’d descended to a depth of 99 fsw (30 msw). At the surface, the diver stated that he was sore over the left side of his ribcage and had coughed up blood (he’d counted about 50 roughly dime-sized spots of blood since the start of his symptoms). Prior to calling DAN, the diver had discussed these issues with a freedive trainer, who had advised that he rest for a few weeks. The diver’s condition remained unchanged over the five days leading up to the phone call. His ribs were still sore, though he was no longer coughing up blood.

*Comment: Coughing up blood after a deep breath-hold dive may be due to various causes. In this case, the “hiccup” may have been a provocative factor that contributed to lung damage and bleeding in the victim’s alveoli. The soreness on one side of his chest immediately upon ascent may indicate some degree of pneumothorax and warranted examination and chest imaging. Other possible causes of spitting blood after a breath-hold dive include bleeding from any part of the airway, between the glottis and the alveoli, as well as bleeding from the sinuses. Another possible cause besides barotrauma is lung squeeze, but, as in immersion pulmonary edema, the blood is mixed with gas and water. This diver’s reported symptoms were serious enough that he should have sought medical evaluation immediately. And the persistence of his symptoms five days after the incident no longer qualifies as an emergency but still calls for a thorough medical evaluation.*

#### Case 4-03 Hearing loss after freediving

A 30-year-old female freediver found herself suffering from very loud tinnitus after a 16-foot (5-meter) dive that she cut short due to discomfort and equalization problems. She sent the following email:

Dear DAN,

I have found your contact via searching the internet for finding some answers for an issue which deeply affects the quality of my life.

Four weeks ago, I was freediving and experienced some equalization problems at around 16 feet (5 meters). Normally, I dive as deep as 66 feet (20 meters) with no problem, and I have also completed a freediving course. I immediately returned to the surface. However, I started experiencing severe hearing loss and very loud tinnitus, but without any pain or significant vertigo as far as I remember. Two hours later, I put Maxitrol drops into my ear, and the next day I felt that much of my hearing had returned.

Nevertheless, I visited a specialist 48 hours after the incident, and he performed an audiogram that showed severe high-frequency hearing loss down to 65 dB at 5792 Hz and 8192 Hz, but across the rest of the frequency range my hearing was completely normal. Before the incident, my hearing was perfect. I had already had an audiogram two years before, because my hobby is opera singing. The specialist diagnosed me with hypoacusis sensorineuralis (diminished hearing) and prescribed me Stugeron Forte (an antihistamine) to enhance the blood flow across my ear and vitamin B to help regenerate my damaged nerves. He also advised that I visit a hyperbaric chamber to breathe pure oxygen but told me that it was already quite late to do so. Sadly, I did not have a chance to visit a hyperbaric chamber at the time. After 14 days of therapy with pills, my hearing has not improved significantly and I still have tinnitus at around 6000 Hz.

I kindly ask you for your opinion on this problem — is it possible that this was some kind of round window rupture that healed

in a few days but damaged hair cells? My hearing at speech frequencies was perfect already by two days after the incident when the audiogram was first performed. Was it wrong to put Maxitrol into my ear? Do you think this will be permanent hearing loss, or do you think that at least the tinnitus will disappear? Do you believe I can freedive safely with this condition? I was freediving for seven days after the incident without any problem, because the doctor said that I could, as in his opinion only hair cells had been damaged.

*Comment: A loss of hearing due to barotrauma may occur without rupture of the oval or round windows. In the case of ear barotrauma, the only drops one should immediately use are nasal drops to reduce congestion of the Eustachian tubes. Nothing should be put in the ears unless it's been prescribed by a physician after an examination. Regarding a return to diving, most dive medicine physicians will generally recommend against diving for their patients if the hearing loss is unilateral and severe, simply because the risk of complete hearing loss (from damage to the good ear) outweighs the benefits of diving. In the case of this opera singer, her hobby is an additional reason to quit freediving. The final recommendation should come from an otolaryngologist who is trained in and knowledgeable about dive medicine.*

#### Case 4-04 Snorkeling with with heart disease

A 79-year-old male freediver was snorkeling from a boat when, after about five minutes, his buddy noticed water coming from his snorkel. The buddy called for help and got the diver back aboard the boat, where CPR was administered until help arrived and emergency responders took over. Neither a respirator nor a defibrillator were available in the boat's first aid/emergency kit. Later, the victim was taken to the nearest hospital, where he was pronounced dead. Hypertensive and atherosclerotic cardiac disease were the suspected disabling conditions, with seawater drowning as the final cause of death. A toxicology report came back negative. The diver had undergone quadruple bypass surgery in 1999.

#### Case 4-05 Snorkeling alone

A 69-year-old male was snorkeling and breath-hold diving with a buddy. After about 10 minutes, the two went in different directions, and the buddy left the water first, which was normal for them. After an hour passed and the diver did not return, the buddy called the local EMS. The diver was found floating face down and was promptly pulled from the water and CPR was commenced. He was taken to the hospital, where he was pronounced dead. The cause of death was determined to be an acute cardiac event with terminal seawater drowning. A toxicology report was negative, and the case was deemed death by misadventure.

*Comment: In many cases when an elderly diver dies in the water, there is not enough evidence to pinpoint a specific cause. However, the medical history of such victims is often loaded with heart disease risk factors, and the autopsy often finds extensive atherosclerosis and other such other morphological changes. The cause in this case may have been a blackout due to hypoxia of ascent, a sudden cardiac dysrhythmia resulting in cardiac arrest, loss of consciousness, and then drowning.*

#### Case 4-06 A history of heart disease

A 55-year-old female was snorkeling with a group in up to 15 feet (5 meters) of calm water. She returned to the boat under her own power, but without her mask on her face, and complained about being out of breath. She was placed on oxygen, under the assumption that she was having a panic attack. She soon lost consciousness and CPR was started as she was brought back to shore. She was pronounced dead at the hospital, and the cause of death was ruled to be atherosclerotic cardiovascular disease. She had a known history of high blood pressure and she was seeing a doctor for mild fainting spells and high cholesterol. She had family history of heart attacks, and she smoked half a pack of cigarettes a day and drank alcohol occasionally. The autopsy findings included moderately severe atherosclerotic cardiovascular disease involving the coronary arteries and a narrowing of 70% or greater in her right main, left main, left anterior descending, and left circumflex coronary arteries.

*Comment: A history of fainting spells usually indicates episodes of serious dysrhythmia and is a contraindication for water activities — even leisurely swimming. Such a history also calls for a serious cardiological evaluation to seek possible preventive actions. In this case, it is likely that the victim's dysrhythmia progressed to the point that her heart's pumping action became inefficient and came to a complete stop. The start of her dysrhythmia in the water may be just coincidental, although the immersion-related shift of blood to the chest increases the heart's load and could have been a decisive provocative factor.*

#### Case 4-07 Death of abalone diver

A 57-year-old male with 30 years of abalone diving experience was found floating face down while freediving for abalone. He could not be resuscitated. His blood alcohol content was 0.230%. He was also a smoker and had a history of high blood pressure and “other heart problems,” reported his friends.

*Comment: Abalone diving takes a toll every year, mostly among older divers in poor health. Except for a permit requirement, this diving activity is not regulated. Abalone divers are often not be associated with any organization, and thus there is no centralized channel for delivering preventive information. The best chance may be to work with the authorities who issue permits and provide intervention at the time the permit is granted.*

#### Case 4-08 Possible mediastinal emphysema

A male freediver, who stated that he'd done an estimated 100 dives that day to a depth of 40 fsw (12 msw) while hunting snapper, called the DAN Medical Services Emergency line and stated that after his dives (which occurred over an unknown time period), he'd felt a lump in his throat. His symptoms included pain in his throat, voice changes, and difficulty swallowing, and he could feel a number of bubbles under the skin of his neck and around his trachea. The victim decided to wait and not seek medical attention immediately and later discovered that he had also developed what seemed to be a reddish rash, which he described as bumpy and sandy-feeling. He'd originally assumed it to be sunburn, but the condition persisted for two days.

*Comment: The description this diver provided is quite characteristic of mediastinal emphysema, the escape of alveolar gas into interstitial tissues and then its ascent along the tissue layers into the neck and under the skin. It is more common in divers breathing from a compressed-gas source underwater, but it may also occur in breath-hold divers due to a spontaneous rupture of lung tissue, straining (for example, when reloading a speargun), or lung packing (which was likely not practiced in this case). The reported rash is not necessarily related to the emphysema and could be anything from a hazardous marine life injury to sunburn. The photo that the diver sent supported this conclusion. Unfortunately, the diver never called back so we do not know if he ever sought medical evaluation.*

## SECTION 5. IDAN INJURY SURVEILLANCE

SALIH MURAT EGI, DANILO CIALONI, MASSIMO PIERI, MARTA MARROCCO, ALESSANDRO MARRONI (SECTION 5.1), YASUSHI KOJIMA, HIROYOSHI KAWAGUCHI, AKIKO KOJIMA (SECTION 5.2), JOHN LIPPMANN (SECTION (5.3))

### 5.1 DIVING SURVEILLANCE IN DAN EUROPE

Founded in 1983, DAN Europe is an international nonprofit foundation registered in Malta. Europe's multilingualism requires making provision for citizens of all EU countries to access the organization's services in their native language. Therefore, DAN Europe has branch offices, directorates, and sub-directorates within continental Europe and in the areas in

which DAN Europe is active, as established by the IDAN Board of Directors.

DAN Europe operates in Continental Europe through head offices in Malta and in Roseto, Italy, and through DAN Europe Regional Offices and Affiliates.

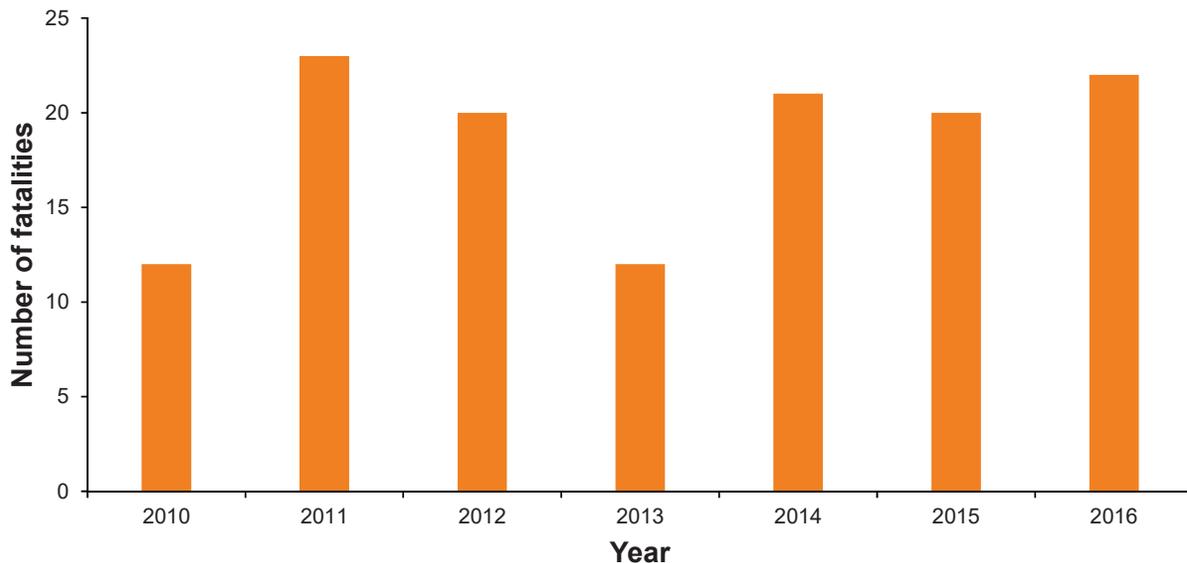


Fig 5.1-1. Distribution by year of fatalities reported to DAN Europe among recreational divers (including recreational professionals) from 2010–2016

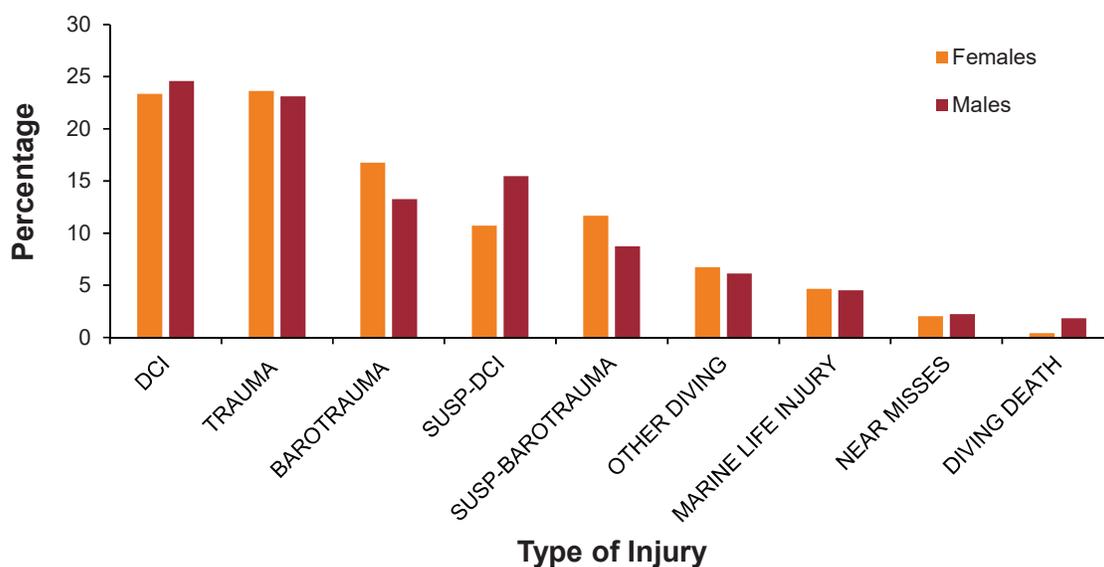


Figure 5.1-2. Claims for diving injuries among DAN insured dive professionals over the period 2010-2016, by sex and injury type

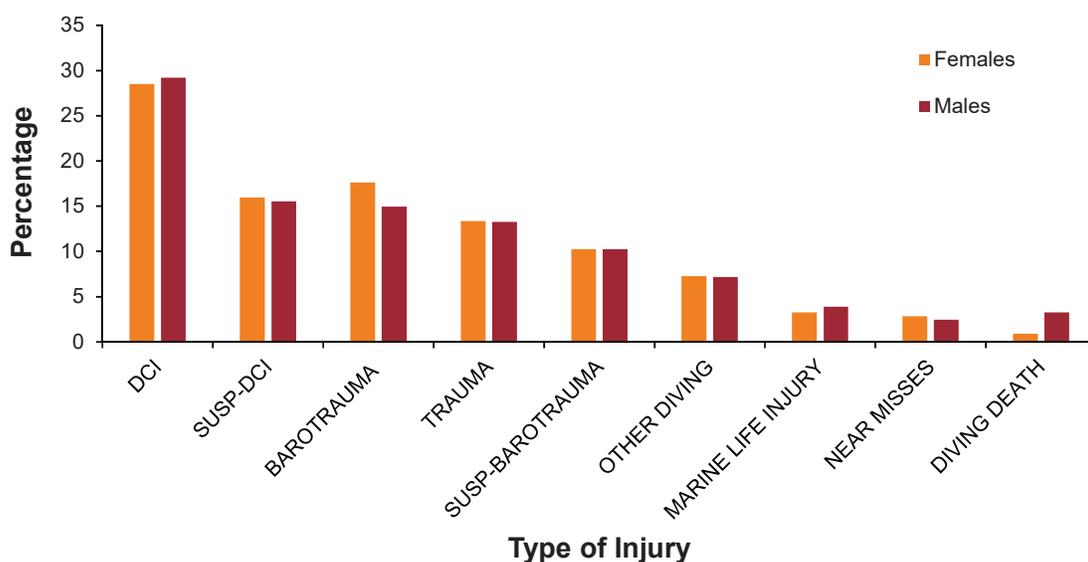


Figure 5.1-3. Claims for diving injuries among DAN insured recreational divers over the period 2010-2016 by sex and injury type

DAN Europe is not an investigative agency but does collect diving fatality information throughout its operational regions, through reports from DAN Europe members and through insurance claims. From 2010 through 2016, inclusive, 130 diving fatalities were reported to DAN Europe (see Figure 5.1-1).

There were a total of 6,234 diving injury claims made in that same period, an average of 890 per year. Among the 2,777 claims by recreational divers insured through DAN Europe, 728 (26%) were made by females and 2,049 (74%) by males. The most common claims were for decompression illness ( $n=674$ , 24%) and trauma ( $n=646$ , 23%), as shown in Figure 5.1-2. Among the 3,457 claims by recreational

divers insured through DAN Europe, the most common claims were for decompression illness (n= 1,002, 29%) and barotrauma (n=546, 16%), as shown in Figure 5.1-3.

The various manifestations of DCI, which is a notoriously protean disease, are shown in Figure 5.1-5.

Claims for decompression illness (DCI) remained relatively steady from 2010 through 2016, at around 160 cases per year, as shown in Figure 5.1-4.

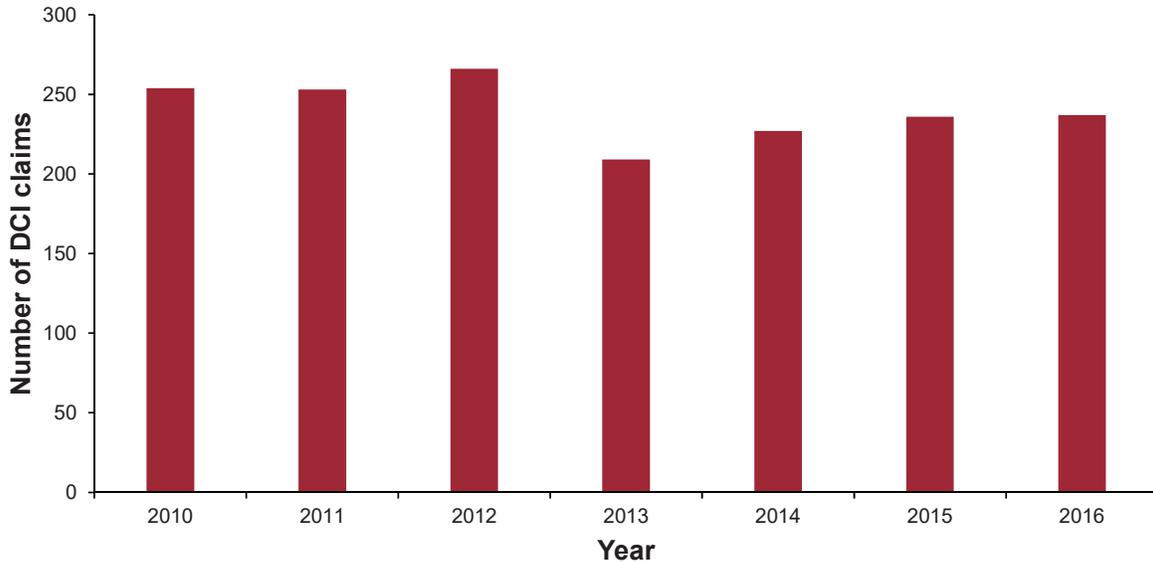


Figure 5.1-4. Claims for decompression illness (DCI) among DAN insured recreational divers over the period 2010-2016

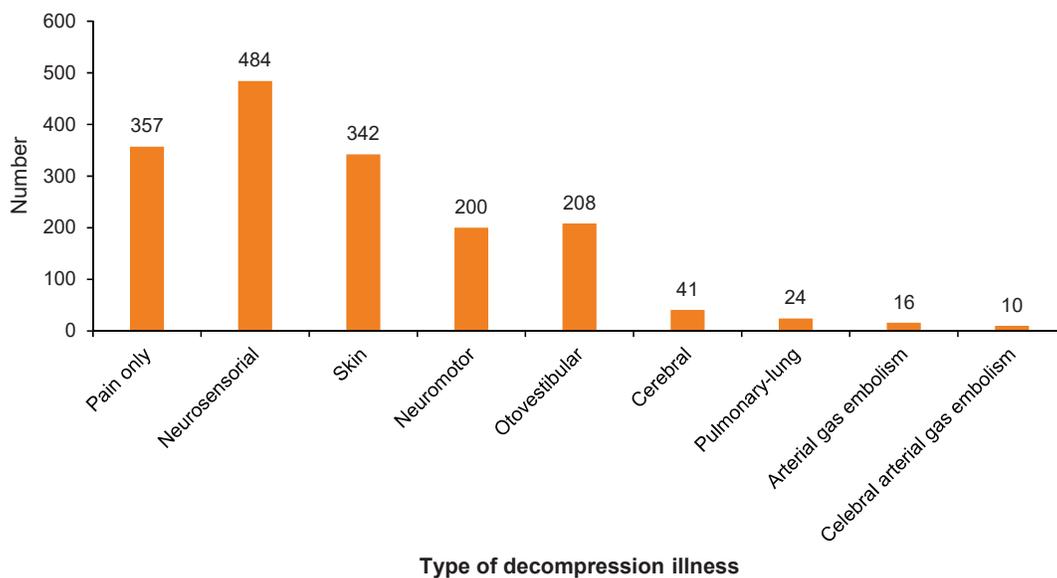


Figure 5.1-5. Distribution by type among claims for DCI among DAN Europe-insured recreational divers from 2010-2016

## 5.2 RECREATIONAL DIVING-RELATED FATALITIES IN JAPAN, 2016

Last year, we reported recreational diving-related fatalities in Japan, 2005-2015.<sup>1</sup> In this year's report we review Japanese diving fatalities in 2016.

Fatality data was collected by the Japan Coast Guard (JCG), by DAN JAPAN, and through information located online. There were 14

recreational diving-related fatalities reported in Japan during 2016. Around fifteen recreational diving-related fatalities are reported every year in Japan (see Figure 5.2-1).

As we did last year, we classified dive style as group, buddy, or solo. Group diving is a popular style for many divers in Japan. A group typically

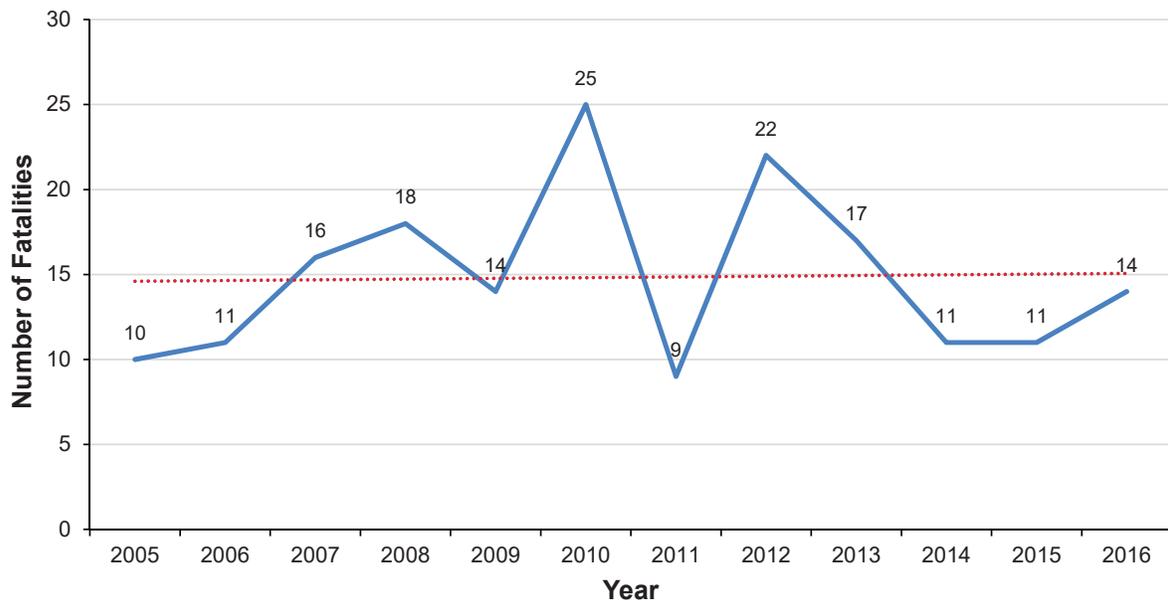


Figure 5.2-1. Number of fatalities by year in Japan from 2005-2016

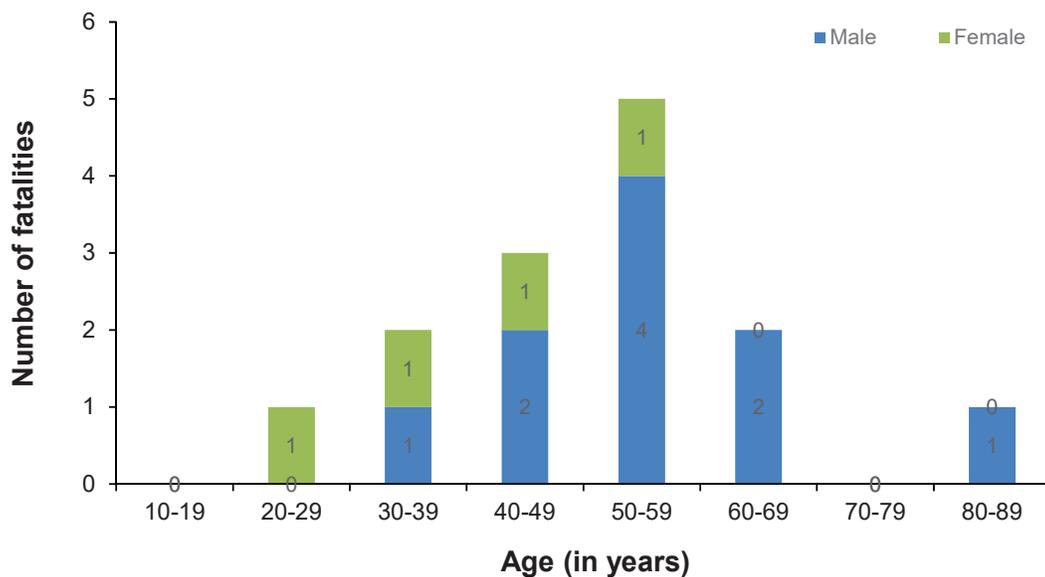


Figure 5.2-2. Distribution by age and sex of diving fatalities in Japan in 2016

includes one or two instructors/divemasters and either a few buddy pairs or a single dive group. We identified the triggers and causes of all fatalities according to the method described by Denoble (2008).<sup>2</sup>

There were 10 males (71%) and 4 females (29%). The decedents' mean age is unknown because the ages of the victims in 8 of the 14 cases were recorded only in decade increments. There

was one fatality among divers in their 20s, two among those in their 30s, three among those in their 40s, five among those in their 50s, two among those in their 60s, and one among those in their 80s. Of the 14 fatalities, 11 (79%) involved divers 40 or older, and 8 (57%) were in divers 50 or older (see Figure 5.2-2). The pattern of more fatalities involving males and older divers was similar to that of previous years.

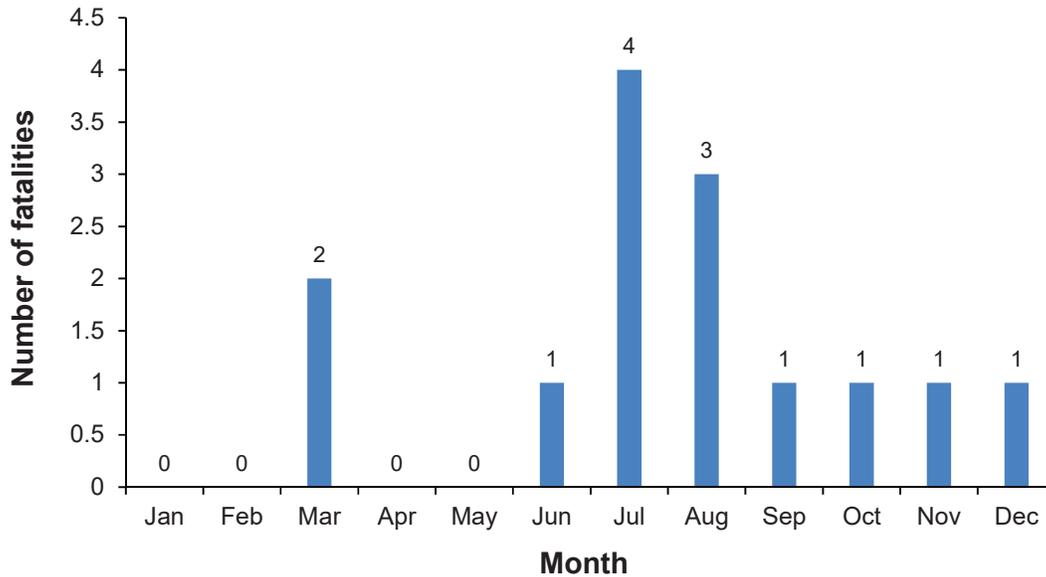


Figure 5.2-3. Distribution by month of diving fatalities in Japan in 2016

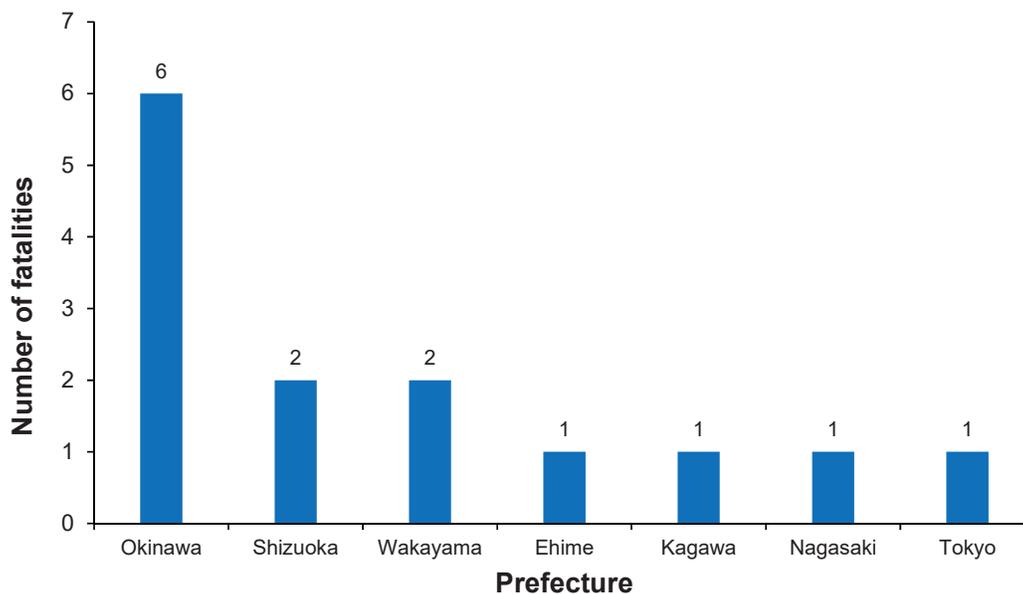


Figure 5.2-4. Distribution by prefecture of diving fatalities in Japan in 2016

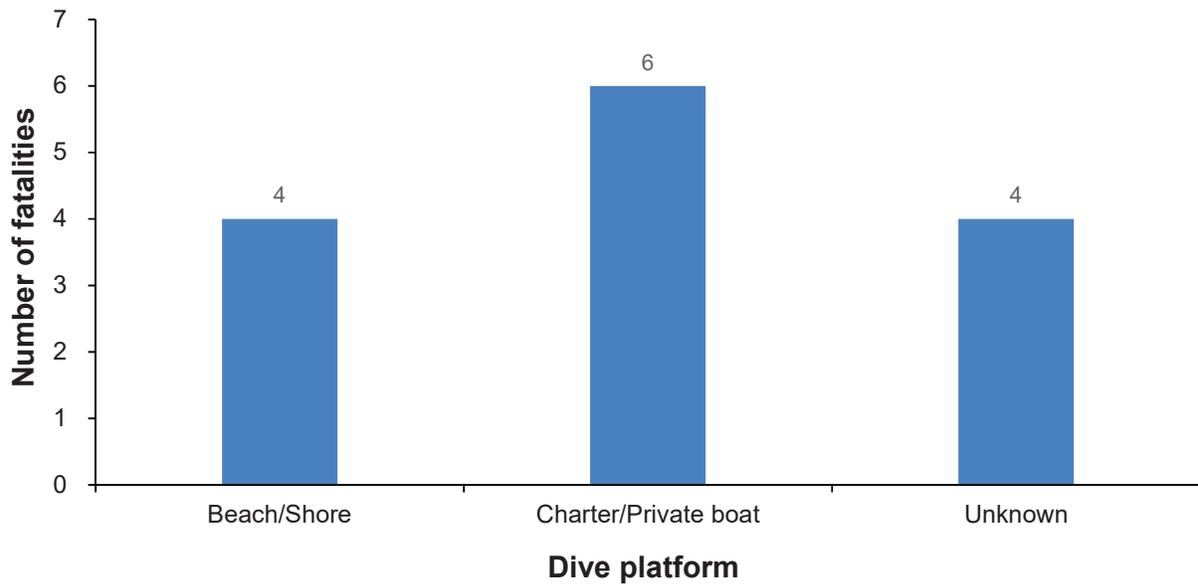


Figure 5.2-5. Dive platforms associated with diving fatalities in Japan in 2016

Figure 5.2-3 shows that eight fatalities (57%) occurred during the summer (July to September). This is not surprising, since more divers go into water in the summertime.

Figure 5.2-4 shows the geographic distribution of fatalities by prefecture. The top three are the same as in the 2005–2015 data. Again, this is not a surprise because these three prefectures are known to have many popular diving sites, and many divers are known to dive there.

Figure 5.2-5 shows the dive platforms associated with the 2016 fatality cases. There were no fatalities in 2016 among divers on liveboard boats. However, we cannot conclude that liveboard diving is safer based on this data, since liveboard diving is thought to be not as popular in Japan as diving from other platforms.

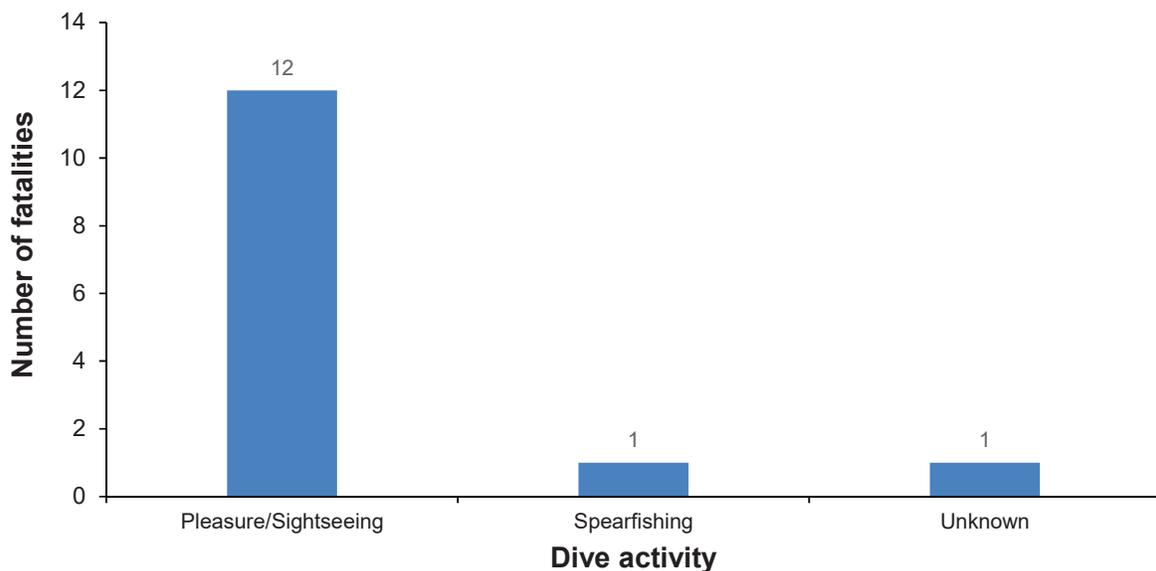


Figure 5.2-6. Distribution by dive activity of diving fatalities in Japan in 2016

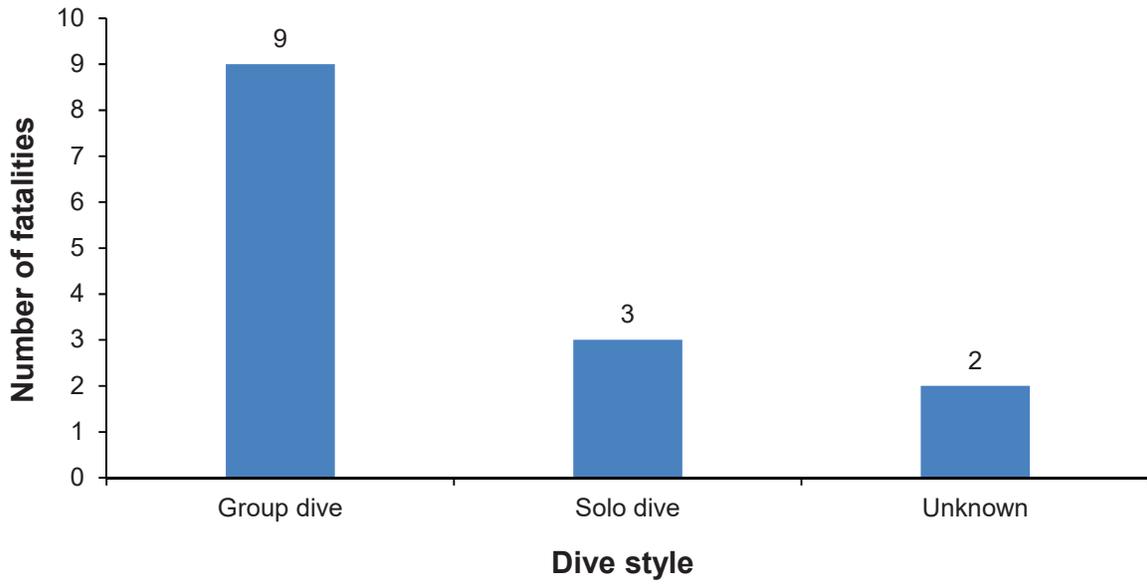


Figure 5.2-7. Distribution by buddy status of diving fatalities in Japan in 2016

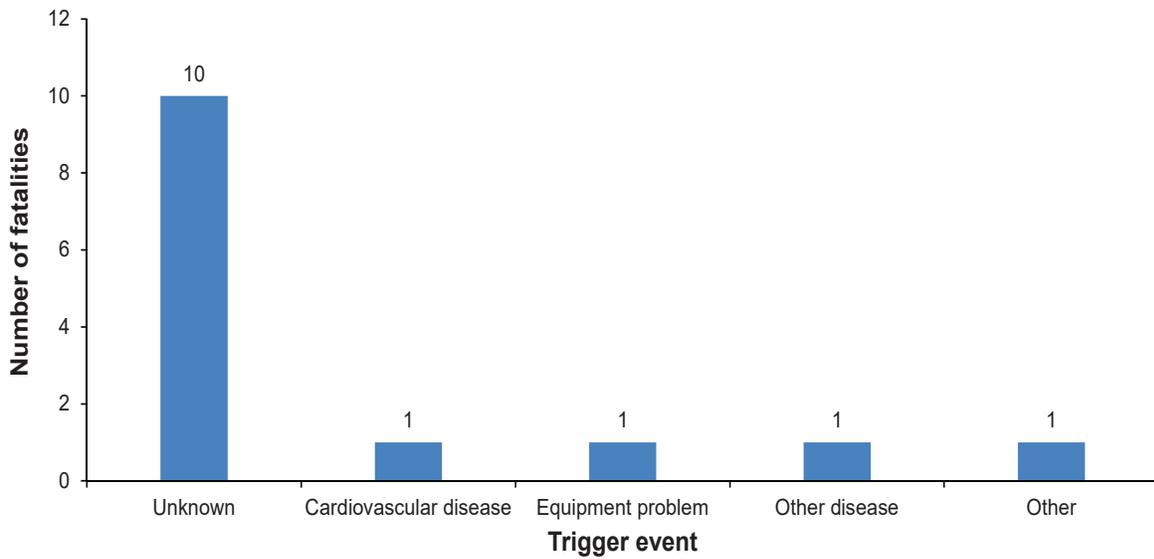


Figure 5.2-8. Distribution by trigger event of diving fatalities in Japan in 2016

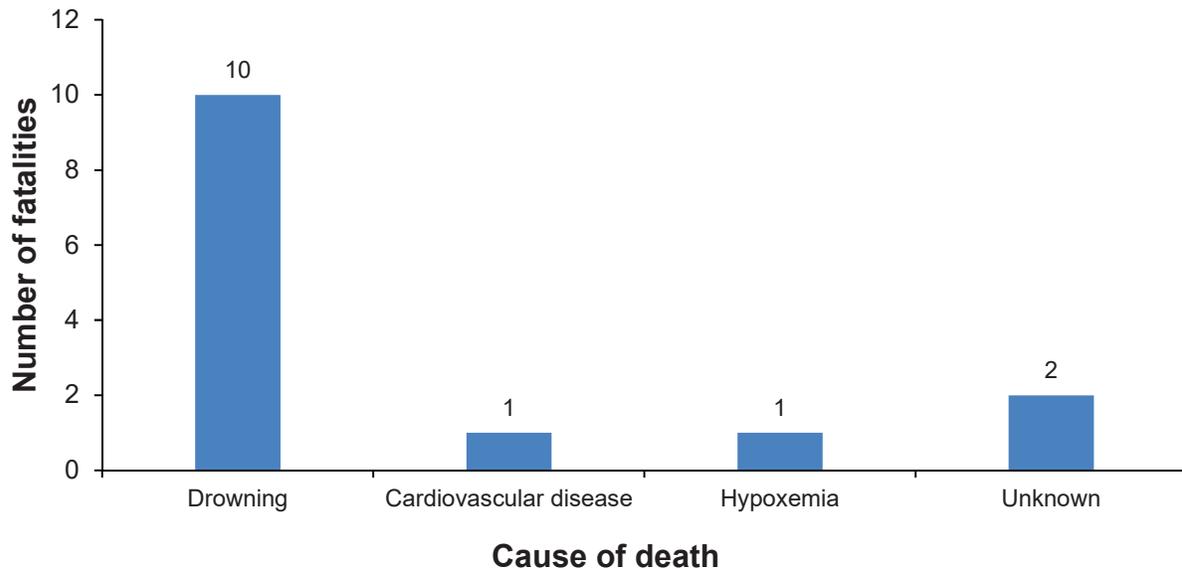


Figure 5.2-9. Distribution by cause of death of diving fatalities in Japan in 2016

The dive style of 9 fatalities (64%) was group diving. As we mentioned in last year's report, however, we cannot conclude that group diving is a risk factor, because of the popularity of group diving in Japan.

Trigger events were identified in only 4 fatalities (29%); 1 involved cardiovascular disease, 1 another disease, 1 equipment trouble, and 1 another trigger (see Figure 5.2-8).

The cause of death was identified for 12 of the fatalities (86%) by medical doctors who reviewed the available data. Drowning was the most common cause of death; 10 cases were due to drowning, 1 to cardiovascular disease, and 1 to hypoxemia (see Figure 5.2-9). We have to note, however, that we could not confirm the autopsy findings for these cases, so the causes of death reported here may not be correct.

Panic was associated with 3 cases (21%). The triggers for the panic were an equipment problem in 1 case, another event in 1 case, and an unknown event in the third case. The frequency of panic was similar to that observed in the 2005–2015 data, where it was 16%.

The experience level of divers was not clear in many cases (see Figure 5.2-10). In the range identified, there were a number of fatalities among divers with only a few years of experience and with low frequency of diving. In 2 victims, the number of previous lifetime dives was none. Figure 5.2-11 shows that in the range identified, fatalities were more likely to occur on the first day of a planned consecutive diving series, but they did not always occur during the first dive of the day.

## REFERENCES

1. Buzzacott P, ed. 2017. DAN Annual Diving Report, 2017 Edition. Durham, NC: Divers Alert Network.
2. Denoble PJ, Pollock NW, Vaithyanathan P, Caruso JL, Dovenbarger JA, Vann RD. 2008. "Scuba injury death rate among insured DAN members." *Diving and Hyperb Med* 38(4):182-8.

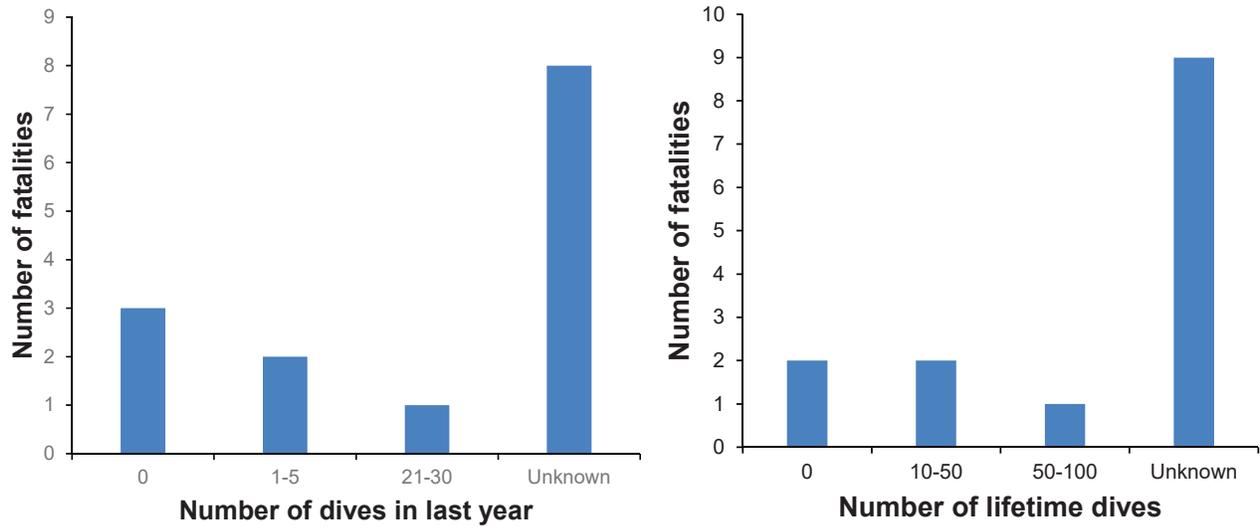


Figure 5.2-10. Distribution of experience levels among victims of diving fatalities in Japan in 2016

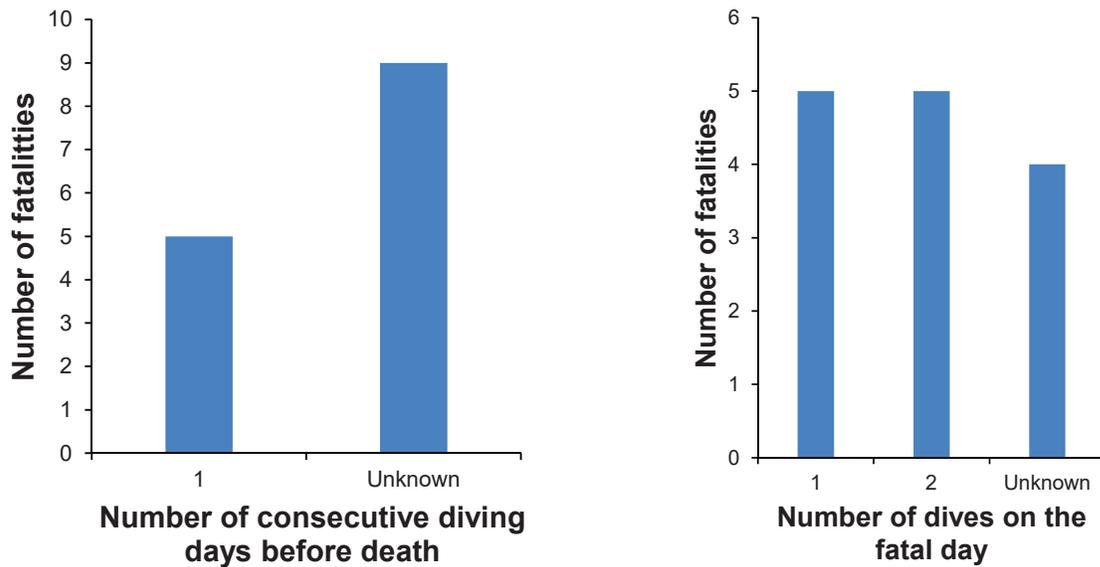


Figure 5.2-11. Distribution of consecutive diving days and dives on the fatal day in diving fatalities in Japan in 2016

### 5.3 DIVING FATALITY REPORTING IN THE ASIA-PACIFIC

The Divers Alert Network Asia-Pacific (DAN AP) is a charity based in Melbourne, Australia with a mission to improve the safety of recreational diving activities throughout most of the Asia-Pacific region.

#### AUSTRALIAN FATALITIES

In Australia, the publication of diving fatality reports began formally in 1969 with G.J. Bayliss, who reported civilian diving fatalities between 1957 to 1967, inclusive. The reporting of fatalities in Australia continued with the introduction of Project Stickybeak by Dr. Douglas Walker, who compiled and reported data on snorkeling and compressed-air diving fatalities from 1972 through 2003. Walker's annual reports have been published in the journals of the South Pacific Underwater Medicine Society. In 2003, John Lippmann, on behalf of DAN AP, assumed responsibility for Australian dive mortality surveillance. Subsequent fatality reports have continued to be published in *Diving and Hyperbaric Medicine*.

Initial accident data are collected by on-scene investigators, such as the police and/or workplace, health, or safety officers. Autopsies are routinely conducted after diving fatalities in Australia, except in rare cases if the family did not give consent or the victim's body was not found. The investigative and autopsy information, together with witness statements, is reviewed by the relevant coroners, and a coroner's report is produced, with or without an inquest, as determined by the individual coroner.

The information sought and recorded includes:

- Demographic and temporal data
- Medical history
- Diver training
- Diving or snorkelling experience
- Equipment used and problems found with it upon examination
- Environmental conditions
- Autopsy report, including histology and toxicology studies

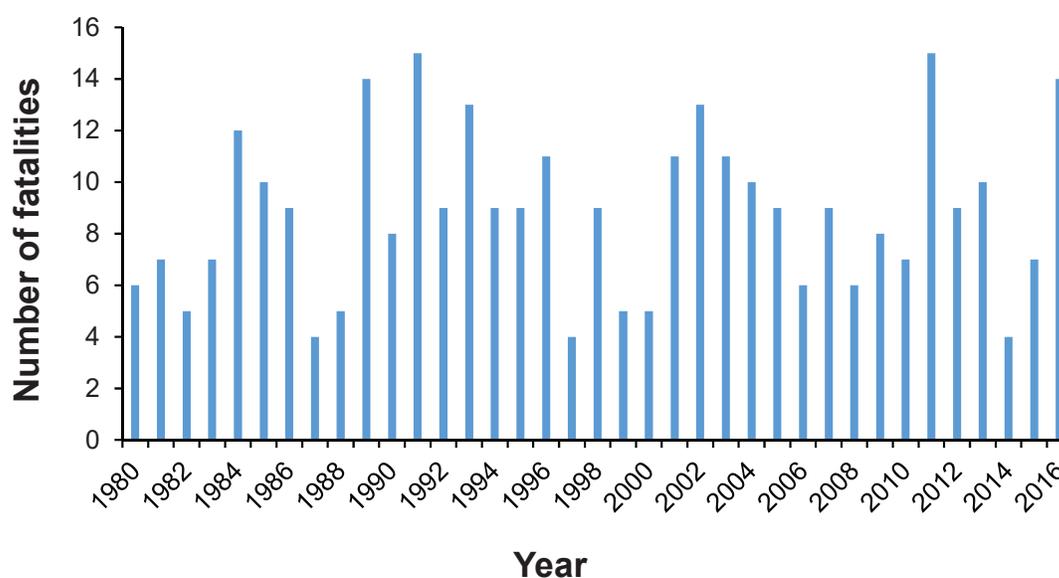


Figure 5.3-1. Distribution by year of all recorded scuba diving fatalities in Australia from 1980–2016

Australia's National Coronial Information System (NCIS) was launched in 2000 and includes all deaths reported to state or territory coroners since that time. In addition, it has more recently included data from New Zealand. The information available for each case includes the coroner's report, a brief summary of the police report, and, sometimes, the autopsy report. In order to obtain more complete data, DAN AP liaises with Australia's state and territory coroners, who often provide (with relevant ethics approvals) complete case files. These files generally include full police reports; witness statements; and, often, decedents' medical and diving histories and equipment reports. Key information from these sources is recorded in the DAN database.

DAN AP has constructed a database of all reported dive-related deaths in Australia since 1965. Figure 5.3-1 shows all recorded scuba diving fatalities in Australia from 1980 through 2016.

With the exception of New Zealand, Singapore, and Hong Kong, which have well-developed coronial and media reporting systems, it is difficult to obtain reliable and useful diving fatality data from most other countries in the Asia-Pacific region. However, DAN AP continues to expand its reach and collects and reports on available data.

Figure 5.3-2 shows all recorded scuba-related deaths in New Zealand from 1980 through 2016.

Figure 5.3-3 shows the scuba-related deaths (including those involving rebreathers) of which DAN AP is aware that occurred in the Asia-Pacific region (excluding Japan) from 2010 through 2016, inclusive. However, it is very likely that in some countries there were significantly more deaths that went unreported. There were also individual deaths reported in various other countries in the region that are not included here for the sake of simplicity.

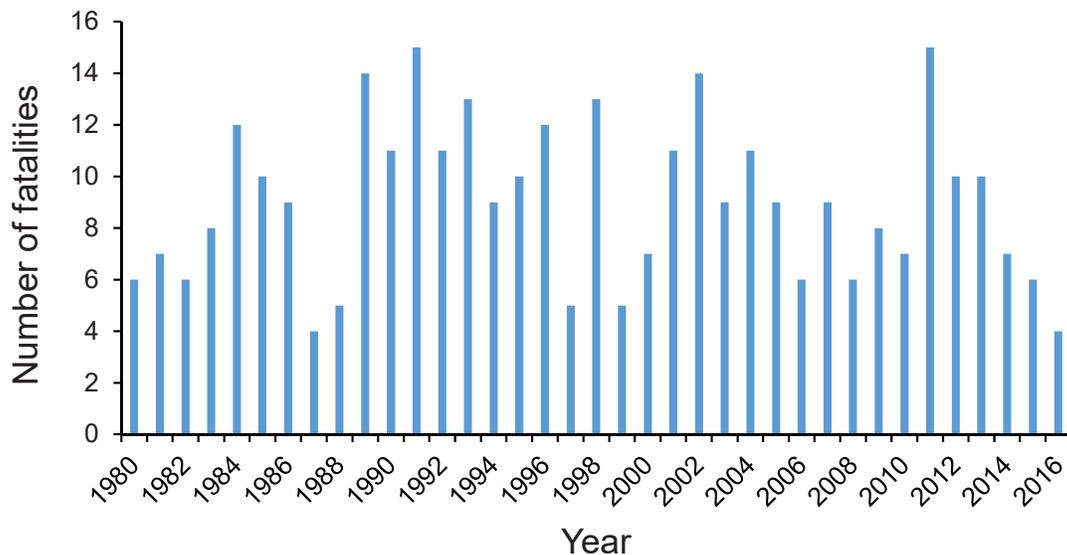


Figure 5.3-2. Distribution by year of all recorded scuba-related deaths in New Zealand from 1980–2016

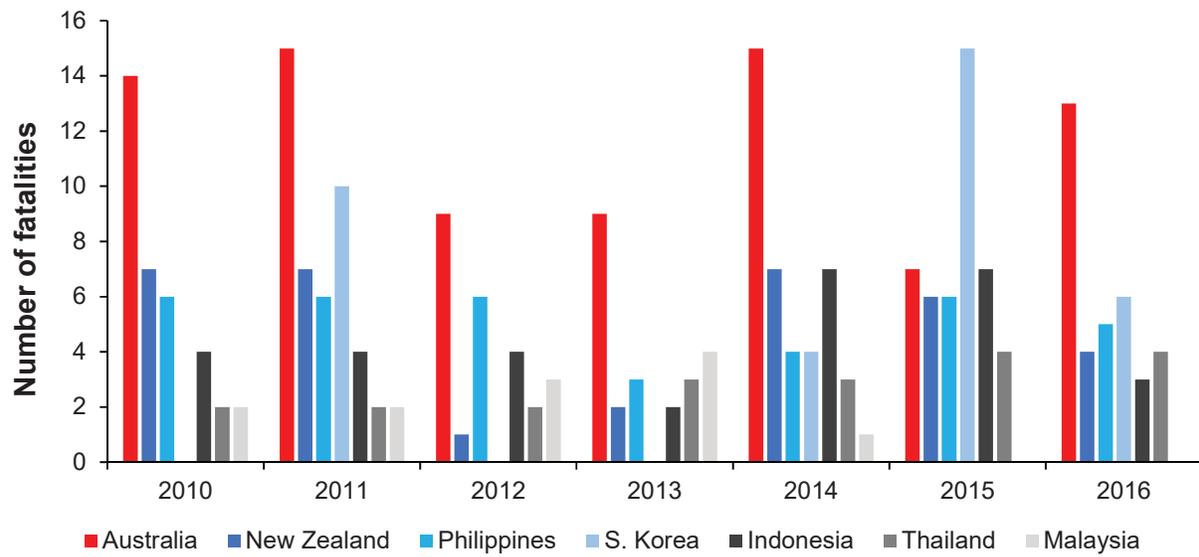


Figure 5.3-3. Distribution by country and year of scuba-related deaths (including those involving rebreathers) in the Asia-Pacific region (excluding Japan).

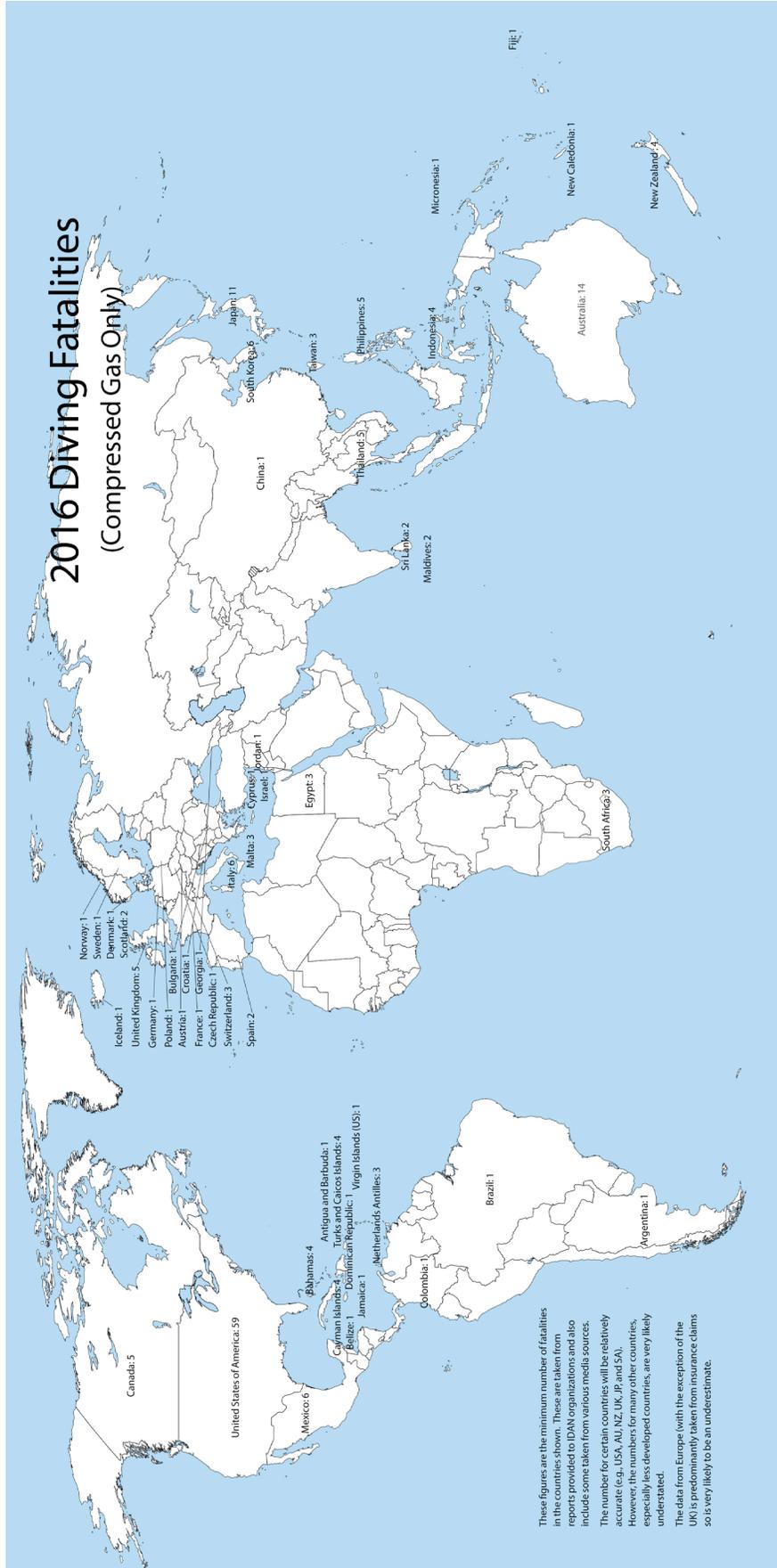


Figure 5.3-4. Distribution by country of scuba-related fatalities. AS compiled by John Lippmann and Scott Jamieson in 2016

## APPENDIX A. INTERNATIONAL INJURY MONITORING AND PREVENTION

BRITISH SUB-AQUA CLUB, NEW ZEALAND UNDERWATER ASSOCIATION,  
COMHAIRLE FO-THUINN - IRISH UNDERWATER COUNCIL, UNDERWATER  
COUNCIL OF BRITISH COLUMBIA

### BRITISH SUB-AQUA CLUB INCIDENT DATABASE AND REPORTING

CLARE PEDDIE, JIM WATSON, BEN PEDDIE, BRIAN CUMMING

#### BSAC INCIDENT REPORTING HISTORY

In 1953, in the UK, a group of enthusiasts got together and founded an amateur organization to promote the nascent sport of sub-aqua diving. That organization was named the British Sub-Aqua Club (BSAC), and it flourishes to this day, with around 27,000 members.

BSAC is a club-based organization, with branches all over the world. The branches organize their own activities following guidance and training programs laid down by the governing body. The branches are supported by a coaching scheme, and BSAC also operates commercial schools and centers in the U.K. and elsewhere.

As the sport grew, it became apparent that safety was a primary consideration and that capturing information about problems that divers experienced could be used effectively to educate others, to influence training, and to help to prevent such problems from reoccurring. To that end, in 1965, BSAC generated its first annual incident report, summarizing incidents and drawing lessons from them. BSAC has produced a report every year since 1965.

Currently, the BSAC receives around 250 to 300 incident reports a year. Figure A-1 shows the number of incident reports received over the last 20 years; there are now more than 8,000 incident reports in its database. The decline in incident reporting from 2011 to 2015 almost certainly reflects what we understand about engagement in the sport in the U.K. over that period, although actual participation data is not available.

BSAC is the U.K. national governing body for the sport, and as such we report on all sport-related diving incidents, regardless of the affiliations of the individuals involved. We also report on incidents outside the U.K. that involve BSAC members in some way. Personal information is kept strictly confidential, and no critique is given on any individual incident; there are two reasons for this. First, we respect the courage and candor of those who report incidents to us (since they often openly recount mistakes that they have made). And second, we are very aware that any such commentary would cause our flow of information to quickly dry up.

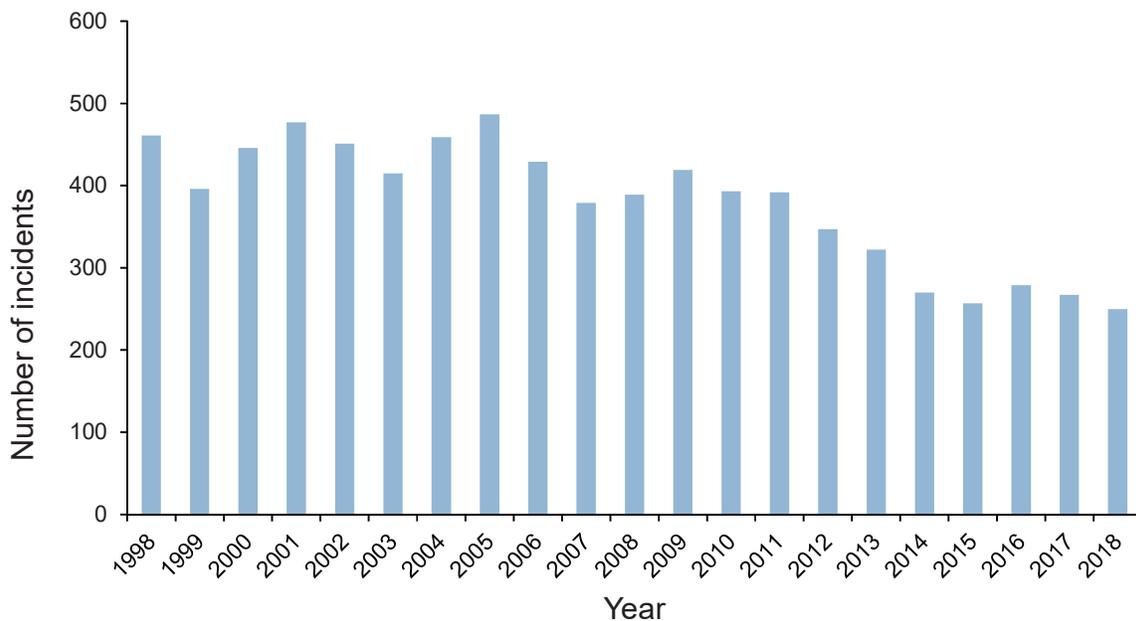


Figure A-I. Distribution by year of incident reports in the BSAC database from 1998–2018

Reports from recent years are available on our website (<http://www.bsac.com/incidentreport>). A review of each year's incidents is presented at our technical conference, and a recording of this year's presentation is also available on the website. In the interest of promoting safe diving, this information is available online, free of charge, to all divers, regardless of whether or not they are BSAC members.

#### DATA COLLECTION AND COMPILATION

The report covers all reported incidents that occur in the U.K., regardless of the affiliation of those involved, as well as any incidents that occur outside the U.K. and involve a BSAC member in some way. Information for the report comes from a number of different sources, including the following:

- Divers who complete the BSAC incident report form (available on our website), which supports the collection of relevant data through a structured format; this reporting method is available to all divers, regardless of their affiliation;
- The Ministry of Defence;
- The Maritime and Coastguard Agency (MCA);
- The Royal National Lifeboat Association (RNLI);
- Key diving centers;

- Media reports, including online media;
- Other diving organizations (some of which use the BSAC incident form); and
- A variety of other forms of information.

All of these data are gathered together for analysis into the incident database. One of the challenges is to compare multiple reports from different sources to ensure that duplication is avoided but information capture is maximized. Each incident is coded into the database so that critical factors of the event can be easily identified, then synopses are written that summarize the sequence of events associated with each incident.

#### RELATIONSHIPS

BSAC has direct relationships with other bodies that contribute to the incident reporting system described above and that have broader involvement in the diving industry and beyond.

#### SAFETY PARTNERS

BSAC receives data directly from rescue bodies, including Her Majesty's Coastguard (HMCG), a branch of the MCA, and the RNLI, and their contributions are highlighted within the BSAC's annual report. These bodies largely provide data on maritime incidents. In addition, also there are

a significant number on inland-based dive sites, and the busiest among these provide reports direct to BSAC for inclusion in the annual report. BSAC is a founding member of the British Diving Safety Group (BDSG) and both presents its annual report to this group and provides specific analysis where necessary. DCI incidents in the U.K. are treated in recompression chambers that are members of the British Hyperbaric Association (BHA), and while we do not currently receive any details from the BHA we are liaising with them to receive such data in the future.

As a founding member of and long-term contributor to the National Water Safety Forum (NWSF) in the U.K., we contribute to and consequently have access to and can extract data from the Water Incident Database (WAID) maintained by members of the NWSF. BSAC safety advisors have provided expertise in the wider context of water safety to the NWSF for many years, holding the positions of chair of the Watersports Group and deputy chair of the Coordinating Committee. Our contributions also include the U.K. National Drowning Prevention Strategy, expert advice to the Marine Accident and Investigation Branch (MAIB), and event water safety risk management.

## LESSONS LEARNED

Lessons learned from the annual incident analysis are used to guide our training programs and to provide safety advice to divers. This is particularly important when changes are made in the sport. There have been many such changes since 1965, and our incident analysis has helped us to understand these issues and to develop mitigation actions. Such changes include the introduction of adjustable buoyancy life jackets (initially it was considered too risky for a trainee to wear one!), single hose regulators, modern drysuits, buoyancy compensators, alternative gas sources, dive computers, nitrox, mixed gases, and rebreathers. At the same time, there has been a growing awareness of diving physiology; key examples of our contributions in this area include the role of patent foramen ovale in decompression illness, the aging nature of the diving population in the U.K., and, most recently (and possibly linked to the aging of divers), the risk of immersion pulmonary edema. In each case, we have been able to study the evidence, derive associated safety

advice, and, if necessary, adjust our training recommendations.

The BSAC incident database informs the diving industry and diver training agencies and as a consequence likely reduces the number of divers lost at sea. The database contains information on the circumstances surrounding over 8,000 reported incidents. This information is extremely detailed in some cases, but in other cases the reports can be a simple record of a diver being airlifted to a hospital. Currently, we receive reports of around 250 incidents a year, and trends from these incidents are identified when, over the course of a number of years, the proportion of one type of incident changes with respect to the others, often as a result of an increase or decrease in a given diving activity. In the 1980s, for example, an increasing number of divers were being lost at sea; in some cases, divers were adrift for many hours before being found. As a consequence of incident reports highlighting the prevalence of this problem, the diving industry responded by developing a number of safety products a diver can carry, including extendable, highly visible flags; larger, brighter delayed surface marker buoys (many experiments were conducted at sea to identify the best color for these); personal emergency position-indicating radiobeacons (EPIRBs) that can withstand underwater use; dye pouches; whistles; and sirens. In addition, diver training agencies responded by including in their training programs both theoretical and practical content on vigilance by safety boats and on the appropriate use of these products, which have helped to make divers more visible on the surface. Since this period of intense activity and discussion in the diving community, the number of divers lost at sea in the U.K. has declined significantly. Despite our best efforts, however, we have been unable to produce similar evidence in our incident reports regarding the incidence of decompression illness (DCI). While the number of decompression incidents has definitely fallen, the proportion of reported incidents involving decompression illness has remained largely static. Figure A-2 shows that from 1998 through 2018, inclusive, the proportion of reported incidents related to DCI has fluctuated between 15% and 35%.

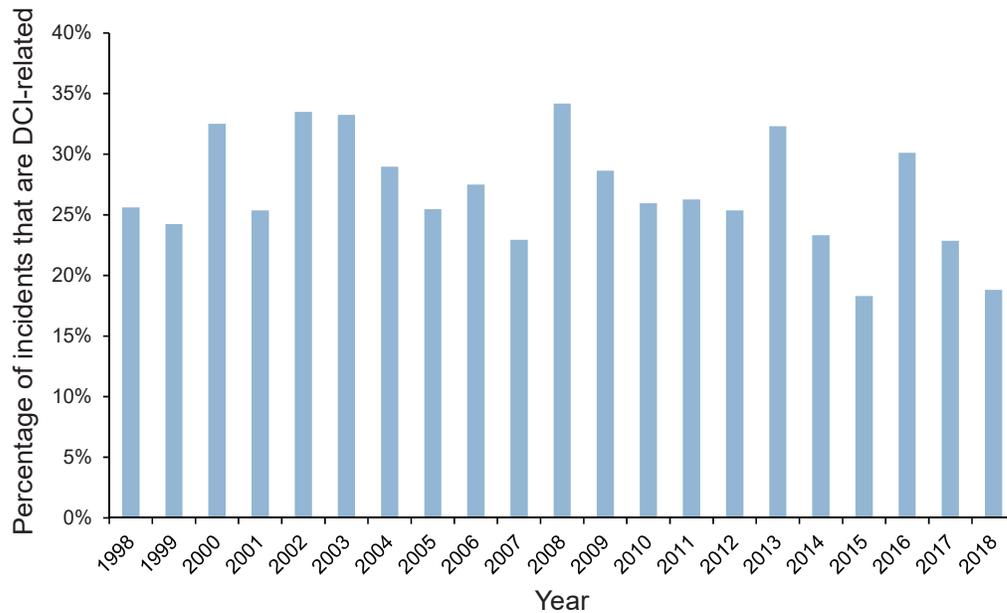


Figure A-2. Distribution by year of the percentage of incident reports in the BSAC database that involve DCI from 1998–2018

The BSAC incident report database remains a valuable resource for divers in the U.K. The data is analyzed annually and is used to provide evidence-based advice on key trends that are identified, for the benefit of the diving population and the diving industry. Incident data capture is essential to providing an evidence base in order to inform and justify the development of training programs, the design of equipment, and the development of a growing body of dive safety advice. However, the data alone is not sufficient and requires careful, unbiased analysis and consideration within the wider implications of a multifactorial sporting activity. Analysis of individual incidents has significant value; however, only identification of trends from a wider body of data allows for true evidence-based conclusions.

## NEW ZEALAND UNDERWATER ASSOCIATION (NZUA)

MIKE TORR, JEFF STRANG

The New Zealand Underwater Association (NZUA) is New Zealand's leading not-for-profit organization promoting and advocating for safe and enjoyable underwater activities in a protected marine environment. The organization's key missions are as follows:

- Driving marine safety messaging, specifically where it relates to underwater sports and activities;
- Advocating for and supporting marine environmental campaigns;
- Supporting NZ underwater clubs, specifically those involved in scuba diving, snorkeling, spearfishing, and underwater hockey;
- Promoting participation in underwater sports and recreational activities throughout New Zealand; and
- Lobbying the government on behalf of all New Zealanders to protect and advocate for their interests in matters of safety and the protection of the marine environment.

With regard to injury monitoring, NZUA collates data obtained from Water Safety NZ, the Accident Compensation Corporation (ACC, known as Te Kaporeihana Āwhina Hunga Whara in Maori), and the NZ media. In New Zealand the ACC is the sole insurer for injuries, regardless of how

they were sustained, and anyone who is injured while in New Zealand may claim compensation from the ACC. Table A-1 shows the number and cost of compensation claims in New Zealand for underwater diving over the last 5 financial years (the financial year in New Zealand runs from July 1 to June 30). As can be seen, underwater diving in New Zealand results in around 300 new claims each year, with around 400 active claims ongoing in any year, and costs the community around \$2 million NZD (\$1.3 million USD) per year in compensation alone.

Given the relative size of New Zealand's population, diving fatalities are relatively rare when compared with more heavily populated countries. Figure A-3 shows the number of scuba diving and snorkeling/freediving fatalities per year from 2011 through 2017. There are, on average, 4 scuba diving fatalities recorded in New Zealand each year.

Table A-2 presents the demography of the victims of fatalities, by activity. As can be seen, most of the decedents were male. The victims' ethnicity was known in 40 cases; 16 of those 40 (40%) were reportedly Maori, and 12 (30%) were New Zealand residents of European descent. The majority (16 of 28 scuba deaths, 26 of 31 snorkeling/freediving deaths) occurred during the summer months, between November and April.

Financial year	New claims	Active claims	Total cost (in NZD)
July 2013-June 2014	299	436	\$1,853,255
July 2014-June 2015	296	413	\$2,139,180
July 2015-June 2016	277	399	\$1,869,989
July 2016-June 2017	254	369	\$1,750,605
July 2017-June 2018	294	403	\$1,952,022

Table A-1. Distribution by year of claims made in New Zealand for underwater diving injuries from 2013-2018

Demography	Scuba (n=28)	Snorkel/Freedive (n=31)	Total (n=59)
Mean age (SD)	44 (11)	44 (12)	44 (12)
Number males (%)	24 (86%)	28 (90%)	52 (88%)

Table A-2. Demographic characteristics of victims of New Zealand diving and snorkeling/freediving fatalities from 2011-2017

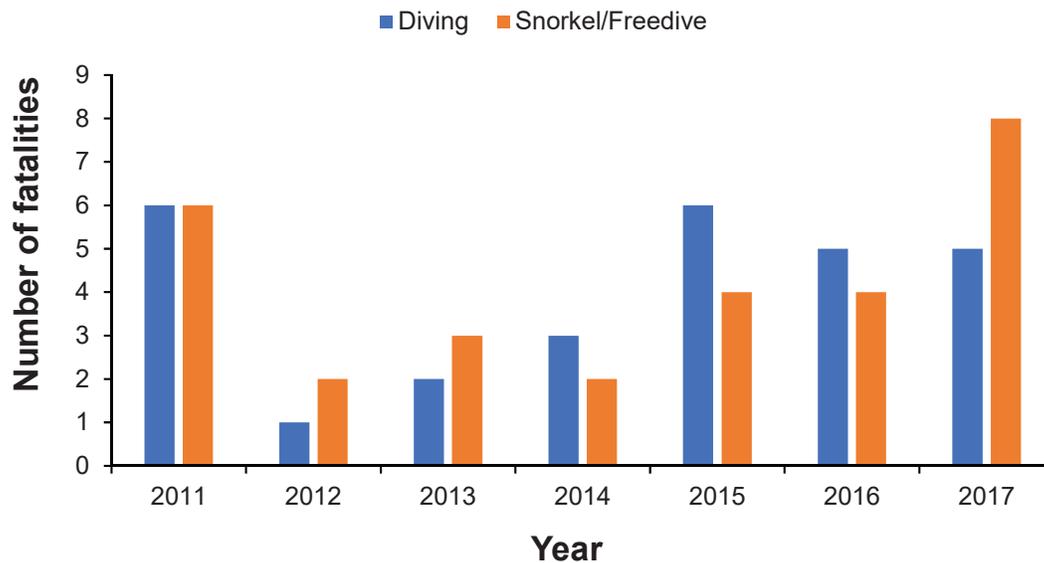


Figure A-3. Distribution by year of scuba and snorkeling/freediving fatalities in New Zealand from 2011–2017

In recent years, key NZUA safety messages have included promoting diver safety through a dive flag promotion. Their “Fly The Flag” video on YouTube has been viewed 56,000 times, plus receiving a further 110,000 impressions. Males aged 25 to 54 responded best to the promotion, representing almost 50% of all views, and viewers’ commentary/engagement exceeded expectations. For the Fly the Flag campaign, a small budget was allocated to high-interest sites, such as MetService.com, marine news on Stuff.co.nz, and NZHerald.co.nz. The audience was highly targeted for optimized ad relevance, which ensured that the people most likely to be influenced were reached. More than 1,200,000 ad impressions were delivered during the summer campaign. The “Fly the Flag” video was deployed on the YouTube network to a similarly targeted audience of divers, spearfishing enthusiasts, open water swimmers, and skippers of recreational vessels. This execution is viewed as the most successful component of the Fly The Flag campaign to date, delivering a view rate greater than 70% in the target audience, for a total of 71,000 views. This figure takes total video views for “Fly the Flag” to 127,000. The video can be viewed at <https://www.youtube.com/watch?v=VV0qXWpdU0g>.

NZUA also encouraged people, particularly males over 40, to get a fitness-to-dive medical check before engaging in dive activity. The Get Tested – Fit to Dive! project is a behavioral change campaign

currently underway and managed by NZUA to ensure that males aged 45 and over engage in routine health checks before scuba diving, freediving, spearfishing, or snorkeling, particularly if they’re returning to underwater activities after a hiatus. The primary issues addressed in the campaign include heart health and general health and fitness. The promotion had 14,000 views on Facebook. The associated “Get Tested – Fit to Dive!” video garnered 212,544 impressions from 74,000 individuals. Total video views exceeded 86,000. As with the Fly the Flag campaign, a budget was allocated for placements on high-interest sites, such as [MetService.com](http://MetService.com), marine news on [Stuff.co.nz](http://Stuff.co.nz), and [NZHerald.co.nz](http://NZHerald.co.nz), as well as the wider web display network in NZ. The target audience was more compact than for Fly the Flag, as it focused on divers over the age of 45. Regardless, the campaign achieved 4,129,175 impressions, making it the largest campaign in recent NZUA history. Indeed, it is probably the most successful of all time. The “Get Tested – Fit to Dive!” video was also deployed on YouTube, likewise to an audience of older divers. While not as successful in this format as “Fly the Flag,” this video still enjoyed more than 17,000 30-second views. Combined with Facebook, this resulted in a total of 103,000 video views. This video can be viewed at <https://www.youtube.com/watch?v=ELZTKVlfC2c>.

## COMHAIRLE FO-THUINN - IRISH UNDERWATER COUNCIL

### RAY YEATES

Comhairle Fo-Thuinn (CFT), also known as the Irish Underwater Council (IUC), is recognized by Sport Ireland as the national governing body for recreational diving and underwater sports in the Republic of Ireland. It was founded in 1963 and is the Irish representative to the Confédération Mondiale des Activités Subaquatiques (CMAS), with affiliations on the Sports, Technical, and Scientific Committees. CFT-IUC is also a member of CMAS Europe and of the European Underwater Federation. CFT-IUC is both a supporter and a member of the National Steering Group of the Marine Conservation

Society's Seasearch program, which seeks to gather information on seabed habitats and associated marine wildlife in Britain and Ireland, through the participation of volunteer recreational divers.

CFT-IUC organizes and promotes recreational scuba diving and snorkeling via a federation of independent clubs. It is administered by an executive committee that is supported by the following four commissions: a Technical Commission, which sets standards and tests for diving courses offered by its memberclubs; a Medical Commission, which advises on diving medical standards and treatment of diving medical conditions and monitors developments in hyperbaric medicine; a Sporting Commission, which organizes underwater sports and photographic events and an event known as the national gala; and a Scientific Commission, which promotes underwater biology and archaeology. Its membership, consisting of both clubs and individuals, as of 2018 numbered approximately 2,000 members. While the majority of its activities are in the Republic of Ireland, a small number of members and clubs are located in Northern Ireland. The organization is incorporated as a guarantee company without share capital (the Irish term for a nonprofit) under the name Comhairle Fo-Thuinn – Irish Underwater Council. The organization also uses the brand Diving Ireland and the URL [www.diving.ie](http://www.diving.ie).

Some of the other activities the organization is involved in include the following:

- Organizing the annual Dive Ireland show;
- Serving as a member of the British Diving Safety Group;
- Providing 8 regional search and recovery units for the Irish Coastguard; and
- Conducting Seasearch marine surveys.

While the CFT-IUC does not maintain diving datasets for analysis, some significant figures include the following:

- There are an estimated 3,000 recreational divers in Ireland (including members of PADI, BSAC, etc.).
- Around 2,000 are members of the national body (i.e., CFT-IUC members).
- Ireland has approximately 12 dive shops countrywide.
- There are about 400 diving certifications issued per year in Ireland.
- Diving fatalities are very rare in Ireland; for example, there have been none for past 3 years.
- There are, on average, around 25 diving incidents per year reported to CFT-IUC.
- There are 2 or 3 cases of decompression sickness treated in Ireland per year.
- Similarly, there are 2 or 3 divers rescued per year in Ireland.
- All wrecks in Irish waters that are 100 years old or more are protected by the state.
- There are more than 1,000 known wrecks, but the number of permits obtained each year by divers to access marine reserves or shipwrecks is not known in Ireland because permits are free.

## UNDERWATER COUNCIL OF BRITISH COLUMBIA (UCBC)

SCOTT C. MEIXNER

The Underwater Council of British Columbia (UCBC) is a nonprofit society formed to represent the recreational diving community and to promote diver safety and environmental protection. It is UCBC's mandate to act as a unified voice for recreational divers in government consultations, land use proposals, and any community issues that arise which may affect safety and access to dive sites.

Since its inception in 1996, UCBC has been managed by a diverse team of people spanning many disciplines, from doctors and engineers to scientists and students, all of them recreational divers.

Many of our initiatives require collaboration among diverse and sometimes conflicting groups of people, which often puts UCBC in the role of mediator or facilitator. The ability to bring the dive community together to secure funding and resolve issues is our greatest strength.

The ebb and flow of the years has brought many projects to UCBC, but our core values and endeavors remain the same. Promoting safe recreational diving through education and accessibility is paramount among our goals.

## FATALITY REPORTING

Although recreational diving fatalities are rare in British Columbia, when they do occur they shake our tight-knit local dive communities. Often the decedent's family and friends, and the dive community at large, have questions that are not easily answered by news reports. In addition to welcoming general questions and discussion surrounding fatalities, UCBC maintains a relationship with the BC Coroners Service to produce public reports for use in education.

UCBC's fatality reports cover all diving fatalities that have occurred in the province since 1985. Following a dive fatality, the official coroner's report is released to UCBC's safety officer. The

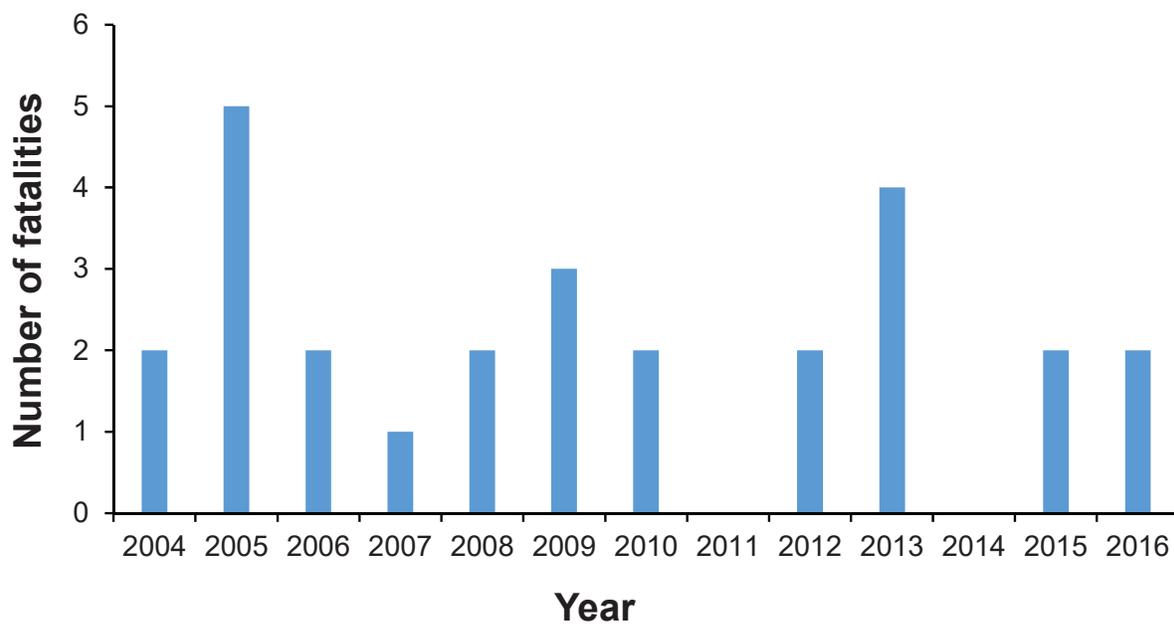


Figure A-4. Distribution by year of recreational diving fatalities in British Columbia from 2004–2016

Medical issue	n (%)
No known medical issue	10 (32)
Hypertension	5 (16)
Migraine	4 (13)
Back pain	4 (13)
Asthma	3 (10)
Previous decompression sickness	3 (10)
Ear/sinus problems	2 (6)

Table A-4. Medical histories of BC divers diagnosed with decompression sickness at Vancouver General Hospital from 1996–2008 (n=31)

report is then summarized and stripped of all personal information relating to the victim and witnesses, leaving only the facts of the incident. The result is a concise description of the events leading up to the fatality, which serves as a valuable tool and often a sobering reminder of what can go wrong on a dive. Figure A-4 shows the number of diving fatalities in BC by year. Between 2004 and 2016, there were, on average, two recreational diving fatalities per year. This is nearly half the average annual number of diving fatalities reported between 1996 and 2008, during which time there were 50 in total, an average of 3.8 per year (although that number likely included commercial and scientific divers, too, whereas Figure A-4 presents only recreational diving fatalities).

In addition to regular fatality reporting, the Abacus Project, produced by UCBC and published in 2002 in both the *South Pacific Underwater Medicine Society Journal* and the *Undersea and Hyperbaric Medicine Journal*, represents a pioneering study relating diver fatalities to the overall number of dives in British Columbia.<sup>1,2</sup> This report quantified air fills supplied throughout the province over 14 months, the number of nonfatal hyperbaric treatments given to divers in BC over the same period, and the number of diving fatalities. Unfortunately, on average, only 65% of the fill stations reported numbers of air fills; therefore, the risk estimated based on these figures is likely greater than the risk that divers face in reality, but the results were nonetheless encouraging. The risk of decompression illness was estimated at 10 cases per 100,000 dives, and the risk of death at 2 per 100,000 dives.

Between 1996 and 2008, inclusive, there were 51 known cases of decompression sickness originating in BC; 31 of those (61%) were treated at Vancouver General Hospital. The medical histories of those 31 divers are shown in Table A-4.

Seven of the 31 divers (23%) reported engaging in strenuous activity during the dive, and five (16%) reported doing so immediately following the dive. Medications taken by the divers included antidepressants (n=4), decongestants (n=3), antihypertensives (n=2), lipid-lowering drugs (n=2), and a bronchodilator (n=1). Notable adverse conditions during the dives included cold water (n=10), currents (n=4), and rough water (n=4). The majority of the divers (n=28, 90%) wore drysuits, and 3 (10%) wore wetsuits. The breathing gases used included trimix (n=4), nitrox (n=6), and air (n=21). Problems reported during the dives included rapid ascent (n=8), heavy exertion (n=7), a long surface swim (n=7), cold (n=5), ear problems (n=3), an equipment malfunction (n=2), a missed decompression stop (n=2), and running out of air (n=1).

## DAN IN BC

Historically, the dive community in BC has had strong links with DAN. More than 60 instructors have taught DAN courses in BC, ensuring that the community is prepared to provide first aid and oxygen first aid to injured divers. There are currently more than 100 DAN courses offered in BC each year, by more than a dozen active DAN instructors.

## WEIGHT REPLACEMENT PROGRAM

An analysis of local fatality reports over the past two decades has clearly shown a common theme: that a failure to abandon dive weights during emergencies is associated with dive fatalities. In an attempt to address this issue, UCBC developed a Weight Replacement Program through which UCBC will replace the lost weights of any local diver who drops their weights in an emergency situation.

Through this program, we stress the importance of education about and awareness of dropping weights to establish positive buoyancy on the surface. In many fatal incidents, the diver made

it to the surface after the initial emergency but was unable to establish positive buoyancy and sank back underwater. Diving weights are all designed with a quick release mechanism in mind, but it is each diver's own responsibility to become familiarized with the workings of their own system and to practice ditching their weights regularly. Although ditching diving weights at depth can potentially be hazardous, divers should not hesitate to ditch their weights during a dive emergency upon surfacing. Ensuring that a diver has positive buoyancy on the surface is the first priority in all emergencies, and dropping one's weight system is generally the most effective and easiest way to do so.

Requests to replace lost weights are accepted from certified divers who are current residents of British Columbia. Weights will be replaced at no cost to the individual, but an anonymous report is requested for educational purposes, detailing the events and conditions that led to the emergency situation.

### MOORING BUOY PROGRAM

In addition to UCBC's direct safety initiatives, our flagship program makes diving safer through the placement of mooring buoys on commonly dived reefs. The cold, dark waters of the Canadian Pacific can be intimidating, particularly for less experienced divers. The presence of a permanent mooring provides a stable line to the bottom for controlled descents and ascents, as well as something to hold on to during safety stops. The mooring buoys offer the added benefits of providing a secure topside connection for boats, so operators do not risk collisions with divers, and of protecting reefs from repeated anchor damage. Additionally, UCBC mooring buoy sites have become focal points for creating rockfish conservation areas. These sites not only protect divers, but they protect the fish and habitat that divers treasure.

In 2018, the UCBC Mooring Buoy Program entered an exciting new phase. The discovery at recreational diving depths of ancient glass sponge bioherms has presented an

unprecedented opportunity for scientific study, tourism, and diving experiences. These amazing sites, unique in all the world, are mountains of glass sponge, beginning at a depth of 82 feet (25 meters) and dropping precipitously to the ocean floor. As these sites are located in open water, are often subject to strong currents, and are inherently disorienting, extreme care and planning must be used when diving them. Couple these factors with the fragile structure of the sponge, and a mooring buoy becomes almost essential.

After years of planning, lobbying, and fundraising, UCBC has just completed the first phase of mooring buoy installation at one glass sponge bioherm site, utilizing 4 anchor points drilled into rock at a depth of 75 feet (23 meters). When complete, this mooring will provide recreational divers and scientific study teams with consistent, safe access to the site, while eliminating the need for sponge-damaging drop lines.

Furthermore, UCBC has assisted with developing a Bioherm Sponge Diver specialty course. Focusing on glass sponge biology and techniques for safely diving these advanced sites, this course will be required for anyone who visits the site via a dive charter. Proper buoyancy control and safe descent/ascent methods are key components of the course and skills that must be mastered before diving the bioherm.

### THE FUTURE

With the high-profile installation of the glass sponge mooring buoy, there is a renewed interest in UCBC, and we have experienced an influx of young, ambitious volunteers. Moving forward, we plan to expand our mooring buoy program throughout British Columbia and continue to lobby for protection of surrounding reefs. Fatality reporting will continue, with greater detail, thanks to recent connections made with local hyperbaric facilities. Citizen science and education will be the focus of the coming years, especially ongoing monitoring of fish populations, habitat damage, and the safety of diving in BC.

## ACKNOWLEDGEMENTS

Thanks are given to Dr. David Harrison from Vancouver General Hospital and Sherri Ferguson, director of the Environmental Medicine and Physiology Unit in the Faculty of Science at Simon Fraser University, for supplying historical numbers of decompression sickness-related fatalities and treatments, and to Patty Seery for compiling the figures on DAN instructors in BC.

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# APPENDIX B. DAN OPERATIONAL SAFETY PROGRAMS

FRANÇOIS BURMAN

## PART 1: HAZARD IDENTIFICATION, RISK ASSESSMENT AND RISK MITIGATION

### THE DAN HIRA INITIATIVE: PROMOTING A CULTURE OF SAFETY AT DIVE BUSINESSES

#### INTRODUCTION

Dive businesses and professionals are the gateway to diving for most recreational divers. The services these businesses and individuals provide directly impact the safety of divers.

DAN and dive businesses share a common interest in the safety of divers. While its primary mission is to assist injured recreational divers, DAN's vision is to make every dive injury-free. Without identifying and mitigating the risks associated with diving operations, this would not be possible. Preventing injuries and losses from happening requires a culture that generates awareness, control, and, ultimately, mitigation of health and safety risks.

So how does one create, promote, and then build such a prevention-oriented program?

After much deliberation and engagement with our dive-industry partners, DAN established a Hazard Identification and Risk Assessment (HIRA) initiative and formulated the following overall objectives:

- To provide risk and safety awareness education to all participants
- To offer guidance in risk mitigation and control based on actual operational aspects of businesses
- To initiate and then grow participation among dive service providers
- To monitor incidents to continually assess the status of progress toward our vision

Achieving these objectives requires inclusion and cooperation at all levels, primarily through the empowerment of facilities to understand and then accept their responsibilities regarding safety.

Before describing the process, it is important to state that DAN is not a regulatory agency. We are not the “scuba police”; we believe the best way to promote a culture of dive safety is through positive, mutually beneficial engagement with all parties involved. DAN will only engage in this process when specifically invited to do so by a dive business. This is crucial for engagement on a voluntary basis.

## THE PROCESS: THE DAN HAZARD IDENTIFICATION AND RISK ASSESSMENT (HIRA) PROGRAM

DAN's 16 years of experience with the Recompression Chamber Assistance Program (RCAP, described on the overleaf in Part 2 of Appendix B) has clearly shown that there is great value in providing a structured, methodical, and consistent process of developing a culture of safety. The DAN Risk Assessment Guide for Recompression Chambers, available in multiple languages and used around the diving world, has been instrumental in this regard.

The same concept is extended to dive businesses by means of a structured, documented process — the DAN Risk Assessment Guide for Dive Operators and Professionals. The guide offers a means for realistically assessing actual operational hazards and safety solutions, covering the whole spectrum of dive businesses' activities — from the welcome to the water. The focus is on identifying real and present risks — not theoretical or superficial ones. We refer to this as identifying the potential hazards.

We follow this identification with a risk assessment using practical measurement tools and resources to quantify the risks. In addition to obvious elements, such as compressed-air quality testing, we also address less-familiar concerns, such as the assessment of harmful environmental noise exposure and the provision of safe, adequate lighting.

Risk mitigation is the next step. The source of the risk should be clearly identified and isolated so it can then be addressed in a meaningful way. There is a tiered approach to any risk associated with an interface between humans and technology. The options for risk-mitigation begin with efforts to eliminate risks at the source using some technical or engineering intervention, such as a barrier. If this is not feasible, then operational methods are employed. Instruction through policies or procedures (direction on proper ladder use, for example) can be implemented to reduce the risks associated with interacting with potential hazards. If neither of these actions is possible, then physical protection is required — supplying hearing protection to compressor workers, for example.

As with any program, monitoring and measurement are required to confirm its effectiveness. Regular review allows for feedback on the success of the risk assessment and the mitigation steps over time and for their application to a wider range of operational situations. For the purpose of establishing a lasting safety culture, however, personal, on-site discussion with dive-business staff is required; all parties need to appreciate the risks and agree to the various mitigation and monitoring strategies.

## TOOLS

In the actual implementation of a risk-mitigation strategy, there are two primary concepts that need to be established.

First, we must determine the critical control points — the main sources of the hazards — so we can be sure to address the root causes and plan for routine safety assessments and interventions to ensure optimal risk reduction.

Second, not all risks are of the same magnitude. A risk-measurement system focuses the priorities of a business and provides some degree of assurance that resources and efforts will be directed appropriately, where they will have the most impact.

The assessment tool is encapsulated in an accepted definition of the term risk: the probability that the exposure to a hazard will lead to negative consequences.

Through such an assessment, we can consider all the potential hazards and then determine the likelihood that people, facilities, or equipment could actually be exposed to these hazards and also determine whether the potential damage would be severe (i.e., unacceptable) or not. This turns the theory into practice; it allows us to distinguish the significant issues from those that can be dealt with later or disregarded.

The concepts of probability, exposure, and consequence can all be quantified using a relatively simple Likert 1-to-5 scale. The actual risk is then scored by multiplying these three scores by each other and presenting them in a risk score table.

Risk score	Risk level	Rating	Description
> 100	5	Very High	Attention and risk mitigation are critical and must be given highest priority. A potentially dangerous situation may exist, with the possibility of very serious or catastrophic consequences in the event of an adverse incident. The activity should stop immediately until effective mitigation is in place.
50 – 100	4	High	Attention and risk mitigation are required and must be given high priority. This risk represents a serious situation that could endanger people or equipment or seriously disrupt or jeopardize the business. Various solutions or actions may mitigate the risk, and they should be recorded in writing.
20 – 50	3	Medium	Attention to the risk is required. Eventual exposure to this risk could result in an incident. Outcomes could include business disruption, financial or liability consequences, injuries, or equipment damage. Mitigation of the risk should be accomplished within practical time and cost considerations.
5 – 20	2	Low	Attention to the risk is recommended for the optimal functioning of the dive operation. Risk mitigation steps already in place should be recorded in writing.
< 5	1	Very Low	The risk is acceptable. Note should be taken of the risk, but either it has already been suitably mitigated or its impact is of justifiably low significance.

Table B-1. Risk score table

## ADHERENCE TO REGULATIONS

All businesses have an obligation to provide a safe working environment and to protect the health and safety of their employees and clients. Each country has a defined occupational health and safety regimen captured in a series of written instructions. Statutory and industry-regulating documents vary depending on national, local, and industry-specific requirements. It is essential that all businesses know which of these apply to them and what their relevant responsibilities are.

Regulations concerning the following issues typically apply to the recreational diving industry:

- Health and safety at work;
- Occupational noise exposure;
- Personal protective equipment (PPE);
- Fire protection;
- Exposure to hazardous substances;
- Medical services and first aid;
- Compressed gas and equipment;
- Electrical safeguards;
- Requirements for recreational diving instructors and diving guides;
- Compensation for occupational injuries and illnesses;
- Safe operation of machinery;

- Minimum hygiene requirements (ventilation, lighting, restrooms, etc.);
- Boating, including boat safety and registration and requirements for the use of boats;
- Public health and safety, including requirements for compressed air used for breathing;
- Marine parks, sanctuaries, beaches, and protected and ecologically sensitive areas; and
- Employment and labor relations.

There are many additional documents that provide guidance, instruction, and recommendations regarding gas cylinder valves, cylinder markings, medical gas cylinders, equipment testing, cylinder filling requirements, and more.

## PARTICIPATION

Encouraging a dive business to join the program and educate its staff in the process of risk assessment and mitigation requires a progressive series of stages. Each stage involves an online self-assessment, specifically designed to be uncluttered and to include basic safety considerations.

The first, known as HIRA Level 1, focuses on training and on acquiring the associated emergency response equipment. The ability to provide appropriate support in the event of basic diving-related injuries, together with having the necessary equipment, is a fundamental starting point. Essential standard operating procedures (SOPs) and emergency action plans (EAPs) need to be in place and be followed. An online checklist provides specific details of the requirements and can be completed simply with yes or no responses (see <https://www.diversalertnetwork.org/member/hira/>).

HIRA Level 2 commences after completion of Level 1. The business provides instructor-level emergency training to providers, together with a greatly expanded list of EAPs. Every business is different, and some may offer other activities in addition to diving. Unique EAPs are developed, documented, and checked for each activity. Most importantly, all EAPs need to be drilled. Once again, yes or no responses are recorded based on the selected applicable elements of the business.

The final stage is HIRA Level 3. After Level 2, the business mitigates assessed risks across the entire diving operation. The online tool noted above is a comprehensive Risk Assessment Guide for Dive Operators and Professionals, a step-by-step approach intended to address the realistic risks that face any dive operator or dive professional.

While Level 1 is essentially an assessment of fundamentally important safety aspects of the business, Levels 2 and 3 represent significant increases in preparedness planning. Level 3 is detailed enough that some dive businesses may need to request additional education and assistance from DAN. The essential resource we can offer is on-site education provided by a formally trained and experienced DAN Dive Safety Advisor (DSA). While the operator continues with self-assessment, the on-site visit encompasses more detailed education about the process. The final outcome at Level 3 should be the knowledge by the dive business that it has done everything realistically possible to mitigate all the likely risks present in its operation.

## OPERATIONAL CONSIDERATIONS

Every business is different. All dive professionals will have their own way of instructing and managing safety. Both the business and the professional will need to determine the applicable parts of the HIRA process.

Essential aspects include the following:

- Staff health and safety (this concern applies even to the individual professional);
- Client health and safety; and
- Staff training and certification.

Other potentially applicable areas may include the following:

- Training pool area;
- Training room;
- Dive retail shop;
- Diving and diving boat operations;
- Compressor and tank filling area;
- Equipment storage area;
- Small instrument workshop;
- Vehicle safety; and
- Travel and health advice for clients.

## DAN'S EXPERIENCE

Field visits commenced in 2013 and have continued steadily since. To date, we have assessed more than 50 dive businesses around the world. The information gathered from these assessments has facilitated further development of the Risk Assessment Guide. Through exposure to a significant range of varied businesses, the program has now become more refined and comprehensive.

The HIRA process is an established practice in many industries; the DAN HIRA program is tailored to recreational diving and its associated activities. The process provides the dive operator with a self-assessment tool and recommended mitigating actions. The ultimate intention is for the DAN HIRA process to become the dive industry standard for developing safety awareness and ensuring safe dive operations.

## PART 2: THE DAN RECOMPRESSION CHAMBER ASSISTANCE PROGRAM (RCAP)

### RISK MITIGATION OF RECOMPRESSION CHAMBERS

Recompression facilities, especially those located in remote areas and thus commonly underutilized, are often lacking adequate staff, training, and funding and essential maintenance. This impacts directly on their availability and reliability and, most importantly, on the safety of the services they offer.

Treatment in a recompression chamber is often essential for divers with decompression illnesses. Injured divers and emergency medical services expect DAN to refer them to the nearest facility that has the appropriate capabilities to treat such a condition.

Dive medicine physicians frequently make use of recompression chambers without fully realizing their legal and ethical responsibilities toward the safety of their patients and the chamber's staff. Few dive medicine physicians have specific training in the technical or operational aspects of these facilities; this deficiency is exacerbated when recompression chambers are established in remote areas.

Similarly, emergency service physicians and medical personnel frequently refer patients to these facilities with little or no knowledge of their capabilities and the quality of the services they offer, nor even of the reliability and safety of these medical treatment units.

Most current regulatory, manufacturing, safety, and operational guidance documents are not flexible enough to be applied universally, nor do they offer practical guidance on the recognition and the mitigation of the unique and relevant risks at a given facility. The goal of integrated safety is rarely achieved.

The Risk Assessment Guide for Recompression Facilities,<sup>1</sup> for use in assessing chambers intended for the treatment of injured scuba divers, was developed by DAN as a tool to qualify the actual safety status of a hyperbaric facility and to offer guidance on how to improve and maintain such facilities. This risk assessment guide (RAG) has been implemented in the

field over the past 18 years, and a retrospective analysis of the most common safety concerns was conducted in 2013.<sup>2</sup>

In 1993, DAN established the Recompression Chamber Assistance Program (RCAP), a dedicated outreach program created to assist qualifying facilities to be able to offer safe and effective recompression treatments. Since 2000, DAN has assessed chambers that could potentially treat injured divers, using the RAG noted above. These have been predominately, but not exclusively, located in more remote areas.

A detailed retrospective analysis of the data obtained in the field, specifically from risk assessment reports following the RAG, was performed to 1) identify the most common safety concerns affecting facility status as identified by the RAG; 2) use the data derived from the analysis to produce a predictive model of likely safety status for unassessed facilities; and 3) consolidate the results in the form of specific recommendations to improve and maintain facilities' safety status.

Data collected from the consistent application of the RAG over a period of 13 years, covering 105 applicable facilities, was analyzed by means of a consolidated Risk Assessment Score (RAS) to determine the common safety concerns. The resulting RAS values permitted comparisons among all the facilities assessed over that period.

The data from the assessed chambers, especially the consolidated RAS figures, were further analyzed against a range of 12 associated factors, including location, year of assessment, referral rating, operating age, type of treatment protocol, type of chamber, availability, utilization, reliability, sustainability, medical supervision, and, finally, staff training.

The correlation of nine of these factors against the safety status of each facility, as represented by its RAS, proved to be significant.

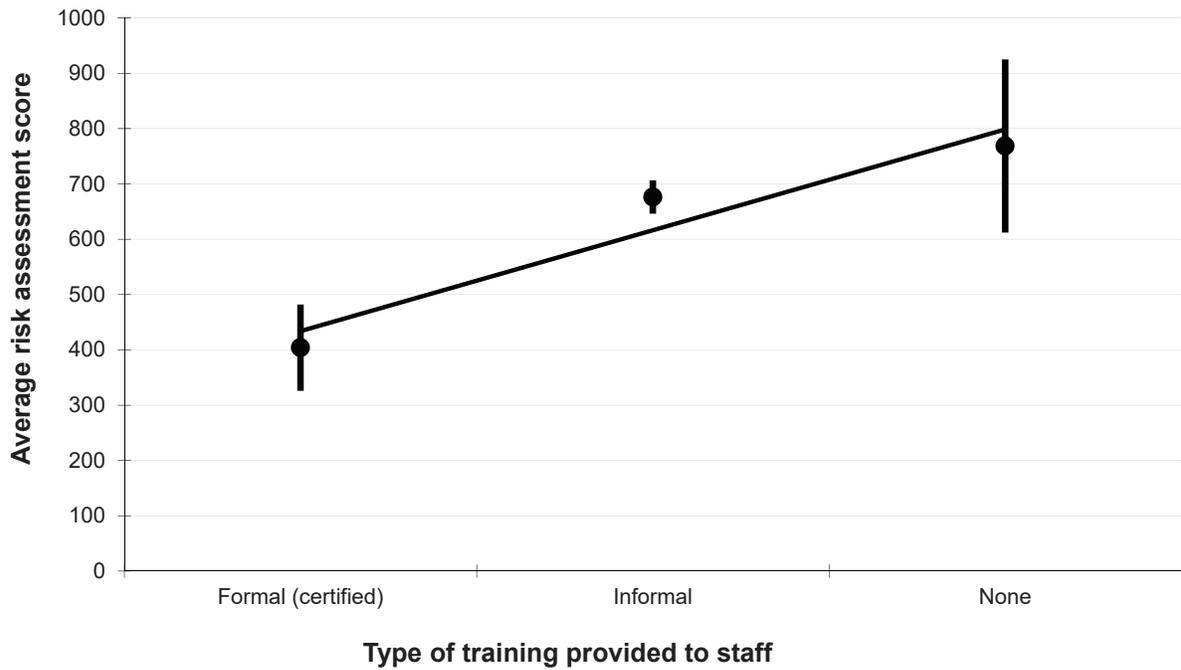


Figure B-1. Average risk assessment scores of recompression chambers (with 95% confidence intervals) by type of staff training

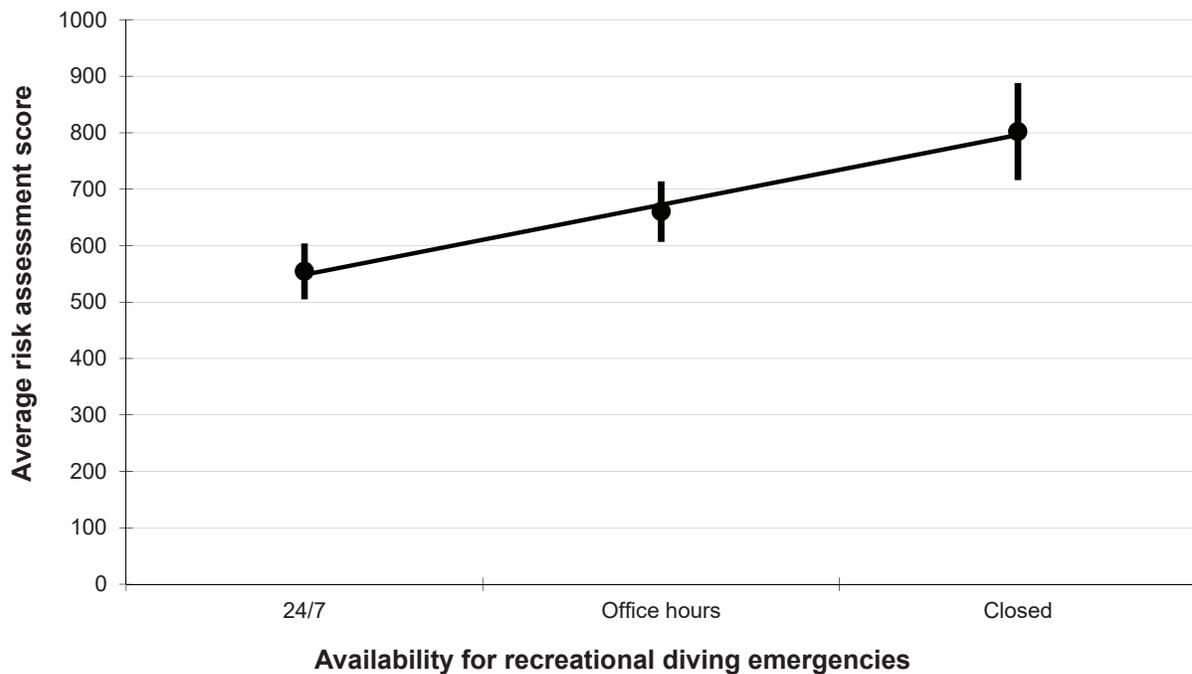


Figure B-2. Average risk assessment scores of recompression chambers (with 95% confidence intervals) by chamber availability

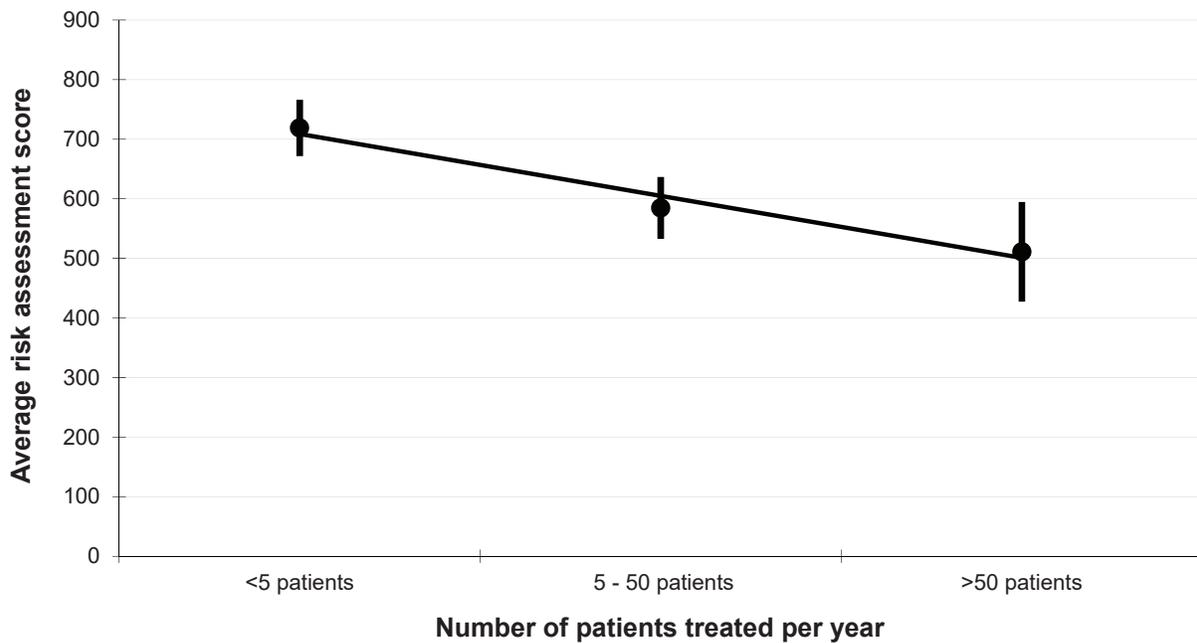


Figure B-3. Average risk assessment scores of recompression chambers (with 95% confidence intervals) by number of patients treated annually

Regression analysis determined that four of these factors could be used to predict the RAS of an unknown chamber. These included the type of chamber (monoplace or multiplace), its utilization (number of treatments per year), the training its staff had received, and its availability (operating hours).

Figures B-1, B-2, and B-3 illustrate the variation in safety scores when correlated against selected associated factors.

The conclusions of this project were 1) that the DAN RAG is an appropriate tool to assess recompression chamber facilities for risk elements relevant to their safety status, while simultaneously filling knowledge gaps to enable a facility to improve and/or maintain its level of safety and 2) that predictions of potential safety at unknown facilities can be made to provide medical practitioners with the necessary information regarding whether a given facility is appropriate for patient referral.

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Razdan P. Studying Deep Reefs and Deep Divers. *Alert Diver*. 2017;33(1):22-24.

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Smith F, Joseph J. Prepare for Safe Dive Travel. *Alert Diver*. 2017;33(4):64-65.

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Nochetto M. Possible *Mycobacterium marinum* infection. *Alert Diver*. 2017;33(4):66-67.

Smith F. Who to Call First: DAN or EMS? *Alert Diver*. 2017;33(4):69.

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Smith F. Diving after dental extraction. *Alert Diver*. 2017;33(3):57.

Smith S. Would a pulse oximeter help an injured diver? *Alert Diver*. 2017;33(3):58.

Pollock NW. What is "oxygen ear"? *Alert Diver*. 2017;33(3):56-57.

Pollock NW. Is dehydration the No. 1 cause of DCS? *Alert Diver*. 2017;33(3):57.

## ABSTRACTS

Buzzacott P, Chimiak J, Nochetto M, Denoble PJ. Paediatric Scuba-related Morbidity at U.S. Emergency Departments. *Ann Epidemiol*. 2017;27(8):539.

## DAN TRAINING MATERIALS

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Seery P, editor. Emergency Oxygen for Scuba Diving Injuries. ; v 2.1. Durham (NC): DAN. 2017.

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Seery P, editor. First Aid for Hazardous Marine Life Injuries. v 2.1. Durham (NC): DAN. 2017.

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Seery P. Examiner Handbook. v 2.1. Durham (NC): DAN. 2017.

## APPENDIX D. PRESENTATIONS (2017)

JEANETTE P. MOORE

Burman F. International ATMO Safety Director, Acrylics and Hyperbaric Facility Maintenance courses. San Antonio (TX). January 16–21, 2017.

Buzzacott P. Hazards Associated with Diving and Epidemiology of Diving Injuries. DAN Weekly Medical Lecture Series. Durham (NC). January 18, 2017.

Burman F. Assessing the Safety of Diver Recompression Chamber Facilities. Medicine of Diving 2017. Divi Flamingo Beach Resort, Bonaire, Dutch Caribbean. January 29–February 3, 2017.

Burman F. IDAN — International ATMO. Simon Fraser University, Vancouver (Canada). February 10–13, 2017.

Buzzacott P. Technical and Mixed Gas Diving. DAN Weekly Medical Lecture Series. Durham (NC). February 23, 2017.

Seery P. Instructor Trainer Workshop for NAUI. Our World Underwater. Chicago (IL). February 25, 2017.

Seery P. 2017 Instructor/Instructor Trainer Updates. Our World Underwater. Chicago (IL). February 25, 2017.

Buzzacott P. Our World Underwater. Chicago, IL. February 25, 2017:  
Non-Fatal Close Calls and Lessons Learned from Scuba Diving Incidents  
Trends in Recreational Diving Injuries and Fatalities  
Hazards of Underwater Photography  
Prepared Diver Program, with Rachelle Deal.

Nochetto M. Our World Underwater Show. Chicago (IL). February 26, 2017:

Delta P & Barotraumas

Harvesting Your Own Seafood? What you need to know about seafood safety

Recompression Therapy: One does not just squeeze bubbles

Operational Gas Toxicities

Buzzacott, P. Divers Alert Network Pre-Existing Medical Conditions Project. Gillings School of Global Health, UNC Chapel Hill. March 3, 2017.

Buzzacott P. Aging, diving, death and DCS. North Shore Frogmen, Palmer Yacht Club, Danvers (MA). Thursday March 9, 2017.

Buzzacott P. Injury Prevention Research. MIT Scuba Club, Massachusetts Institute of Technology, Boston (MA). Friday March 10, 2017.

Buzzacott P. Non-Fatal Close Calls & Lessons Learned from Scuba Diving Incidents. Hilton Doubletree, Danvers (MA). March 11, 2017.

Buzzacott P. Hazards of Underwater Photography. NOAA Beaufort Lab, Pivers Island (NC). March 24, 2017.

Seery P. 2017 Instructor/Instructor Trainer Workshop for NAUI. Beneath the Sea. Secaucus (NJ). March 25, 2017.

Seery P. 2017 Instructor/Instructor Trainer Update. Beneath the Sea. Secaucus (NJ). March 25, 2017.

Buzzacott P. Hazards of Underwater Photography. DAN Public Lecture Series, Durham (NC). April 5, 2017

Buzzacott P. Hazards of Underwater Photography. Richmond Dive Club, O'Toole's Restaurant, Richmond (VA). April 5, 2017.

Buzzacott P. Non-fatal incidents and lessons learned. Dive Tech Scuba Club, Bricks 'n Barrels Restaurant, Charleston (WV). April 11, 2017.

Buzzacott P. Non-fatal incidents and lessons learned. Western Illinois University, Macomb (IL). April 12, 2017.

Buzzacott P. The frontier of decompression science (and tips for safety). Joint meeting of the Four Lakes Scuba Club and the University of Wisconsin Hoofers, at University of Wisconsin, Madison (WI). April 12, 2017.

Burman F. Analyzing & Modifying Medical Equipment: Risk Assessment & Mitigation. International Congress of Hyperbaric Medicine. Belgrade (Serbia). April 14, 2017..

Seery P. Instructor/Instructor Trainer Workshop for NAUI. Long Beach Dive Show. San Diego (CA). May 19, 2017.

Seery P. 2017 Instructor/Instructor Trainer Update. Long Beach Dive Show, Long Beach (CA). May 19, 2017.

- Seery P. Instructor/Instructor Trainer Workshop for NAUI. Baton Rouge (LA). May 19, 2017.
- Seery P. Instructor/Instructor Trainer Workshop for NAUI. Tampa (FL). May 23, 2017.
- Buzzacott P. Aging, diving, death and DCS. San Diego Dive Club, San Diego (CA). June 1, 2017.
- Buzzacott P. DAN Breath-hold data. University of California, San Diego, breath-hold diving colloquium. San Diego (CA). June 2-3, 2017.
- Burman F. International ATMO Safety Director, Acrylics and Hyperbaric Facility Maintenance courses. San Antonio (TX). June 12-17, 2017.
- Buzzacott P. Aging, diving, death and DCS. Villages Dive Club. Villages (FL).. June 27, 2017.
- Buzzacott P. Epidemiology of morbidity and mortality in US and Canadian recreational scuba diving (poster and oral presentation). 2017 Undersea and Hyperbaric Medicine Society Annual Scientific Meeting. Naples (FL). June 28-July 1, 2017.
- Buzzacott P, Chimiak J. Acral peeling skin syndrome (APSS) in a recreational diver. 2017 Undersea and Hyperbaric Medicine Society Annual Scientific Meeting. Naples (FL). June 28-July 1, 2017.
- Burman F. Hyperbaric Facility Safety Management, Gozo (Malta). July 12, 2017
- Chimiak J. Diving injury first response. Coast Guard Sector. North Carolina. July 24, 2017.
- Buzzacott P. Morbidity and mortality among children divers in the US. Chinese Diving and Hyperbaric Medicine ASM. Lake Fuxian (China). July 28, 2017.
- Seery P. Instructor/Instructor Trainer Workshop for DAN. Johannesburg (South Africa). August 1-2, 2017.
- Seery P. Instructor/Instructor Trainer Workshop for NAUI. Johannesburg (South Africa). August 3-4, 2017.
- Burman F. International ATMO Safety Director, Acrylics and Hyperbaric Facility Maintenance courses. San Antonio (TX). September 8-23, 2017.
- Buzzacott P, Chimiak J, Nochetto M, Denoble PJ. Paediatric scuba-related morbidity at U.S. emergency departments (oral presentation). Proceedings of the European Undersea and Baromedical Society 43rd annual scientific meeting, Ravenna (Italy). September 13-17, 2017.
- Chimiak J. Diving Medicine. Wilderness Medicine Seminar. September 22, 2017.
- Buzzacott P, Chimiak J, Nochetto M, Denoble PJ. Paediatric scuba-related morbidity at U.S. emergency departments (poster). Proceedings of the American College of Epidemiology 35th annual scientific meeting, New Orleans (LA). September 24-26, 2017.
- Sorrell L. Medical Preparedness & First Aid for Cruisers. TrawlerFest. Bay Bridge (MD). September 26, 2017.

Sorrell L. Challenges in diagnosing DCS (webinar). Blue Dolphins Skin Diving Club. Erie (PA). October 11, 2017.

Chimiak J. First aid for boaters and cruisers. University of Annapolis. Annapolis (MD). October 17, 2017.

Smith F. Emergency Medicine at Sea. Fall Rendezvous sponsored by the American Great Loop Cruisers Association. Rogersville (AL). October 18, 2017.

Burman, F. Merida Diplomate Course. Yucatan (Mexico). October 20-21, 2017:

- Introduction: facility safety management
- Medical gases & delivery systems
- Q&A Accreditation of hyperbaric facilities
- Safety management of hyperbaric facilities, part 1
- Safety management of hyperbaric facilities, part 2

Burman F. Recompression Chamber Assistance Program Safety Course, Cozumel (Mexico). October 23-25, 2017.

Burman, F. Equipment and Marketing Association (DEMA) Show 2017. Orlando (FL). November 1-4, 2017:

- DAN RCAP Initiative: a risk-based approach to recompression chamber safety
- Hazard identification and risk mitigation for dive professionals
- The safety improvement plan: a necessity for all dive businesses

Burman F, Nochetto M. Customizing your Emergency Action Plan. Diving Equipment and Marketing Association (DEMA) Show 2017. Orlando (FL). November 1-4, 2017.

Buzzacott P. Equipment and Marketing Association (DEMA) Show 2017. Orlando (FL). November 1-4, 2017:

- Frontiers of Decompression Research
- High altitude “fizziology” – diving in the clouds
- Lessons from the first 500 diving incident reports
- 30 Years of the DAN Annual Diving Report

Denoble P. Equipment and Marketing Association (DEMA) Show 2017. Orlando (FL). November 1-4, 2017:

- Guidelines for Field Management of Diving Injuries
- Project dive exploration results: the future of big data and dive safety research

Morgan S, Seery P. DAN First Aid Courses - Better preparation through blended learning. Equipment and Marketing Association (DEMA) Show 2017. Orlando (FL). November 1-4, 2017.

Nochetto M. Telemedicine for diving injuries – possibilities and limitations. Equipment and Marketing Association (DEMA) Show 2017. Orlando (FL). November 1-4, 2017.

Seery P. 2018 Instructor/Instructor Trainer Update. Instructor Training Workshop for DAN. Equipment and Marketing Association (DEMA) Show 2017. Orlando (FL). November 1-4, 2017.

## APPENDIX E. RECENT RESEARCH POSTERS

PETER BUZZACOTT

The following posters are included as examples of DAN research that may not necessarily end up published as full papers:

Buzzacott P, Bennett CM, Denoble PJ. Analysis of 500 self-reported recreational scuba diving incidents. Presented at the Undersea Hyperbaric Medicine Society Scientific Annual Scientific Meeting, Orlando (FL). June 28–30, 2018.

Buzzacott P, Grier JW, Walker J, Bennett CM, Denoble PJ. Estimated workload intensity during volunteer aquarium dives. Presented at the Undersea Hyperbaric Medicine Society Scientific Annual Scientific Meeting, Orlando (FL). June 28–30, 2018.

Kovacs C, Buzzacott P. Self-reported physical activity and perceptions of the importance of structured exercise in certified divers. Presented at the Undersea Hyperbaric Medicine Society Scientific Annual Scientific Meeting, Las Vegas (NV), June 9–11, 2016.

Buzzacott P, Sutton J, Denoble PJ. Cardiovascular risk factor prevalence among Australian recreational divers. Presented at the Tricontinental Scientific Meeting on Diving and Hyperbaric Medicine, Reunion Island (France). September 2013.

Buzzacott P, Pollock N, Rosenberg M. Exercise intensity inferred from air consumption during recreational scuba diving. Presented at the Tricontinental Scientific Meeting on Diving and Hyperbaric Medicine, Reunion Island (France). September 2013.

Denoble PJ, Nelson CL, Ranapurwala SI, Caruso JL. Prevalence of cardiomegaly and left ventricular hypertrophy in scuba diving and traffic accident victims. Presented at the Annual Scientific Meeting of the Undersea and Hyperbaric Medical Society, Orlando, (FL). June 12–15, 2013.

Denoble PJ, Vaithyanathan P, Vann RD. Annual diving fatality rates among insured DAN members. Presented at the Annual Scientific Meeting of the Undersea and Hyperbaric Medical Society, Salt Lake City (UT). June 18–27, 2008.

Denoble PJ, Ellis J, Pollock NW, Vann RD. Fatalities in divers using rebreathers. Presented at the Annual Scientific Meeting of the Undersea and Hyperbaric Medical Society, Kapalua Maui (HI). June 13–17, 2007.



ANALYSIS OF 500 SELF-REPORTED RECREATIONAL SCUBA DIVING INCIDENTS

Buzzacott P,<sup>1\*</sup> Bennett CM,<sup>1</sup> Denoble P-J,<sup>1</sup>  
<sup>1</sup>Divers Alert Network, Durham, North Carolina, USA  
 \*Corresponding author

**Introduction**

- While self-reported incidents say little about the prevalence of events in the wider community, they have the capacity to shape preventive interventions.
- Voluntary reporting of recreational diving incidents may provide details missed in fatality data, including the chain of events and root causes.
- In scuba diving, incident reports are collected by various governmental bodies, training agencies, and online diving forums but many collections are not systematically examined and published results are rare.
- In the 1980's Dr. Chris Acott published numerous analyses of recreational diving incident reports.<sup>1</sup>
- This study aims to determine if the recreational divers of today are suffering the same incidents as the divers of two decades ago.

**Methods**

- The Diving Incident Reporting System (DIRS) collected diving incident reports lodged through the DAN website.
- We analyzed the first 500 compressed gas incident reports, collected September 2012 through February 2018.
- After giving informed consent, reporters were prompted to describe divers' training and experience, equipment, environment, profile, unplanned incidents and outcomes.
- Many divers opted to leave contact information in which case follow-up questions were possible.
- In addition to the descriptive fields completed by the reporter, free format responses describing each incident were examined and binary classifications were noted for, wreck dives, training, injury, hurting, rapid ascent, loss of buoyancy control, running out of breathing gas, failing to open the valve fully before diving, if gas contamination was declared, and if an item of equipment reportedly failed.
- Where an injury or equipment failure was noted, the type of injury or equipment failure was also recorded.

**Results**

- The incidents reported by divers often involved rapid ascents (15%), running out of gas open (2%), loss of buoyancy control (5%), or starting the dive with the tank valve not fully open (2%).
- Seventy-five percent of reports involved an injury (Table 1)
- In running out of gas incidents, proportionally more injuries were reported when consequential ascents were rapid than when ascents were controlled.
- The majority were reported by the diver who experienced the incident, most commonly within one month of the incident occurring.
- Skty-eight percent of the divers in this study were male and mean age was 45 years.
- Around half of the incidents happened during the diver's first visit to the dive site, often on the first day of a dive series, most often within the first year or two since certification.
- Most divers were in a group or with a buddy, engaged in a diving activity they reported having prior experience in.
- More than half of the dive occurred during the day, in the sea, in water that would be considered warm (>20°C), with moderate/excellent visibility.
- More than half of the incidents occurred while diving from boats.

**Limitations**

- The limitations of this study include the self-reported nature of the data, that there was rarely an opportunity to corroborate an incident report, and that incidents resulting in injuries appear more likely to be reported than 'near miss' incidents.
- While this data is not suitable for statistical inference, individual case summaries provide valuable lessons for interested divers.

**Conclusions**

- A number of divers had insights that conform to the principles of a reflective practice, a technique often used in the disciplines of education and medicine by which participants improve performance through post-hoc introspective analysis of experiences.<sup>2</sup>
- Many divers provided their insights about the root causes within their textual descriptions of the incidents, identifying potential triggers or operational faults that preceded the incident.
- Many of the divers expressed hope that, by sharing these incidents and the root causes they identified, other divers might avoid the same issues.
- Divers today experience unplanned incidents that are similar to those reported 20 years ago.<sup>1</sup>

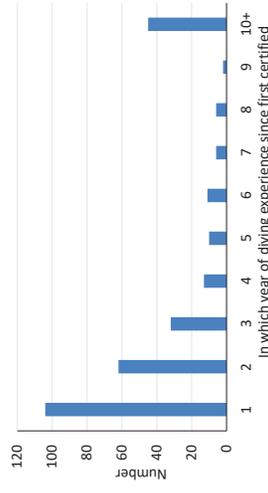


Figure 1. Experience of divers in years since certification when incident occurred

**Acknowledgements**

- DAN thanks everyone who supplied incident reports. We thank Charlie Edelson for his assistance with compiling the final dataset for analysis and we encourage divers to report their next diving incident through the DAN website.

**References**

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Table 1. Types of injuries reported n=374

Injury (n=374)	n (%)	Equipment failure (n=77)	n (%)
Decompression sickness	75 (20)	Regulator free flow	12 (16)
Fatality	47 (13)	BCD* Inflator Stuck	9 (12)
Loss of consciousness	27 (7)	Regulator stopped delivering gas	7 (9)
Barotrauma (ears)	23 (6)	Hose failure	5 (6)
Immersion pulmonary edema	16 (4)	Second Stage detached	5 (6)
Vomiting/nausea	15 (4)	DIV valve dust exploded	3 (4)
Hazardous marine life	12 (3)	Tank Explosion	3 (4)
Dizziness	12 (3)	Second stage flooded	3 (4)
Headache	9 (2)	Weight belt/pocket fell out/off	3 (4)
Difficulty breathing	7 (2)	Other	27 (27)
Paraesthesia	6 (6)		
Vertigo	6 (6)		
Water inhalation	6 (6)		
Sinus barotrauma	5 (5)		
Near drowning	5 (5)		
Other	102 (27)		

**Discussion**

- Now that DIRS is well established, it is collecting around 100 recreational diving incidents per year.
- Decompression sickness was the most commonly reported injury and regulator free-flow was the most commonly reported equipment problem.
- Inexperience may have been a factor in many incidents. Where known, incidents most often occurred within the first year or two since certification as a diver.
- However, this may be when divers are most likely to report unexpected incidents and no inferences can be drawn regarding the prevalence of unplanned incidents in the wider diving community.
- We do not know what the attrition rate is and how many divers continue to participate past their first year following certification.
- New dive sites or the start of a dive series featured commonly in reported diving incidents, the majority of which resulted in self-reported injuries.
- Most divers were diving with a buddy or in a group.
- The mean incident dive depth (23 msw) was deeper than what basic open water divers are trained to dive to (18 msw), though it is not known how many of the incidents were reported by divers trained beyond basic open water diver.
- In agreement with Acott<sup>1</sup>, among divers in this study who reported running out of gas, the proportion of rapid ascents that resulted in injury was greater than the proportion of non-rapid ascents that resulted in injury, although the sample size is still too small to reach significance.
- Pre-dive safety checks and closely monitoring remaining gas pressure throughout a dive may prevent incidents.

ESTIMATED WORKLOAD INTENSITY DURING VOLUNTEER AQUARIUM DIVES



Buzzacott P,<sup>1,2</sup> Grier JW,<sup>3</sup> Walker J,<sup>4</sup> Bennett CM,<sup>1</sup> Denoble P.J.<sup>1</sup>

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<sup>4</sup>Oregon Coast Aquarium, Newport, Oregon, USA



**Introduction**

- This study aimed to characterise the physiological demands of working dives on volunteer divers at a public aquarium in the US.
- There are at least 80 public aquariums in the United States and many have volunteer scuba divers to complete tasks in display tanks.
- Underwater work increases stress on the cardiovascular system but it is unknown to what extent while making aquarium dives.
- Knowledge of workload intensity and heart rate is important so diving safety officers (DSOs) can direct volunteers to appropriate tasks according to their history of cardiovascular risk factors.

**Methods**

- Participants completed a medical and diving history questionnaire.
- Measurements included blood pressure before and after diving and continuous ECG (Holter) monitoring during dives, including a pre- and post-dive resting heart rate.
- Dive profiles were recorded using dive loggers attached to the buoyancy control devices.
- Mean workload was estimated from total air consumption.
- All divers were assigned tasks in the various tanks ranging from vacuuming gravel and wiping windows to acting as a protective guard in the shark exhibit (by guiding the sharks around the divers with a PVC tube).

**Results**

- Twenty-seven divers recorded 49 air dives over five days.
- Mean heart rate was recorded for 30 dives.
- Two thirds were male and ages ranged from 40-78 years.
- Typically each diver made two dives with a 30-60 minutes surface interval between them.
- Mean heart rate during the dives was 100 beats per minute.
- The highest mean recorded heart rate was 120 bpm over 40 minutes, while vacuuming the floor in the shark exhibit.

**Table 1. Anthropometry and dive characteristics of volunteer aquarium divers (n=27)**

Anthropometry	n	%	Overall (n=27)
Sex males:females	18:9	(67:33)	
Age (years)	$\bar{x}$ (SD)		59.5 (10.5)
Weight (kg)	$\bar{x}$ (SD)		86.7 (18.0)
Height (m)	$\bar{x}$ (SD)		1.76 (0.09)
Body Mass Index (m.kg <sup>2</sup> )	$\bar{x}$ (SD)		28.0 (4.7)
Pre-Dive Blood Pressure* (mm Hg)	$\bar{x}$ $\bar{x}$ (SD/SD)		145/88 (14/8)
Post-Dive Blood Pressure* (mm Hg)	$\bar{x}$ $\bar{x}$ (SD/SD)		136/84 (16/10)
<b>Diving History</b>			
Years since first dive certification	Median (range)		22 (2-47)
Number of lifetime dives	Median (range)		400 (32-10,000)
Number of dives in previous six months	Median (range)		18 (1-120)

**Table 2. Dive characteristics and physiological variables during volunteer aquarium dives (n=49)**

	Reef Ecosystem (n=13)	Inshore (n=14)	Open Sea (n=22)	Overall (n=49)	
Ave depth (msw)	$\bar{x}$ (SD)	5.6 (1.3)	5.8 (0.9)	5.4 (1.3)	5.6 (1.2)
Water temp (°C)	$\bar{x}$ (SD)	8.6 (0.1)	8.6 (0.1)	13.7 (1.6)	10.9 (2.8)
Dive Time (mins)	$\bar{x}$ (SD)	42 (14)	29 (9)	35 (13)	35 (13)
Mean HR* (bpm)	$\bar{x}$ (SD)	99 (6.6)	99 (11.9)	100 (11.2)	100 (9.3)
SAC <sup>b</sup> (V <sub>E</sub> (L.min <sup>-1</sup> ))	$\bar{x}$ (SD)	19.7 (3.5)	23.2 (4.9)	21.7 (7.8)	21.6 (6.1)
SAC/kg (L.min <sup>-1</sup> .kg <sup>-1</sup> )	$\bar{x}$ (SD)	0.24 (0.05)	0.28 (0.07)	0.25 (0.10)	0.26 (0.08)
V <sub>O</sub> 2 (L.min <sup>-1</sup> )	$\bar{x}$ (SD)	1.57 (0.09)	1.66 (0.12)	1.63 (0.20)	1.62 (0.16)
METS <sup>c</sup>	$\bar{x}$ (SD)	5.7 (1.1)	6.1 (1.7)	5.5 (1.3)	5.7 (1.4)

\*Heart Rate, in beats per minute, <sup>b</sup>Surface Air Consumption, <sup>c</sup>Metabolic Equivalents

**Results continued**

- The mean estimated workload during the dives recorded during this study was 5.8 METS, with a range from 4.1 to 10.5 METS.
- There was no difference detected between pre- and post-dive blood pressure.
- The correlation between heart rate and estimated V<sub>O</sub>2 was 0.43
- Mean heart rate and SAC.kg<sup>-1</sup> had a correlation (r) of 0.62

**Figure 1: A diver cleans the acrylic while her buddy wards off sharks**



**Discussion**

- Overall, the mean estimated workload during these aquarium dives was 5.8 METS, which is a level reported by recreational divers as a moderate workload.<sup>1</sup>
- The highest estimated workload recorded, while cleaning the acrylic windows in the shark exhibit, was 10.5 METS which is above the level of recreational divers have described as severe or exhausting.<sup>1</sup>
- That there was no difference in pre- and post-dive blood pressure may be explained by the delay in surfacing from the dive and the recording of the post-dive blood pressure.
- Heart rate is highly variable and influenced by factors other than workload.
- There was no detectable association between heart rate and water temperature.
- The correlation between heart rate and V<sub>O</sub>2 was much lower than =0.74 found among younger male divers exercising heavily underwater in wetsuits.<sup>2</sup> The difference could be caused by numerous factors including age, workload, water temperatures, differences in equipment, etc.
- This difference calls into question the validity of adjusting decompression obligations for recreational divers based on heart-rate inferred workload as some dive computers claim to do.

**Limitations**

- Divers always dived in RE or IS exhibits first, before making any dives in the relatively warmer shark exhibit.
- The estimated work load intensities reported in this study are based on tank pressure reduction between the start and end of the dive and those differences may be exaggerated due to tank cooling, inflation of BCDs and drysuits, mask clearing, equalization, and/or free-flow events.
- Values presented in this report should be viewed as maximums with actual consumption rates and workloads likely less.

**Conclusions**

- It may be prudent for aquarium DSOs to regularly monitor SAC/kg and heart rate in volunteer divers so divers with cardiovascular risk factors might be employed in dives with lighter workloads.
- Volunteer divers at this aquarium required mean workload intensity that was described by recreational divers as moderate.
- The highest workload, at 10 METS for 23 minutes, would be considered by many recreational divers as exhausting.<sup>1</sup>

**Acknowledgements**

The authors and Divers Alert Network thank the volunteer divers at Oregon Coast Aquarium.

**References**

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# Self-reported physical activity and perceptions of the importance of structured exercise in certified divers

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WESTERN ILLINOIS UNIVERSITY

## Introduction

- It is crucial for divers to maintain fitness levels necessary to cope with unexpected demands, such as current, entanglement, or emergency situations, especially amongst older divers where additional health risks are more likely present.<sup>1,2</sup>
- An increased understanding of actual exercise and physical activity behaviors in the diving community may lead to a greater understanding of the potential physical risks of diving, and support targeted education of the importance of fitness in active divers.
- This study examined self-reported physical activity and perceptions of exercise importance among certified divers in two distinct age and occupational groups; university students and non-students.

## Methods

- Questionnaires were distributed by hand at dive sites in three states, half to students from an academic program in scuba diving at a regional university, half to recreational divers recruited at popular dive sites.
- The 18-question survey included questions about health status, dive history, certification levels, structured exercise activity levels (including Godin-Shephard exercise scores) and perceived importance of regular exercise to their health, diving ability, and safety.
- 188 questionnaires were completed; 32 were ineligible due to being incomplete or not yet certified to dive, leaving 156 completed questionnaires for analysis.
- Data were imported into SAS 9.4 (Cary, NC) and significance was accepted at p<0.05.

## Results

- Anthropometry, dive experience and health status are presented in Table 1.
- Three questions examined perceived importance of regular exercise. Chi Square tests investigated differences between occupational status.
- There was no detectable difference between groups in perceived exercise importance to health (p=0.69), diving ability (p=0.75), or diving safety (p=0.25).
- Trends for differing perceptions of importance of exercise to health, diving ability and diving safety were tested for with Mann-Whitney U test. Chi Square tests. There were no detectable trends towards different perceptions of importance of exercise to health (p=0.93), diving ability (p=0.29), or diving safety (p=0.15).
- Fitting age, sex, occupation and number of dives to a generalized linear model to predict Godin-Shephard scores, number of dives was removed first (p=0.43), followed by student status (p=0.33).
- Remaining predictors of Godin-Shephard exercise scores were age (-0.004 per year, p<0.0001) and sex (males= +0.11, 95% CI 0.04, 0.17, p=0.0012).

## Limitations

- Limitations in the study included:
  - Limited sample size of data that were collected
  - Potential regional bias due to the majority of the participants residing in the Midwestern region of the United States
  - Accuracy of the self-reported physical activity behaviors

## Discussion

- The benefits of regular physical activity include an increased cardiorespiratory endurance, increased muscular strength and endurance, decreased risk of sudden cardiovascular death, and improved cognitive function.<sup>3</sup>
- These benefits have a direct influence on safety in diving and a regular exercise program should be considered a necessary part of any active divers lifestyle.
- As recent research has suggested,<sup>2</sup> a better understanding of the relationship between cardiovascular health and dive fatalities, knowledge of actual exercise behavior and perception of exercise is needed to develop educational interventions highlighting the need for structured physical activity in the dive community.
- This preliminary study suggests that although there were no differences between groups, descriptive data indicated that divers across multiple age groups do participate in regular physical activity and reported understand the importance of exercise to dive safety.
- This data, however, may conflict with anecdotal data that suggests divers are less healthy and physically active, which may have been related to differences in the average age of surveyed divers in this study compared with the wider US diving population.

## Conclusions

- Non-students were older than the students and had greater diving experience, in years of diving and number of logged dives.
- Both groups reported similar structured exercise regularity, overall health and perceived importance of regular exercise for health, diving, and safety.
- Despite acknowledging the importance of exercise, Godin-Shephard scores for physical activity decrease with age. This is similar to findings among non-divers.

## Future Research

- Future work may examine physical activity behaviors through the use of more objective methods of data collection, including the potential use of "wearable" technology that can track and record actual physical activity levels.
- Additionally, research examining the relationship between physical activity patterns and specific diving "seasons" might provide for a more accurate representation of actual exercise behavior in divers.
- An examination of more detailed regional exercise patterns would also provide a more comprehensive view of the role that exercise plays in cold-water vs. warm-water divers and may lead to an increase in education about the importance of exercise across all types of diving behavior.

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3. American College of Sports Medicine (2014). *Guidelines for Exercise Testing and Prescription*. Wolters Kluwer, 9th Ed.

Table 1. Anthropometry, diving experience and health factors by occupational status

	Students (n=73)	Non-Students (n=83)	Overall (n=156)	P-value
% Male : %Female	78:22	86:14	82:18	0.23
Open Water Diver only	n (%)	11 (13)	44 (28)	<0.0001
Beyond open water diver	n (%)	71 (87)	111 (72)	
Mean years certified to dive	(SD)	12 (12)	7 (11)	<0.0001
Current structured exercise program?	%	69	72	0.26
How often do you work up a sweat each week?				
➤ Often	n (%)	34 (41)	73 (47)	0.22
➤ Sometimes	n (%)	23 (32)	59 (38)	

# CARDIOVASCULAR RISK FACTOR PREVALENCE AMONG AUSTRALIAN RECREATIONAL DIVERS



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## Introduction

At the turn of this century hypertension and coronary artery disease were reported by 10% of Australian recreational divers.<sup>1</sup> Cardiovascular risk factors are increasingly noted among diving fatalities.<sup>2</sup> Consensus at the DAN Diving Fatality workshop included that cardiovascular health is a priority for recreational divers.<sup>3</sup> More recently cardiovascular risk factors have been found in a majority of professional divers.<sup>4</sup>

## Methods

DAN's Project Dive Exploration (PDE) collects data regarding demographics, diving experience, recorded depth-time profiles, and reported problems. From 1991-2010, PDE collected over 150,000 dives by more than 15,000 divers. Data from Australian recreational divers (n=220) were extracted from the DAN PDE database. Cardiovascular risk factors were identified.

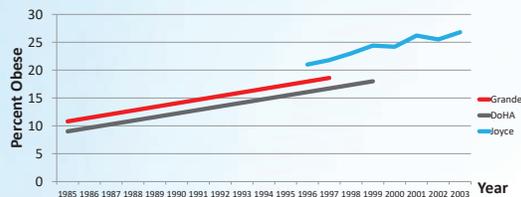


Figure 1: BMI > 30 was reported by 34/161 (21%) of males. Obesity is increasingly prevalent in Australia



Figure 2: Smoking was reported by 10% males and 15% females

## Results

Anthropometric data are presented as mean and standard deviation in Table 1. Dive experience are presented as median and range. Among males (n=161, 73%), median 40 years old (range 25-65), previous cardiovascular problems were reported by 12 (nine hypertension and three hyperlipidemia, 8%), smoking by 14 (10%, national prevalence =18%), coronary-related medication by nine (six hypertension and three hyperlipidemia, 6%) and BMI > 30 in 34 (21%, national prevalence =26%). Among females (n=59, 27%), median 36 years old (range 22-58), a cardiovascular problem was reported by just one diver (high blood pressure, 2%), smoking by 8 (15%, national prevalence =15%), coronary-related medication by the same diver and BMI > 30 in 5 (8%, national prevalence =27%).

## Limitations

The limitations of this study include the self-reported nature of the data and selection bias towards divers who submit electronic dive profiles.

Table 1. Australian recreational divers (n=220) anthropometry

	Males (n= 161, 73%)	Females (n= 59, 27%)	Overall (n=220)
<b>Demography (mean, SD)</b>			
Age	42 (9)	39 (9)	41 (9)
Height	179 (7)	167 (9)	176 (9)
Weight	87 (13)	67 (11)	82 (16)
BMI	27 (4)	24 (4)	26 (4)
<b>Experience (median, range)</b>			
Years of diving	8 (0-36)	10 (0-39)	10 (0-39)
Dives prev. yr	28 (0-200)	28 (0-400)	28 (0-400)
Dives 5 yrs	135 (0-1500)	101 (0-2000)	120 (0-2000)

## Conclusion

At least one cardiovascular risk factor was found in 62/220 (28%) of this sample of Australian recreational divers. This is lower than found among professional divers although this study relied upon self-reporting.<sup>4</sup> The prevalence of smoking approximated that found in Australian females (15% vs. 15%) but was lower among male divers (10% vs. 18%). BMI > 30 was less common among this sample than among Australian adult males generally, (21% vs. 26 and 8% vs. 27%, males and females respectively).<sup>5</sup> We postulate that divers with more severe cardiovascular risk factors may be more likely to retire from diving and, therefore, the prevalence of risk factors among divers may be lower than in the general population. This is speculative however and cardiovascular risk factors remain a concern for diving safety.

## References

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# Exercise Intensity Inferred From Air Consumption During Recreational Scuba Diving



THE UNIVERSITY OF  
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## Introduction

Episodic exercise is a risk factor for acute cardiac events and cardiac complications are increasingly recognized as common in fatalities during recreational scuba diving.<sup>1</sup> What is not known is the exercise intensity involved in a typical range of recreational diving.

## Methods

This study used pre- to post-dive gas cylinder pressure drop to estimate air consumption and, from that, exercise intensity during recreational dives. Dive profiles were captured electronically and divers self-reported cylinder pressure changes, perceived workload, thermal status and any problems during the dives. All dives were made breathing compressed air. The dive profile was used to determine mean depth, which was then used to derive mean surface air consumption (SAC) rate. From this, oxygen consumption (VO<sub>2</sub>) was inferred (VO<sub>2</sub> = 0.0256V<sub>E</sub> + 1.070; a formula derived in a previous study of divers in controlled open water trials<sup>2</sup>). From this, mean exercise intensity was then estimated (reported in metabolic equivalents [MET], multiples of assumed resting metabolic rate [3.5 mL·kg<sup>-1</sup>·min<sup>-1</sup>]). Data are reported as mean±standard deviation.

## Results

A total of 959 recreational air dives were monitored:

- 20±9 msw maximum depth
- 11±4 msw mean depth
- 50±12 min underwater time
- 15°C to 29°C minimum water temperature range

Dives were completed by 139 divers:

- 42±10 y age
- 26.4±4.1 kg·m<sup>-2</sup> body mass index
- 11±10 y of diving
- 12% smokers
- 73% male

Problems were reported with 129/959 dives:

- buoyancy (45%)
- equalization (38%)
- rapid ascent (10%)
- vertigo (5%)
- other (2%)

Assuming a conservative 10% overestimate due to cylinder cooling and uncontrolled gas loss, the estimated exercise intensity associated with monitored dives was 5±1 MET (Table 1).

Table 1: Gas consumption and inferred exercise intensity (MET) by perceived workload (mean [SD])

	'Resting/Light' (n=683)	'Moderate' (n=247)	'Severe/Exhausting' (n=9)	Pooled (n=959)
Weight (kg)	84 (16)	78 (17)	78 (16)	82 (17)
Mean depth (msw)	10.6 (4.3)	11.0 (4.4)	10.4 (3.4)	10.8 (4.3)
Mean underwater time (min)	51 (12)	49 (12)	45 (7)	50 (12)
SAC (V <sub>E</sub> ) (L·min <sup>-1</sup> ) <sup>a</sup>	17.4 (5.4)	17.9 (5.5)	22.3 (6.2)	17.7 (5.4)
VO <sub>2</sub> (L·min <sup>-1</sup> ) <sup>a</sup>	1.52 (0.14)	1.53 (0.14)	1.64 (0.16)	1.52 (0.14)
SAC/kg (L·kg <sup>-1</sup> ·min <sup>-1</sup> ) <sup>a</sup>	0.21 (0.07)	0.23 (0.07)	0.29 (0.06)	0.22 (0.07)
VO <sub>2</sub> /kg (mL·kg <sup>-1</sup> ·min <sup>-1</sup> ) <sup>a</sup>	18.6 (3.6)	20.4 (4.4)	21.5 (3.1)	19.0 (3.9)
Exercise intensity (MET) <sup>a</sup>	<b>5.3 (1.0)</b>	<b>5.8 (1.3)</b>	<b>6.2 (0.9)</b>	<b>5.4 (1.1)</b>

<sup>a</sup>estimated



Figure 1: Buoyancy accounted for 58/129 (45%) of reported problems

## Discussion

Mean±2SD, or 7 MET, captures the effort associated with the vast majority of dives monitored. This value is similar to recent expert opinion and consensus statements recommending a minimum 6-7 MET aerobic capacity for recreational divers.<sup>3</sup>

## Limitations

The estimates of tank pressure drop were fairly inexact approximations. Subjects were not cautioned to report starting cylinder pressures after cooling was complete or to avoid breathing from the cylinder at the surface. In addition, our study involved free-swimming recreational divers with more variable averaging than was used in the more controlled reference study.<sup>2</sup>

## References

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## Conclusion

Our estimates suggest that a 7 MET aerobic capacity may generally be adequate to complete uncomplicated recreational dives. Higher levels of aerobic fitness are still strongly recommended to ensure ample reserves. Further research is needed to quantify energetic demands of recreational diving during both typical and emergent events.

## Acknowledgements

We thank Dr Petar Denoble and DAN for permission to use PDE survey forms and for adapting the PDE database to suit this project. We thank Lisa Li of DAN and Robin Mina of the School of Population Health, the University of Western Australia for database management.



## PREVALENCE OF CARDIOMEGALY AND LEFT VENTRICULAR HYPERTROPHY IN SCUBA DIVING AND TRAFFIC ACCIDENT VICTIMS

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### INTRODUCTION

- Left ventricular hypertrophy (LVH) is an independent predictor of SCD and may be found in asymptomatic subjects.
- We hypothesized that diving may increase a prevalence of LVH for scuba divers and that the prevalence of LVH may be greater among scuba divers than among traffic fatalities.

### MATERIALS AND METHODS

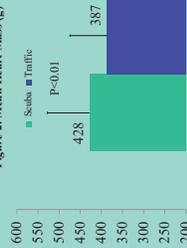
- We compared autopsy data for 100 scuba fatalities with 178 traffic fatalities.
- Extracted data contained information on age, sex, height (H), body mass (BM(kg)), heart mass (HM), left ventricular wall thickness (LVWT), inter-ventricular wall thickness (IWT), and degree of coronary artery stenosis.
- Calculated values:
  - BMI = BM(kg)/[H(cm)]<sup>2</sup>
  - BSA (m<sup>2</sup>) = 0.007184 x [H(cm)]<sup>0.725 x [BM(kg)]<sup>0.725</sup></sup>
  - HMP%BM = [HM(kg)/BM(kg)] \* 100
  - rHMBM = HM (g)/BM (kg)
  - rHMBSA = HM(g)/BSA(m<sup>2</sup>)
  - rHMBMI = HM(g)/BMI
  - rHMHI = HM(g)/H(m)
- A case was classified as LVH if the LVWT was > 15 mm.
- Log risk models were used to compare HM and LVWT in two groups; the prevalence of LVH was compared using Pearson's test.

### RESULTS

Table 1. Characteristics of 100 Scuba Fatalities and 178 Traffic fatalities

	Scuba Fatalities	Traffic Fatalities	F-test	P-value
N	100	178		
Age	54.1 ± 7.1	54.8 ± 8.3		0.48
Body mass, kg (SD)	91.2 ± 18.4	89.6 ± 20.2		0.31
Height (cm)	176.1 ± 9.7	170.1 ± 13		< 0.0001
Male%	84	63		0.0002 (chi-sq test)
BMI	29.78 ± 5.7	31.14 ± 7.7		0.13
HM (g)	423 ± 100	387 ± 87		R = 1.11 (1.05, 1.17)
HM%BM	0.46 ± 0.08	0.44 ± 0.08		< 0.024
rHMBM	4.6 ± 0.9	4.4 ± 0.9		0.136
rHMBSA	202 ± 30	193 ± 34		0.035
rHMBMI	14.5 ± 3.1	12.8 ± 2.8		< 0.0001
rHMHI	239 ± 42	228 ± 48		0.046
Severe CAD (%)	29	18		0.015

Figure 2. Mean Heart Mass (g)

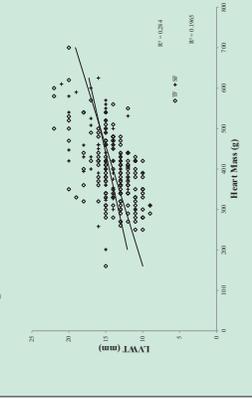


**Heart Mass**

- The mean heart mass was 428.3 ± 100 for divers and 387.8 ± 87 for controls.
- The heart mass correlated best with body mass (R<sup>2</sup> = 0.44). The correlation with the body mass (R<sup>2</sup> = 0.41) was better in TF (0.44) than in SF (0.37) group.
- Correlation of heart mass with body surface area and body weight was weaker for females regardless of the group.
- The crude HM ratio for scuba fatalities vs. controls was 1.11 (1.05, 1.17). When controlled for sex, age, and body mass the final model given by formula 1 below, the final model best fit and the ratio was 1.06 (1.01, 1.09).

Formula 1  
 $Ln(HM(g)) = a + b_1(Group) + b_2(SC) + b_3(Age) + b_4(BM(kg)) + error$

Figure 1. Correlation of LVWT with Heart Mass



**Left Ventricular Wall Thickness**

- The LVWT was available in 67% SF and 88% controls. The mean LVWT was 15.3 ± 5.5 for divers and 14.2 ± 7 for controls (p = 0.0017).
- The LVWT correlated with the heart mass and was better in TF (R<sup>2</sup> = 0.284) than in SF (R<sup>2</sup> = 0.196) as shown in Figure 1, but did not correlate with indexed heart mass measures (HM%BM, rHMBM, rHMBSA, rHMBMI).
- The LVWT in females did not correlate with heart mass or with its indexed measures.

### The Prevalence of LVH

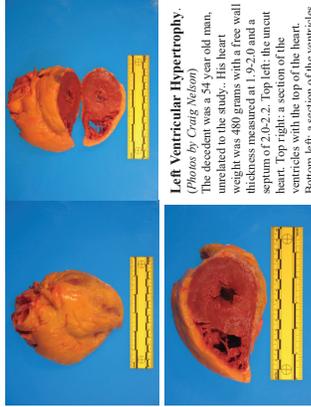
The prevalence of LVH (LVWT > 15 mm) in cases was 31% vs. 20% in controls (p = 0.042). The data is shown in Table 2.

Table 2. Frequency of LVH

Group	LVWT > 1.5 cm		Missing LVWT
	Yes	No	
Scuba Fatalities	21	46	33
Traffic fatalities	32	124	22

### CONCLUSIONS

- Heart mass and left ventricular wall thickness measured at autopsy were greater in scuba related deaths than in traffic fatalities.
- This may indicate that diving increases the propensity for arrhythmia in subjects with left ventricular hypertrophy.
- Better autopsy data are needed to corroborate or disprove these findings.



**Left Ventricular Hypertrophy.**  
 (Photos by Craig Nelson)  
 The decedent was a 54-year-old man, unrelated to the study. His heart weight was 480 grams with a free wall thickness measured at 1.9-2.0 and a septum of 2.0-2.2. Top left: the uncultured heart. Top right: a section of the heart ventricles with the top of the heart. Bottom left: a section of the ventricles.



# ANNUAL DIVING FATALITY RATES AMONG INSURED DAN MEMBERS



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## Introduction

The annual count of injury deaths in USA and Canada has been surveyed since the sixties. Peaking at 150 in mid-seventies, the death count has been fairly stable for more than one decade at 84±5 (range 77 – 91).

Without knowing the number of exposed persons, it is impossible to evaluate how the safety and riskiness of scuba diving change over time or to identify divers with greater than average risk.

Cardiovascular disease has also become increasingly recognized as a factor in the death in older divers but the association has not been tested due to lack of data<sup>1</sup>.

This study computed fatality rates among insured members of the Divers Alert Network (DAN), and tested effects of age and gender on overall rates and on cause specific rates.

## Methods

Age, gender, and death while diving were extracted in de-identified form from about 150,000 insured DAN members for each year from 2000-2006.

Annual fatality rates were computed per 100,000 members.

Association with age and gender was tested with logistic regression (p<0.05).

The relative risks for divers <50 and ≥50 years of age for drowning, arterial gas embolism (AGE), and cardiac incidents were computed.

## Results

### Age of Insured DAN Members

There was a total of 1,141,367 insured members- years. Males made 64%, and their mean age was 3 years greater than mean age of females. In seven year since 2000, mean age increased for 3 years for both genders.

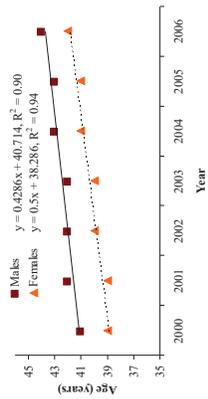


Figure 1: Mean age of insured DAN members.

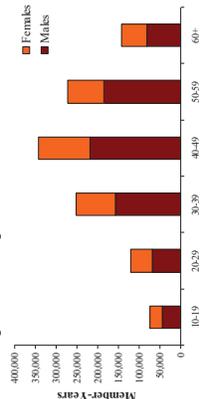


Figure 2: Age distribution of insured DAN members.

### Annual fatality rates

Overall fatality rate was 16.4 (95%CI:14.2-18.9). Annual fatality rates varied from 12-23 per 100,000 with no trends during the observed period.

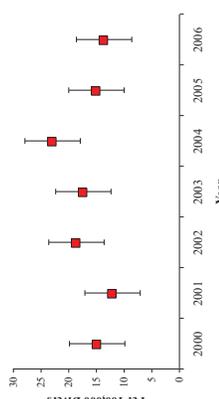


Figure 3: Annual fatality rates for DAN insured members

### Age- and gender-specific fatality rates

The overall rate was greater for males (21.2) than for females (7.6) (2.8 OR, 1.9-4.5 95% CL). Rates increased with age both for males and females. The difference in rates diminished with age, becoming similar after age 60.

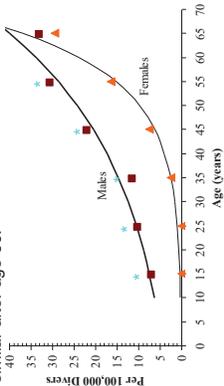


Figure 4: Fatality rates by age and gender

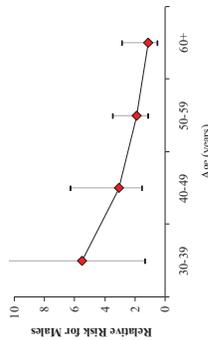


Figure 5: Relative risk for males in comparison to females

### Cause-specific relative risks for older divers

In divers ≥50 years, cardiac disease is leading (37%) suspected cause of death while diving. In the same age group, the relative risk of cardiac related scuba death is 12.9 times greater than in group under 50.

Table 1. Cause specific RR

Cause of Death	≥50 years (n=153,828)	Lower RR Limit	Upper RR Limit		
Cardiac	5	29	179	5.0	31.5
AGE	8	14	19	1.6	9.1
Drowning	15	17	25	1.3	5.1
Unknown	15	16	19	0.9	4.1
Other	7	3	10	0.2	3.7
Total	50	20	79		

## Discussion

DAN insured divers may not be representative of all recreational divers but their aging seem to reflect similar trends in population.

Annual number of fatalities are small and thus random variations may affect year-to-year changes of fatality rates.

Relative increase of risk with age may be associated with prevalence of heart disease in population that increases with age, too.

## Conclusions

In addition to specific risks in diving - AGE and drowning - older divers are exposed to additional, health-related risks.

Healthy life style and regular exercise may help reduce risk in diving.

Divers with risk factors for heart diseases should seek medical evaluation prior to diving.

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## FATALITIES IN DIVERS USING REBREATHERS

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### INTRODUCTION

- ❖ The number of diving deaths involving rebreathers appears to be increasing worldwide.
- ❖ We conducted a preliminary investigation of differences in fatalities for divers using rebreathers and open-circuit breathing apparatus.

### METHODS

- ❖ Root Cause Analysis (1) was applied to DAN diving fatality surveillance data.
- The goal was to identify Trigger events, Harmful Actions and Disabling Injuries, where possible.
- ❖ Information about non-US/Canada residents was difficult to obtain and limited.

	Rebreather	Open-Circuit (1)
Cases (years)	78 (1988-2006)	947 (1992-2003)
Age (Y: mean±SD, range)	45±11 (24-72)	43±13 (12-79)
Male (%)	97	81
US/Canada Cases (%)	40	100

### RESULTS

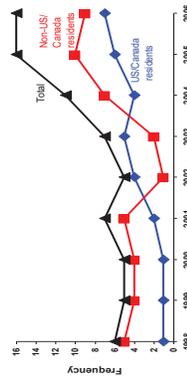


Figure 1. Rebreather fatalities identified worldwide 1998-2006 increased after 2002.

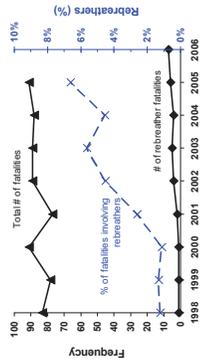


Figure 2. Rebreather fatalities represent a growing share of total diving fatalities in US/Canada since 2000.

- ❖ Equipment & buoyancy problems more common Triggers with rebreathers than open-circuit (Fig. 3).
- 11 equipment procedure problems (e.g., gas or power off, incorrect set-up, gas leak)
- 3 equipment malfunctions (e.g., flooded display, O<sub>2</sub> supply failure)
- 4 buoyancy problems specific to rebreathers (i.e., surfaced, left mouthpiece open, lost buoyancy, sank)
- 3 general buoyancy problems (drysuit blow-up, lift bag entanglement)

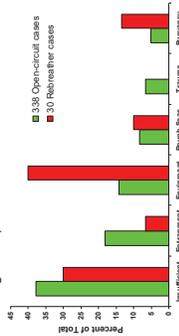


Figure 3. Triggers.

- ❖ Hypoxia/Seizures and equipment trouble were more common Harmful Actions with rebreathers (Fig. 4).

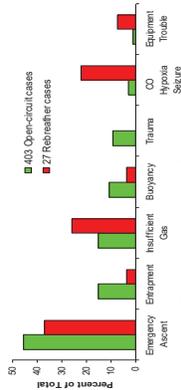


Figure 4. Harmful Actions

- ❖ Drowning and cardiac incidents were less common Disabling Injuries with rebreathers than open-circuit (Fig. 5).
- ❖ Inappropriate gas was the major Disabling Injury with rebreathers.
- 13 rebreather divers lost consciousness early in the dive, suggesting hypoxia
- 5 rebreather divers were observed to have seizures, suggesting oxygen toxicity

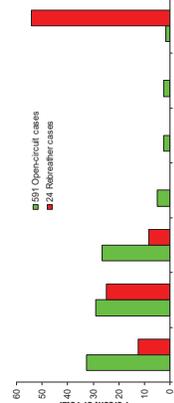


Figure 5. Disabling Injuries

### DISCUSSION

- ❖ The rise in rebreather fatalities is probably associated with their increasing popularity.
- ❖ According to the Pareto principle (1), the greatest reduction in rebreather fatalities might be achieved by emphasizing training and safety guidelines related to equipment trouble and hypoxia/seizures.
- Equipment procedural problems (diver error) seemed more common than equipment malfunction.
- ❖ Investigation of non-US/Canadian cases was difficult, but perhaps this can be overcome by cooperation among International DAN affiliates.
- ❖ Equipment recovered after a fatality should enter a formal chain of custody.
- Qualifications for equipment inspection & inspectors remain to be defined.

### LIMITATIONS

- ❖ The number of rebreather fatalities missed by the DAN surveillance system is unknown.
- ❖ Information about rebreather fatalities is more limited than about open-circuit fatalities

### CONCLUSIONS

- ❖ Focusing on the most frequent problem areas can have the greatest impact in reducing fatalities.
- ❖ Inferences concerning rebreathers are preliminary.

### REFERENCES

1. Denoble PJ. Application of the Pareto principle to recreational diving deaths. 2007 UHMS Meeting.



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