



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

2016 Edition

2014 Diving Fatalities, Injuries and Incidents

# **DAN Annual Diving Report**

## **2016 Edition**

A report on 2014 data on diving fatalities, injuries,  
and incidents

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Editor

Divers Alert Network  
Durham, NC

Buzzacott P (editor), DAN Annual Diving Report 2016 Edition - A report on 2014 data on diving fatalities, injuries, and incidents. Durham, NC: Divers Alert Network, 2016; pp. 129.

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ISBN: 978-1-941027-75-2

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# Annual Diving Report 2016 Edition

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# Acknowledgments

Data for the 2016 Annual Diving Report were collected and assembled by DAN employees and associated professionals. DAN wishes to recognize the following for their important contributions:

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DAN thanks all of the individuals involved in the worldwide diving safety network. This network includes many hyperbaric physicians, DAN on-call staff, nurses and technicians from the network of chambers who complete DAN reporting forms. DAN also thanks local sheriff, police, emergency medical personnel, US Coast Guard, medical examiners, coroners and members of the public who have submitted incident data.



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# International DAN

International DAN (IDAN) is comprised of independent DAN organizations based around the world that provide expert emergency medical and referral services to regional diving communities. These local networks have pledged to uphold DAN's mission and to operate under protocol standards set by DAN. Each DAN organization is a nonprofit, independently administered organization. Each DAN depends on the support of local divers to provide its safety and educational services, such as emergency hotlines. In addition, each country has its own rules and regulations regarding insurance. Each regional DAN is cognizant of the insurance regulations of its territory.

## **DAN**

DAN America serves as the headquarters for IDAN. Regions of coverage include the United States and Canada. Diving Emergencies: +1-919-684-9111 (accepts collect calls)

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Region of coverage is Brasil.

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Regions of coverage include Europe, the countries of the Mediterranean Basin, countries on the shores of the Red Sea, Middle East including the Persian Gulf, countries on the shores of the Indian Ocean north of the equator and west of India, as well as related overseas territories, districts and protectorates.

Diving Emergencies: +39-06-4211-5685

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Regions of coverage include Japan, Japanese islands and related territories, with regional IDAN responsibility for Northeast Asia-Pacific.

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Korean Hotline: 010-4500-9113 (Korean and English)

## **DAN Southern Africa**

Regions of coverage include South Africa, Swaziland, Lesotho, Namibia, Botswana, Zimbabwe, Mozambique, Angola, Zambia, Zaire, Malawi, Tanzania, Kenya, Madagascar, Comoros, Seychelles and Mauritius.

Diving Emergencies: 0800-020-111 (within South Africa)  
+27-828-10-60-10 (outside South Africa — accepts collect calls)

## FOREWORD

Divers Alert Network® (DAN®) publishes the DAN Annual Diving Report with the goal of raising awareness of the risks and hazards in diving and leading to safer diving practices and more informed divers. This report is the result of a yearlong effort of gathering, monitoring and analyzing dive incidents, injuries and fatalities. The risks in diving are real, but many of the incidents leading to injury or death are preventable. Even with advancements in equipment, the diligence of training agencies, and the proficiency of dive professionals, incidents still occur and accidents will always happen. As dive safety and injury prevention is of utmost importance to the health of the entire diving community, we encourage you to share the information contained in this report with your peers, superiors and divers. The DAN Annual Diving Report is now available through the National Library of Medicine and PubMed, or you can download a free copy at [DAN.org](http://DAN.org).

Results of our injury monitoring efforts help us better understand why and how injuries occur. In turn, the lessons we learn determine our corporate initiatives. This year we stepped-up our efforts to ensure all divers are educated and informed. The Prepared Diver Program is aimed at students and new divers, addressing the five key preventable contributing factors that lead to diver injury; our risk mitigation initiatives will benefit dive professionals by providing the resources required to mitigate risks and reduce liabilities associated with diving; and DAN's first-aid training programs empower all divers to respond. In addition, we enlisted the assistance of an independent panel to develop guidelines for field and hospital pre-recompression management of diving injuries, while we continue to provide support for remote recompression chambers and staff.

Thanks to the support and participation of our DAN offices worldwide, we will continue to augment the information provided in this report. Diving is a borderless sport, and we must be there for you regardless of where your travels take you. We sincerely hope this report will guide you in the choices you make above – and below – the water.

Petar J. Denoble, MD, DSc  
Vice President, Mission

## INTRODUCTION

In this latest DAN Annual Diving Report we received reports of 50 US recreational diver fatalities occurring in the US in 2014. The Sport and Fitness Industry Association annual participation figures for 2014 estimate that 1.1% of the US population went scuba diving that year, some three million divers, making on average ten dives each.<sup>1</sup> Without knowing how many of those dives were made overseas, and how many dives are made in the US by visiting divers, we cannot say with certainty what the absolute risk of death or injury is while recreational diving.

In Brazil, for example, the annual number of fatalities increased from 0.5 per year in the 1990's, to 1 per year during 2000-2009, to 3 per year 2010-2014. Once again though, it should be remembered that without a reliable denominator we do not know if the absolute number of deaths is increasing in line with increased participation, or if improvements to surveillance are merely identifying a greater proportion of fatalities, or some combination of both.

Work continues towards clarifying these uncertainties in the US and around the world. Meanwhile, our preliminary investigations suggest in the US we may end up finding a fatality rate of around two deaths per million recreational dives, and that around one out of every 10,000 Emergency Room (ER) presentations relate to scuba diving. If such a low prevalence reflects what is happening in ERs then it should be no surprise that DAN Medical Services are so often called by receiving physicians around the US. It is not uncommon for physicians to call DAN for advice in evaluating their very first diving injury patient, and DAN is there to assist any receiving physician, to ensure divers receive the most appropriate treatment available.

Even without reliable denominators more can be done to improve safety while diving, and herein lies the main value of the DAN Incident Reporting System. More than 400 diving incident reports have been received now and, at the time of writing, we are heading steadily towards 500. These reports are classified, analyzed and a selection are reproduced in Chapter 3. More than that though they are currently being used to validate a diving checklist, they support DAN educational efforts such as presentations at dive shows, and they clearly identify a number of modifiable risks that DAN aims to address. In the same vein as the National Transport Safety Board's (NTSB) Most Wanted Improvements List, here is ours:

### **Ten Most Wanted Improvements in Scuba**

- Correct Weighting
- Greater Buoyancy Control
- More Attention to Gas Planning
- Better Ascent Rate Control
- Increased Use of Checklists
- Fewer Equalizing Injuries
- Improved Cardiovascular Health in Divers
- Diving More Often (or more pre-trip Refresher Training)
- Greater Attention to Diving Within Limits
- Fewer Equipment Issues / Improved Maintenance

If every diver took just a few moments to think about each of these improvements, and took even one step towards one improvement in diving safety, then the reduction in risk across our whole community would be significant.



In breath-hold diving 64 incidents were identified in 2014, both fatal and non-fatal, which is in keeping with previous reports. Medical issues again feature prominently, as with other forms of diving, and adherence to safer diving practices appears an obvious area for improvement.

This edition also contains international perspectives from Australia, Brazil, South Africa and the United Kingdom. These reports highlight that surveillance varies from country to country, but also that recreational divers face many similar hazards wherever they dive. We must not be complacent in our diving. The pre-dive check is just as important after 100 dives experience, or even 1000 dives, as it was before dive number 10. Planning with your buddy when to turn around and staying within the limits of training and experience, these are easy steps towards making every dive safer.

DAN continues to develop injury prevention resources for target segments of the recreational diving community such as lobster divers, cave divers, divers in quarries and lakes, and US divers that travel infrequently on dive holidays. Stay up to date with the latest diving safety research through Alert Diver and other DAN publications, and DAN social media such as our Facebook page. No doubt DAN will continue to develop electronic resources to support modern recreational divers, wherever they may go diving.

Peter Buzzacott MPH, PhD  
Director, Injury Monitoring and Prevention

## References

1. Sports and Fitness Industry Association, Participation in recreational diving report. 2015, Sports and Fitness Industry Association. Silver Spring, MD.

## SECTION 1. DIVE FATALITIES

Peter Buzzacott, Jeannette P. Moore, Brittany M. Rowley, James L. Caruso, Craig Nelson,  
Petar J. Denoble

### 1.1 Introduction

The Sports and Fitness Industry Association 2015 report on participation in scuba estimated there were more than 3,000,000 scuba diving participants in the US during the previous year.<sup>1</sup> Without knowing how many of those died while scuba diving overseas, or how many of the divers that died in the US were visitors, based on this number alone we cannot state with certainty what the death rate is with precision. However, to put the risk of dying underwater into context, this year's number of recreational diving fatalities suggests that around 2 out of every 100,000 recreational divers in the US die while scuba diving each year. This number appears relatively stable over time, despite improvements in equipment utility and reliability.

In 2014 there were an estimated 13,860,956 Emergency Room (ER) admissions in the US and US territories, 1,220 of those (0.009%) were for scuba injuries.<sup>2</sup> In the scuba injury pyramid, for each recreational diving fatality we might expect around 20 ER admissions, and many more primary care visits. Therefore, preventive efforts to reduce the raw number of fatalities in recreational diving probably have a cascade effect that reduces ER admissions, then primary care visits, time off work, and eventually even mild discomfort associated with minor injuries. To this aim, DAN prepares this Annual Diving Report to raise awareness of the factors that come into play in recreational diving fatalities in the hope it may better inform the diving community.

#### The Data Collection Process

The data collection process at DAN starts by first identifying a scuba diving death through internet alerts, news, forums or reports from affiliated organizations such as County Coroners, Public Safety Divers, offices of Medical Examiners or members of the public. News reports, mostly online, are monitored constantly for keywords involving diving deaths and scuba. Families of DAN members, friends, and acquaintances of the deceased who are aware of DAN's data collection efforts are also valuable sources in the data collection process. The DAN Medical Services Call Center (MSCC) is also an important resource as the DAN Medical Services Department assists with the management of any scuba diving event that is called in, whether the patient is a DAN member or not.

Once identified, each death is classified whether it should be followed up or not. There are three criteria to the dive fatalities data set for whether a case should be followed up on: 1) the dive must be recreational 2) use of scuba or rebreather 3) dive is located in US or Canada. For instance, fatalities that occur in non-recreational dives such as in military, scientific or commercial pursuits would be classified as no-follow. The use of scuba or rebreather equipment is a criteria for dive fatalities research; breath-hold dives or snorkeling fatalities are followed up separately. All fatalities in the US and Canada that are of recreational in nature and use either scuba or rebreather equipment are tagged as follow up cases. Fatalities that occur in foreign countries or involving foreign nationals are tagged as no-follow up unless it appears likely that additional details can be obtained beyond media reports, such as when the body of an American citizen is returned to the US for autopsy.

### Investigator and Medical Examiner Reports

Once cases are classified as 'follow up', research staff will pursue official investigation and coroner's reports from the appropriate agencies. Most scuba-related deaths in the US are investigated by local law enforcement agencies or the US Coast Guard (USCG) and are subjected to autopsies. The investigation reports and autopsies are integral in DAN's research into the cause of scuba-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 information in addition to compliance to the federally mandated HIPAA (Health Insurance Portability and Accountability Act of 1996) Privacy Rule. Some states consider law enforcement investigation and medical examiner's reports to be public information and are released easily while others are governed by more stringent privacy laws. Within each state, sometimes the regulations (and, hence, ease in procuring reports) can also vary from county to county. As presented in Table 1.2-2, the majority of diving deaths in the US occur in Florida and California. Fortunately, these two states have straightforward protocols for requesting and obtaining copies of reports.

Local investigating agencies (sheriff and police departments) follow similar privacy laws of their respective states as medical examiners. However, since not all the information contained in their reports contain private medical information, they are often able to release reports under the Freedom of Information Act (FOIA).

The US Coast Guard is called after most boating and water related incidents in the coastal regions of the US, and are accustomed at investigating such incidents, making their reports invaluable. Reports for cases that are investigated by the US Coast Guard are posted on their website once completed. However, it may take up to two years after an incident before any case is closed and copies released. The USCG follows FOIA protocols and will not release personal information contained in their reports. A redacted copy, removing all personal and identifying information, is usually provided upon each request. When available, downloaded dive computer profiles are included in each case file.

### Reports from Witnesses and Next-of-Kin

DAN uses the Fatality Reporting Form to collect data from witnesses and family. The form may be downloaded from the DAN website (<http://www.diversalertnetwork.org/files/FATform.pdf>) or may be requested from the research and medical services department. When necessary, the family of the decedent or next-of-kin may be contacted to assist in data collection. They may complete the Fatality Reporting Form and/or provide authorization for the release of their family members' autopsy reports.

The online incident reporting form on the DAN website (<https://www.diversalertnetwork.org/research/incidentReport/>) can also be used by family and witnesses to report a fatality and provide additional details regarding any scuba diving fatality.

### Data Entry and Analysis

DAN research maintains the scuba diving fatality data in a secure server. Once all pertinent information have been gathered and entered into the database, results are analyzed and published in the DAN Annual Diving Report. The autopsy reports, in particular, are reviewed by pathologists who are experienced in investigating diving related fatalities. The official cause of death may or may not be revised for the purpose of research based on their conclusions.

## 1.2 Geographic and Seasonal Distribution of Fatalities

DAN identified 188 fatalities worldwide in 2014. Of the 188 fatalities, 146 cases were determined to meet the parameters of the study as seven deaths involved divers that were not recreational diving and 35 breath-hold were excluded. (Breath-hold fatalities are covered separately in Section 4 of this report) The geographic distribution of these fatalities (n=146) is shown in Table 1.2-1. Of the 146 cases, only the 68 American or Canadian deaths were actively investigated by DAN. Reports of dive-related deaths from other regions were recorded but, due to geographical limitations, were not investigated. Table 1.2-2 shows the geographic distribution of 2014 Canadian or US fatalities by state or province. Florida again leads in the number of US diving fatalities reported to DAN, followed by California and then Washington. These three states accounted for 26 (48%) of the 54 diving fatalities within the US or Canada reported to DAN in 2014.

Table 1.2-1 DAN-received notifications about fatalities by country and region (n=146)

Region	Country	Count
Africa	South Africa	4
<b>Africa Total</b>		<b>4</b>
Antarctic	Antarctica	1
<b>Antarctic Total</b>		<b>1</b>
Asia	Philippines	2
	Indonesia	4
	Malaysia	1
	South Korea	6
	Thailand	5
	Singapore	1
<b>Asia Total</b>		<b>19</b>
Caribbean	Netherlands	1
	Cuba	1
	Bahamas	2
	Jamaica	1
	Saint Kitts and Nevis	1
<b>Caribbean Total</b>		<b>6</b>
Central America	Honduras	1
<b>Central America Total</b>		<b>1</b>
Europe	United Kingdom	12
	Italy	5
	Spain	2
	Malta	4
	France	1
	Ireland	6
	Switzerland	1
	Finland	2
	Norway	3
	Russia	1
	Croatia	1
	Germany	2
<b>Europe Total</b>		<b>40</b>
North America	United States	50
	Canada	4
	Mexico	6
<b>North America Total</b>		<b>60</b>
Oceania	Australia	5
	New Zealand	6
	Fiji	2
	Vanuatu	1
<b>Oceania Total</b>		<b>14</b>
South America	Columbia	1
<b>South America Total</b>		<b>1</b>
<b>Overall Total</b>		<b>146</b>

Table 1.2-2 Number of fatalities in US and Canada by state or province (n=54)

State/Province	Count
Florida	15
California	8
Hawaii	3
Michigan	3
North Carolina	3
Washington	3
Massachusetts	2
Maine	2
New York	2
Ontario	2
Alabama	1
Arizona	1
Illinois	1
Missouri	1
Nova Scotia	1
Oregon	1
Pennsylvania	1
Quebec	1
South Carolina	1
South Dakota	1
Wisconsin	1
<b>TOTAL</b>	<b>54</b>

Figure 1.2-1 shows the occurrence of fatalities in 2014 by month. The number of fatalities reported to DAN typically increases as summer approaches, peaks around July and then diminishes as winter approaches. Individual years differ slightly to the longer term average, due to the smaller number involved in a single year.

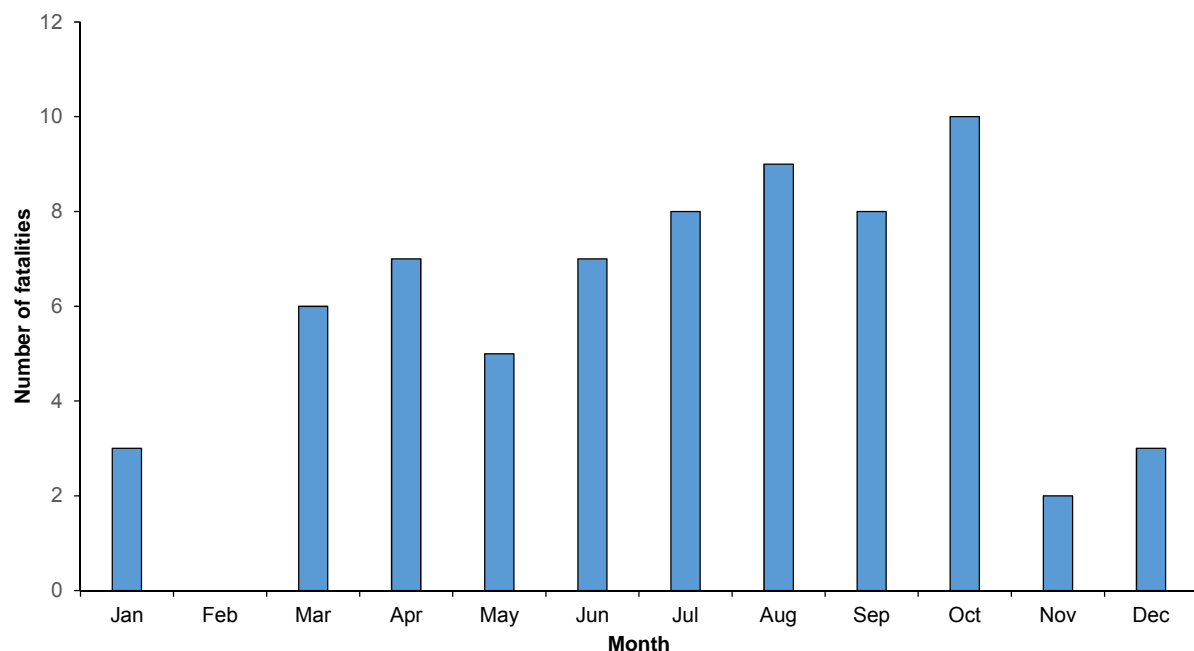


Figure 1.2-1 Monthly distribution of diver deaths (n=68)

### 1.3 Source of Information

Autopsies were available for 33 out of 68 (49%) US and Canadian cases, as shown in Table 1.3.1 below. The body of the decedent was not recovered in six cases (9%).

Table 1.3.1 Medical examination data (n=68)

Avail Autopsy Info	Count
Included	33
Missing	17
Autopsy report not available	9
No body	6
No autopsy	3
<b>Total</b>	<b>68</b>

### 1.4 Age and Health of Decedents

Figure 1.4-1 shows the age distribution for dive fatalities. In 81% of cases, the victims were males (n=55), and in 19%, females (n=13). Eighty-four percent of males and 69% of females were 40 years or older. Fifty-three percent of male and 54% of female victims were 50 years old or more.

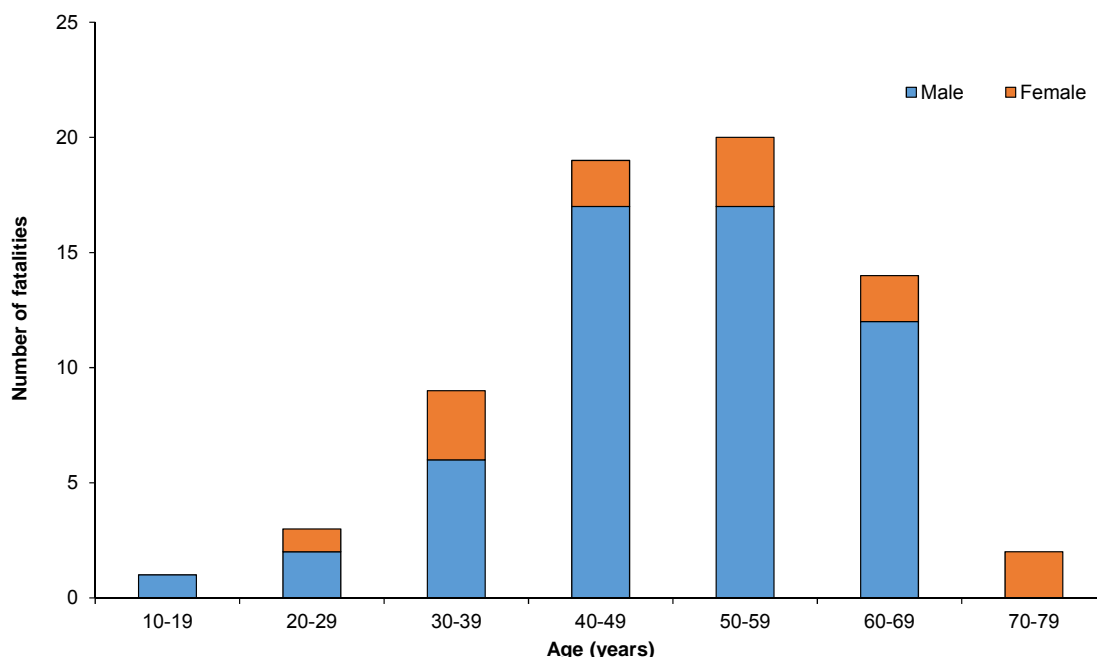


Figure 1.4-1 Overall distribution of fatalities by age and sex (n=68)

#### Case 1-01: Sudden cardiac death in an elderly male with known heart disease

A 69-year-old male, with unknown certification level or experience was diving at 55 fsw (17 msw). After only three to four minutes, he indicated that he needed to surface. He ascended with a dive guide and immediately began to vomit froth. He was pulled onto the boat, was non-responsive and no pulse was found so CPR commenced. This continued until the dive boat reached the shore where there was an AED available. No shock was advised by the AED. When asked, his travel companion said that the patient had a medical history that included cardiac problems and there was a scar on his chest indicating surgery. The autopsy concluded the cause of death was sudden cardiac death in an elderly male with known heart disease and previous heart-valve surgery.



**Medical history** was incomplete or unknown in most cases. It was explicitly reported that there were no known medical conditions in 3 cases (4%). The most frequently reported medical conditions in decedents were high blood pressure (n=4; 6%) and heart disease (n=3; 4%).

Table 1.4-1 Known medical history of decedents (n=16)

Condition	Count
Hypertension	4
None	3
Cardiovascular disease	3
Pulmonary	2
Asthma	1
Back pain	1
Diabetes	1
Seasickness	1
<b>Total</b>	<b>16</b>

The true prevalence of high blood pressure and cardiovascular diseases among victims is not known. The numbers presented in Table 1.4-1 represent only the number of cases with known medical histories. The medical history was not known for many cases and 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.

Body mass index (BMI) was indicated in the autopsy reports of 35 victims (51%) as shown in Figure 1.4-2. According to the Center for Disease Control (CDC) classifications, 20% of victims with known BMI classified as normal weight (18.5-24.9 kg·m<sup>-2</sup>), 29% as overweight (25.0-29.9 kg·m<sup>-2</sup>) and 51% as obese (30.0-39.9 kg·m<sup>-2</sup>). This prevalence of obesity among scuba fatalities is greater than that found in the wider US population, at 35%.<sup>3</sup> Data for the wider scuba diving population is not available however; therefore, we cannot know if obesity is more common in divers than in the wider population, and/or if obesity is linked with an increased risk of dying while scuba diving.

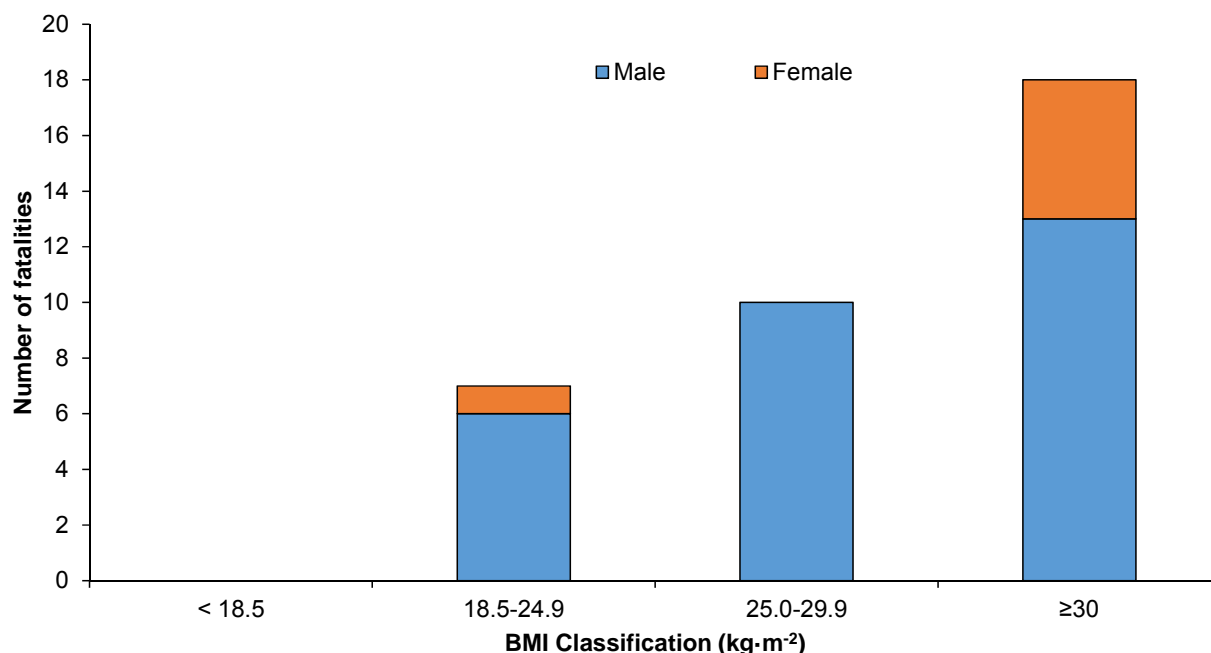


Figure 1.4-2 Classification of fatalities by BMI (CDC classifications)

## 1.5 Diving Certification and Experience

Information about certification was available in 23 cases (34%) as shown in Figure 1.5-1. Most victims had basic open water diving certification (n=7) but there were also six with professional dive leadership certifications and four divers with technical certifications.

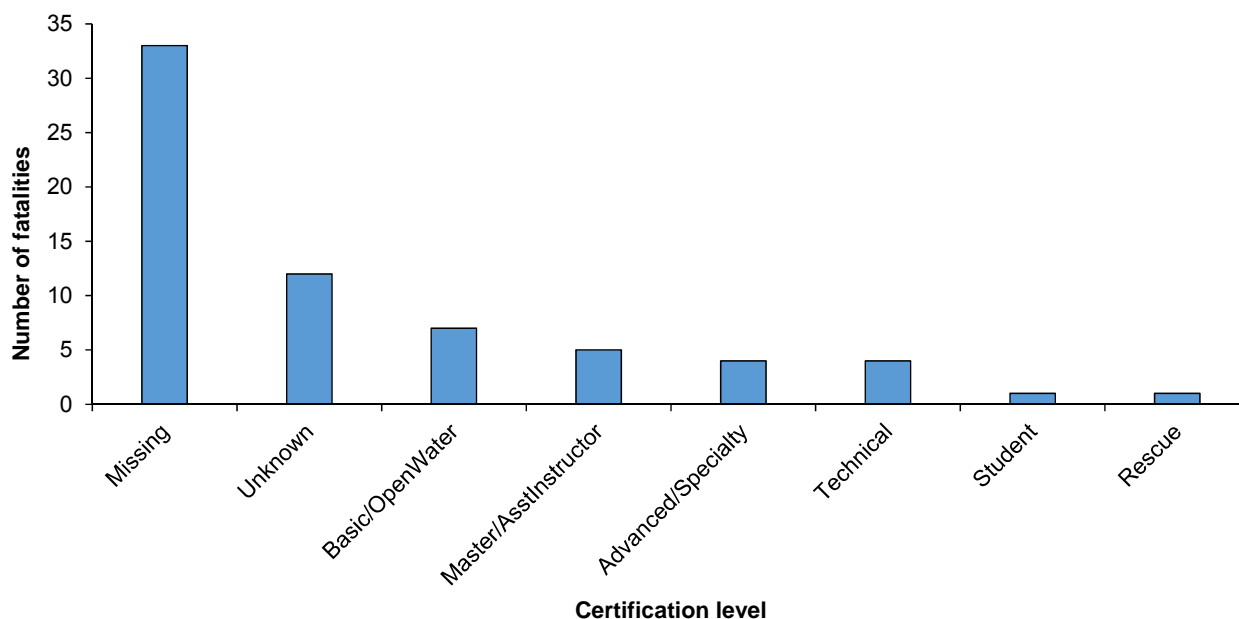


Figure 1.5-1 Diving certifications of fatality cases (n=68)

The experience of divers as indicated by the number of years since certification was known in only 14 cases as shown in Table 1.5-2.

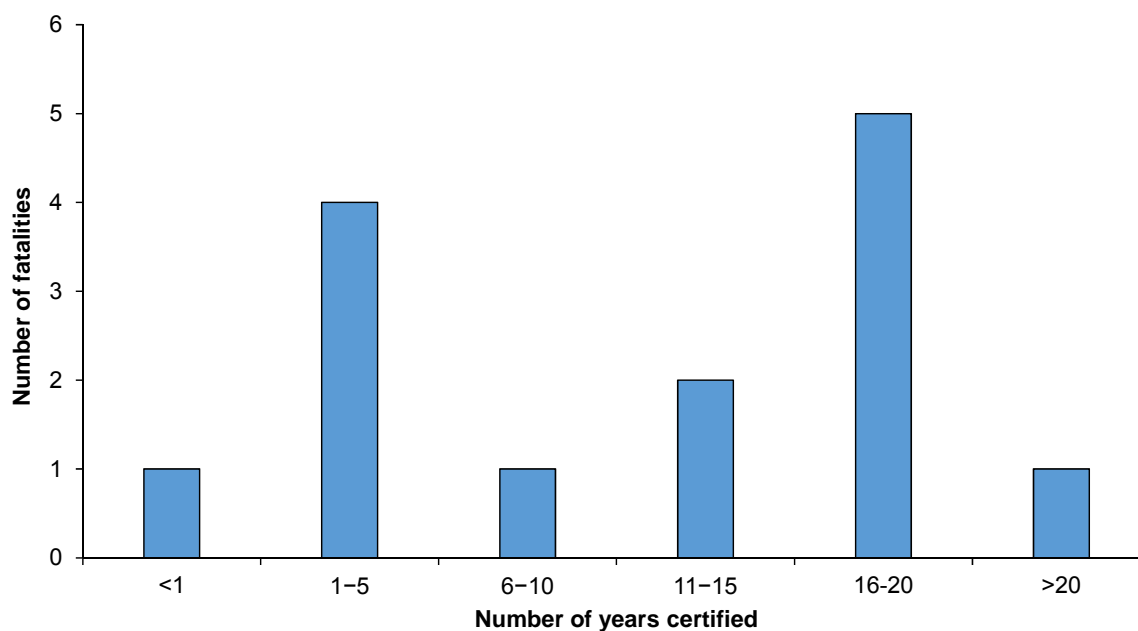


Figure 1.5-2 Number of years since initial certification (n=14)

**Case 1-02: An inexperienced diver in a new BCD sank out of sight**

This 30-year-old female, inexperienced diver, was wearing a new BCD for the first time with integrated weights and a 7 mm wetsuit. She and her dive buddy were diving with a group but they lost sight of the group upon entry. They both went down to about 60 ffw (18 mfw). The buddy let go of the victim's hand prior to ascending so that he could inflate his BCD. He started ascending and assumed the victim was following as he could still see her bubbles. When he reached the surface and the victim did not surface soon after, he called for help. The victim's body was found two days later by two technical divers in 165 feet of water (50 meters), half buried in mud, the tank empty and the BCD inflated but not lifting. The recovery divers believed the diver was wearing too much weight, (~20 pounds, 9 kg), to establish neutral buoyancy at depth even in a 7mm wetsuit and with an empty aluminum tank. An autopsy was not performed and the cause of death was attributed to drowning.

**1.6 Characteristics of Dives**

Figure 1.6-1 shows the type of diving activity during the fatal dive. Information for the type of activity was available for 66 cases (97%). Two cases did not have activity listed. Forty-five (66% of cases) of the fatal dives involved pleasure or sightseeing, 14 cases (21%) involved spear fishing, hunting or collecting game, and 8 cases (12%) involved training.

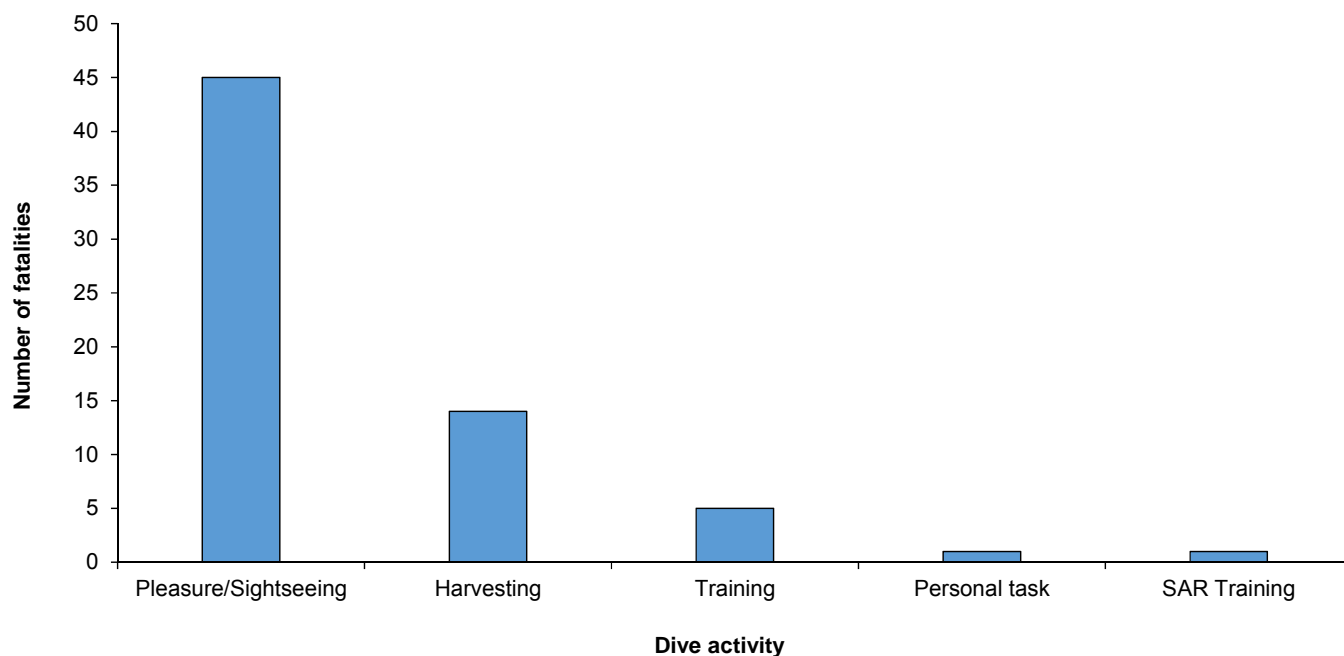


Figure 1.6-1 Diving activity (n=66)

Figure 1.6-2 shows the platform from which the fatal dives began. In most cases, the dive began from a charter boat or private vessel (n=48; 71% of known cases). Dives began from beach or pier in 18 cases (26% of known cases).

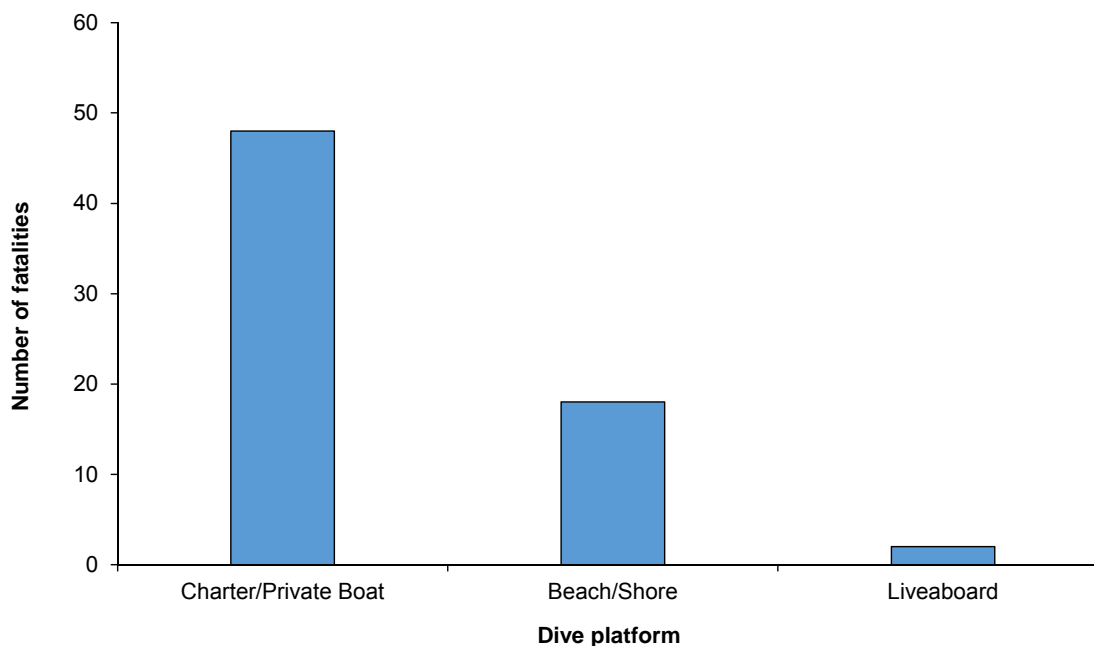


Figure 1.6-2 Dive platform (n=68)

#### Case 1-03: Heavily over weighted diver unable to surface and drowned

The diver was a 41-year-old male, certified advanced open water diver. He was experienced in various dive environments and conditions and had made over 100 lifetime dives, three of them to depths greater than the fatal dive of 105 fsw (32 msw). After reaching depth, the diver spent 10 minutes exploring the reef and also looking for an anchor line. Unable to locate the anchor line, the diver made an ascent in open water. Twenty-three minutes into the dive and fairly close to the surface, the dive buddy ran out of air and was forced to ascend rapidly to the surface, becoming separated from the victim. At about that same time, the victim also ran out of air, but was negatively buoyant and did not surface. The victim removed his 17 lb (8 kg) weight belt, but still sank to the bottom at 112 fsw (34 msw). In addition to wearing a steel tank that was negatively buoyant even when empty, the victim was wearing 50 lbs (23 kg) of lead weight distributed between a weight belt, trim pockets at the rear of the BCD, removable integrated weight pouches and soft weights inside the BCD pockets not designed for carrying weights. When the body was recovered an hour later, the dive tank was empty.

#### Case 1-04: Divers surfaced to find worsening seas and a drifting boat

The diver was a 32-year-old male with unknown certification or experience. Diving with a buddy, they rented a boat and planned several dives for the day. The weather was turning rough and the pair entered the water, descended the anchor line and secured the anchor under a rock. At the conclusion of the dive, the pair could not find the anchor line. They surfaced and found the wind was now blowing from the opposite direction and they saw their boat drifting away from them. They swam after the boat but could not catch it. During the chase, they became separated in worsening seas. After swimming for at least one hour, they still had not reached the boat and lost contact with each other. The buddy reached a mooring buoy at a wreck and clung to it until the US Coast Guard rescued him ten hours later. The missing diver was not recovered.

Most dives occurred in ocean/sea environment (n=42, 62%) with a significant number occurring in stationary fresh water (n=14, 21%) and rivers (n=4, 6%). Eight descriptions (12%) of the environment were missing.

**Visibility** was reported in 21 cases (31%). It was excellent (>50 ft [15 m]) in 10 cases (48% of the 21 cases where it was known), moderate (10-50 ft [3-15 m]) in 8 (38%) and poor (<10 ft [<3 m]) in 3 cases (14%).

**Sea conditions** (sea state) was reported in 25 cases (37%). Calm seas were noted in 13 (19%), moderate seas in 10 (15%) and rough seas were reported in 2 cases (3%).

**Currents** were described in 23 cases (34% of total). Currents were strong in 8 cases (12%), slight in 7 cases (10%) or none in 8 cases (12%).

Information about protective suits worn by divers was available in 28 cases (41% of total). Fifteen of the victims (22%) wore wetsuits, two (3%) wore swimsuits or dive skins and 11 (16%) wore drysuits.

#### Case 1-05: A diver called for help during a drysuit try-dive

This 38-year-old male was a certified diver but not certified for drysuit diving. He was participating in drysuit try-dive. The victim came to the surface in 8-10 feet water calling for help while taking his regulator out of his mouth. He was instructed to inflate his BCD and remove his weight belt, but it appeared to witnesses that the victim was unable to drop his weights. Other divers swam toward him to assist, but the victim sank and did not resurface. Once the victim was brought to the surface, CPR was administered and he was transported to the hospital where he was pronounced dead.

Figure 1.6-3 shows the maximum dive depth reported for known cases (n=45; 66% of total). Fifteen fatal dives (22%) occurred in water up to 30 feet deep, 11 (16%) in the depth range 31-60 feet, 8 (12%) in the depth range 61-90 feet, 5 (7%) in the depth range 91-120 feet, and 1 (1%) occurred in water deeper than 120 feet. Data were not available for 23 cases (34%).

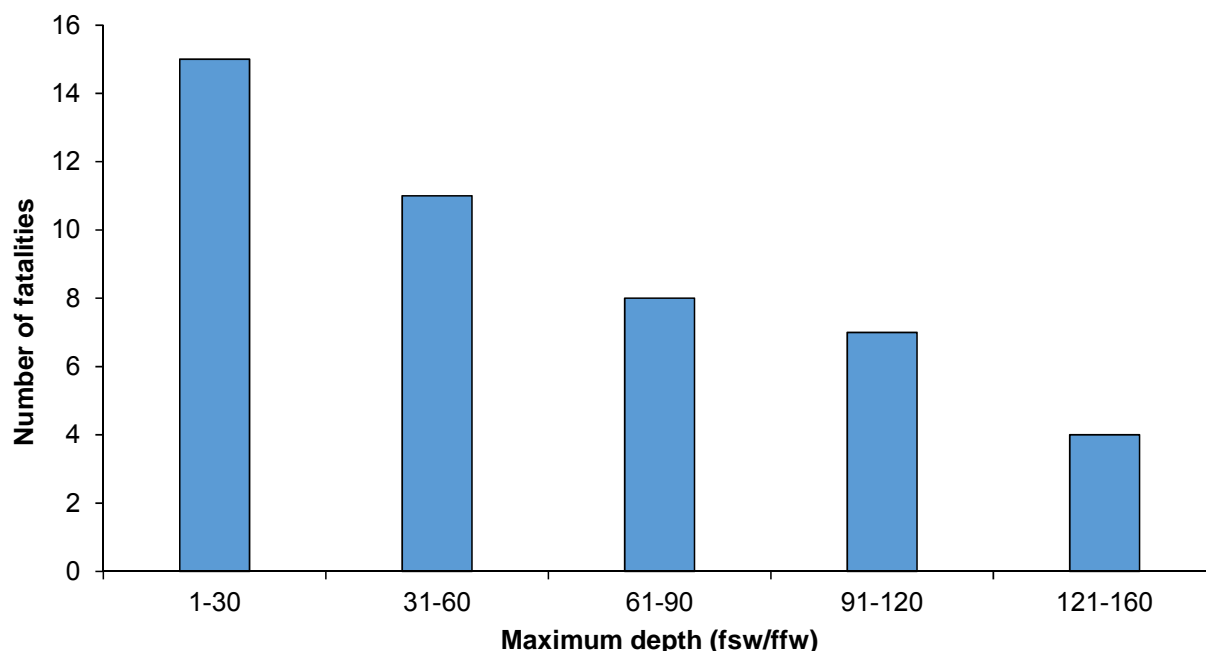


Figure 1.6-3 Maximum depth of the fatal dive (n=45)

While at least 19% of the fatal dives were intended as solo dives, most dives started with a dive buddy. Adherence to buddy system diving is difficult to establish retrospectively. When survivors notice that their buddy is missing, it does not necessarily mean that the buddy intentionally separated; it may rather mean that nobody noticed the diver having problems that eventually led to them dying.

#### Case 1-06: An entangled diver without a buddy to assist

A 58-year-old male was scallop diving off a moored boat with two other people when he failed to resurface. The boat driver radioed in a 'diver down' and emergency crews responded, searching the area for several hours. The victim's body was recovered about four hours after the incident in approximately 60 fsw (18 msw) of water. According to investigators, it seems that the diver was attempting to surface his catch (2 bags weighing approximately 40 lbs) using an air bag. He became entangled in the dive flag line in the process. It appears he attempted to release his weight belt, but it was clipped to his BCD behind his back. He was found with the regulator out of his mouth and his tanks were empty.

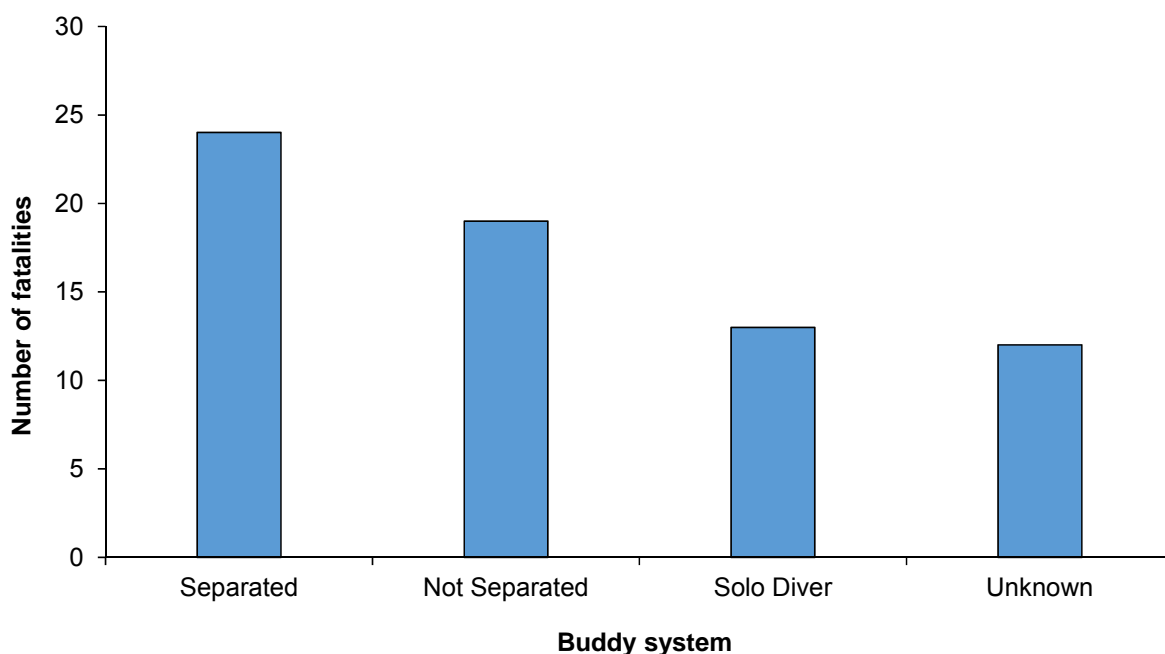


Figure 1.6-4 Buddy status during the fatal dive (n=68)

Open-circuit scuba was used in 62 cases (91%), rebreathers in four (6%) and surface-supply in two cases (3%). Breathing gas was compressed air in 28 cases (41%) and enriched air nitrox was used with scuba in four cases (6%). In one case (1%) oxygen was used and in two cases (3%), a combination of gas mixes were used. Information was not available in 30 cases (44%).

## 1.7 Analysis of Situations and Hazards

We classified each case according to the phase of the dive in which the incident occurred, and the chronological chain of events ending in death.

### 1.7.1 Fatalities by dive phase

Dive phases included: a) on the surface before diving, b) descent/early dive, c) on the bottom, d) ascent, e) on the surface after diving and f) upon exiting the water. This information was available in 41 cases (60% of total). Figure 1.7.1-1 shows the phase of the dive when the deceased lost consciousness. As can be seen, in the majority of fatalities the diver lost consciousness underwater.



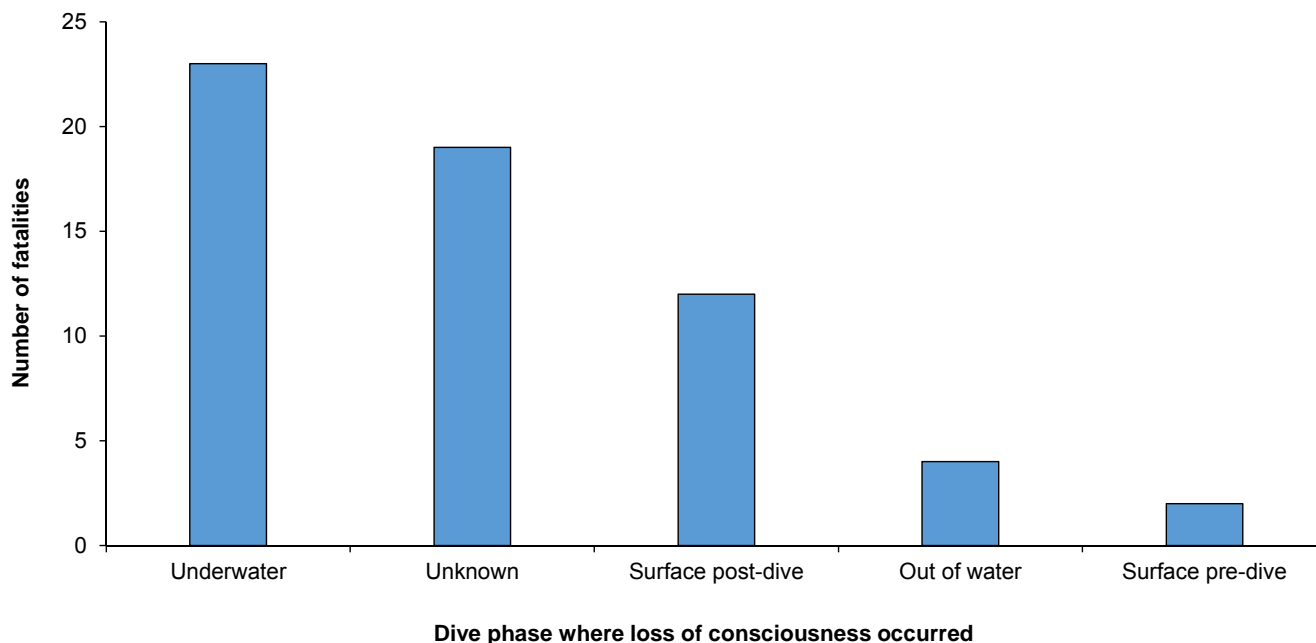


Figure 1.7.1-1 Distribution of fatalities by the phase of the dive when the deceased lost consciousness (n=68)

#### Case 1-07: A diver experienced difficulty underwater

This 61-year-old male dived to a maximum depth of 90 fsw (27 msw). At 75 fsw (23 msw), the diver signaled the dive leader that he was having trouble with his air. The dive leader gave him his octopus and guided him to the anchor line to complete a safety stop. At the boat, the decedent had difficulty breathing and was put on oxygen. After approximately 20 minutes on oxygen, he fainted. He was administered nitrox as the dive boat had by then run out of oxygen. After another 20 minutes, the decedent stopped breathing. CPR was started but the victim did not regain consciousness.

#### 1.7.2 Causes of deaths

Determination of the causes of death was based on: a) autopsy findings and the underlying cause of death reported by the medical examiner, b) dive profile, c) reported sequence of events, d) equipment and gas analysis findings and e) expert opinion of DAN reviewers. The process is described in further detail in a published paper.<sup>4</sup>

Root causes, mechanisms of injuries and causes of death were not established in a large number of cases mostly because of missing information and inconclusive investigation. Based on available data, the most common known triggers were natural disease (18%) and running low on, or out of, air (9%) (Table 1.7.2-1).

Table 1.7.2-1 Common triggers by year and overall (n=68)

Trigger	Total
Alcohol intoxication	1
Entanglement (line)	3
Entrapment in rocks	1
Equipment malfunction	2
Equipment misuse	1
Low on / Out of air	6
Natural disease	12
New dry suit	1
Panic	1
Probable oxygen toxicity	1
Regulator free flow	1
Separated from the boat	1
Surge	1
Unknown	36
<b>Total</b>	<b>68</b>

The most common known harmful events were cardiac events (7%) and insufficient breathing gas (7%) (Table 1.7.2-2).

Table 1.7.2-2 Harmful events (n=68)

Mechanism	Total
Cardiac event	5
Hypertensive/Atherosclerosis cardiovascular disease	2
Insufficient breathing gas	5
Insufficient buoyancy	3
Natural disease	4
Out of air	3
Probable oxygen induced seizure	1
Rapid ascent	2
Struck head	1
Stroke	1
Unknown	40
<b>Total</b>	<b>68</b>

The cause of death as established by medical examiners, in most cases, was drowning. However, according to expert reviewers, once again the data indicated that a leading cause of disabling injuries was an acute cardiac event. Table 1.7.2-3 and Table 1.7.2-4 list the disabling injuries and causes of death and Figure 1.7.2-1 compares disabling injuries and causes of death side by side. It can be seen that in 2014 the leading cause of death and leading disabling injury that led to the death was drowning. However, cardiac events and heart problems continue to be a concern.

Table 1.7.2-3 Disabling injuries (n=68)

Disabling Injury	Total
AGE	1
Atherosclerotic and hypertensive cardiovascular disease	2
Blunt head trauma	1
Cardiac event	9
Drowning	12
Heart problem	7
Hemorrhagic stroke	1
Hypothermia	1
Lung overexpansion	1
Probable cardiac	2
Probable drowning	1
Seizure	2
Unconsciousness	1
Unknown	27
<b>Total</b>	<b>68</b>

Table 1.7.2-4 Causes of death (n=68)

Cause of death	Total
Arterial Gas Embolism	2
Anoxic brain injury	1
Atherosclerotic cardiovascular disease	4
Cardiac event	7
Drowning	21
Hypertensive and atherosclerotic cardiovascular disease	2
Hypertensive cardiovascular disease	1
IPE	1
Probable cardiac	2
Probable drowning	3
Unknown	24
<b>Total</b>	<b>68</b>

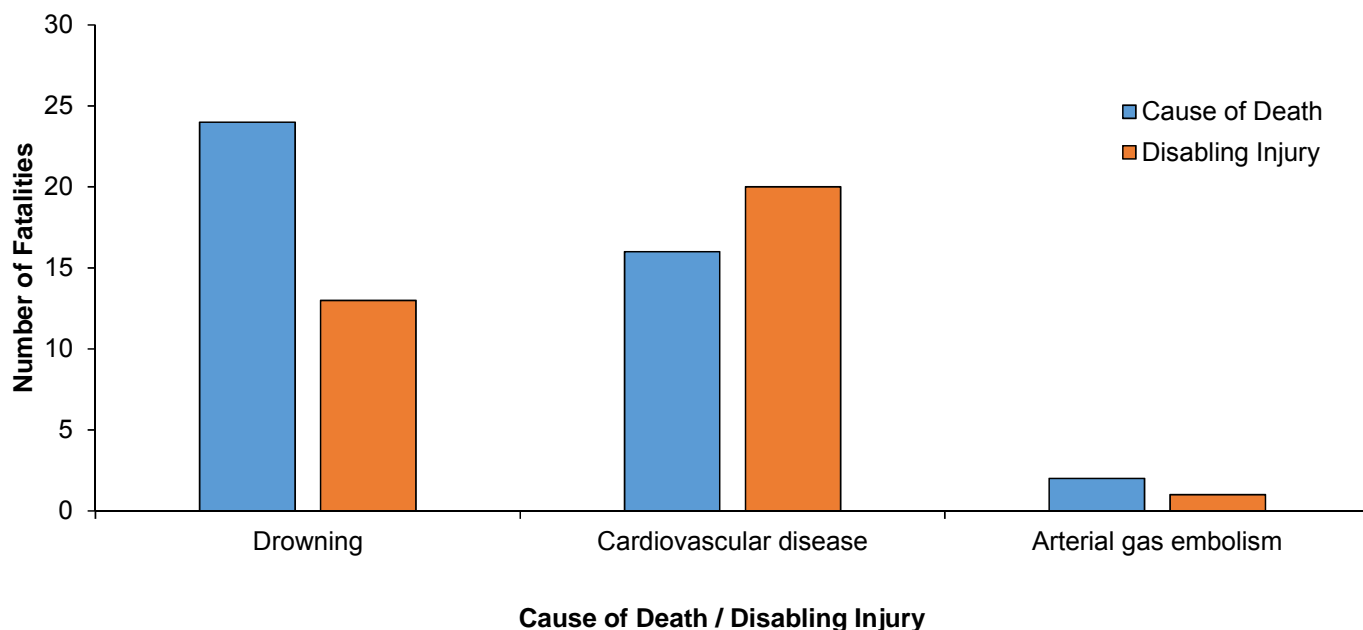


Figure 1.7.2-1 Distribution of three leading disabling injuries and causes of death (n=68)

#### Case 1-08: A returning diver suffered a heart attack

A 66-year-old male with unknown certification level and experience was one of five scuba divers planning to visit a shipwreck. He had recently completed a refresher course, but the duration of his prior absence from diving is unknown. He reportedly entered the water showing no signs of trouble, but shortly afterwards was found on the surface unresponsive and without vital signs. Other divers towed him back to the boat where CPR commenced. Despite resuscitation efforts, the victim was pronounced dead at the scene. There was reportedly a strong surface current and the coroner ruled the cause of death as a heart attack.

#### Case 1-09: A diver suffered chest pain, surfaced and stopped breathing

A 45-year-old male with unknown experience and certification level was on a diving trip with his children. The decedent dived to 100 fsw (30 msw) for 10 minutes then began having trouble as he surfaced from the dive. He complained of chest pain and was assisted onto the boat, where he became unconscious and stopped breathing. CPR was administered and the victim was taken to the marina where paramedics were waiting. He was taken to a local hospital where he was pronounced dead. The autopsy noted mild-to-moderate chronic hypertensive cardiovascular disease.

#### Discussion

The majority of fatalities occurred in relatively shallow water <60 fsw (18 msw), diving with open circuit, most often with a buddy. It is likely these circumstances are by far the most common among recreational divers in the US and Canada. The three leading modifiable causes of death and disabling injuries were again cardiac events, insufficient gas and arterial gas embolism. That more than half of all recreational diving fatalities were aged 50 or over highlights the importance of maintaining fitness to dive as divers age. High blood pressure and heart disease were the most common pre-existing health conditions known among 2014 diving fatalities, and obesity was more common at 51% than found in the general living population at 35%. It may not be unreasonable to speculate that older, heavier divers with pre-existing heart or blood-pressure conditions are at elevated risk of dying while scuba diving, compared with younger, healthier divers.

### 1.8 Lobster Diving Fatalities

This year the report lists ten lobster hunting fatalities, 15% of the 68 that occurred during 2014, to highlight the significance of this group among annual recreational diving fatalities. Divers distracted by the hunt are at elevated risk of running out of breathing gas. The underwater hunt itself may contribute to the workload a diver experiences while diving. Carrying a scoop-net, catch-bag, tickle-stick and/or loop all add to the work of moving around and hunters may even cover more ground during a typical dive, compared with underwater photographers, for example. Some lobster divers rarely dive outside of lobster season and returning to diving after an absence also likely adds to a diver's workload, while the skills needed for efficient buoyancy control and fluid propulsion are being refreshed.

#### **Case 1-10: Low on air diver re-descended for one last lobster**

This 22-year-old male died while diving for lobsters with a large group in 40 fsw (12 msw) deep water. The victim and his buddy surfaced as the buddy was low on air. The victim indicated he still had sufficient air and wanted to go down one more time as he had tied his dive flag near a lobster he wanted to catch. After a few minutes, he was observed to be 'floating' 15 fsw (5 msw) from the surface. The boat's dive guide went in to rescue the victim but found him entangled in the dive line and unresponsive. The victim was surfaced and CPR was initiated but he did not regain consciousness and was pronounced dead at the hospital.

#### **Case 1-11: Entangled hose prevented ascent**

This 26-year-old female with unknown certification and experience, died while diving for lobster. The victim and buddy were in about 12 fsw (4 msw) of water using a "hookah" surface-supplied breathing apparatus. The victim's hose got wrapped around a piling. When the buddy tried to free it, his air got cut off so he had to surface. The victim surfaced a few minutes later, but she was face down and not breathing. She was pulled from the water and CPR was performed. The victim was then taken to the hospital where she was pronounced dead.

#### **Case 1-12: Diver separated from the group during a night dive**

This 36-year-old male diver died on a night dive after he became separated from friends while hunting for lobsters. His buddies saw the victim's light heading for shore and so they followed but when they reached the shore, the victim was not there. They started searching and called for help. The victim's dive light was found several hours later in shallow water and shortly afterward, the decedent was located about a mile offshore.

#### **Case 1-13: Solo diver suffered a cardiovascular death**

This 59-year-old male with unknown certification and experience was diving for lobster but did not return to the boat and was reported missing by his diving companions. The victim had entered the water with two buddies but each went a separate way to hunt for lobster. The two buddies returned to the boat and realized that the victim had not returned for a new tank or left lobster aboard. The victim's body was found more than an hour later, still clad in dive gear, in the shallows about a half mile from his boat. The autopsy found the cause of death was due to atherosclerotic cardiovascular disease.

#### **Case 1-14: Diver lost consciousness soon after entering the water**

This 68-year-old female, with unknown certification level but an experienced diver, was diving from a boat with friends. The victim was briefly underwater to hunt for lobsters in about 10 fsw (3 msw) of water before she lost consciousness. Friends say they saw her struggling on the surface after being underwater for only a few minutes. They pulled her into the boat, began CPR, and called the Coast Guard for help. The Coast Guard brought the victim to shore and paramedics took the victim to the hospital where she was pronounced dead.

#### **Case 1-15: Equipment problems led to death before the dive even began**

This 38-year-old male was diving at night for lobster with two friends from aboard a privately owned boat. The victim was using borrowed equipment that he was unfamiliar with. He had problems with the equipment at the surface pre-dive and started drifting away from the boat. His BCD inflator hose was out of reach behind his left shoulder and he did not release his weight belt. The buddy tried to assist the diver, and attempted to share air and inflate the victim's BCD but this was unsuccessful. By that time, the buddy was now gasping for breath himself. The buddy could not hold on to

the negatively buoyant victim as he sank below the surface. Lifeguards found the victim below the surface, removed his weight belt, inflated the BCD, surfaced and pulled him into the lifeguard boat. The victim was unresponsive and did not have a pulse. CPR was performed but the diver was later pronounced dead at the hospital.

**Case 1-16: A solo diver found unconscious near his boat**

This 53-year-old male was an experienced master diver who was diving alone while hunting for lobster. His unconscious body was found by fishermen floating face down near his boat. Later, it was learned that the decedent was taking prescription medications for both high blood pressure and high cholesterol. The medical examiner ruled that death was due to drowning after an acute myocardial infarct.

**Case 1-17: A new drysuit too difficult to master by reading the instructions alone**

This 40-year-old male was an advanced open water diver, experienced and had been on several dive trips with colleagues in previous years. This trip was planned to coincide with the start of the lobster season. This was the first time the diver was wearing a new drysuit and he was likely over-weighted. He was seen reading the instructions for his new drysuit the night before the fateful dive. The following day, he was seen struggling to descend head-first, as one would while wearing a wetsuit. Drysuit divers, however, more commonly initially descend feet first to allow trapped air to escape through the shoulder valve. That evening, the victim initially entered the water without the drysuit zip closed. After exiting the water for the deckhand to close the zip, the victim then re-entered the water while wearing wet undergarments. He was diving with a steel tank, a borrowed weight belt with 10-12 lbs (4-5 kg) of lead attached, two weight-integrated removable BCD pouches each containing six lbs and there were another two five lbs weights in pockets at the rear of the BCD, all newly purchased the day before. The victim was also wearing ankle weights making a total of about 35 lbs (16 kg) of ballast in addition to the steel tank. The victim was on his third dive of the day and was diving alone (solo) in 110 fsw (34 msw) when the incident occurred. Approximately 25 minutes after entering the water, the diver surfaced, yelled for help, re-sank underwater and remained missing until the body was recovered three days later with his weight belt ditched, but with weights still in the BCD and on his ankles. His dive tank was empty.

**Case 1-18: The exertion of hunting may have been the final straw**

This approximately 40-year-old male diver with unknown experience or certification level experienced chest pain on a night dive. Other divers at the site pulled him out of the water and commenced CPR before a rescue boat arrived. The victim was transferred to a hospital where he was pronounced dead.

**Case 1-19: Heart failure while separated from group**

This 49-year-old male, went on a three day dive trip with two buddies. During the fourth dive of the day, the decedent surfaced early for an unknown reason. The victim complained of nausea during the trip but was unsure if this was a result of sea sickness. The divers were not diving as a group and the decedent was last seen approximately 20 minutes into the dive, at about 20 fsw (6 msw) depth, with no problems. Shortly after the others surfaced, the decedent was found floating face down on the surface of the water and was pulled into the boat and life saving measures were attempted. The diver did not regain consciousness and death was pronounced. The decedent did not have a primary care physician and had not been diagnosed with medical ailments. An autopsy was conducted and the cause of death was determined to be a result of drowning due to congestive heart failure.

Hunting for lobster is an underwater pursuit enjoyed by tens of thousands of Americans and yet each year a very small minority die or are seriously injured. In 2014 there were at least ten lobster hunting fatalities that occurred while breathing compressed gas and the above case vignettes reinforce the importance of diving with a buddy, being familiar with your equipment and keeping an eye on the remaining gas to ensure a safe ascent to the surface. Problems with overweighting are another target for improvement and DAN have a number of tools in development towards this aim.



## 1.9 Rebreather Fatalities

DAN is aware of 28 rebreather cases in 2014 that occurred worldwide. Four of those (14%) were in the US, where follow-up inquiries usually led to further detailed information. The distribution of rebreather fatalities by country is shown in Table 1.9-1. Vignettes from 11 of the 28 cases follow.

Table 1.9-1 Number of rebreather fatalities by country

Country	Count
United Kingdom	5
United States	4
Norway	3
Germany	2
Italy	2
Russia	2
Thailand	2
Switzerland	1
Cyprus	1
Spain	1
Finland	1
Croatia	1
Ireland	1
Philippines	1
South Africa	1
<b>Total</b>	<b>28</b>

### Case 1-20: A 63 year old obese diver could not arrest his descent

This 63-year-old male was an experienced diver but his certification level was unknown. The diver's medical history included an incomplete bundle branch block, sleep apnea, heart arrhythmia, and he was taking thyroid medication. He was diving wearing a drysuit in a group of three divers to a planned maximum depth of 141 fsw (43 msw). He was last seen by the dive group manipulating something on his equipment after a rapid descent deeper than the maximum planned depth, before again rapidly descending to depths below 170 fsw (52 msw). His dive buddies searched for him for a while (the duration of time is unknown) before surfacing and alerting authorities. The victim's body was located at 248 fsw (76 msw) several days later using remotely operated underwater vehicles (ROV). The body was not entangled when found.

The equipment investigation identified a leak in the plastic housing of the victim's BCD inflator valve. When a diluent bottle was attached to the inflator valve and the BCD was filled, bubbles were seen escaping through the plastic although none had been seen by the dive buddies during the fatal dive. It is uncertain if this mechanical issue had any bearing on the outcome. All other equipment was found to be functioning as designed. Cause of death was determined to be sudden death during scuba diving in association with hypertensive and arteriosclerotic cardiovascular disease. The victim had a Body Mass Index of 34.

### Case 1-21: Seizures at depth were followed by anoxic brain injury

This was 56-year-old male, experienced diver, dive professional, and technical diver. According to his dive buddy's dive computer, the pair were at 130 fsw (40 msw) for 20 minutes, and the computer reported five minutes of decompression obligation. They ascended to 85 fsw (26 msw) for a deep stop. At the deep stop, the victim signaled distress to his

buddy and reached for his bail out regulator. The victim spat his regulator out and appeared to be having a seizure. The buddy made an emergency ascent with the victim from 85 fsw (26 msw), (during which the victim potentially suffering an arterial gas embolism cannot be ruled out). The victim was taken to the hospital where he was diagnosed with an anoxic brain injury from the delay between spitting out the regulator and commencement of CPR. A series of epileptic seizures were confirmed by electroencephalogram (EEG) twice daily, possibly after experiencing an oxygen toxicity seizure. He died in the hospital six days later when life support was discontinued.

#### **Case 1-22: Diver made a controlled ascent before drowning**

This was a 54-year-old male, experienced diver, with certification level unknown. The victim was diving with a group but without an assigned buddy. A member of the group saw the victim signal 'OK' before he was found unresponsive in the water a few minutes later. His dive computer showed the diver had ascended in a controlled manner but had omitted required decompression stops. The crew and passengers on the boat attempted CPR until emergency teams arrived. The victim was transported back to shore and pronounced dead. His Body Mass Index was 35 and the post mortem noted left ventricular hypertrophy. The medical examiner concluded, "...that while the decedent appears to have made a controlled ascent to the surface, he was found unresponsive at the surface and made no known cries for help upon reaching it. It therefore appears that he became unresponsive shortly before or after reaching the surface. While his heart disease is a risk for sudden death, a cardiac arrest is expected to be sudden unresponsiveness without [sic] very little warning, and would not be expected to be preceded by a controlled ascent omitting decompression, which indicates awareness of a problem."

It is, therefore, unclear as to how the decedent became unconscious, but once he became unconscious in the water, he would have drowned. Findings supportive of drowning are pulmonary edema and frothy fluid in the airway. Therefore, based on the autopsy findings and circumstances surrounding the death, as currently understood, the cause of death is listed as drowning while rebreather diving. Listed as contributing factor is hypertensive and atherosclerotic cardiovascular disease. The manner of death is classified as accident.

#### **Case 1-23: Lost diver found the next day in the engine room**

This was a 56-year-old male with unknown experience and certification level. On the second dive of the day, the victim and his dive buddies went diving on a shipwreck to 112 fsw (34 msw). The victim became lost in the passageways of the shipwreck and was separated from his dive group. A dive search and rescue team located the victim's body in the ship's engine room the following day.

#### **Case 1-24: Skipping the pre-dive check on a misassembled unit proved fatal**

This was a 41-year-old female, experienced diver and certified dive instructor. The victim was diving with a group and was brought to the surface by one of her dive buddies. According to the investigative report, poor rebreather design and mistakes during pre-dive equipment assembly were found to have triggered the event. It is not known if the diver assembled the rebreather herself. The oxygen cells had expired in 2013 and were overdue for replacement. An inquest determined that carbon dioxide would not have been removed from the counter lungs due to incorrect equipment assembly, which led to unconsciousness about three minutes into the dive. Specifically, the inhale and exhale counter lungs had been attached on the wrong sides, ensuring the one-way inhale valve was butted up against the one-way exhale valve. This meant the diver was in essence breathing in and out of one counter lung and her exhalations were not passing through the scrubber. Recommended pre-dive checks would have identified the incorrect assembly.

#### **Case 1-25: Diver lost consciousness while diving a shipwreck**

This was 57-year-old male, experience and certification unknown. The victim was diving a ship wreck with a group who later surfaced with the unconscious diver. The victim was taken to a local hospital where he was pronounced deceased.

#### **Case 1-26: A 68 year old diver ran out of oxygen before exiting a strong siphon**

This was a 68 year-old male who was an experienced professional diver and a certified cave diver. The victim failed to exit the strongly siphoning cave and ran out of oxygen. The victim's body was recovered at about 131 fsw (40 msw) after about eight hours of searching.

### **Case 1-27: A problem occurred before entering a cave**

This was a 46-year-old male who was an experienced cave and technical diver. Two divers planned to dive to a cave located at 78 fsw (24 msw). According to news reports, one of the victim's dive computers indicated that at 65 fsw (20 msw) a problem started. This means the incident most likely did not occur in the cave. The dive computer indicated the victim stayed at 65 fsw (20 msw) for approximately two minutes, possibly addressing the problem. Then, he made a rapid ascent to the surface.

### **Case 1-28: A cave diver suffered a pulmonary embolism**

This diver was a male of unknown age who was an experienced cave and technical diver. The victim was cave diving with a group of four, in buddy pairs. The victim was found unconscious at the surface by others in the dive group with his rebreather mouthpiece out of his mouth. The victim was recovered by members of the dive group and taken to local hospital, where he later died. According to news reports, the victim died from a pulmonary embolism.

### **Case 1-29: Diver stuck in a restriction in a deep, cold cave**

A party of five cave divers intended to complete a scooter-assisted traverse through a cave flooded with cold snow-melt, reaching greater than 130 mfw (425 ffw) maximum depth. This was the victim's first attempt at this traverse. After an hour of diving, and having passed the deepest section, the victim became stuck in a restriction at 110 mfw (360 ffw) depth and signaled distress to his dive buddy. The buddy attempted to lend assistance but the victim became more agitated and died, wedged in the restriction. By now substantially delayed, the buddy exited after making many hours of decompression and was hospitalized for decompression sickness. Official attempts to recover the victim's body were unsuccessful. Members of the original team returned to extricate the victim, plus a second diver who died during the same dive.

### **Case 1-30: A second death followed aborting the traverse**

The second fatality during this dive involved one of the party of three divers following the first pair. When they reached the first victim stuck in the restriction the first diver of these three negotiated his way around the first victim while the second victim and his buddy turned back towards the entry lake. The second victim died returning through the deepest part of the traverse.

## **Conclusion**

Rebreather diving and rebreather fatalities are growing in frequency. Reading through the 2014 cases should give pause to older rebreather divers with high body mass index and/or existing health conditions. There comes a point in every diver's life when it is prudent to simply accept that his or her most challenging dives have already been made, and it is time to reduce the physiological stress associated with diving. Avoid strong currents, make dives that require carrying less bailout gas, etc, and actively reduce the workload associated with diving.

While rebreathers are continually evolving and their usability has improved greatly over the last decade, they remain an apparatus that deserves current familiarity and not something one should dive with once or twice per year. Divers who do not have the time or ready access to a dive site to maintain their currency with rebreathers are advised to return to open circuit diving.

## 1.10 References

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## SECTION 2. DIVING INJURIES

Daniel A. Nord, Petar J. Denoble, James M. Chimiak

### 2.1 Volume of Calls to MSCC and Treatment Numbers Reported by Hyperbaric Chambers

The two main sources of information about diving injuries collected by DAN are the DAN Medical Services Call Center (MSCC) and the Annual Survey of Hyperbaric Chambers treating injured divers.

Table 2.1-1 presents the volume of calls to DAN's Medical Department. In a five-year period, there were 64,934 calls or emails requesting some kind of assistance, information or consultation. Medical staff answered more than 15,600 calls to the emergency line and more than 36,000 medical information calls and emails. In 2014 there were 5041 calls to the emergency line.

Table 2.1-1 Volume of Medical Services calls in 2010 – 2014

Activity	Year-to-Year Comparison				2014
	2010	2011	2012	2013	
Emergency Line Calls	2,518	3,493	4,382	5,047	5,041
Information Line Calls	5,727	6,266	5,923	5,556	5,506
E-mail Inquiries	3,470	3,444	2,758	3,161	2,642
<b>Totals:</b>	<b>11,715</b>	<b>13,203</b>	<b>13,063</b>	<b>13,764</b>	<b>13,189</b>

#### 2.1.1 DAN Medical Services

The medical information line includes access to medical services via email. The information line phone and email services are staffed Monday through Friday 8:30 AM – 5:00 PM eastern time in the US and can be reached by calling +1-919-684-2948 extension 6222 or visiting the Ask a Medic link on the DAN website at [www.dan.org/medical](http://www.dan.org/medical). Common topics range from diving injuries, to medical fitness, to dive questions. Medical staff also provides consults with healthcare providers so they can best assist their patients who dive. Injured divers who need assistance should not use email channels but should instead use the DAN Emergency Line by calling +1-919-684-9111.

Prevention and education are essential for keeping divers safe. The DAN medical staff provides online and live education on topics from dive planning to emergency care of diving injuries. The DAN knowledge base is continually updated to keep pace with current standards of practice. Additionally, the department helps train and support hyperbaric medicine fellowships, as well as offering training in dive medicine to all levels of healthcare providers.

#### 2.1.2 DAN Emergency Services

The best known service of the medical department is the twenty-four hours a day, seven days a week emergency assistance provided through the “DAN Emergency Services” dedicated telephone line. This service provides around-the-clock access to on-call medical professionals with extensive training and years of experience in diving and travel

medicine. They assist divers in need and healthcare providers with timely consultation. Calls that usually take the most time and assistance are those of suspected decompression illness which may require recompression treatment. DAN assists with helping injured or ill divers to a place where they can receive appropriate evaluation and treatment. Neither diving medicine trained physicians nor hyperbaric treatment facilities are widely available which makes management of suspected DCI cases complicated. Sometimes complicated medical evacuations are indicated in the best interest of the injured diver. These services are available to anyone. DAN provides assistance but the cost of evacuation and treatment is borne by divers and their insurance plan. DAN members, however, receive no-cost evacuation assistance and other benefits that on-call medical staff help coordinate with DAN Travel Assist providers. DAN Emergency Services can be reached 24-hours a day by calling +1-919-684-9111.

### 2.1.2.1 Classification of calls

Each initial call or email is documented within the MSCC and classified as one of two call types – *Information Request* or *Case*. Although the two types are not always mutually exclusive, for purposes of data collection and demographics, these records are generally treated as such.

### 2.1.2.2 Categories of calls

Once calls are classified, they are then assigned to one or more categories according to the nature of the inquiry or complaint. Although most calls pertain to one category, some may pertain to several. The following charts represent a breakdown in the categories of calls to Medical Services for the report year.

For the reporting year, 33% of the calls involved illness or injury that was not necessarily related to diving. Sixty-seven percent of the calls represented information requests.

Table 2.1.2.2-1 Subcategories of medical information calls by body systems and disorders

Body Systems & Disorders	Cases	Info Calls	Total
Ear, Nose & Throat	273	442	715
Musculoskeletal	314	242	556
Respiratory	67	398	465
Cardiovascular	32	336	368
Drugs / Medications	5	286	291
Neurological	48	219	267
Gastrointestinal	39	98	137
Ophthalmology	14	117	131
Dermatology	40	47	87
Endocrine / Metabolic	2	84	86
Psychological / Psychiatric	13	71	84
Dental	15	62	77
Malignant Disease	1	69	70
Hematology	3	57	60
Infectious Diseases	19	24	43
Gynecology / Obstetrics	2	36	38
Genitourinary	6	24	30
Connective Tissue	2	12	14



Information calls regarding medical fitness-to-dive are classified by body systems and are further sub-categorized for particular disorders which are not shown here. The most common categories are ear, nose and throat; cardiovascular, respiratory, musculoskeletal and drug-related questions. The category drugs/medications, does not represent a particular body system *per se*, but is commonly used to identify information calls dealing with medications such as over-the-counter drugs (e.g. for anti-motion sickness), as well as analgesics, or anti-malarials.

Table 2.1.2.2-2 Dive related injury/illness

DIVE RELATED ILLNESS/INJURY	Cases	Info Calls	Total
Barotrauma	890	148	1038
Decompression Sickness	530	40	570
Marine Envenomation	244	31	275
Pulmonary Edema - IPE	48	7	55
Arterial Gas Embolism / AGE	35	0	35
Fatality	29	6	35
Motion Sickness	14	13	27
Finfoot	24	1	25
Mask Squeeze	15	2	17
Near Drowning	15	0	15
Gas Contamination	13	1	14
Loss of Consciousness	13	0	13
Cardiac Arrhythmia	5	0	5
Nitrogen Narcosis	4	1	5

The most commonly reported dive disorder was associated with barotrauma at 49% of the dive injury calls for the reporting year. For divers, barotrauma was sub-divided into ears and sinus; pulmonary; mask squeeze; dental; suit squeeze; gastrointestinal. Calls regarding possible decompression sickness ranked second at 27% of the dive-related cases, while marine envenomation followed at 13%.

Table 2.1.2.2-3 Location or region of calls

World Regions	Totals
United States	4038
Caribbean Basin	627
Mexico	384
Canada	269
Southeast Asia	250
Central America	193
Europe	114
Pacifica	94
South America	81
Australia	67
Far East	51
Africa	45
Middle East	28
Polar	1
<b>Grand Total</b>	<b>6242</b>

DAN America assists callers from all parts of the world. DAN Europe, DAN Asia-Pacific, DAN Southern Africa, DAN Japan and DAN Brazil operate with their respective hotlines and generally manage callers in their regions who contact them for support. However, there are many cases involving the collective efforts of DAN offices around the globe. The primary DAN America region (US, Canada, Caribbean Basin and Mexico) accounted for 85% of the cases handled in the reporting year.

### 2.1.3 Evacuation of dive related illness/injury

DAN members receive a wide variety of travel assistance benefits, one of which allows for no-charge emergency evacuation and repatriation. This benefit covers the cost of medically necessary transfer to the nearest appropriate medical facility. For the year 2014, DAN assisted in providing 94 medically necessary evacuations or transfers in order to receive appropriate treatment. Of that number, 38 evacuations (40%) were for dive related illness and injury; while injuries related to trauma ranked second at 25 evacuations (27%).

Figure 2.1.3-1 below presents types of evacuation for a higher level of medical care by diagnosis and Figure 2.1.3-2 below presents types of evacuation by region.

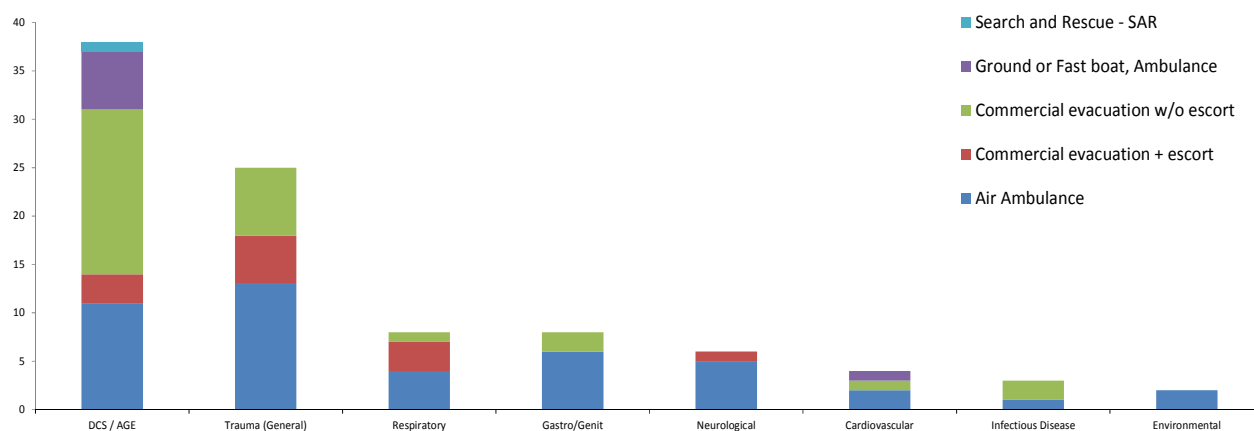


Figure 2.1.3-1 Evacuation by diagnosis

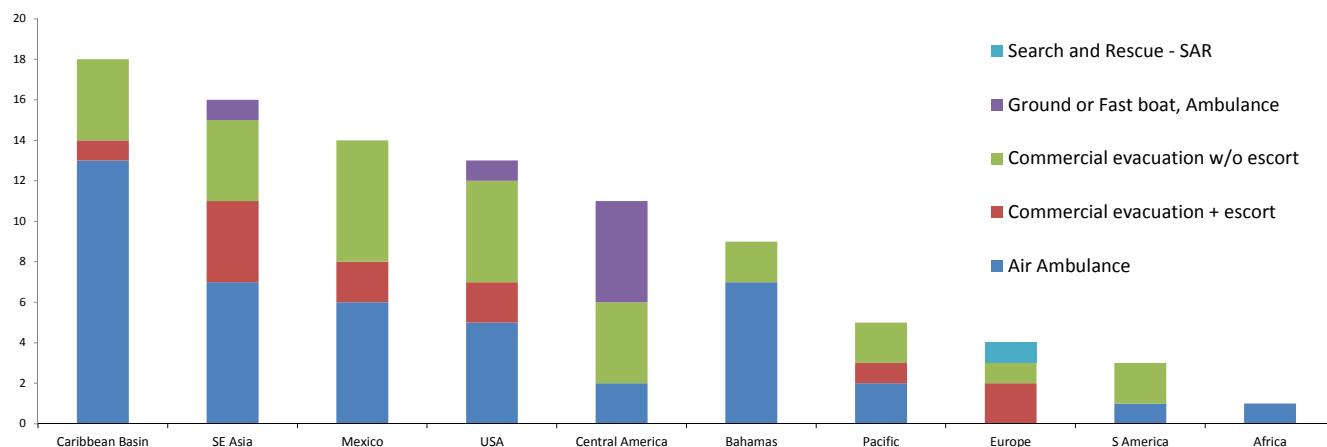


Figure 2.1.3-2 Evacuation of dive related injuries

### 2.1.4 Where are divers being treated?

Each year, DAN surveys the hyperbaric chamber facilities within North America, Central America, Caribbean Basin, and Pacific regions to determine the number of treated cases for DCI. For the regions reporting, there were a total of 709 treated cases of decompression sickness, and a total of 122 treated cases of arterial gas embolism. One fatality was reported by a treating facility in Canada. The following table breaks down the various regions covered by DAN America.

Table 2.1.4-1 Treated cases by region

2014			
	DCS	AGE	Fatalities
U.S. Northeast Region	50	9	0
U.S. Gulf Region	153	29	0
U.S. Pacific Region	193	35	0
U.S. Midwest Region	101	23	0
Canada	36	6	1
Central America + Mexico	60	6	0
Caribbean Basin Region	116	14	0
<b>Totals:</b>	<b>709</b>	<b>122</b>	<b>1</b>

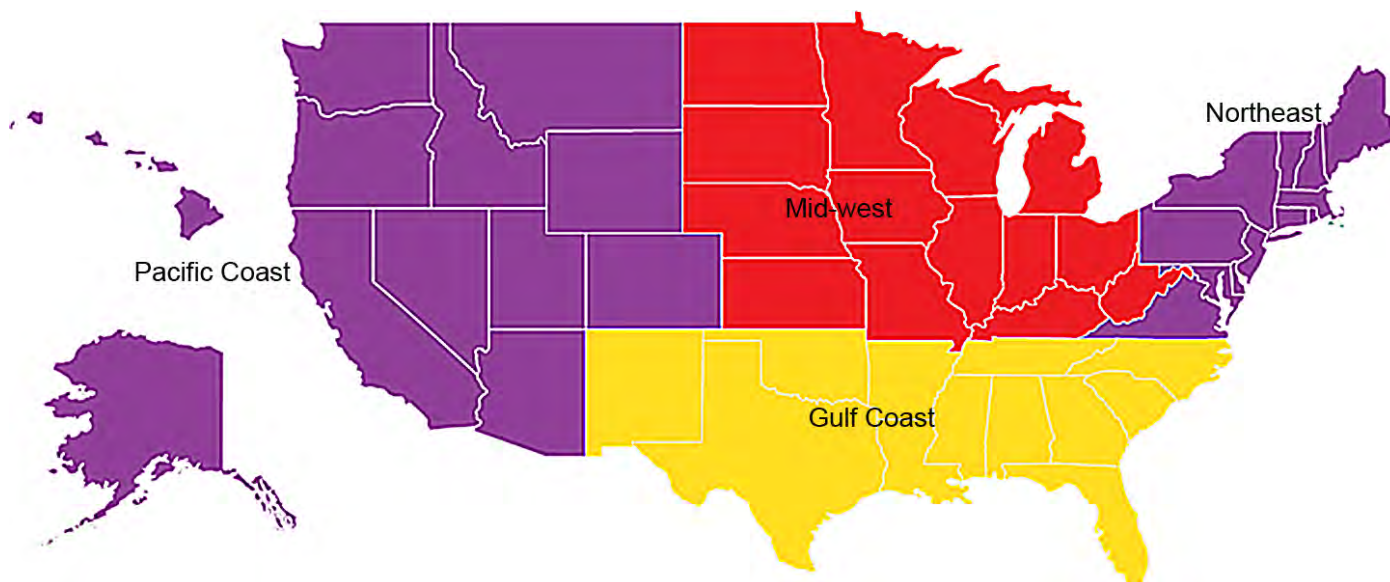
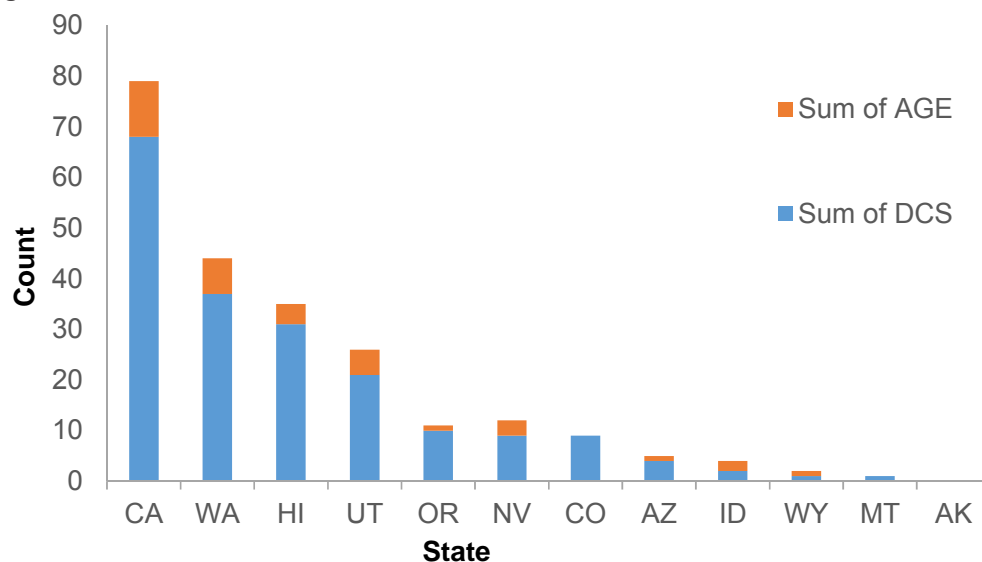


Figure 2.1.4-1 USA regions

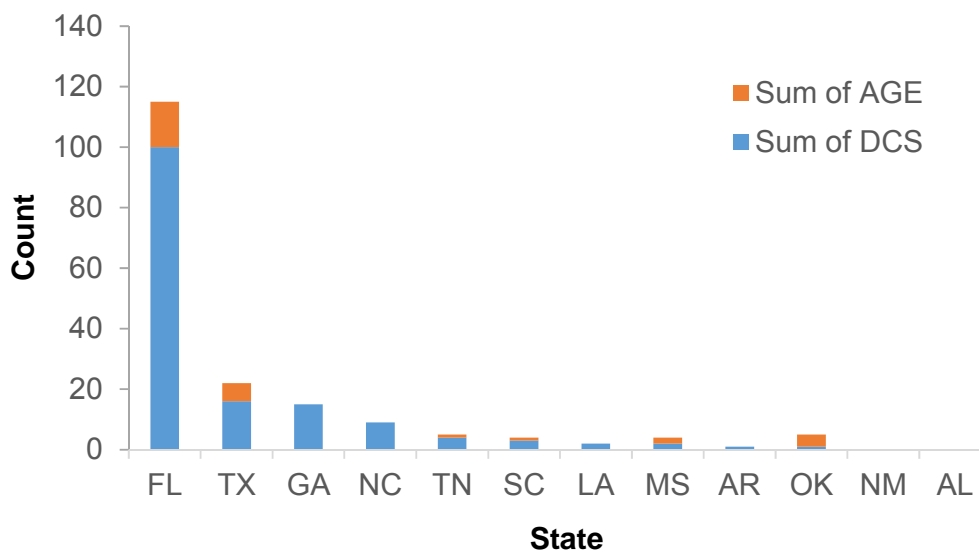
In 2014, chamber facilities within the Pacific coast region reported a total of 193 cases of treated decompression sickness and a total of 35 cases of arterial gas embolism. The three leading states treated 71% of the DCS cases reported and were ranked as California (68); Washington (37); and Hawaii (31). However, California (17), Colorado (3), and Utah (3) reported 62% of the 37 AGE cases treated for that region.

#### Pacific Coast Region:



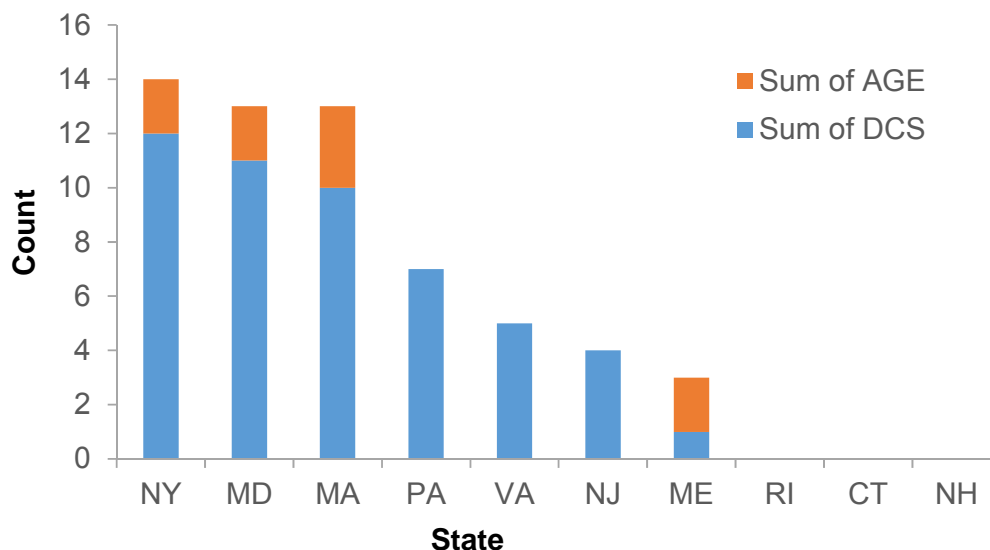
In 2014, chamber facilities within the Gulf coast region reported a total of 153 cases of treated decompression sickness and a total of 29 cases of arterial gas embolism. The three leading states treated 86% of the DCS cases reported and were ranked as Florida (100); Texas (16); and Georgia (15). However, Florida (15) and Texas (6) together represent 86% of the 29 AGE cases treated for that region.

#### Gulf Coast Region:



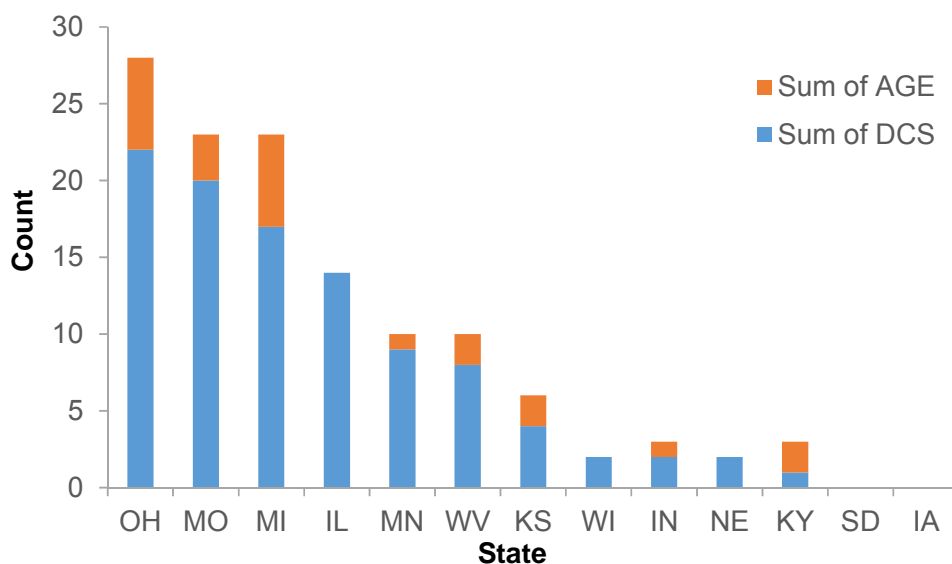
In 2014, chamber facilities within the Northeast region reported a total of 50 cases of treated decompression sickness and a total of 9 cases of arterial gas embolism. The three leading states treated 86% of the DCS cases reported and were ranked as New York (12); Maryland (11); and Massachusetts (10). Only four states, Massachusetts, Maryland, New York, and Maine reported treating any cases of AGE.

#### Northeast Region:



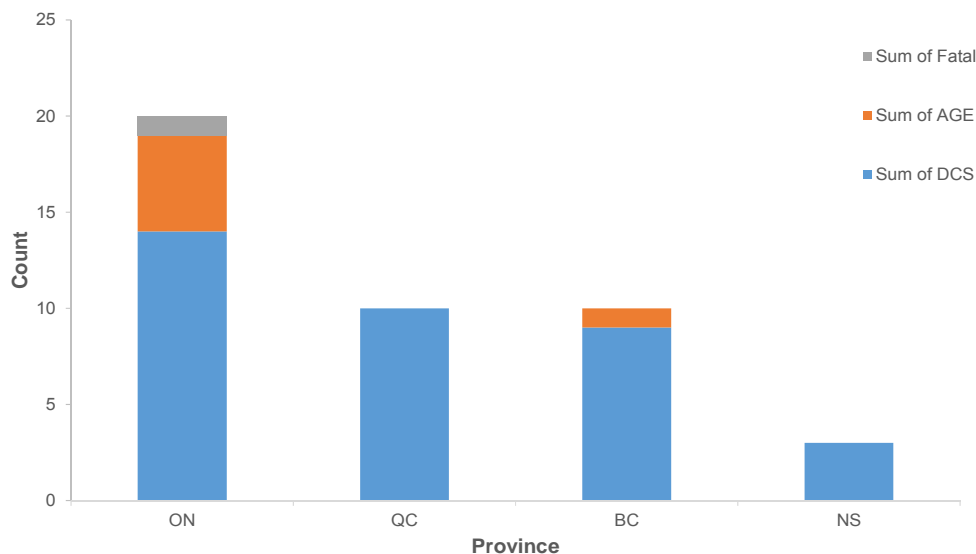
Chamber facilities within the Midwest region reported a total of 101 cases of treated decompression sickness and a total of 23 cases of arterial gas embolism. For DCS, the three leading states treated 58% of the cases reported and were ranked as Ohio (22); Missouri (20); and Michigan (17). However, Ohio (6), Michigan (6), and Missouri (3), reported 65% of the 23 AGE cases treated for that region.

#### Midwest Region:



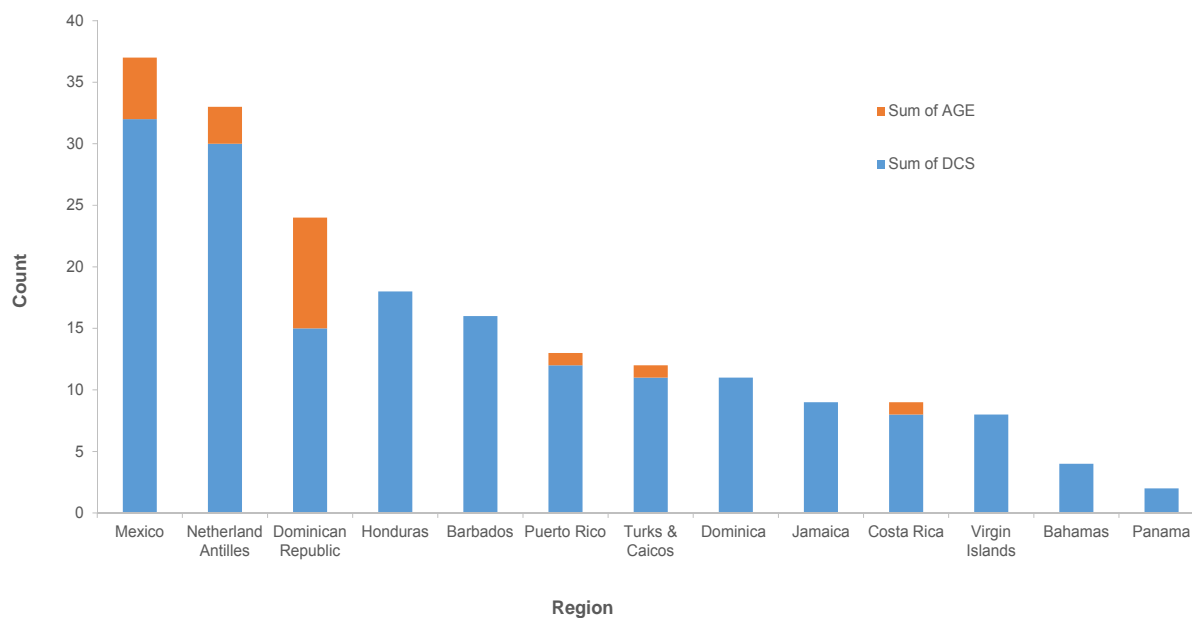
Canada reported a total of 36 cases of treated DCS and a total of six cases of AGE, as well as one dive related fatality. The province of Ontario reported the greatest number at 47% of the combined total for dive related cases.

### Canada



The Caribbean basin, Mexico, and Central America collectively represent a total of 176 (25%) of treated cases reported this year. A total of 20 Arterial Gas Embolism cases were reported for these regions, representing 16% of the total AGEs reported to DAN America. Mexico reported a combined total of 37 (21%) DCS and AGE cases for this region.

### Caribbean basin, Mexico, and Central America



## 2.2 Analysis of Diving Injuries Reported to the MSCC

### 2.2.1 Introduction

The MSCC emergency medical line is intended to provide assistance to injured or acutely ill divers. The objective of MSCC staff is to help divers get proper evaluation and treatment. In cases when injured divers need higher a level of medical care than can be provided in locations where the diver finds himself, and there is no available EMS services, then DAN assists with medical evacuation. The evacuation is a benefit of DAN membership. Non-members receive DAN assistance but the evacuation will often be arranged by their insurance or privately if they have no insurance. Whenever possible, DAN follows up with patients or with healthcare providers to ensure that divers have received the care necessary.

### 2.2.2 The nature of data available in the MSCC

Data captured through the MSCC are mainly case management related. The level of captured clinical information varies. DAN medical staff do not provide tele-medicine services and do not make diagnoses over the phone. When calls are placed by injured divers or their companions, information is limited to subjective comments and lay observations. Even when callers are professional first responders, information about the status of the injured person is rarely sufficient to establish a diagnosis. DAN staff are trained to always consider the worst case scenario and to provide advice. For operational reasons, calls are classified according to patients' complaints and concerns. In some cases, divers follow the advice given and, in other cases, they do not.

Whenever there is an acute condition, DAN offers to follow up with the patient and with the receiving medical institution. However, some divers do not provide contact information, do not seek medical evaluation or medical facilities do not respond to calls. Such cases remain classed as originally labeled without the benefit of additional information obtained from physicians in a proper medical settings. Follow up is arduous work for medical information specialists whose priority is to manage emergencies and sometimes follow up is not always possible. If patients and/or their healthcare providers do not call back, then DAN attempts up to three follow up calls before a case is closed. Unfortunately, many cases are closed without information about medical evaluation, treatment and outcomes. Table 2.2.2-1 shows the frequency of dive related injuries as initially classified at the time of call, based on information received from callers; compared with retrospective classification by reviewers writing this report with the benefit of follow up information. The initial classification was based on calls arriving through the emergency line. For the purpose of this report, we have searched all avenues divers use to contact DAN, including the Information Line and email.

Table 2.2.2-1 Classification of post-dive complaints

Case classification	Initial	Retrospective
<b>Decompression Sickness</b>	<b>484</b>	<b>353</b>
DCS Type II	223	161
DCS Type I (pain)	130	106
Cutaneous	125	81
Pulmonary / Chokes	6	5
<b>Barotrauma</b>	<b>448</b>	<b>530</b>
Ear & Sinus	300	406
Unspecified EBT	0	35
External EBT	0	2
Middle EBT	0	354
Inner EBT	0	15
Arterial Gas Embolism / AGE	32	12
Pulmonary	106	95

Table 2.2.2-1 Classification of post-dive complaints (cont'd)

Case classification	Initial	Retrospective
Mask Squeeze	5	14
Gastrointestinal	3	1
Dental	2	2
<b>Other</b>	<b>164</b>	<b>194</b>
Marine Envenomation	59	124
Pulmonary Edema - IPE	41	19
Non-Fatal Drowning	23	12
Fatality	16	22
Gas Contamination	12	4
Finfoot	7	7
Loss of Consciousness	6	6

### 2.2.3 Decompression sickness

Decompression sickness (n=484) was the most commonly reported concern through the emergency line. However, with additional search of the information line and email records, more barotrauma related complains (n=530) were identified, in the first place pertaining to ear barotrauma.

Decompression sickness may cause acute motoric, sensory and mental dysfunctions which in some cases may leave permanent disability. The symptoms and signs of DCS are not always possible to distinguish from other causes of neurological disease. Positive diagnosis is based on time proximity of symptom onset to a sufficient dive exposure, patterns of symptoms, their evolution and an estimate of the feasibility of free gas in tissues and circulation as their cause. Unfortunately there is no specific clinical test that could prove or exclude DCS. Thus, the diagnosis of DCS depends on the clinical experience of the physician evaluating the diver. DAN case managers need to classify cases into actionable categories with limited information provided by callers and without benefit of physical examination. Because DCS and AGE cases may require specific treatment in a hyperbaric chamber which is not widely available and timely evacuation may be needed, initial classification by DAN is intentionally biased toward these diagnoses. Retrospectively, more strict criteria for classification of cases are used. The most confident classification is based on evaluation conducted by medical professionals which is not always available. Out of 484 cases initially labeled as DCS, more than one third were retrospectively re-classified as something else. Similarly, out of 32 cases initially labeled arterial gas embolism (AGE), only 12 remain in that category after review.

In cases of barotrauma, the number of retrospectively labeled cases is greater than the number of initial cases. This is a result of retrospective reclassification of email inquiries as “cases”. Email is often used by divers to ask for advice regarding ear problems and possible hazardous marine life injuries (HMLI). Divers rarely use email when they are concerned with an emergency, and mainly use e-mail only if there is no other option to contact DAN. Divers dealing with emergencies should always contact DAN by phone. That is the only way to have an instantaneous response and to verify your concerns.



### 2.2.3.1 Decompression sickness Type 2 (DCS 2)

Cases with post-dive neurological symptoms like numbness, tingling (paresthesia), muscular weakness (paresis) or complete loss of power (paralysis), bladder and bowel dysfunction, loss of coordination, vertigo, disturbed vision or hearing and mental confusion or loss of consciousness are classified as DCS 2. The San Diego Diving and Hyperbaric Organizations (SANDHOG) criteria for DCS are very helpful with diagnosis.<sup>1</sup>

#### **SANDHOG Criteria for DCS<sup>1</sup>**

##### **3 Points**

1. Signs and symptoms of transverse myelitis with both sensory and motor changes within 2 hours of a dive.
2. Monoparesis with pathological reflexes and associated sensory changes within 2 hours of a dive.
3. Cutis marmorata.

##### **2 Points**

1. An exposure (without decompression) that is greater than the loading seen with exceeding the Navy no stop limits by 10% or missed decompression greater than 5 minutes.
2. Any sign or symptom in the 3 point category occurring 2-6 hours after a dive.
3. Syndrome of cough, substernal chest pain, and shortness of breath.
4. The syndrome of inner ear (vestibular) DCS characterized by vertigo, tinnitus, and hearing loss occurring within 2 hours of a dive.
5. Deep boring pain in a major joint within 2 hours of surfacing from a dive.
6. Isolated sensory changes in a single limb or at a spinal cord level plus hyperreflexia within 2 hours of surfacing from a dive.
7. Lymphadema occurring within 24 hours of a dive.

##### **1 Point**

1. Deep boring pain in a major joint occurring 2-6 hours after a dive.
2. Isolated sensory changes in a single limb or at a spinal cord level plus hyperreflexia 2-6 hours after a dive.
3. Complete relief from joint pain within 10 minutes of initiation of recompression therapy.
4. Complete relief of motor and sensory changes within 40 minutes of therapeutic recompression, or a full number improvement in motor signs during the first two hours of recompression.
5. Scintillating scotomata occurring after a dive in a patient without prior history of migraine headaches.
6. A dive profile (without decompression stops) between the "no stop" limits of USN '55 and VVAL 18 or a properly conducted single dive requiring staged decompression.

##### **Half Point**

1. Isolated parasthesias or "tinglies" occurring after a dive.
2. Fatigue, dizziness, headache, nausea, or vomiting.

##### **Minus One Point**

1. Presence of a fever.
2. History of hypochondriasis or anxiety disorder.

In the most severe cases, symptoms occur soon after a dive and quickly progress making the diagnosis quite obvious. In mild cases especially with delayed onset, the diagnosis can be quite uncertain. At the time of call, 223 cases were suspected DCS 2. With additional information accrued in the process of case management and follow up, only 161 cases remained in that category. Here are few typical cases.

**Case 2-01: Delayed report of paraparesis**

The caller was a male diver in his sixties who became weak, dizzy and confused twenty minutes after surfacing from his dive the day before. He had been diving for four consecutive days, two dives per day to a depth of 80 fsw (24 msw) for 40 minutes, on air. The dives were uneventful as he recollected and all within the parameters of his computer. He returned to his room and after resting the dizziness and confusion resolved. The next day, the weakness was still present mostly in his legs and he called DAN. He also reported muscle spasms in his legs along with difficulty urinating. He was due to leave the dive resort the following day.

This is an example of divers underestimating their symptoms. The early post-dive onset of weakness, dizziness and confusion are signs for alarm. These are some of the typical symptoms of DCS. Difficulty with urination usually is not noticed early because many divers empty their bladder while diving. However, when it is noted and associated with post-dive weakness of the legs, the diagnosis of DCS affecting spinal cord is most likely. In this case, DCS should have been suspected from the onset of symptoms and first aid oxygen administered, not waiting until next day. The diver also did not report objectively the situation with his legs because on examination it turned out that he had a serious muscular weakness and loss of skin sensation on both legs (paraparesis). This diver was lucky that weakness did not progress to a full paralysis. He received several recompression treatments before he regained full control of his bladder and strength of his legs. However, some loss of sensory functions remained.

The SANDHOG criteria applied to this case (as described previously) in a creative way yielded total score of **4.5**.

- Motor weakness within two hours post-dive of severity less than 4/5 (patient was walking thus overcoming gravity and bearing additional weight) does not meet the criteria for 3 nor for 2 points – but with associated sensory changes it does; **2 points**
- Bladder dysfunction was not addressed in the SANDHOG criteria but it should carry at least **2 points**
- Dizziness and confusion – **1/2 point**

**Case 2-02: Loss of sensation in both legs**

This was another diver in his sixties, who developed fatigue and paresthesia in his legs 45 minutes post dive but underestimated the seriousness of it. The call came from the boat captain, 22 hours after symptoms onset. The patient ate dinner that night but continued to be unsteady on his feet. There was a physician aboard who examined the diver and found normal vital functions. The patient was placed on oxygen for 15 minutes on and off for several minutes via demand valve at 25 lpm. The vessel was within three hours of a navy hospital with a hyperbaric unit. The physician onboard was not familiar with diving medicine and a little hand-holding helped to confirm the absence of other possible symptoms of DCS. Despite initial denial, the patient accepted to go to a hospital when the vessel reached the port. The navy physician there found that the patient had extensive sensory deficit in both legs which responded well to two recompression treatments.

**Case 2-03: Leg weakness with relapse**

The diver called on the emergency line. He completed a single dive that day to 80 fsw for 30 minutes. Immediately after the dive, he developed weakness of the left leg, lost feeling in both feet, had lower girdle pain and abdominal tenderness. The symptoms resolved on first aid oxygen. He was admitted to a nearby hyperbaric chamber and treated following USN TT6. During the treatment, leg weakness and urinary retention returned (relapse). It took two more treatments to resolve it. This case is a reminder to everybody that the resolution of symptoms on first aid oxygen does not mean that diver is necessarily cured. Symptoms may return, especially in cases of spinal DCS, and admission to a hospital for evaluation and definitive treatment with HBOT is always recommended.

**Case 2-04: Gas in biliary tract with delayed onset of paraplegia**

This commercial conch diver, 57-year-old male, presented to a local hospital with chest pain which occurred "a few minutes" after his last dive. He reported localized pain at his lower center chest which he described as "hurts". The physician reported the pain as acute onset, non-radiating, non-pleuritic, non-tender to palpitation. Patient denied dizziness or dyspnea. No cough noted. Lungs sounded clear on both sides. EKG was normal. CT showed a small pulmonary bleb in the right apex but no evidence of pulmonary injury, no pneumothorax or mediastinum. However, there was a gas in the biliary system/liver, evenly distributed. No abdominal tenderness or other signs or symptoms.

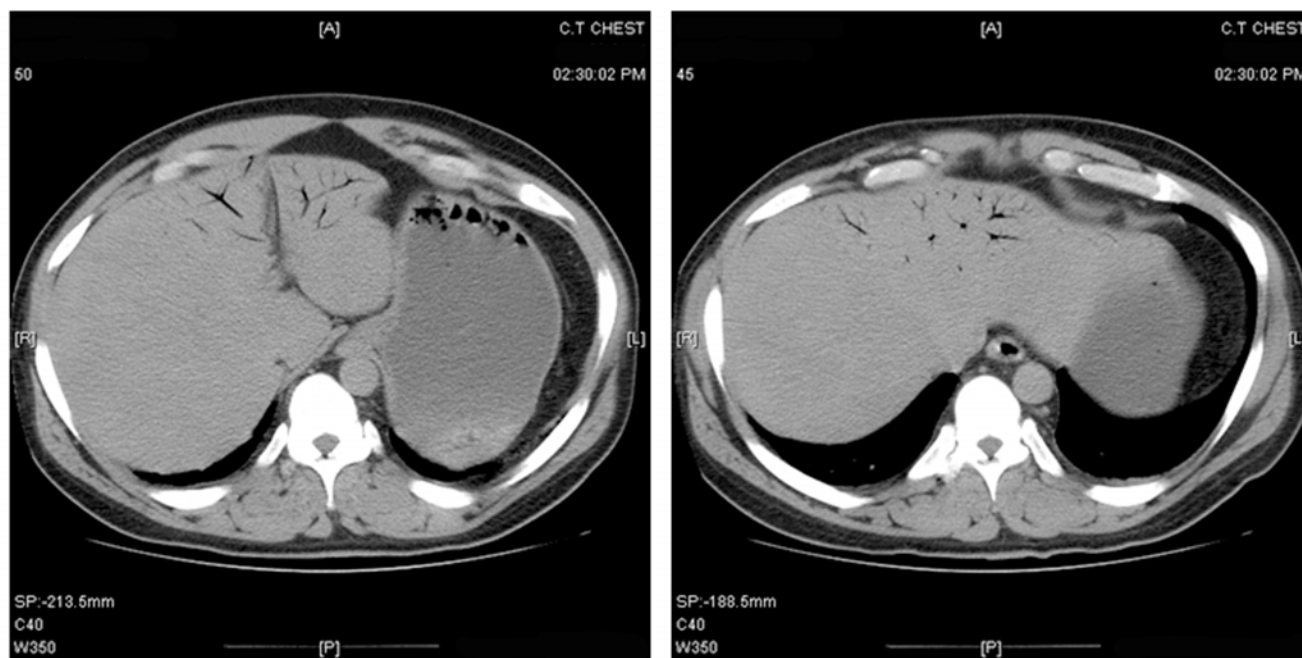


Figure 2.2.3.1-1 CT scan showing bleb in right apex

Symptoms occurred after a series of five bounce dives to about 120 fsw (37 msw) without monitoring time or depth. The diver said that he usually dives the duration of a scuba tank. He returns to the surface to drop his catch, change tanks, and immediately descends for the next dive. He does this several times per week. Most days he does three to four bounce dives but he states that this series was no different than any other series. He has hypertension and diabetes, both untreated.

The patient was transferred to a recompression chamber. Subsequently, at admission to the hyperbaric facility, six hours after the dive, he developed paraplegia. He was recompressed to USN TT6. The chest pain subsided after ten minutes at pressure and repeated CT scan later confirmed complete resolution of biliary gas. After multiple treatments (initially USN TT6 with extensions) he recovered sensation but with involuntary movements which he could not feel. About 48 hours after his presentation, he also developed marked hyperkalemia, acute renal failure and paralytic ileus. Eventually, after intensive treatment his general status improved but significant weakness of his legs remained.

### 2.2.3.2 Decompression sickness Type 1

Classically, DCS Type 1 includes pain only and/or cutaneous manifestations of DCS, without neurological signs or symptoms. Numbness and tingling are neurological symptoms that may be caused by damage of the central nervous system. If they occur peripherally to joint or muscle pain then they may be just a manifestation of local osteo-muscular DCS with the same prognosis as any DCS 1.

Pain only DCS affects major limb joints and muscle groups. It can be easily confused with sprains, strains and similar injuries but in that case, the diver will often remember provocative factors. The first impression based on a caller's complaints and their dive history is correct in over 80% of cases and would be even higher without DAN specialists intentionally erring on the side of safety and labeling some cases as DCS until proven otherwise.

#### Case 2-05: Left shoulder pain

The caller stated he and his buddy completed a series of planned decompression dives about three hours previously. Upon surfacing from the last dive his buddy complained of acute left shoulder pain. He could not raise or abduct his arm. After breathing 100% oxygen for 20 minutes his symptoms decreased. The caller was asking for advice. This

case looked like DCS Type 1 but, without hands on evaluation and exclusion of other possible causes, the diagnosis was not certain. The diver was referred to a nearby hyperbaric facility for evaluation and treatment as needed. As usual with mild cases, the diver did not call back and follow up attempts failed.

#### 2.2.3.4 Cutaneous DCS

Cutaneous manifestations of DCS may vary in appearance. Mottling of the skin (marbling, cutis marmorata) after diving is most likely the result of DCS. Here is how it is described in the SANDHOG criteria which assigns three points toward the diagnosis of DCS when marbling is present:

*“Cutis Marmorata, not an erythematous rash, but true marbling of the skin. Linear streaking is not cutis marmorata. Although cutis marmorata can rarely be seen in other conditions it is generally only associated with shock like states, except in DCS. Therefore, if it occurs after a dive, the finding is specific enough to be diagnostic of DCS. ( 3 points)”*

Certainty of diagnoses in cutaneous DCS would be expected to be high, but only 65% of calls complaining about possible skin bends ended up being DCS. A professional eye may recognize cutaneous manifestations of DCS with much higher confidence, but divers who have not seen it before may suspect any cutaneous rash to be DCS. And that is a good approach. It is better to be safe than sorry.

We encourage divers to take a photo of their skin discoloration and send it to DAN whenever skin bends are suspected. It would help us provide proper directions and with more pictures and stories we could publish, divers would learn about it and be able to recognize it.

Skin manifestations suspected for DCS are reported more often with recent increased public awareness. In the 2014 MSCC data, out of 353 DCS cases, 81 had cutaneous manifestations as a leading sign.

The exact prevalence of cutaneous DCS is not known because many cases go unreported. Also, many cases are seen by local physicians and get resolved without DAN involvement. We asked the DAN Preferred Providers in Cozumel, which is situated close to many dive sites, to give us information about the prevalence of cutaneous DCS among cases admitted for evaluation. In over two years, out of 64 cases with post-dive symptoms, there were 39 DCS cases, nine of which were with cutaneous manifestations (23%). Four cases with cutaneous manifestations had also neurological symptoms and they received HBOT. Five cases were with skin only manifestations and resolved without treatment.

Here is one typical case of cutaneous DCS:

#### Case 2-06: Itchy rash on torso

The caller on the emergency line stated that ninety minutes after surfacing from her second dive she developed a red, itchy rash on her torso. She took a shower and self-treated with cortisone cream. The itching was getting better but the skin got blotchy. The rash began to resolve during the conversation with a DAN medic and when asked, she indicated no other symptoms or signs.



Figure 2.2.3.4-1 Itchy rash on torso



The pictures she took with her smart phone and sent to DAN showed red-bluish patchy discoloration often seen in skin bends. She was advised to go to the hospital emergency for evaluation to make sure there are no neurological signs. The emergency physician did not think it was DCS and prescribed Benadryl which cleared up the rash quickly. A positive reaction to antihistamines in some cases is reported previously and we think that such response does not exclude the diagnosis of cutaneous DCS. Divers have to be aware that a full evaluation of their condition should be done. Some divers may have repeated occurrences of skin bends and they should be checked for a patent foramen ovale (PFO). The existence of PFO may make them more prone to neurological DCS due to possible paradoxical embolism. This diver went back to diving a week later but switched to nitrox and to a more conservative algorithm available on her dive computer.

### Case 2-07: Tinea and sunburn, not skin DCS

The caller on the emergency line was concerned about what he reported as marbling on his skin after completing two open water dives the previous day. Dives were to a depth of between 40 fsw (12 msw) and 50 fsw (15 msw) for 45 minutes each, both on air. The dives were a part of an open-water certification course and made with an instructor. He had completed a pool session the day before. He was wearing a wet suit and does not remember brushing up against anything. He was nauseated on the boat but thought it was sea sickness. He vomited when he was taking his gear off after his second dive. He has been doing internet researches, concerned because he is scheduled to fly the following evening. He denies any shortness of breath, chest pain or tightness. He was seen at the local hospital. A physician, who was not trained in dive medicine, but who had seen skin bends in the past, described the patient's skin changes as erythema, red areas with clear demarcation. The patient denied pain and/or itching. Neurological examination was normal. The physician concluded that this did not look like skin bends and she sent photos to DAN for consultation (Figure 2.2.3.4-2).



Figure 2.2.3.4-2 Tinea and sunburn

The consulting DAN physician advised that this was most likely fungal skin disease (tinea) in combination with sunburns. The patient received proper medications and was released.

### Case 2-08: Breast tenderness and swelling

Cutaneous DCS may affect the area of the breast. It is probably the result of lymphedema which may also affect other parts of the body. The SANDHOG criteria: *“Lymphedema occurring within 24 hours of a dive. This is quite specific for DCS. However, one must make sure to differentiate this from hives and swelling due to trauma, stings etc. (2 points).”*

Out of 81 cases with probable cutaneous DCS, 15 reported breast tenderness, all by women. Breast tenderness and lymphedema are probably more specific to DCS although the SANDHOG criteria do not mention this location explicitly.

**Case 2-09: Breast tenderness, swelling and flat red rash**

The caller on the emergency line reported tenderness and swelling of the left breast with the skin being harder than on the other side. Three hours earlier she had completed a 68 fsw (21 msw) for 38 mins dive on air. She denied any problems other than a flat red rash.

**Case 2-10: Swollen and sore both breasts – lymphatic DCS**

The caller on the emergency line stated that she had just returned home the previous day from a week of diving. She had developed skin bends after diving for several days. She denied any skin mottling but stated her breasts were swollen and sore, her mid-section was red and sore, and she also noticed some redness and tenderness around her hips. The caller stated, "my fat is sore". All symptoms resolved after normobaric oxygen. She had a 48-hour surface interval between the last dive and return flight back home. During her return flight which lasted several hours, she developed swelling in her calves, ankles, and feet. She was concerned if it was a return of DCS symptoms. DAN advised her to seek medical evaluation. This was possibly related to lymphatic DCS. There were a few other cases with similar late edema. Unfortunately, this patient was lost to follow up.

**Case 2-11: Pain in breasts and abdomen with skin mottling**

This caller stated that, after diving, she developed pain in her breast and abdomen with skin color change to what appeared as bruising. She denied any neurological symptoms. She was currently heading to another island to see the HBO physician. Earlier, she received first aid oxygen at the resort and felt better. Eventually she received HBOT (USN TT5) and her symptoms improved and the bruising almost disappeared.

**Case 2-12: Abdominal pain and skin mottling, a history of seizure**

A call came from the home office of a liveaboard company. They had a diver en route to shore with apparent skin bends. On the first day of diving, the diver had pain in her abdomen after the first dive which she ignored to continue diving. The pain reportedly disappeared during the second dive while at depth but returned after surfacing. It was accompanied by marbling on the abdomen and breast. The diver reported symptoms to the crew who immediately called the office ashore, placed the diver on oxygen, moved the diver to a boat, and started transit to shore.

All her dives were on air. The exact dive profiles were unknown, but maximum depths at the dive sites were 82 fsw (25 msw) and 69 fsw (21 msw) with total times less than 60 minutes and two hours surface interval in between. The diver refused first aid oxygen because she had a history of seizures and was currently on Dilantin. She was cleared to dive by her physician prior to the trip. When she reached the hospital, an HBO physician evaluated her and found that her symptoms were resolving. She still had some abdominal pain and pale mottling. She received oxygen and was dismissed the next morning. She returned to the liveaboard but did not dive again. It turned out that her seizures were due to a scarring of the brain, forty years ago for which she has been on Dilantin since. She had her last seizure twenty-five years ago.

The physician who has the opportunity to conduct a hands-on evaluation is in the best position to establish a diagnosis and prescribe proper treatment. Historically, abdominal pain and abdominal skin mottling occurring together were considered serious warning signs that a severe spinal form of DCS may follow. In this case, the abdominal pain lasted for hours and began resolving before the patient reached the hospital. With the benefit of time, the physician considered this mild form of cutaneous DCS and proceeded accordingly.

**Case 2-13: Severe abdominal pain and breast tenderness**

The call came from a captain of a liveaboard. He was an "experienced diver" who developed a rash across the breast and abdomen with general tenderness the day before. The rash was described as "raw and red". The following day the diver continued diving. Within two hours after the last dive the rash developed into strawberry colored patches, with severe abdominal pain, tenderness in the breast (worse on left side), and tenderness in the hips. The boat crew placed the diver on 100% oxygen and they were 30 minutes out from the marina at the time of call. The captain asked for the location of the closest hospital with a chamber which, fortunately, was nearby. The patient was seen that evening and treated with HBOT for about one and half hours. All symptoms resolved.

### 2.2.4 Ear Barotrauma

Ear barotrauma is the most common injury in scuba diving. In 2014, over 400 cases were reported through the MSCC. The most common form of ear barotrauma was middle ear barotrauma (355). Eardrum perforation was reported in 42 cases. Inner ear barotrauma was suspected in 15 cases. You can read more about ear barotrauma on the DAN website at: <http://www.diversalertnetwork.org/health/ears> or take a refresher seminar here: <https://www.diversalertnetwork.org/auth/login.aspx?aspid=476470026&redirect=seminars>

### 2.2.5 Pulmonary Barotrauma

Pulmonary barotrauma usually occurs when the lung is overinflated. This commonly occurs in scuba diving when the diver fails to exhale properly or at all during ascent. Pulmonary over-inflation syndrome (POIS) occurs under these conditions and can manifest as mediastinal emphysema, subcutaneous emphysema, pneumothorax and arterial gas embolism. We will address the cases of arterial gas embolism in a separate section.

There were 95 cases of pulmonary barotrauma identified in the MSCC. After review of the individual cases, 61 indicated the diver had suffered pulmonary barotrauma. In the majority of cases, the diagnosis was based on the history and subjective history of the diver. Air outside the anatomic air spaces was often not found despite a compelling presentation. A history of a novice diver making an uncontrolled ascent secondary to panic, lack of buoyancy control, running out of air, etc, remained a common theme for many of the case of pulmonary barotrauma. There were cases of experienced divers where coughing underwater was the only event that could be linked to the POIS event.

Obtaining definitive diagnostic results was difficult in a timely manner, as was the ability to confirm the findings in mild cases of suspected POIS.

Chest pain was reported by the majority of suspected POIS cases. This symptom may not be present in all POIS cases but if present it is more likely that the diver will ask for help because of the general high level of concern that chest pain evokes in anyone experiencing it.

Neck pain or a sore throat appears to be more specific to POIS, perhaps as a symptom that occurs as gas dissects along tissue planes and into subcutaneous tissues. Although subcutaneous emphysema is seen in POIS, it was not a common finding upon physical examination. Chest pain with a sore throat and neck pain was more commonly reported.

A majority of the cases occurred at depths shallower than 35 fsw (10 msw) and this correlates with the greatest pressure/volume changes for small depth changes. In addition, shallower depths are generally utilized by novice divers for both initial training and early open water dive exposure. Panic, loss of buoyancy control and inadvertent breathholding are also a problem with this group of divers. POIS is seen in the novice diver so it follows that younger divers can be seen in the cases. Several cases in children (one as young as six years old) were reported. These cases occurred during initial training with chest pain being the only complaint fortunately.

POIS was seen in experienced divers too. Several instances occurred in such divers following coughing spells at depth. There were two cases of chest pain in divers over 50 years of age with that were taken to the emergency room where attention was shifted to a cardiac etiology with further workup. Shortness of breath was seen in some divers that may have had a cardiopulmonary etiology such as an arrhythmia, pulmonary edema etc.

There were three cases of POIS in free divers. In one case, the diver breathed from a regulator at depth and then held his breath to the surface. Another breathed from an underwater observation station that had trapped air available to breathe before ascending. The third case was a free diver who experienced difficulty equalizing and coughing while at depth who complained of chest pain upon reaching the surface.

Hemoptysis was reported in two cases only. A third questionable case occurred seven days following a dive.

**Case 2-14: Difficulty equalizing led to additional problems and subsequent treatment**

A 26-year-old female was diving in a remote location. She conducted multi-day repetitive diving over four days. She had difficulty equalizing her ears and as well as significant problems with buoyancy control during these dives. On her last day, she continued to have difficulty diving and made two uncontrolled ascents due to perceived problems at depth. She surfaced and shortly began complaining of shortness of breath and tightness that radiated into the neck. She had no neurologic findings, or skin changes. She was put on oxygen and seen at an ER. There were negative imaging studies. Because of the uncontrolled ascent, she was treated with USN TT6 and as expected, the chest pain and tightness quickly resolved with recompression. She probably had mediastinal emphysema.

Recompression in this case was probably not necessary since the same result would probably have been obtained with surface oxygen administration. Relief may have been quicker with recompression but increased speed of relief can be outweighed by the risk of worsening a subtle pneumothorax if one exists. A pneumothorax can pose a serious challenge during ascent in a chamber and possible need for an emergent intervention.

**2.2.6 Arterial Gas Embolism**

Arterial Gas Embolism (AGE) is a subset of pulmonary over inflation syndrome (POIS). The inciting mechanism of an over-pressurization of the lung that results in gas escaping into surrounding tissue is the common pathway. Therefore, someone who experiences POIS may exhibit some or all of the subtypes of POIS that include mediastinal emphysema, subcutaneous emphysema, pneumothorax as well as AGE. AGE results when the lung is subjected to over-pressurization with gas from the lung escaping directly into the pulmonary vasculature, returning to the heart where it is then dispersed by the arteries. Some of these bubble emboli find themselves both occluding as well as damaging the blood supply to the nervous system. This results in dramatic symptoms ranging from numbness and tingling to paralysis, loss of consciousness and even death. Fortunately, it appears that clinical AGE is not as common as the other subtypes of POIS that are reported. And this may be even more true since reporting bias probably favors the dramatic findings of AGE in a given dive accident. The findings of loss of consciousness, arrest, paralysis, visual disturbance etc, are very likely to get prompt attention and reporting than neck pain might.

There were 13 cases initially reported as possible AGE. Most of the cases occurred within 15 minutes of surfacing after a rapid ascent. Symptoms of global weakness, hemiparesis and visual disturbances were seen. Novice divers predominated but there were two cases of instructors involved in training that required them to move up and down in the water column without a known inciting event other than a cough in one and difficulty equalizing in the other.

Two 15-year-old divers experienced AGE. The first experienced an out of air episode with a breathhold ascent. He did not seek attention until several days later as the headaches and dizziness persisted. The other was a breathhold diver who was breathing from air pockets at depth before holding his breath and ascending to the surface.

An excellent emergency response was recorded for a diver who, after surfacing, sank back to 70 fsw (21 msw), was quickly recovered, brought to the surface and resuscitated. The patient was evacuated to a chamber and regained consciousness soon after being compressed to 60 fsw (18 msw) on oxygen.

**Case 2-15: Aggressive dive profile led to AGE**

A 37-year-old very experienced male diver made a series of dives in a remote location. A closed circuit rebreather was utilized with the partial pressure of oxygen set to 1.3 atmospheres absolute. Two back-to-back, long, deep decompression dives were made with a surface interval between them. The dive was conducted within the limits of his decompression computer and the dive was considered uneventful until just arriving on deck following his second dive where he collapsed. He was apneic and pulseless. A well trained crew successfully resuscitated him. He had a severely impaired mental status, paralyzed on his left side and a marbled rash seen on his abdomen. To protect his airway, he was intubated. He required aggressive fluid management, pressors to maintain his blood pressure and a Foley catheter. It took several days to evacuate to a chamber capable of handling his condition and the diver needed multiple recompressions.



He was unable to relay whether he had any problems with his ascent where he may have held his breath or coughed. The onset of his symptoms were rapid and consistent with AGE. His dive profile was indeed aggressive and severe decompression sickness cannot be ruled out or be in addition to AGE. There was no evidence days later to conclusively show evidence of POIS. There was significant cerebral infarcts noted on subsequent imaging studies.

The quick effective first aid provided at the initial presentation was no doubt key to this diver's survival.

### **2.2.7 Immersion Pulmonary Edema**

Immersion Pulmonary Edema (IPE) is the progressive development of lung fluid outside the pulmonary vascular space. This occurs when the dynamics dictated by the pressures between the lung's intravascular and extravascular compartments become so unbalanced that it results in fluid accumulating in the lung itself. Some of this fluid can leak into the small gas exchanging sacks or alveoli resulting in the copious pink frothy sputum seen in severe cases. This fluid impairs critical gas exchange and further adds to this imbalance and worsens the condition. If allowed to continue, hypoxia, loss of consciousness and death can ensue. Dyspnea and panic can lead to poor decision making while underwater such as an uncontrolled rapid ascent leading to POIS or DCS. The venous gas emboli that results from the rapid ascent itself may further worsen the condition.

There were eight cases of suspected IPE. One case involved a 53-year-old male who was snorkeling only. He displayed the onset of dyspnea soon after entering the water and exerting himself. He was placed on oxygen and his symptoms improved. He has had previous episodes before with subsequent normal cardiac evaluation.

Most of the scuba divers suspected of IPE ranged in age from 55 to 67 years of age. One had a history of valvular insufficiency, another had a pacemaker.

It is interesting to note that a majority of these older divers emphatically stated that they had never experienced difficulty with breathing on hundreds of dives that preceded this event. In fact, the dive conditions, depth and time of the inciting dive were one of the least rigorous dives they had typically made over their diving career. There seemed to be a bit of routine swimming that preceded the dive, occurred with descent and worsened on ascent. Both factors could merely be the progression of the condition and the fact the symptoms were the cause of the dive abort and subsequent ascent. No one factor usually prevails in the previously asymptomatic diver. Attention to breathing resistance, hydration, constrictive clothing, hydration, medications, venous gas bubble, aspiration and heart conditions are some IPE inciting factors to consider. The condition responds positively to aborting the dive, exiting the water, oxygen and diuretics (hold aggressive hydration efforts). Disregarding it while in the water or repetitive diving following an incident is not recommended. Differentiation from an acute cardiac event must be considered. Water aspiration must also be considered as either the primary event for the symptoms displayed or could be another factor in the development of IPE. And lastly, cardiopulmonary DCS or injuries from pulmonary barotrauma must also be considered in the differential. It is important to identify the cause of the cardiopulmonary distress quickly since early treatment can halt a deleterious cascade. With the exception of aspiration, the other conditions in the differential diagnosis have different emergency therapies specific for their treatment. In addition, cold urticaria, asthma and other medical disorders may produce or simulate pulmonary edema and be aggravated by the diving.

### **Case 2-16: Diver aborted dive after feeling “uneasy”**

A healthy 73-year-old experienced female diver with no known cardiovascular disease stated she became uneasy on her first dive of the day to 77 fsw (23 msw) shortly after arriving at depth. She felt anxious and short of breath which compelled her to abort her dive. She felt the urge to cough with each breath. She was able to ascend to the surface, brought back onboard and placed on oxygen with resolution of her complaints soon afterwards. She attempted to explain that the symptoms were secondary to less than optimal visibility but she had dove under similar and even worse conditions on many previous dives.

This was a probable early IPE with an experienced diver recognizing that something was not well and she, therefore, aborted her dive early. The transient nature of the condition once on the surface is often discounted and attributed to a host of other reasons that may have had little or nothing to do with contributing to the development of IPE.

It is important that the diver NOT resume diving until the cause(s) are identified and corrected.

### **Fin foot**

Fin foot is described as a foot pain that occurs after the foot is constricted for a period of time and the constriction is released. The subsequent hyperemia that occurs with the return of blood flow can cause pain in the affected portion of the foot. But one must certainly entertain the many causes of foot pain that are most likely the cause for a foot pain in diving. Foot pain may be under reported due to its perceived importance. Even when reported, obtaining adequate timely workup and follow-up reporting is often not completed by the diver. Beside fin foot, the other causes of foot pain can be, but are not limited to: infection, contusion, trauma, fractures, sprains, burns, neuromas, neuropathies (numerous etiologies), metatarsalgias, gout, ingrown toenails, dermatitis, envenomations, etc.

In 2014 there were 19 reported cases of fin foot of which 13 were consistent with the diagnosis. The other six included the possibility of dermatitis, generalized lower extremity edema, gout, infection, vascular insufficiency and contusion. The suspicion of fin foot should not lull a diver to complacency. Serious medical conditions should be ruled out if suspected. Attention to properly fitting equipment should be addressed to prevent problems and not only to keep a painful foot condition from an otherwise great diving experience.

### **Case 2-17: Fin foot suspected after redness and swelling on toes**

A 26-year-old male was undergoing initial scuba training with rented equipment. He completed a long pool training period without difficulties. Soon after arriving home, he experienced swelling, erythema and pain to his fourth and fifth digits. Overnight, the pain resolved and his toes appeared normal. He paid careful attention to ensuring all his gear fit well the day before. He stated his fins were particularly snug with a different set of booties he had purchased.

It appears that this diver suffered from fin foot when he subjected his foot to increased compression during a prolonged pool period.

## **2.3 References**

1. Grover I, Reed W, Neuman T. The SANDHOG criteria and its validation for the diagnosis of DCS arising from bounce diving. Undersea Hyperb Med 2007. 34(3); 199-210. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/17672176>

## SECTION 3. DIVING INCIDENT REPORTING SYSTEM

Peter Buzzacott

The Diving Incident Reporting System (DIRS) collects voluntarily reported diving incident reports through the DAN website. Divers are encouraged to report any unplanned incident that occurs during diving. Reports of fatalities are forwarded to the diving fatality investigation team. The DIRS project commenced in late 2012. There were eight incidents reported in 2012 followed by 66 in 2013 and 136 in 2014, divided between open circuit (n= 126, 93%), rebreather incidents (n=4, 3%) and breath-hold incidents (n=6, 4%). The six breath-hold incidents are discussed in Chapter 4. The remainder of this chapter concerns the other 130 incidents, 81 (62%) involving males, 40 (31%) females and 9 (8%) not declared.

The majority of the reports (n=117, 90%) were made in English, the rest (n=13, 10%) in Portuguese. The victim of the incident being reported made the report first hand in 83 cases (64%) and reports involving third parties accounted for the remaining 47 cases (36%). The monthly distribution of reports for 2014 is shown in Figure 3-1.

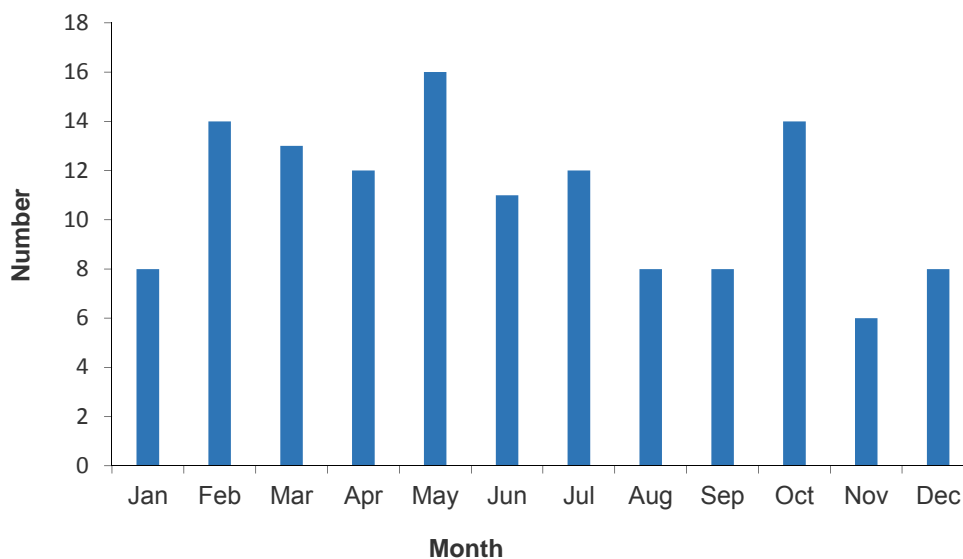


Figure 3-1 Month distribution of compressed gas diving incident reports in 2014 (n=130)

Eighty-four incidents (65%) were reported to have occurred during 2014 and another 19 (15%) incidents had occurred during the previous year. The remainder (n=27, 20%) occurred more than one year before they were reported to DAN. The majority of incidents happened on the first day in a diving series, as shown in Figure 3-2.

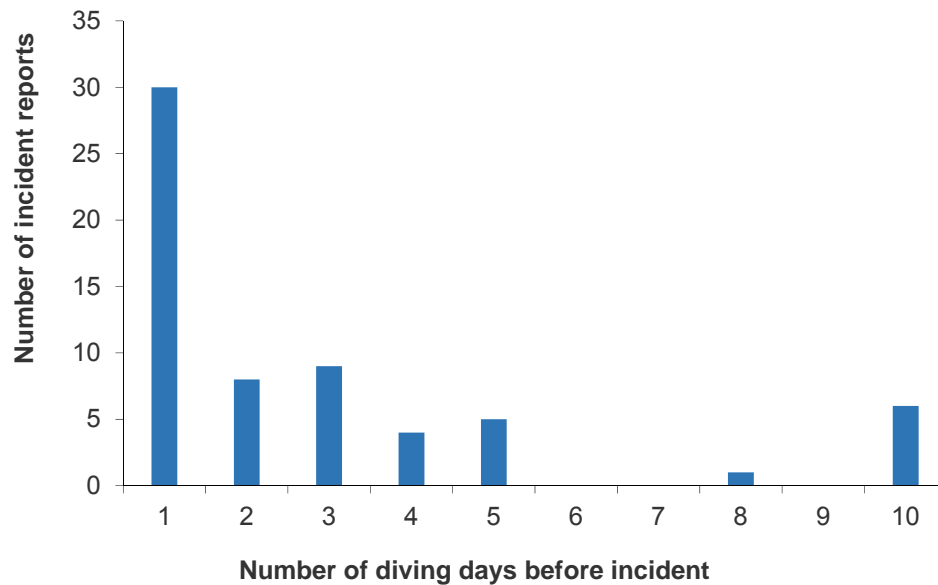


Figure 3-2 Number of days in the diving series before the incident occurred, where known (n=63)

Familiarity with the incident dive site was reported in 111 cases. In 60 of those cases (54%) the diver was diving at the site for the first time while 51 incidents (46%) occurred during return visits. The majority of incidents (69%) took place during the first dive of the day, 26% during the second dive and 3% the third dive. Inexperience featured prominently in reported incidents, with 50% of reports involving divers with less than two years since first certified to dive. Indeed, of the 116 divers who reported their training status, 11 divers (9%) reported having received no formal training. Self-reported experience level in the activity engaged in at the time of the incident is presented in Figure 3-3.

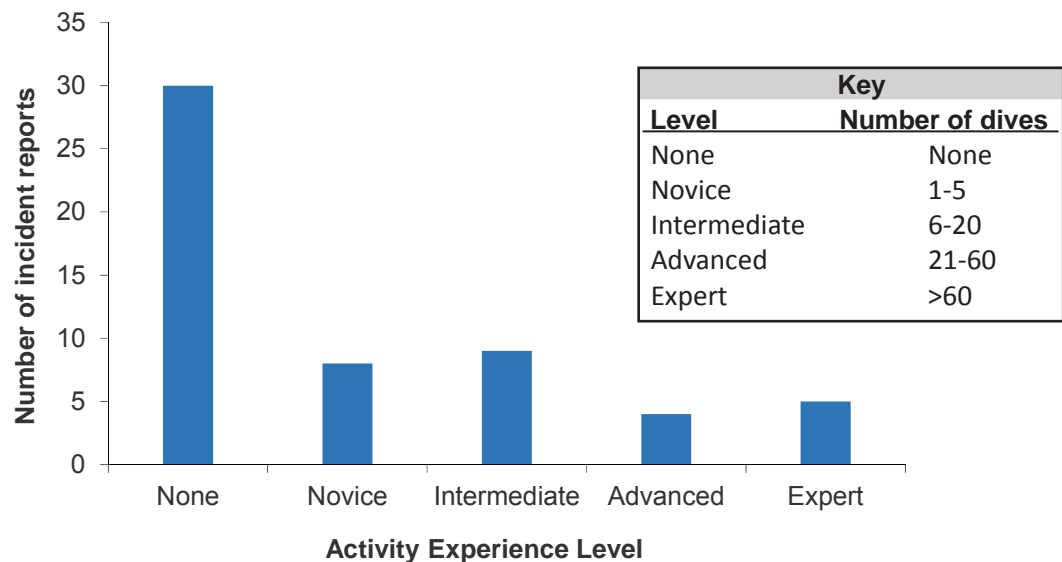


Figure 3-3 Self-reported experience level in the diving incident activities

Four divers reported having made 3,000 dives or more. The mean number of dives made by the 95 other divers who reported their experience was 146 dives (range 0-1500). The mean number of dives made within the previous year, for all divers, was 34 dives (range 1-350) and within the previous month 7 dives (range 1-12). The year in which divers reporting incidents were first trained to dive is shown in Figure 3-4.

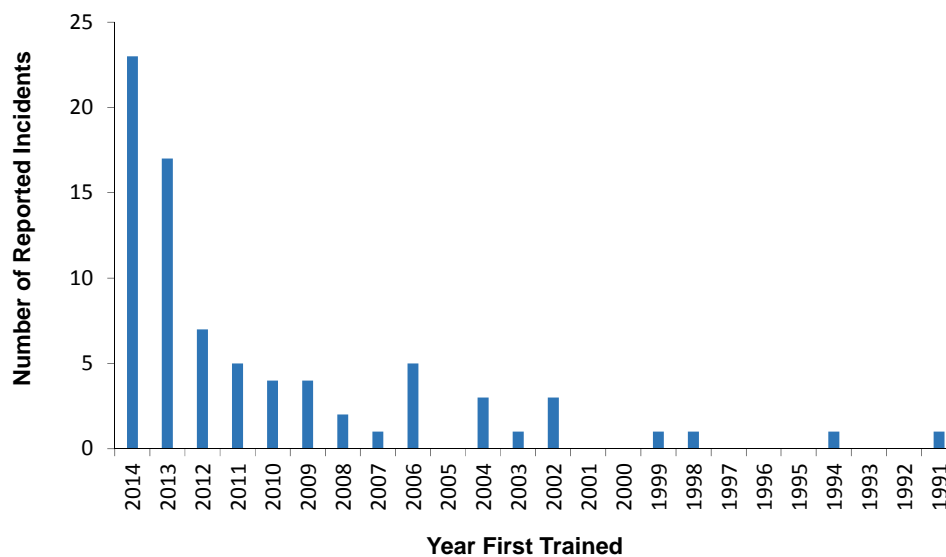


Figure 3-4 Number of reported incidents in 2014 by year first trained to dive (n=79)

Characteristics of the divers involved in reported incidents are given in Table 3-1.

Table 3-1 Anthropometry of divers involved in reported incidents

	Male (n=81)	Female (n=40)	Overall (n=121)
Age	45 (range 18-69)	43 (range 12-70)	45 (range 18-70)
Body Mass Index	27 (n=69, range 20-37)	23 (n=27, range 18-35)	26 (n=96, range 18-37)

Depth was not reported in 28 incidents (22%) and among the remaining 102 reports (78%) mean depth of the incident was 23 msw (74 fsw). The mean maximum depth previously reached by the diver affected by the incident (n=96 reported, 74%) was 36 msw (119 fsw).

The type of support each incident involved is presented in Table 3-2.

Table 3-2 Type of support through incident dives

Surface support type	N (%)
Dive partner – limited supervision	75 (58)
Dive partner – direct supervision throughout dive	51 (39)
Not reported	4 (3)

Time of day when the incident occurred was noted in 68 cases and were in the day (n=103, 79%), at night (n=5, 4%), at dawn (n=4, 3%) or at dusk (n=1, 1%). Ninety-three dives (72%) were made in the ocean/sea, 16 (12%) in open freshwater, 4 (3%) in springs, one (1%) in a pool and 16 (12%) were not described. Water temperature showed a preference for warmer water, as shown in Table 3-3.

Table 3-3 Water temperature for reported incidents 2014 (n=130)

Temp °C	<4	4-9	10-15	16-20	21-26	27-32	Unknown
Temp °F	<39	39-48	50-59	60-68	69-79	80-90	Unknown
N (%)	4 (3)	7 (5)	24 (18)	16 (12)	25 (19)	37 (28)	17 (13)

Reported visibility during incident dives ranged from poor (<3m, <10 ft, n=17, 13%), moderate (3-15m, 10-50 ft, n=49, 38%) to excellent (>15m, >50 ft n=48, 37%).

The altitude of incident dive sites was reported in 11 cases and ranged from 0-305 m (0-1,000 ft n=105, 81%), 305-1,000m (1,000-3280 ft, n=4, 3%) to >1,000m (>3,280 ft, n=2, 2%).

The dive platform from which incident dives occurred are presented in Table 3-4.

Table 3-4 Dive platform for incident dives 2014 (n=130)

Platform	N (%)
Day boat	69 (53)
Beach/shore	25 (19)
Liveaboard	17 (13)
Other	5 (4)
Not declared	14 (11)

The severity of the outcome was reported in 120 cases, as either death (n=16, 12%), injury (n=46, 35%) or no injury reported (n=58, 45%). Case summaries describe incidents happening while diving wrecks (n=8, 6%), underwater hunting (n=7, 5%), during training dives (n=13, 10%), rapid ascents (n=18, 14%) and/or loss of buoyancy control (n=25, 19%). Twenty-one incidents (16%) involved a diver running out of gas and two more (2%) involved the diver starting a dive with the tank valve not fully open, which only became noticeable at depth when it got harder to breathe. Three incidents (2%) were possibly associated with gas contamination and 18 (14%) were due to equipment malfunction, as shown in Table 3-5.

Table 3-5 Types of equipment malfunction reported to DAN through DIRS in 2014 (n=18 cases)

Equipment Failure	Frequency	Percent
Corrugated hose disconnected from BCD	2	11
Sensor/SPG stuck on false pressure reading	2	11
Free flowing regulator	2	11
BCD inflator free flow	2	11
Air dump valve failure	1	6
Modified regulator in rebreather	1	6
Inflator-regulator combination failure	1	6
Leaking BCD	1	6
Leaking dryglove	1	6
Lost integrated weight pouch	1	6
Regulator first stage malfunction	1	6
High pressure hose explosion	1	6
Necklace bungie twisted, octopus unusable	1	6
BCD set on fire	1	6

Of the 18 incidents involving equipment failure, nine (50%) involved an air supply problem eight (44%) a buoyancy control problem and one (6%) a thermal insulation issue.

In 16 (12%) of the 130 reported incidents the outcome was fatal, in 59 (45%) of cases a non-fatal injury resulted, as shown in Table 3-6. The remaining 55 reports (43%) included no details of an injury.

Table 3-6 Non-fatal injuries reported to DAN through DIRS in 2014 (n=59 cases)

INJURY	Frequency	Percent
Decompression Sickness	18 <sup>a</sup>	31
Ear barotrauma	6	10
Pulmonary barotrauma	5 <sup>b</sup>	8
Headache	5	8
Loss of consciousness	5	8
Near drowning	3	5
Nausea / vomiting	3	5
Back injury	2	3
Immersion pulmonary edema	2	3
Possible gas poisoning	2	3
Broken collarbone	1	2
Doubtful DCS	1	2
Subconjunctival haemorrhage	1	2
Sea-jelly sting	1	2
Torn quadracep tendon	1	2
Sore groin	1	2
Soreness from BCD	1	2
Vertigo	1	2

<sup>a</sup>Includes 3 "skin bends" and 1 "spinal decompression sickness"

<sup>b</sup>includes 2 pneumothorax and 1 sub-cutaneous emphysema

While statistics certainly assist identify possible targets for preventive interventions, case vignettes are richer in detail and often provide learning points. A selection of edited case reports now follows. These are actual reports from divers received through the DAN Diving Incident Reporting System (DIRS). Units of measurement have been converted into both imperial and metric, 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 readers will get a more authentic feel for the experiences being reported. DAN thanks everyone who supplied incident reports in 2014.

## Rebreathers

### Case 3-40: A forgotten drysuit hose vacuum-packed a rebreather diver

An experienced open and closed circuit diver with hundreds of hours underwater in many different types of diving conditions boarded the boat with five other experienced divers. His dive partner also was using a rebreather, but the two had planned to separate once in the water. The diver told his partner he did not want to spend much time at the surface before he descended, so the only equipment check conducted was a quick bubble check on the initial descent. After the bubble check, both divers continued to descend but on their own. The dive partner said he last saw the diver below him at 90 to 100 fsw (27-30 msw). He said this occurred at the beginning of the dive. The dive partner said it appeared the diver was lying on the bottom and looking at something. The dive partner stated he had no idea the diver was probably already unconscious on the bottom.

None of the other divers that entered after the first diver saw him during any portion of the dive. When the diver did not surface as planned, the group became worried and began sending divers to look for him. The captain of the boat also notified the US Coast Guard and lifeguard divers were dispatched to assist in the search. After a six hour search, the diver was located at a depth of 92 fsw (28 msw) at the same location he had descended. The diver was brought to the surface and pronounced dead.

The lifeguards that found the diver said he was lying on his back with the rebreather mouthpiece not in his mouth. The mouthpiece was also closed. They also noted the diver did not have a low-pressure hose connected to the drysuit inflation valve or the BCD inflation valve. They said the diver appeared vacuum-packed in the drysuit.

The diver's bailout regulator was no longer attached to his BCD harness, and it appeared he had removed the regulator to use it. The regulator, however, had an inline on/off valve that was still in the off position. The investigation revealed that the diver placed the on/off valve above the second stage to prevent the second stage from free flowing. When tested, the on/off valve was very hard to open, especially with gloves on. The diver had plenty of bailout gas left in his cylinder, but none of the gas appeared to have been used.

Equipment testing revealed the diver was using 27 pounds of added weight on his rebreather rig. This was in addition to the negative buoyancy created by his bailout system and underwater camera equipment. The examination and testing of the rebreather showed the unit worked as intended, but did not provide direct answers as to why the diver went off his working rebreather loop and closed the loop mouthpiece. This decision could have been made because the volume of gas contained in the loop felt insufficient, the diver had some other equipment issue (tight drysuit), or had some type of medical emergency.

Once closed however, the diver would have quickly needed an alternate air source to survive underwater. The diver had two choices: The regulator attached to his bailout bottle and the regulator attached to his BCD. The problem was that no low-pressure hose was attached to the BCD regulator and the on/off valve on his bailout regulator was hard to open.

The autopsy showed the diver had water in both his lungs and stomach consistent with drowning. If the diver took a breath from either regulator during the emergency, the diver would have inhaled only cold saltwater. When combined with the added weight and no way of adding air to his BCD or drysuit, the diver sank directly to the bottom and drowned.

### Case 3-54: Wearing mask under the hood ended a CCR dive

On my second dive, my mask flooded after jumping into the water. On the surface I cleared the mask. Continuing the dive, my mask flooded again at a depth 15 fsw (5 msw). I couldn't tighten the straps on my mask because I was wearing a hood over the mask. By now my counter lungs were empty of air from clearing the flooded mask and I was gasping for air. I went to the surface and called for assistance (a line to pull me to the ladder). This ended my second dive.



### Fatal Incident Reports

#### Case 3-41: Diver witnessed diving fatality aftermath

I was not on the dive boat. I was approaching the shore by boat and witnessed a police boat and a dive boat. On the rear, as they were approaching, someone was receiving CPR and looked unresponsive. It was an overweight older man. The rescue team met them and eventually took him away with an automatic chest compression machine attached. I caught part of the report given to a police officer. The diver stated "We were at 80 feet (24 meters) and started surfacing, at 50 feet (15 meters), he started choking and grabbing for my reg." That is all I caught of the conversation.

#### Case 3-99: A second witness confirmed tank was empty

I did not witness the incident directly but wanted to submit a report of what I saw with the hopes DAN may be able to follow-up and learn more. My wife and I were diving together. Upon surfacing we deployed our SMB to signal the dive boat that we were ready to be picked up. The dive boat began heading our direction when it appeared another set of divers surfaced between us and the boat. The boat stopped and appeared to pick them up. Shortly thereafter, the boat began heading to shore at a high rate of speed. Later, another dive boat recovered us from the water. At that point we learned that one diver's equipment (tank, regs, BCD, weight belt) had been found on the ocean bottom and we were told that there had been a diver fatality. A diver on this second dive boat dove down and recovered the equipment. That diver placed it on the boat and instructed the rest of us to not touch the equipment as the coast guard and police would want to see it first. However, I could clearly see the psi gauge and it was registering empty. The boat returned us to where our own boat was docked and we went on board to gather the rest of our clothes and equipment.

*Editor: The two witness accounts above concerned the same incident, which DAN followed-up for additional information. Our thanks to these divers. If anyone witnesses a diving fatality then please report it to DAN.*

### Possible Polluted Gas

#### Case 3-89: Diver felt sick after breathing from tank with water and oil in it

Our first dive lasted about 40 minutes and went to a maximum depth of 60 ffw (18 mfw). We were diving at a lake and at the end of the first dive I felt dizzy and a little nauseous. We took an hour break until my head cleared. I ate a couple of energy bars and a piece of fruit and I felt pretty good. We had no explanation for the dizziness. I was well rested, in good condition, had a normal breakfast, and had been diving in the same location a couple weeks before.

We went in for our second dive and after about 15 minutes at a depth of 65 ffw (20 mfw) I began to feel very nauseous and thought I might vomit. I signaled to my buddy that I felt ill and we began a gradual ascent and surfaced where we began our dive. On surfacing I felt extremely dizzy and had to use my buddy for support to keep from losing my balance. About one minute later, I vomited. After a half hour or so, I felt well enough to leave so we drove home.

We analyzed what had happened and the only thing we could come up with was bad air, but we recognized that the chance of that happening was pretty remote. Nonetheless, that's all we could come up with. The following day I called the dive shop where I got the air and the owner told me they'd received no complaints and had not had any problems. My buddy dropped our tanks off at a different dive shop, closer to home, and told them what had happened. The store owner called the next day and reported that three of the four tanks had water and an oily substance in them and one tank was clean. He then scrubbed the tanks and refilled them for us.

#### Case 3-36: Divers given "foul, poisonous smelling" nitrox, not charged for it

We were three divers all on nitrox. After descending to the bottom I noticed a foul, poisonous smelling odor coming from my second stage. I stopped to think about what to do. I had to wait for the rest of the group so I concentrated on how I was feeling. Was I getting dizzy, nauseous etc? Nothing was happening. I gave my buddy, when he arrived, the "something is wrong" signal. Unable to really describe what was going on I glued myself to my buddy and continued on. Back on board, I told the dive guide that my nitrox was foul. He said it was not. I asked the other diver I did not know to tell me what he thought. Then he smelled my buddy's nitrox and said it is not as bad as mine but still bad. Then this diver asked me to smell his nitrox. Same smell but not as bad as mine. The dive guide refused to acknowledge the problem. We complained to the owner of the operation. She said that nothing was wrong. She inspected the tanks

and said corrosion was inside and that is why the nitrox was smelling foul. She did not charge any of us for the nitrox. Could this smell come from just corrosion? I know I should have aborted the dive. It would have meant that everyone abort the dive because we were only three of us. The dive would have been over, and we'd go back to the shop. All six of the tanks on board had the same smell.

*Editor's comment: DAN supplies air quality testing kits to divers who suspect receiving a polluted fill. The divers must have legal control of the tank to be tested and it must still contain the polluted gas. For a kit call DAN Research on (919) 684-2948.*

## Incidents During Training

### Case 3-25: Unrehearsed valve shutdown training led to confusion underwater

While taking a sidemount technical diving course, I was performing tank shut down drills at around 60 feet (18 meters) and switching to my "usable" tank and regulator. I had not practiced this drill before and simply discussed it with my instructor and another student in the class. While performing the drill, I got a bit confused. I did not have a regulator in my mouth and was exhaling while attempting to switch tanks. I tried to place my regulator from my short hose in my mouth and could not get it as the necklace it was on was twisted. I could not exhale or hold my breath any longer at this point and started to inhale water. My instructor gave me his regulator on his long hose, grabbed ahold of me and we started our ascent. It was a controlled ascent and we performed a safety stop at 15 feet (5 meters). While ascending, I was coughing continuously in my regulator and trying to get a good breath. When I reached the surface, I spit up and coughed up water and secretions. I was assisted back onto the boat and was able to catch my breath.

## Decompression Sickness

### Case 3-57: Diver ignored dive computer, omitted decompression and got the bends

It was the second dive of the day. All divers were certified, using their own gear and computers. There were two dive masters present, along with seven divers. We had completed our first dive to a maximum depth of 70 fsw (21 msw) with a total bottom time of 50 minutes. After our surface interval, we headed out for our second drift dive. The average depth was 60 fsw (18 msw) and we had a total bottom time of 40 minutes. It was at the end of this dive when the majority were completing their safety stops, there was a turtle on the sand at a depth of between 40 and 50 fsw (12-15 msw). One diver decided to stay with the turtle to take pictures, ignoring her computer and the dive masters. On her ascent, her computer told her a decompression stop was required at 25 feet (8 meters). She completed her stop. However, she did not stop again even though her computer told her a second decompression stop was required. Upon exiting the water, the lady was fine; she entered the boat, climbing the ladder with her gear, unassisted, and we took the short boat ride back to the island. We dismantled the equipment, rinsed off and headed for lunch. It was while waiting for our lunch that she complained of feeling nauseous and light headed. Her partner told her she must be dehydrated. Upon attempting to eat lunch, the lady vomited and fainted. We laid her down on her side, raised her feet and placed a cool rag across her forehead. Still under the impression she was dehydrated, her partner prepared her an electrolyte drink, and we took her to her room to rest. Later in the evening, the lady told us she was feeling better, but was still light headed. It wasn't until the following morning that the lady now complained of numbness in her legs, and so we took her to the nearest chamber. We called DAN, and they informed us that her symptoms were not typical of decompression sickness, but it would be best for her to head to the chamber for assessment. We were able to contact her a couple of days later and were informed that she was fine after having three sessions in the chamber.

### Case 3-58: Suspected bends after first dive got worse over next three dives

Diver completed four dives over three days. All dives were completed on air. Water temperature at depth was approximately 50 degrees. Full 7 mm wetsuit with hood and gloves. Minor symptoms were present after first dive to a max depth of 88 fsw (26 msw) on day one. Symptoms lingered on day two throughout dives two and three. 69 fsw (21 msw) was the maximum depth on both dives. One dive with max depth of 84 fsw (26 msw) was completed on day three before departure. Pain worsened, fatigue increased and marbled rash appeared en route.

### **Case 3-67: A post-dive shower generated abdominal skin decompression sickness**

We flew to Mexico and I went for two 60-minute dives with a surface interval of 90 minutes. The other divers were very experienced, and we used their dive computers for a slow ascent with a long pause at 15 feet (5 meters). I was very anxious since I had not dived for five years. I was also nauseated from diesel fumes all day and the ocean was a bit rough. I am a very healthy 65-year-old female, 5'6" and 130 lbs, with no health issues, and I was accompanied by a scuba instructor the whole time.

After we were back at the condo, about two hours after the dives, I took a shower and noticed a red rash on my abdomen. It itched like crazy. We all thought it could be sensitivity to the neoprene or some sea allergy. The next day my husband and I did not dive. On the third day, I felt fine and did not want to miss out. I was much more relaxed, and again, my husband and I were accompanied the whole time by a scuba instructor. The dives were beautiful, we had a long surface interval, and took a good long time to come to the surface, using the dive computers that three of the other divers had.

The second dive was a drift dive. It was beautiful, but I think I fought the current a bit. I took care to get out of the wetsuit ASAP, and took another shower. This time, after about two hours, again the abdominal rash started, which spread up over my ribs and around my hips a bit. My abdomen was blanched white, and purple veins were visible. My muscles felt as if I had done a lot of situps, and I could see fractured light around the periphery of my visual field.

*Editor's comment: After diving, a warm/hot shower can cause "skin bends" or a form of decompression sickness involving blotchy skin, itching, pain, hardness or a variety of other symptoms. Before showering, it is best to let the dissolved gas in our bodies gradually return to the atmosphere. How long that might take depends upon the depth, time, and number of dives. In mild cases, the "rash" may even resolve itself but divers should always consult medical advice in case the rash is merely the first sign of a worsening injury. Also, every diver should plan their own dive either with tables or a dive computer. It is not safe to follow other divers' computers. This diver dived without any dive plan or dive computer and suffered decompression sickness.*

### **Case 3-94: Diver suffered likely decompression sickness, tried deep knee bends for relief**

I was spear fishing at a maximum depth of 106 fsw (32 msw). I traveled along a ledge about ten to fifteen feet high sometimes on the sand looking for lobster but most of the time half way up the ledge looking for fish to spear. As I approached the yellow zone on my dive computer, I went to the top of the ledge and headed back toward the anchor. When I arrived at the anchor, I still had about four minutes of no-stop time left before earning a decompression obligation. I decided to take a quick look back down at approximately 106 fsw (32 msw) for lobster just under the anchor. I didn't see any lobster so headed back up to the anchor. During the ascent, I paid close attention to my rate. Once I reached the hang line, I moved toward the fifteen foot mark over the next four minutes. I surfaced after my stop and handed my fish and gun to someone on the boat. Once on the boat, I sat on a box and talked to a guy for a few minutes when I noticed my left leg tingling. Assuming I had cut off circulation, I walked around trying to reduce the numbness. A few minutes later, I noticed my right foot and leg also felt tingles and slight numbness. I decided to go to the front of the boat and try to get my circulation to improve by doing deep knee bends. I noticed while returning to the rear of the boat my coordination was not quite right. I asked the Captain if he had oxygen onboard and began breathing it. After approximately ten minutes on oxygen, my right leg felt normal. Another ten minutes and my left leg also felt normal. I continued for an hour on the oxygen. Once on shore, I called DAN and asked for advice about going to the doctor. Approximately five hours after the dive, I went to the local hospital. The doctor that examined me called DAN and communicated the condition I was in. I have since decided future dives will be more conservative. Thanks for your help.

*Editor's comment: During decompression experiments in clinical facilities, under the supervision of a diving doctor, divers are asked to make knee bends to deliberately generate bubbles; however, DAN does not recommend divers make knee bends to improve circulation, especially if a diver is feeling tingling or numbness. This diver was lucky his condition improved rather than worsened, and breathing oxygen was a prudent decision.*

## Out of Gas Reports

### Case 3-80: Poor gas planning led to running out of gas

Poor gas management coupled with equipment failure led to my buddy's emergency ascent and my uncontrolled ascent. My buddy and I were diving in the deeper section of a quarry, using half tank turn pressures rather than the rule of thirds, and my buddy was the first to run out of air. I donated my primary regulator, then we both ran out of air shortly thereafter. My buddy's pony bottle regulator then failed catastrophically on deployment. My buddy made an emergency ascent from approximately 60 ffw (18 mfw), reached the surface without serious injury, but had a subsequent headache and chest pain that quickly resolved. I had an uncontrolled ascent with apparent gastric distention and shortness of breath on the surface, which was relieved with belching. No further injury or illness from this incident. We lost a reel on the bottom that we retrieved the next day using appropriate gas planning with rule of thirds. This was a turning point in our diving procedures, and many lessons were learned that day. We should have known better and were lucky that nothing more serious occurred.

### Case 3-17: Diver made a second dive without re-filling tank, then ran out of gas

The diver had several hundred dives logged, all on open circuit air. The boat briefing stated the dive procedures used by the boat crew. One of the briefing items was that divers, on exiting a dive, are to remove their first stage regulator in order that the tank filler know which tanks need refilling during the surface interval. The diver and his buddy jumped behind another buddy team, and the two teams were to meet at the bottom of the mooring line and proceed with the dive as was agreed on the surface. The first buddy team arrived and waited for the second team which included the diver. After a time, the diver's buddy appeared at the mooring line on the bottom, without the diver. The diver had apparently continued a free descent after his buddy had stopped to clear his ears. When he realized he had lost his buddy, he eventually joined another group with whom he surfaced later. A discussion was had with the diver about maintaining buddy contact. This dive profile was 82 feet (25 meters) for 30 minutes.

After a two hour surface interval, the boat re-located for an oil rig dive, and dropped 18 divers, including the diver and his buddy, into a clear, no-current sea, but with a surface swell of about 4-5 feet through the rig structure. At about 14 minutes into the dive, a diver was seen at the surface inside the rig giving an "OK" sign, and climbing up a ladder on one of the rig legs. Boat crew dive guides were dispatched to retrieve the diver, who was towed back to the boat and recovered without incident, but again without his buddy. Onboard, the diver advised the crew that he had experienced an out-of-air situation at about 80 feet (24 meters) inside the rig. He could not locate his buddy and approached another buddy team who did not recognize his out of air signal. The diver approached another buddy team and one of those divers air-shared with the diver.

The diver had not removed the first stage after the first dive, so the tank was not refilled and the diver did not check his tank pressure prior to descent off the boat. Buddy contact was again ignored, resulting in an emergency ascent with another diver who knew proper emergency air share procedures.

*Editor's comment: DAN recommends every diver check the tank pressure before entering the water. Open the tank valve all the way and take two breaths while looking at the SPG or dive computer. It is also a good habit to practice out-of-air drills, including clear signaling.*

## Ear Injuries

### Case 3-43: Distraction led to barotrauma

I had a leaking dry glove as I was descending. I was trying to deal with the problem and failed to clear my ears properly. The result was barotrauma to my right ear.

### Case 3-10: Ear barotrauma prevented further diving on dive trip

We got in the water and I made sure to equalize all the way down to the reef at 65 fsw (20 msw). I never felt any pain, nor did I feel like I had to equalize more than normal. However, this particular reef had lots of elevation changes, so we would go from 65 feet (20 meters) to 44 feet (13 meters) and back to 60 feet (18 meters). I normally prefer wreck dives, so I'm not used to a dive that includes a lot of up and down like that. I still never felt any issues other than having

to equalize frequently. At one point, I felt I needed to equalize and I tried, but nothing happened. Seconds later, my left ear made a pop sound and I felt relieved. We finished the dive by ascending slow and stopping at 15 feet (5 meters) for 3 minutes. About 1-2 hours after the dive, I felt my throat getting sore, like I was having lots of drainage causing some irritation. Shortly after, I started feeling pain around my ear and in my jaw. I decided to see the property nurse who called in a doctor. By the time the doctor arrived, I estimated the pain to be a 7 out of 10. Movements like yawning hurt. The doctor examined me and said that I had ear barotrauma and prescribed a cocktail of drugs to treat it so that I could fly home six days later. The medicine cleared the pain quickly. I did not dive again on the trip.

### Loss of Consciousness Reports

#### **Case 3-72: Unconscious diver fell head-first to sea floor, was rescued and survived**

According to the boat crew, the crew noticed the victim descending without her buddy (who was still on deck kitting up). There were other divers on the surface and there were also divers already underwater at approximately 80 fsw (24 msw) on the bottom. Due to the excellent visibility, all four divers (two groups of two) saw the victim descending down through the water column head-first, "rag-doll-style". They witnessed her strike the bottom head-first. Three of the divers (all rescue-trained) made their way immediately to her while the fourth diver made his way to the surface to call for help. The three divers brought the victim to the surface and they were approx 10 yards from the boat's swim step.

The victim was brought aboard unresponsive, non-breathing, lips blue, and with blood coming out of her mouth, so CPR was immediately initiated. The boat captain called the coast guard. After approximately 2-3 minutes of CPR faint breaths were detected coming from the victim. Breathing increased slightly in strength over the next couple of minutes. Oxygen was applied during this time and after a few minutes the victim began moaning.

After approximately ten minutes, the victim began crying out in pain, but did not respond to questions or stimuli. A doctor was on board and the victim was turned over to her care. The coast guard notified our boat captain that a helicopter was on its way. After a time the victim was able to open eyes, nod her head in response to a question, and remained in a semi-responsive state for the duration.

The victim was picked up, placed in the hyperbaric chamber and reported to have become extremely lucid once she was at depth. Upon reaching port (about 5½ hours later), I went to the hospital. The victim had just come out of a CT scan, was sitting up in her bed, was responsive, emotional, and could remember nothing of the day except "waking up" in the chamber. She was released the next day (Sunday) with a broken ear drum and soreness, but otherwise healthy.

#### **Case 3-77: Second witness account, from one of the rescuers**

This was our first dive of the day and the trip. My buddy and I descended along the stern anchor line. Five minutes into our dive we reached 80 fsw (24 msw) and I could easily see the bottom of the boat from 80 feet (24 meters) down. Horizontal visibility was roughly 50 feet (15 meters). It was then that I observed a diver plunging head first, straight down at a high rate of speed. She was at a depth of roughly 40 fsw (12 msw) when I first spotted her. Her arms were by her side and I could see hoses trailing behind her. She was not flailing. Her limbs were not moving.

I began swimming towards her while simultaneously signalling to my buddy with my light. Most of the time I kept the falling diver in my sight. I looked twice at my buddy to confirm that she had received my signal and was following, which she was. I reached the diver roughly 10 seconds after she hit the bottom. The point of impact was roughly 25 horizontal feet (8 meters) from the spot where I first observed her. She was too far away for me to catch her.

The diver hit the bottom head first and there was a puff of sand on impact. Her body then fell into a supine position before I reached her. Upon reaching her, the regulator was not in her mouth, her mask was half filled with water, she was unconscious and her nose began to bleed. I attempted to snap her out of unconsciousness by grabbing/shaking her right arm while pulling her body into a more seated position and placing her regulator up to her mouth. We are trained not to put a regulator into the mouth of a diver we find at the bottom. This did occur to me at the time, but I thought she might gain consciousness and gasp for air. I did not attempt to jam it into her mouth, but pressed it against her lips. Probably five seconds passed while I attempted to revive her. She did not respond to me and I knew we had to get



to the surface fast. At that moment my buddy arrived and one other diver from nearer the surface. I rapidly signaled thumbs up that we needed to get up fast. I then grabbed the diver's BCD inflator and depressed the inflate button. I could feel air flowing through it, but she didn't instantly move. I kept the button depressed and eventually she started moving. The total time from impact to beginning the ascent was roughly 30 seconds.

We lifted off the bottom and began an emergency ascent. At some point two other divers joined us. At about 40 feet (12 meters) I could hear the alarm on my computer and was able to see it on my wrist. We were ascending at over 99 ft/min. Because of the orientation of my left arm holding her right arm, my drysuit valve began to dump air and I kept dumping to slow us because I didn't want us to suffer injury. But knowing that my buddy and I had only been down for five minutes, this was the first dive of the trip and we were on EAN32, I stayed with her to the surface.

At the surface I handed the diver off to others because I was oriented furthest from the boat and exhausted. I yelled "Diver emergency. Diver emergency. This is not a drill." The diver was taken to the boat, lifted aboard and CPR started. She started breathing on her own about three minutes later. A coast guard helicopter arrived, lifted her in a basket and took her to a medical center. After continuing to improve in the the chamber she was released the following day.

*Editor's comment: There is no doubt these quick-thinking trained rescue divers saved this diver's life.*

## Immersion Pulmonary Edema

### Case 3-44: Immersion pulmonary edema

The diver reported difficulty breathing after seven minutes, at 20 fsw (6 msw) depth dive. No specific incident that led to aspiration. Received oxygen in route to hospital. Oxygen and observation at hospital. Symptoms improved after 2.5 hours. Chest x-ray confirmed fluid in lungs. No heart abnormalities. No history of breathing problems. Experienced diver, 32-year-old female.

### Case 3-52: Routine dive ended in pulmonary edema

I had a refresher course with dive instructor prior to diving. The swim from the shore to the dive site was uneventful. Our group descended with the dive guide. Maximum depth was 37 fsw (11 msw) and the dive time 46 minutes. Ascent was controlled and uneventful. I stayed with the dive guide for the entire dive. Once on the surface, I developed shortness of breath with persistent cough. I required assistance to return to the shore area. Shortness of breath and coughing continued. Oxygen was administered and the paramedics called. They took me to a hyperbaric chamber where I was evaluated and then transferred to a medical center by helicopter for medical treatment. Diagnosis was pulmonary edema with shortness of breath. I was held overnight for observation and released next day.

## Weight and Buoyancy Problems

### Case 3-16: Diver lost buoyancy control while adjusting his weight belt

During a night shore dive off an island, at depth in about 65 fsw (20 msw), I decided that my weight belt was uncomfortably tight. It was the type of belt I often see at dive shops. Nylon, about two inches wide, with removable lead weights, and a simple plastic flip-open buckle. I was unable to see it, due to my mask and partial obstruction by my BCD. I found the buckle with my hands and opened it, at which time it slipped completely undone, pulled by the dangling weights. I was unable to get the end slipped back into the buckle after trying fruitlessly for about a minute. I began to ascend inadvertently, being mentally unable to simultaneously struggle with my weight belt and maintain buoyancy. When I discovered that I was ascending, I stopped working with the weight belt and concentrated on descending again. As I was in the rear of the group of three dive buddies, they were moving steadily away from me across the bottom. I decided to signal for help, thinking that a buddy might be able to see my weight belt and easily get it buckled for me. Fortunately, one of my friends responded to my light signals and came to my aid. He was able to fasten my belt, and we continued our dive uneventfully. This is not the only time I've been bewildered by these, in my opinion, poorly designed and too-easy-to-open weight belts.

*Editor's comment: To adjust a weightbelt simply hover horizontally before opening it, and let your back take the weight while your hands focus on the buckle.*

### **Case 3-55: Over-weighted diver ran out of gas**

This was my tenth dive after being certified and I went spearfishing from a boat in about 40 fsw (12 msw). It was dark and cold and I was wearing a number of newly purchased items, such as a 7 mm wetsuit and BCD, and was grossly overweighted with 30 lbs of lead. I had made one successful dive (dive nine) with a good friend but on the fateful dive I was partnered with a new buddy. We were quickly separated in the pursuit of various fish, but came together shortly after and I pointed out my SPG showing 600 psi of air remaining. He instructed me to surface while he would remain below, as he still had 2000 psi.

On my ascent I made it to approximately 20 fsw (6 msw) and sensed the air supply getting constricted, much like I had felt in the pool when my instructor turned off the air to show me how that would feel should I ever run out. I recalled that if I ascended further, I might get one more sip of air, which was true, however it was not enough. I had a plan to orally inflate my BCD on the surface and had my inflator hose at the ready as I kicked up, but with zero air in my BCD I had no way of assisting my lift other than plain kicking, but the large amount of lead really held me back.

Finally I did surface and gulped air, but as I tried to inflate I went straight back down. I feel VERY lucky and grateful to be alive. I did return to diving three weeks later, but reduced my weight to the appropriate level (16 lbs). I keep a much closer eye now on my air consumption and will not leave my dive partner ever again.

### **Case 3-62: Inflator valve stuck causing rapid ascent**

I usually dive using a BCD I purchased in 1993. A number of years ago, I had just started a dive by descending to 85 fsw (26 msw). I hit the inflator valve to give my BCD a small squirt of air. To my surprise, I started to ascend. I hit my dump valve, and copious quantities of air continued to stream out. My dive buddy saw what was happening and grabbed my fin as I was heading for the surface. He had to let go as we were both heading up. Then I realized that my inflator valve must have stuck open! I quickly disconnected the inflator hose from my BCD and dumped the excess air. I had popped up to about 65 fsw (20 msw), before becoming neutral. Fortunately, I figured out the problem, fixed it, and was able to have a great dive using the oral inflator on my BCD. I have my equipment serviced regularly, but never thought much about the inflator valve on my BCD.

## **Valve Not Open Fully**

### **Case 3-73: Barely open valve caused shortage of gas underwater**

I was diving with a tank valve on the left instead of the right. The valve was partially closed and cracked open a quarter turn. After 40 minutes at around 30 fsw (9 msw), I noticed breathing was a little labored. Looked at my SPG and the air pressure was fluctuating between 1,600 psi and under 500 psi. At this point, I knew the tank valve was closed. I tried to reach the valve but could not so I quickly swam over to the divemaster. I signaled to him that I was out of air and he gave his primary regulator, then he took his secondary regulator which was on a necklace. I signaled to him to open my valve. Once he did that, my air was ok and the SPG reading at over 1,000 psi was stable so I returned his primary and went back to my own regulator.

### **Case 3-56: Dive tank valve turned on only a quarter turn**

On a recent boat dive trip with my girlfriend, we decided to do back rolls at the same time to avoid being separated by the current. Once under, we made contact and gave each other the OK signal before descending to catch up with the rest of the group that was already heading down to the bottom. At about 30 feet (9 meters) down, I looked to find my dive buddy but, to my surprise, she was not there. I headed for the surface. In my hurry to find my partner, I inadvertently ascended too fast and my dive computer alarm warned me to make a safety stop even though I had only been in the water between 2 to 3 minutes and no deeper than 36 fsw (11 msw). I knew that my risk of DCS was minimal at this point. However, I vaguely remembered reading in my owner's manual that if I ignored a mandatory safety stop, the dive computer would lock me out for any dives in the next 24 hours. I stayed at 15 feet (5 meters) in order to comply with the safety stop parameters. When I got closer to the boat, I could see my dive buddy hanging onto the back of the boat. Before my safety stop ended, my partner came down and joined me and we caught up with the group. After we finished the dive and were back on the boat, she explained to me that her regulator was breathing hard as we went down and, rather than continue down in the strong current with an unknown problem, she surfaced and went back to

the boat to figure it out. It turned out that her regulator valve was screwed down to an almost closed position and she had not realized it.

*Editor's comment: The days we needed to turn a tank valve back a quarter turn are long gone. Before entering the water divers should ensure the tank valve is turned all the way (on or off), then take a couple of breaths while looking at the SPG. If the needle stays in the full zone then the valve is fully on.*

## Pulmonary Barotrauma

### Case 3-88: Diver broke golden rule and held breath to take photo

Diver was taking pictures at about 12 fsw (4 msw) depth with some ups and downs. During the actual shooting, he would hold his breath briefly. After the dive he noticed that his voice has changed and he felt tenderness on the right side of his neck. About three hours later he told me about it. I was able to feel crackling under the skin on his neck. Otherwise, he did not feel any difficulties or show any signs of disease. However, he mentioned that he had a similar episode last year (but did not go to see the physician).

He did not know the DAN emergency number and he did not have his DAN membership card. I lent him my phone and provided the DAN emergency line number (+1 919 684 9111). DAN advised him to go to a local emergency room because he needed a neurological exam and chest x-ray. He learned that DAN has a contract with the local hospital on this island and insured divers have nothing to pay out of pocket.

Next morning, I met the diver again. He went to the ER after 7 p.m. and was seen by a physician knowledgeable in diving medicine. He received a clinical neurological exam which revealed no abnormal findings. His chest x-ray was not conclusive and he was ordered to come later in the day for a CT (a sophisticated method of imaging by layers which provides more details). The CT revealed a small amount of gas in around the heart and large vessels in the chest. The doctor asked him to come tomorrow for another neuro exam and said that he should not fly for another two weeks.

## Miscellaneous Reports

### Case 3-65: Diver forgot to equalize his mask, suffered serious eye injury

My husband adjusted his own scuba mask prior to our dive and realized during the descent that it was too tight. The mask became tighter as he continued to descend until he wasn't able to break the seal to clear the water inside. The dive master attempted to help him but in retrospect we feel the damage was already done before he loosened the mask. He continued with the 20 minute dive at about 35 fsw (11 msw) and then ascended. When he removed his mask his eyes already had severe subconjunctival hemorrhaging and his skin was purple where the edges of his mask were. He also had a petechial rash below his eyes. His last but most important symptom was a headache to the back of his head. A neurologist stated he believes that his continued headache, which has never subsided and has on three occasions become so severe that he required an Emergency Room visit and felt near death, is a result of a slow cerebral spinal fluid leak from a tear in the meninges surrounding the optic nerve caused by trauma from the scuba mask. The neurologist states that it will heal in time (approximately six months) on its own.

*Editor's comment: A diving mask will get tighter and tighter on a diver's face during descent unless the diver equalizes it by exhaling through the nose. It doesn't take much to rupture a blood vessel in the eye, but these injuries usually look worse than they feel. In this case however, symptoms went beyond a little blood in the eye and the diver was prudent to seek medical advice.*

### Case 3-19: A hose exploded but diver handled the pressure

Our dive equipment received an annual service prior to our overseas dive trip. After a morning shore dive with no issues, went for an afternoon boat dive. The only people on the boat were the dive guide and boat captain from the dive operation, my husband and I (only the two of us had signed up for the afternoon boat dive.) Using air, my tank pressure prior to diving was 3,000 psi. My high pressure hose split lengthwise as I was descending from the boat, at around 50 fsw (15 msw) depth. The dive guide immediately came over to assist. No assistance needed, really. I relied on my training



and did not panic. I ascended slowly to the boat ladder, breathing normally through my regulator in spite of the torrent of bubbles coming from my split hose. Got back on board and saw I still had about 1,500 psi remaining in the tank.

The high pressure hose was 13 years old; perhaps I should have replaced it earlier, even with no apparent issues. But the morning dive the same day went absolutely fine, so there was really no way to tell ahead of time that the hose would fail. I was pleased to note that I didn't panic, that I realized immediately I could ascend safely, and did so. I was able to get the hose replaced that same afternoon and had no further issues the entire week.

*Editor's comment: This diver ascended in a controlled manner after a hose ruptured underwater. Low pressure hoses are known to empty a dive tank much quicker when they rupture than high pressure hoses, due to the small hole in the connection to the first stage.*

### Conclusion

The value of the DAN Diving Incident Reporting System grows each year. Once again it appears as though the majority of reported incidents occurred during the first day of diving, more often than not at an unfamiliar dive site, and the majority were reported by newly-trained divers. It must be remembered, however, that these reports were made voluntarily and therefore should not be thought of as a survey of random divers. Incidents that may seem more important to some divers would be more likely to be reported, even though they may not be the most common incidents in diving, and this may explain why the most commonly reported injury was decompression sickness when that is, in fact, much rarer than, for example, ear barotrauma.

Once again, reported equipment problems were largely divided between buoyancy and breathing gas, and these two issues are of obvious importance to divers. As the case vignettes illustrate, many (but not all) of these problems could have been avoided. The value of training is apparent both in the case of a diver reacting to a split high pressure hose and in the rescue of the unconscious diver. After the training is over, DAN recommends maintaining proficiency in the skills developed through regular practice. Rusty skills in a few reports such as mask clearing and weight-belt adjustment are also good learning points for divers to consider and DAN thanks all the divers who reported incidents in 2014.

## SECTION 4. BREATH-HOLD DIVE INCIDENTS

Neal W. Pollock, Niles W. Clarke, Payal S. Razdan

### 4.1 Introduction

Breath-hold diving is defined as in-water activity involving some diving equipment, but no self-contained or surface-supplied breathing gas. Breath-hold divers operate in a wide range of environments, pursue an assortment of goals, and wear various combinations and designs of suit, external weight, mask, snorkel, and/or fin(s).

Common breath-hold activities include snorkeling, spearfishing, collecting, and freediving. Snorkelers may remain completely on the surface with no purposeful breath-hold, or they may use breath-hold in typically limited surface diving efforts. Breath-hold spearfishing incorporates the act of underwater hunting for food into the breath-hold exercise. Collecting generally refers to underwater hunting without spear devices. Maximizing breath-hold time and/or depth is generally not the primary motivator for either spearfishing or collecting. The challenges of the hunt, however, can encourage divers to push their limits. Freedivers are explicitly employing breath-hold techniques, with or without descent from the surface. Increasing breath-hold time and/or dive depth are common goals. The nature of the dives will vary dramatically with the individual skill and training level of participants.

Competitive freediving continues to grow in popularity. Discovering a talent for breath-hold performance can rapidly catapult a competitor from novice to elite status. The field has developed rapidly as an extreme sport. The International Association for the Development of Apnea (AIDA; <http://www.aida-international.org>) recognizes numerous competitive disciplines. The organization tracks record performance and ensures compliance with accepted safety standards. The disciplines and current record performances are summarized in Table 4.1-1. These records are not shown to promote a focus on competition, only to demonstrate that breath-hold diving can involve an intensity quite different from the classic view of the activity.

Table 4.1-1 AIDA-Recognized Competitive Freediving Disciplines and Record Performance (current June 2016)

Discipline	Description	Record Performance	
		Male	Female
Static (min:s)	resting, immersed breath-hold in controlled water (usually a shallow swimming pool)	11:35	9:02
Dynamic - with fins (ft [m])	horizontal swim in controlled water	935 (285)	778 (237)
Dynamic Apnea - no fins (ft [m])	horizontal swim in controlled water	761 (232)	597 (182)
No-Limits (ft [m])	vertical descent to a maximum depth on a weighted sled; ascent with a lift bag deployed by the diver	702 (214)	525 (160)
Variable Weight/Ballast (ft [m])	vertical descent to a maximum depth on weighted sled; ascent by pulling up a line and/or kicking	479 (146)	427 (130)

Table 4.1-1 AIDA-Recognized Competitive Freediving Disciplines and Record Performance (current June 2016) (cont'd)

Discipline	Description	Record Performance	
		Male	Female
Constant Weight - with fins (ft [m])	vertical self-propelled swimming to a maximum depth and back to surface; no line assistance allowed	420 (128)	331 (101)
Constant Weight - no fins (ft [m])	vertical self-propelled swimming to a maximum depth and back to surface; no line assistance allowed	331 (101)	235 (72)
Free Immersion (ft [m])	vertical excursion propelled by pulling on the rope during descent and ascent; no fins	406 (124)	299 (91)

Extensive safety and disqualification protocols have kept the incident rate in competitive freediving low. The same level of safety does not always exist outside of organized events. The risk of injury or death is higher for breath-hold divers who do not have proper training or who fail to ensure the presence of adequate safety backups when pushing their limits. The minimal equipment requirements should not be equated to inherent safety, but they do mean that almost anyone can get in trouble if they are not informed of the hazards. Breath-hold divers are susceptible to the physiological stress of immersion, hypoxia, hypercapnia, and, if diving vertically, potentially immense squeeze forces. Loss of consciousness is the most obvious concern with breath-hold diving, but it is not the only risk.

Active collection of breath-hold incident case data on DAN's behalf began in 2005. The initial effort included a retrospective review of cases from 2004 (those reported to DAN or found through active Internet searches). Automated keyword searches were then established to capture new reports as soon as they appeared online. A database was developed to target information of primary interest. Details on the structure of the database can be found in the proceedings of the 2006 breath-hold workshop.<sup>1</sup> Unlike the data analyzed by DAN for compressed-gas diving accidents, the breath-hold incidents include cases without geographical restriction. Reviews of breath-hold incidents have been included in DAN annual diving reports since 2005. Electronic copies of these reports are available for download at no cost (<http://www.diversalernetnetwork.org/medical/report>).

The number of cases captured from 2004 through 2014 (mean±standard deviation) was 65±17 (range 30-83; Figure 4.1-1).

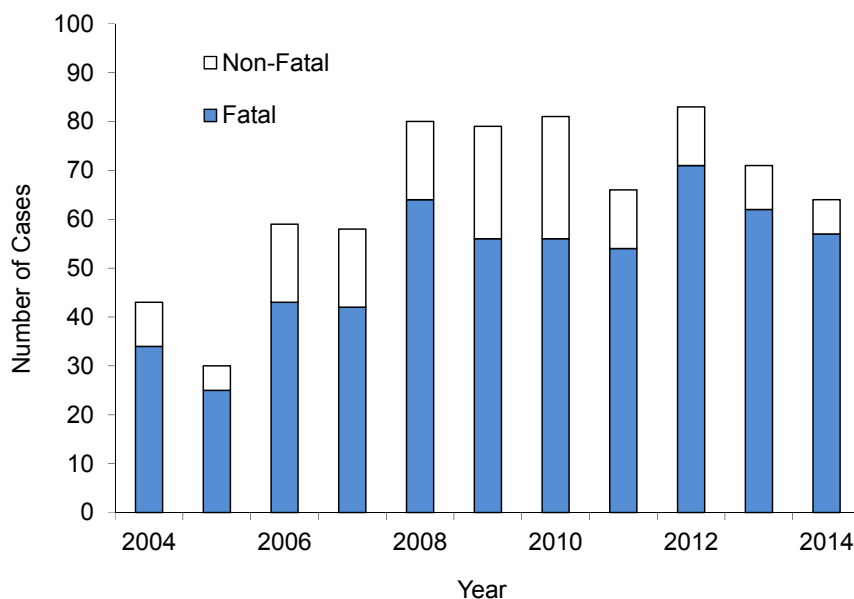


Figure 4.1-1 Breath-hold incident case capture, 2004-2014, fatal and non-fatal (n=714)

The purpose of incident data collection and analysis is not to assign blame but to learn from past events. Some accidents occur even when sound experience, planning, equipment, and support are in place. Such events serve as reminders of the fundamental risks and encourage us to evaluate our behaviors accordingly. Other accidents arise from flaws in equipment maintenance, equipment use, training, or procedures. Incident analysis and program review can reduce the future risk for all participants.

A fundamental challenge in the study of breath-hold incidents is incomplete information. The investigative effort can require a substantial amount of deductive reasoning and often some guesswork to interpret events. In this report, we summarize the available data and speculate when reasonable.

## 4.2 Cases in 2014

Most cases were initially identified through automated internet searches, typically as online news articles. Some cases were reported to DAN directly by individuals involved in or aware of particular incidents. Complete details were rarely available.

A total of 64 breath-hold cases were captured in 2014; 57 fatal (89%) and 7 non-fatal (11%). Incidents were reported from 14 different countries. Fifty-eight percent (n=37) occurred in the US, reported in three states: Hawaii (23 cases; 67%), Florida (9 cases; 24%), and California (5 cases; 14%). This pattern of distribution is similar to that seen in previous years and almost certainly reflects the popularity of water-related activities and possibly some reporting bias. It is highly unlikely that our fatal case capture reflects true total numbers. It is certain that some fatal events that could have involved breath-holding are not reported in such a way as to enter our database. This situation is even more marked for non-fatal cases. The non-fatal cases represent an anecdotal sample, useful for insight and illustration but should, in no way, be thought representative of the frequency of related events.

All of the incidents captured in 2014 occurred in the ocean. The primary activity described for the incident dive was most frequently snorkeling (n=43; 67%), collecting (n=10; 16%), spearfishing (n=6; 9%), and freediving (n=5; 8%). The utility of this categorization may be limited for fatal cases. The presence of specific equipment, for example, a speargun, or a history or communicated plan for an outing provides weight for categorical assignment, but specific actions or events contributing to an incident can easily confound categorical distinctions, as can reporter bias.

Figure 4.2-1 presents the sex and age breakdown for the 2014 cases. The majority of victims were male (n=54; 84%). The mean age ( $\pm$ standard deviation) was  $47 \pm 18$  years, ranging from 17 to 81 years.

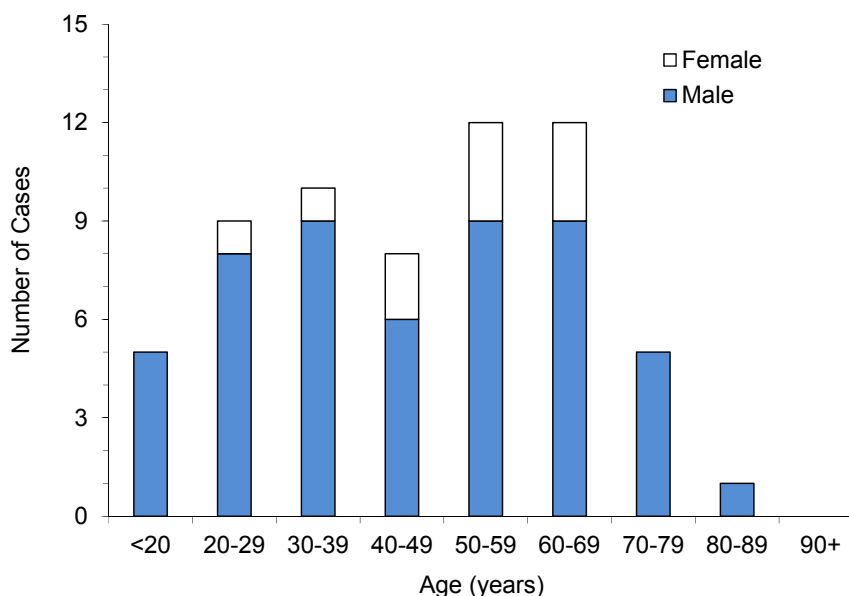


Figure 4.2-1: Age and sex distribution of breath-hold incident victims in 2014 (for 61 of 64 total)

Information regarding the support available to divers was captured in 59 (92%) of the cases. The most common patterns were diving with a group (n=26; 44% of known), solo diving (n=17; 29% of known), and diving with a partner (n=16; 27% of known). The effectiveness of oversight is difficult to evaluate in most cases, but the delay to recognize a developing problem is a factor common to many accidents. There is no chance of someone else being able to recognize problems and render aid when diving alone. Protection may be only somewhat improved by others remaining on shore. Close supervision and the capability to take immediate and appropriate action can resolve many potential problems before they become serious. This is typically best achieved by a partner or group standing by in the water providing close support.

Evaluating the effectiveness of the assistance provided to stricken victims can be difficult. Immediately bringing an otherwise healthy but unconscious breath-hold diver to the surface and then protecting the airway from water entry or further water entry can be highly effective in preserving life. A slower recovery would likely be less effective, but the determination of the impact of a delay is challenging, if for no other reason than, it is often not known exactly when the critical point in the development of the incident occurred. It should also be appreciated that even a quick response might not make a difference for a medically-compromised individual.

Close and informed support is likely to improve outcomes. The informed partner or monitor can ask questions to more fully appreciate and be prepared for risk. The lack of informed supervision may grow, for example, if efforts to ban breath-hold activity in swimming pools gain traction. It is easy for swimmers to hide such activities from lifeguards or other swimmers, leaving potential rescuers much less prepared if problems do occur. Rather than banning breath-hold, the prudent course would be to ensure that all swimmers, breath-hold divers, instructors, lifeguards, and responsible parties appreciate the risks and the reasonable limits of safe practice. Understanding factors playing a role in incidents is one of the best ways to improve preparedness.

### 4.3 Cause of Death or Injury and Contributing Factors

Cause of death is typically determined by medical examiners assigned to fatality cases. The usefulness of the findings can be limited, particularly if the cause of death is determined to be drowning. More important are the efforts to identify root causes, triggers that can initiate a cascade of events, factors contributing to the unchecked cascade, and/or specific disabling agents or injuries leading directly or indirectly to the outcome. The search for contributing factors is challenging, particularly in the case of unwitnessed events, because physical evidence is often not present or possibly confounding.

The factors that lead to the inevitability of an incident are difficult to determine, but certainly of great value in preventing future occurrences. The available data were reviewed to identify the primary disabling agents (Table 4.3-1). The effort was considered inappropriate for 13% of cases, some for which the body was not recovered, or those for which only minimal information was available.

Table 4.3-1 Primary disabling agent ascribed to 2014 breath-hold incidents

Disabling Agent	Count	Percentage
Medical health	27	48
Procedure/Behavior	11	20
Environmental conditions	7	13
Boat strike	4	7
Animal-involved injury	4	7
Poor physical fitness	3	5
<b>Total</b>	<b>56</b>	<b>100</b>

### Medical Health

Medical health issues appeared to be the most commonly identified disabling agent (n=27; 48%), particularly for older subjects. Many of these presented with reasonable to strong evidence of cardiac involvement; some were more ambiguous and could have involved cardiac issues or physical fitness issues. Not having complete autopsy results for some of these cases makes confirmation difficult. The associations between age, health, and diving fatalities have been described for divers.<sup>2</sup>

While water activities can be healthful, they do create a physiological strain that can be problematic for individuals with compromised health. Immersion in water, regardless of depth, prompts an increase in blood returning to the heart that causes it to contract harder. Inspiration pressures increase when in the water subject to hydrostatic pressure or to counteract the compressive force of a wetsuit. Breathing resistance and physiological deadspace are further increased by breathing through a snorkel. Wearing bulky equipment, and particularly a weight belt, can increase the strain of swimming, as can entry and exit requirements in rising sea state conditions. The initial exposure to immersion and any in-water activity is best done under benign conditions with easy entry and exit options and no pressure to continue should discomfort arise. It is not uncommon for vacationers to want to participate in 'once in a lifetime activities' that may expose them to more physiological stress than expected. Those who are medically or physically compromised can be at undue risk, a situation that may not be appreciated by them or by event organizers.

### Procedure/Behavior

Procedural or behavioral errors stand as the second most commonly identified class of disabling agent (n=11; 20%). This class has ranked highest in many years. The relative decline in this year could be a statistical anomaly, but it could also reflect a growing awareness of both risks and good practice within the community. A range of efforts have been developing over the past decade to provide safety-oriented certification training to breath-hold divers, for example, by Performance Freediving International (PFI) and Freediving Instructors International (FII), and to collect and share incident information and promote good practice, for example, our efforts at DAN and those of DiveWise.

Even if the protective messaging is reaching the community, continued efforts are required to further minimize this high risk, decision-based class of incidents. Cases in 2014 include ineffective buddy operations, unsupported or unmonitored activity, and excessive efforts to prolong breath-hold time. The issue of excessive effort is the most challenging to document since there is typically no physical evidence left behind. Combining inadequate support with excessive efforts to increase breath-hold time can increase risk. The lack of evidence makes it difficult to assess the breadth of the problem. It is likely that some of the cases for which a disabling agent could not be assigned with confidence belong in this category, but that is speculation. In any case, sustained efforts to educate both new and experienced breath-hold divers are required.

While the absolute number in the current data set may be difficult to confirm, it is likely that a substantial number of incidents were the consequence of intentional action. Outside of casual snorkeling, many breath-hold divers employ strategies to extend breath-hold time, most notably hyperventilation. This does increase breath-hold time, but by delaying or effectively deactivating the normal warning system that limits breath-hold. The absence of physical evidence associated with fatal events involving apparently young and physically fit individuals has led some to speculate on the possibility of relatively exotic conditions like long Q-T syndrome being contributing factors. While this is certainly possible, the much simpler and more likely explanation in most cases is that excessive hyperventilation was the underlying problem. The risk increases even higher if a diver chooses to employ such techniques when alone. For the purposes of rescue, a diver is effectively alone if his or her partner or partners are not providing close supervision throughout the breath-hold. Close supervision requires the ability to act in response to a problem, not simply to observe. A support team must be able to respond immediately wherever a diver may run into trouble.

There is no simple formula to differentiate between safe and unsafe (excessive) hyperventilation. Breath-hold divers must be sufficiently informed to appreciate the risk and then be encouraged to err on the side of safety. It is critical for all to realize that a loss of consciousness will typically develop without warning. Knowledge and thoughtful action are essential to carry out safe practice. Ignorance, or believing that the physiological hazards come with a warning, can encourage high mortal risk practices that are evident in our fatality case reports every year.



Each normal respiratory cycle is followed by a brief interruption of breathing (apnea) prior to the next inspiration-expiration cycle. The duration of the apnea is primarily controlled by the partial pressure of carbon dioxide in the arterial blood. The range is fairly narrow during relaxed, involuntary respiration, from a high of 45-46 mm Hg at the start of the respiratory cycle to a low of approximately 40 mm Hg at the end of the cycle. Voluntary breath-hold can allow the carbon dioxide partial pressure to climb well into the 50 mm Hg range or beyond depending in large part on motivation. Eventually, however, a breakpoint is reached when the urge to breathe is overwhelming. Many breath-hold divers learn that ventilating the lungs in excess of metabolic need, that is, hyperventilation, will flush carbon dioxide from the body and delay the point at which carbon dioxide accumulation reaches breakpoint during a subsequent breath-hold. The accumulation of oxygen stores associated during hyperventilation is trivial in comparison with the clearance of carbon dioxide since the normal concentration of carbon dioxide in the blood is 140-160 times the concentration found in the atmosphere. Without hyperventilation, there is a buffer in oxygen stores when the urge to breathe becomes intolerable. Any hyperventilation reduces carbon dioxide levels enough to erode the oxygen buffer. Limited hyperventilation will not erode the buffer enough to create a high risk of loss of consciousness, but it is a very fuzzy line beyond which excessive hyperventilation can delay the urge to breathe long enough for the oxygen partial pressure to fall below the level necessary to maintain consciousness. Again, as a crucial reminder, a loss of consciousness can develop before any urge to breathe is perceived. It is critical to understand that the loss of consciousness associated with hyperventilation-augmented breath-hold can occur with absolutely no warning. There is no aura, instinct, or innate superiority that will preserve consciousness; generally just luck. The problem with experiencing good luck is that it can reset a sense of acceptable or safe practice. Bad luck can just as easily follow good luck, with devastating outcomes.

Breath-hold physiology is more complicated when divers travel vertically through the water column. The increasing ambient pressure during descent increases the partial pressure of gases in the lungs and bloodstream. This effectively makes more oxygen available to the cells. While the partial pressure of carbon dioxide concentration is also increased by the ambient pressure increase, it will likely remain well below breakpoint in the first phase of the dive, particularly if hyperventilation was employed to lower it before the dive.

The most critical phase of a vertical breath-hold dive occurs during the final phase of surfacing, when the partial pressure of oxygen falls at a dramatic rate due to the combined effect of metabolic consumption and the decrease in ambient pressure. A state of acute hypoxia can develop rapidly, particularly in the shallowest water where the relative rate of pressure reduction is the greatest. The carbon dioxide partial pressure will not help in this phase since it is also decreased by the reduction in ambient pressure, potentially reducing the urge to breathe. Ultimately, the risk of hypoxia-induced loss of consciousness without warning is elevated. The classic presentation of this condition – hypoxia of ascent – is seen in a diver who loses consciousness just before or shortly after surfacing. Losing consciousness after surfacing and taking a breath is possible because it takes time for the newly inspired oxygen to reach the brain. Many will be familiar with the term 'shallow water blackout,' but this label is frequently misapplied to cases where the change in ambient pressure is not a factor. Further complicating the terminology is the fact that the term was originally used to describe a very different condition of high carbon dioxide levels associated with scrubber failure in closed-circuit oxygen rebreather divers. For these reasons 'hypoxia of ascent' is preferred.

The categorization of cases of blackout as hypoxic loss of consciousness (HLOC) or, more specifically, as hypoxia of ascent is generally dependent on witness observations or the presence of a dive computer that logs information at a fast sample rate. Confirming where the loss of consciousness developed is frequently not possible in unwitnessed events. A victim found on the bottom could have lost consciousness there, but it is also possible that consciousness was lost near the surface and was followed by a loss of airway gas (and the positive buoyancy it provides) that ultimately caused the victim to sink to the bottom.

Hyperventilation-induced blackout is probably the greatest single life threat in breath-hold diving. The cases identified almost certainly represent a marked underestimate of the problem even within our sample. At least some of the unwitnessed fatal cases likely involved hyperventilation-induced loss of consciousness, but this cannot be confirmed even with autopsy because there is no specific physical evidence left to be discovered. Most cases that are resolved without serious outcome are unlikely to be reported.

It is very common for a diver rescued from blackout to wake within seconds and have no memory of the event. Some may initially argue that they did not blackout until they realize that they came to their senses in surroundings different from last recall. Those who experience these events firsthand (as victim or rescuer) realize how close anyone can be to loss of consciousness in a very unforgiving environment. Regardless of what some want to believe, neither training nor experience produce a warning mechanism to avoid blackout, hopefully just the insult to stay comfortably within personal limits and to have adequate backup. The effect of hyperventilation to increase breath-hold diving risk was described in the medical literature more than 50 years ago<sup>3,4</sup> and we are still losing divers to aggressive practice. Limiting hyperventilation to no more than the equivalent of two full ventilatory exchanges will increase breath-hold time but will likely not remove so much carbon dioxide that the urge to breathe will be delayed long enough for consciousness to be threatened. Hyperventilation in excess of this limit will produce an escalating risk of suppressing the vital drive to breathe.

### **Environmental Conditions and Physical Fitness**

Environmental conditions were identified as the primary disabling agent in 7 cases (13%), and poor physical fitness in 3 cases (5%). The incidents for both typically involving rough water conditions or strong currents. It is likely that the interaction of demanding conditions and inadequate physical capacity was critical to the outcome in at least some of these cases. Physical fitness is rarely well documented, but can play a huge role in determining an individual's tolerance for adverse conditions. High levels of physical fitness create a reserve capacity that can be called upon whenever needed. Addressing emergent needs quickly and without pushing physical limits can stop the cascade of events that can otherwise lead to poor outcomes. Similarly, individuals who recognize that they may have limited physical capabilities should choose, or be encouraged to choose, to participate in water activities only under increasingly benign conditions. It is important for those with higher levels of physical fitness to appreciate that their capabilities may not be matched by others. Conditions reasonable for them could be very stressful for others.

### **Boat Strikes**

There were 4 cases (7%) involving boat strikes. The physical trauma, typically involving propellers, can be devastating. It is possible that boat strikes are overrepresented in the database due to the presence of physical evidence and media attention. It is also possible that careful consideration of the area of operation, use of dive flags and high visibility personal equipment could improve surface safety.

### **Animal-Involved Injury**

There were 4 cases (7%) of animal-involved injury. These typically involved sharks, but one event involved a killer whale. In each of the captured cases the diver was carrying speared fish. The animal-involved category is a class of incident most likely to be overrepresented in our database, given the potential for physical evidence of the altercation and the substantial media attention. At the same time, it is certain that many minor animal-involved injuries will not be reported.

A cross-section of illustrative case studies is found in Appendix A.

## **4.4 Reducing Breath-Hold Risks**

Breath-hold diving includes a wide range of activities. Some are appropriately described as extreme; others as relatively benign. The margin of safety can be quite wide for casual, surface, or near surface activity for healthy individuals. At the same time, the margin of safety can become almost non-existent for extreme diving. In all in-water activity, appropriate safety precautions and backups are essential. The safety procedures employed in competitive freediving are usually effective. Shifting away from the tight controls of the competitive field or from the medically healthy, physically fit, and well-trained participant can increase the risk.

The medical and physical fitness of individuals must be considered prior to participation in any diving activity. Those with significant medical issues should be evaluated in advance, and may well be discouraged from participation. Those close to the low physical fitness end of qualification should participate only under the most benign conditions. An orientation in a shallow pool or confined water is much more appropriate than being dropped off the back of a boat in deep water with the possibility of current, wave, or weighting challenges. Implementing an orientation step for persons of possible concern might encourage some to appropriately reconsider participation and others to participate with more comfort and confidence.



The blackout hazard associated with pre-breath-hold hyperventilation stands out as the greatest risk to generally healthy individuals participating in breath-hold activity. Efforts to discourage hyperventilation face powerful resistance because it is so effective at increasing breath-hold time. The risk of loss of consciousness without warning may be difficult for the enthusiast to appreciate. Competitive freedivers increasingly acknowledge the risk of blackout in association with hyperventilation-augmented dives. They protect themselves, however, by limiting hyperventilation and ensuring close support throughout and following every dive.

The greatest risk is to divers without extensive backup support, whether these are unmonitored novices who have discovered hyperventilation or experienced spearfishermen determined to not let a fish get away. Safety-oriented education and rational guidelines are required for both groups to keep them safe. Buddy-diving in a one-up, one-down manner in good visibility water shallow enough for all divers to get to the bottom easily can take the novice safely through the relatively high-risk phase of learning. A group of three (one-down, two-up) may be preferable as dive depths begin to increase. It is a typical rule of thumb to allow a recovery period of at least twice the dive duration for modest dives, progressively longer for deeper dives. A group of three or four, diving in series, facilitates this schedule and ensures that one or more of the divers available at the surface for backup is at least partially rested. This is important since it is highly unlikely that optimal performance will be achieved during the stress of a rescue. Establishing safe habits in the beginning can help keep safe habits in place. Safety protocols become more complicated as dive depths are increased, potentially involving counterbalance systems or mixed-gas diver support, but a commitment to safety can keep personal and group practices evolving appropriately.

Freedivers should be defensively weighted, neutrally buoyant with empty lungs at 30 ft (9 m) or deeper, to ensure that if they have problems at or near the surface they are more likely to remain at the surface where they can be found and assisted more quickly and easily. Overweighting can cause a diver to sink; especially if gas is expelled from the airway during ascent. Momentum established during ascent can carry the diver to the surface even if consciousness is lost. Adequate support requires an appropriate network. Close support protocols that have divers shadowed during the final portion of their ascent and the first 30 seconds of the post-dive period can address the majority of issues. The risk of loss of consciousness continues post-breath-hold until the oxygen in an inspired breath reaches the brain to counter hypoxia. The critical first aid when a victim is reached immediately after losing consciousness is to quickly get and hold the airway clear of the water. If the airway is protected, then consciousness is often quickly restored with no sequelae.

Another technique that creates some risk for breath-hold divers is lung packing. It is used to increase the volume of gas in the lungs above normal total lung capacity immediately prior to commencing breath-hold. While it can assist the diver, it also increases the risk of pulmonary barotrauma.<sup>5</sup> The hazards of all techniques must be appreciated as well as the benefits. Each should be used thoughtfully and with caution foremost.

The solo freediver takes on much greater risk in all respects. The major price of independence is the loss of support in the moments upon which a life can turn. A sense of self-confidence, if not invincibility, often stands in the way of smart decision-making. The idea that blackout can occur without warning - while true - is a direct challenge to this self-perception.

There are a couple of ways to strike a compromise. The simplest is to carefully restrict pre-dive hyperventilation. Two or three deep inspiratory-expiratory exchanges prior to breath-hold will still reduce the carbon dioxide levels in the blood and increase breath-hold time, but without creating the high risk of hypoxia-induced blackout associated with more hyperventilation. The alternative is to hyperventilate freely, but then limit dive time. Butler reviewed published data and concluded that limiting breath-hold time to 60 seconds could accommodate varying patterns of hyperventilation and physical activity with minimal risk of loss of consciousness.<sup>6</sup> While the time limitation is too restrictive for some, it may be a good alternative for those making safety the top priority.

A freediver recovery vest is also now available for breath-hold diving that will automatically inflate after a user preset time at depth, or maximum depth, or if another descent immediately follows surfacing. While such a device would not eliminate the risk of blackout or guarantee survival, it may improve the odds of survival by returning the diver unencumbered by overhead environment or entanglement to the surface.

Breath-hold divers spend a lot of time on the surface. To reduce the risk of undesirable boat interactions, they should avoid boat traffic areas whenever possible and clearly mark their dive site with high visibility floats, flags and other locally-recognized markers. In addition, they should wear high visibility colors to mark themselves. The predominance of equipment in dark colors or, more recently, camouflage patterns, runs contrary to visual safety practices. The safest choice is high visibility throughout - suit, hood, snorkel, gloves, fins, and whatever else might break the surface. Underwater hunters may argue for the benefits of reducing their visibility underwater. If low visibility equipment is worn, the camouflaged divers have to rely more on the surface floats, support boats, and tenders to warn surface traffic of their presence.

All divers need to be aware of the hazards they face and strategies that can reduce their risk. Receiving initial training by qualified persons makes the transition into any activity smoother and safer. Ongoing education, which includes learning from the mistakes of others, is important to ensure that the risk of participation remains low. Further background can be found in a separate review.<sup>7</sup> As a final note, it must be remembered that problems not unrelated to diving can develop during periods of diving activity. Appropriate and timely medical evaluation is at least prudent, but may also be critical for a good outcome.

#### **4.5 Ongoing Research**

The greatest challenge in studying fatal events is that complete details are rarely available. DAN has established an online reporting system to expand the collection of cases, particularly non-fatal events for which more complete details may be available. It is expected that the additional insights will be extremely helpful in identifying additional factors contributing to incidents. Visit the site at: <http://DAN.org/IncidentReport>. Continued effort is required to promote awareness among breath-hold enthusiasts and community leaders.

#### **4.6 Conclusion**

A total of 64 breath-hold diving incidents were collected by DAN in 2014; 57 fatal (89%) and 7 non-fatal (11%). The victims were most often male (84%). The most commonly identified disabling agents were medical health, procedural, or behavioral errors (often involving support systems and likely facilitated by excessive hyperventilation), extreme environmental conditions, inadequate physical fitness and animal-involved or boat-involved interactions, respectively. Improving the appreciation of hazards may offer the greatest defense against future adverse events. Sharing incident information is an important part of that process. Our efforts will continue to expand case collection, both fatal and non-fatal, and to provide insights for the community.

## 4.7 References

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## APPENDIX A. BREATH-HOLD INCIDENT CASE REPORTS

Neal W. Pollock

The following are provided as examples of cases represented in the breath-hold incident database. They are categorized under the factor deemed to be most important. It is common for multiple factors to play a role in individual events.

### Medical Health and Environment

#### **Case A-713: An outgoing current took snorkeler away from the shore**

This 61-year-old male was snorkeling from shore in front of a beach resort when an outgoing current took him away from the beach. He tried unsuccessfully to swim against it, stopping when he developed breathing difficulties. He held on to a buoy until a kayaker reached him, and then held on to the kayak while he was towed back to shore. He collapsed and lost consciousness shortly after reaching the beach. Cardiopulmonary resuscitation (CPR) efforts were unsuccessful.

Both environmental conditions and medical health likely played critical roles in this case. It is generally not well appreciated that even benign water conditions impart a significant physiological load. Immersion in water causes a shift in blood from the periphery to the central circulation, putting an additional burden on the heart as it pumps harder to manage the increased volume. Breathing through a snorkel increases breathing resistance and adds ventilatory deadspace, further increasing the physiological workload. These stressors can be well tolerated under benign conditions when the person is relaxed, but the added strain of trying to fight a current, particularly if the snorkeler is not skilled, and the anxiety of the situation can increase the physiological burden to intolerable levels.

#### **Case A-728: A snorkeler swept away by a current**

This 65-year-old female tourist was snorkeling from shore with two others in tropical waters when a current carried them offshore. Lifeguards responded on rescue boards to the signaling by her companions to find the victim unresponsive. CPR efforts were unsuccessful.

See comments in case above.

#### **Case A-714: Friends assisted snorkeler back to shore**

This 64-year-old male was snorkeling from shore with a group of friends in relatively calm, tropical conditions. He developed troubles and the group turned back to shore. He then lost consciousness, at which time he was towed to shore by his friends and others from the beach. CPR efforts were unsuccessful.

Similar to the two cases above, both medical health and environmental exposure likely played a role. In this case, the environmental stress was more modest, making medical health issues the primary agent. It is important for those wanting to spend time in the water to appreciate that it does impart some stressors not experienced in daily life. Regular participation in physical fitness and aquatic activities helps to ensure that the positive benefits outweigh the hazards.

**Case A-716: A snorkeler was found unresponsive**

This 81-year-old male vacationer was snorkeling in front of a rocky shoreline when he was noticed to be unresponsive in a face down position. He was assisted out of the water where he remained unconscious but breathing on his own. He died later that day while in the local hospital.

**Case A-718: An elderly snorkeler lost consciousness after ten minutes**

This 78-year-old male was vacationing in the tropics when he went snorkeling on a commercial day boat with a friend. The conditions were considered benign. The victim lost consciousness after approximately 10 minutes in the water. He was lifted out of the water onto the boat and cardiopulmonary resuscitation efforts initiated. He regained consciousness, but only transiently. CPR was continued during transport to the local hospital where he died.

**Case A-724: Lifeguards noticed an unresponsive snorkeler**

This 63-year-old male tourist was snorkeling from shore at a popular site when lifeguards noticed him unresponsive on the surface 50-65 ft (15-20 m) off shore. He was brought up the beach and CPR was initiated. He was transported to the local hospital where he died several days later.

**Case A-740: Breathing difficulties led to loss of consciousness**

This 42-year-old female was snorkeling with a partner from the beach at a popular tropical tourist site. The conditions were benign. She began to experience breathing difficulties and lost consciousness while approximately 150 ft (50 m) off shore. Rescuers recovered her to the beach. CPR was initially successful, but she died later in the local hospital, with a stated cause of death by drowning.

## Procedural Problems

**Case A-707: An accomplished spearfisherman failed to surface**

This 35-year-old male was an apparently healthy, physically fit, accomplished spearfisherman, diving with a group from a private boat anchored offshore. The surface waters were calm with some current running. The diver was wearing a wetsuit and 13 lb (6 kg) weight belt. The diving was conducted in a loosely organized manner over a multi-hour period. Concerns were raised some time after the diver failed to surface from his final dive. The initial search was unsuccessful. The victim's body with weight belt intact was found several days later. There was no evidence of entanglement or animal involvement reported to explain the events.

The unwitnessed nature of the events makes any interpretation speculative, but some speculation is reasonable. It is very easy for good conditions and individual comfort to lead to a relaxation of good practice. The risk is that problems that can be, often easily, corrected by a partner or partners will carry a much higher life threat for the solo diver. The lack of close support is certainly a critical shortcoming in this case. While it is possible that a medical issue incapacitated the diver, it is more likely that the problem was brought on by blackout. It is not known if, or to what degree, the diver hyperventilated prior to his breath-hold dive, but this certainly is a common practice to extend breath-hold time by reducing the levels of carbon dioxide in the blood at the start of the breath-hold. Extreme hyperventilation could have resulted in a loss of consciousness at the bottom, but it is more likely to have occurred during the final stage of ascent, when the drop of partial pressure of oxygen through metabolic effort is augmented by a rapid fall in ambient pressure. This hypoxia of ascent (HOA; also commonly known as shallow water blackout) is suspected in many cases with no clear alternative explanation. The dynamic nature of spearfishing can increase the metabolic demands for oxygen on a given dive. The current reported to be present around the time of the incident could further increase the demands of the dive. Hyperventilation works by cutting into the physiological safety buffer between the urge to breathe and the point at which consciousness is lost. Hyperventilation between the recommended maximum (the equivalent of two or three maximal ventilatory exchanges [or vital capacity exchanges]) could have put the diver at increased risk during a dive with dynamic conditions. The diver's weight belt may have also played a role in the events. The amount of ballast lead worn was likely ample, if not excessive, for the buoyancy of the suit worn. If HOA occurred in this case, as is most likely, any excess weight would have slowed the final ascent, making it more difficult for the diver to reach the surface and easier for him to sink more quickly once consciousness was lost. Defensive weighting calls for divers to be neutrally buoyant at a depth proportional to the dive depth, but typically no shallower than approximately 30 ft (9 m), to make it easier for an impaired diver to reach the surface and to be rescued if support personnel were available on the surface.

**Case A-745: A teenager's friends recovered him but CPR was unsuccessful**

This 17-year-old male was freediving with a group from a boat anchored offshore. His companions began to look for him when he did not surface when expected after his final dive. They found him and were able to bring him to the surface. CPR efforts were unsuccessful. He was pronounced dead at the local hospital.

The unwitnessed events again make interpretation speculative. Hypoxic blackout, probably during ascent, is the most likely explanation. It is possible that exertion at the bottom could prompt loss of consciousness if excessive pre-dive hyperventilation was employed, but it is more likely that blackout occurred during ascent, when oxygen levels fall rapidly through the combined effects of metabolic use and decreasing ambient pressure. This can occur after much more limited pre-dive hyperventilation. If the diver was not positively buoyant when consciousness was lost then he would sink to the bottom. Maintaining close visual contact could have helped recognize the problem sooner if loss of consciousness did occur in the ascent, particularly late in the ascent. Faster recognition can reduce the time required to get a victim to the surface. Survivability is much greater if the airway is quickly clear of water.

**Case A-748: Drowning was preceded by hyperventilation**

This 27-year-old male was known to be practicing hyperventilation techniques to increase his breath-hold time for spearfishing. He was doing so in 7 ft (2 m) of water, presumably believing this to be safe strategy. He lost consciousness and was not brought to the surface before drowning.

If a diver hyperventilates (ventilates the lungs in excess of metabolic need) aggressively enough then carbon dioxide levels can be depressed so far that they do not achieve a level triggering an urge to breathe before the oxygen content falls while the diver remains on the bottom. This is best described as hyperventilation-induced hypoxic blackout. The fall in oxygen levels associated with ascent is not required for blackout in such cases. With less extreme hyperventilation, ascent from the bottom, typically from deeper depths, increases the risk of blackout as the partial pressure of oxygen in the blood falls faster as the ambient (surrounding) pressure is being reduced. The combination of pre-dive hyperventilation and substantial vertical travel through the water column can lead to hypoxia of ascent, also commonly known as shallow water blackout. The distinction may seem academic, but it is important to appreciate how the impact of different behaviors can compound the final risk. A modest amount of hyperventilation would be unlikely to cause loss of consciousness in a breath-hold diver not descending beyond very shallow water. The same amount of hyperventilation would result in a greater risk with significant vertical excursions. The risks must be appreciated and appropriate caution applied. It is generally held that hyperventilation limited to no more than the equivalent of two or three maximal ventilatory exchanges will produce a low risk of loss of consciousness under normal diving circumstances. As conditions become more extreme, either in terms of the diving activity or the absence of close support by a partner or partners, any use of hyperventilation should be increasingly conservative. A capable support diver watching closely should be able to bring a diver to the surface quickly from shallow water to protect the airway from exposure to water, thus reducing the life threat even if consciousness is lost. Employing techniques to increase breath-hold time without adequate support creates a critical and unnecessary risk to life.

**Environmental Conditions****Case A-742: An abalone diver swept along rocks**

This 44-year-old male entered the water as part of a group intending to use breath-hold diving to collect abalone. The waters were temperate, the coastline rock, and the surf conditions high. The victim could not hold onto the rocks as the others did, and was battered and swept along the rocks. His partners attempted to aid him, but were overcome by the ocean conditions. They swam away to protect themselves and called for help. The victim's body was recovered two days later.

Incidents involving seafood harvesters are common, particularly during short open seasons. The time pressure can increase the risk to participants, encouraging them to exceed their capabilities. The risk is increased if participants do not maintain their skills and physical fitness outside of the season. Efforts should be made to ensure physical readiness in advance of the opening. Rough conditions create additional hazards, making it unsafe to be in the water. If caught in worsening conditions, a rapid exit is generally best, avoiding rough terrain, if possible.



### **Case A-743: An unexpected squall proved deadly**

This 50-year-old male was on a commercial combined diving and snorkeling tour. While on site, a short-lived squall reportedly brought in 40-60 mph winds and 8-12 ft (3-4 m) breaking waves. The snorkelers in the water were pushed towards an adjacent rocky area. This victim suffered from extreme physical trauma. He was recovered unconscious from the water. CPR efforts were unsuccessful.

Rough sea states can be troublesome for divers, particularly when they are on the surface and trying to get back on a vessel. Prudence should dictate when water activities are cancelled. If rough conditions develop while in the water, and exit to shore or boat is feasible, it should be done as quickly as possible to avoid potentially worsening conditions. If exit options appear to have high risk and the impression is that the conditions are likely to be transient, rough conditions may be well managed in the water if stable, positive buoyancy can be maintained. In this case, holding a safe distance from structures that could create trauma is warranted.

## **Boat Strikes**

### **Case A-736: A passing boat struck two snorkelers**

This 26-year-old male was snorkeling with a partner from a personal boat with others onboard. A passing boat struck both; this victim died in hospital from the wounds suffered. His partner had only minor injuries.

Breath-hold divers spend more time on the surface than compressed gas divers do. Safety from boat traffic must be considered in activity planning. Flying appropriate and recognized dive flags, staying close to marked and staffed safety platforms, avoiding all but low traffic areas, wearing high visibility equipment, watchfulness, and public education are all important elements to promote safety. Boat operators are generally responsible and do not set out to injure others, but the onus remains on the surface swimmer to protect his or her own safety.

### **Case A-752: Lone diver struck by passing boat**

This 63-year-old male was spearfishing and collecting lobster using breath-hold techniques. He had been dropped off by a boat operated by his partner who proceeded to another location to scuba dive for lobster. The victim had a dive flag attached to a tire truck inner tube that housed his cooler. He was tethered to the inner tube by a 75 ft (23 m) line. He had completed multiple dives, collecting several lobster and fish in the process. After surfacing from one of his dives, the diver saw an approximately 35 ft (11 m) boat rapidly approaching. He immediately dived down, and the boat's engines struck one foot and ankle. The boat did not stop. The diver waited in the water for approximately one hour before his partner returned. The tight garment worn over the foot and ankle had helped to control the bleeding. He was taken to a local clinic for treatment.

Even with a float and dive flag, a solo diver operating far away from shore will be unexpected, and more easily missed than when diving from a larger vessel. Inattentive boat operators may fail to see floats, or may be cavalier, expecting compressed gas divers that are less likely to be on the surface. Steps taken to maximize surface visibility and ready support are important to reduce risk and manage incidents.

## **Animal-Involved Injury**

### **Case A-715: An Orca stole this diver's catch**

This 23-year-old male entered the water from shore with a partner to collect invertebrate seafood. After some time in the water the pair later noticed a pod of killer whales (*Orcinus orca*) swimming approximately 100 ft (300 m) away and decided to swim into shore. Before making much headway, an orca grabbed a catch bag attached to one diver's arm and towed him underwater for an estimated 40 seconds. The line connecting the diver to the bag separated just as the diver felt he was about to lose consciousness. His arm was numb, but he was able to release his weight belt and ascend to the surface. His partner then assisted him to shore. He was medically cleared the next day.

Animals can be attracted to divers out of curiosity or out of interest in the prey they may have with them. It is generally best to keep catch on a line separate from the diver and to be ready to abandon it if predators give it too much attention. The speed, power, and mobility of most aquatic predators is sufficient to put divers at a marked disadvantage.



**Case A-747: Spearfisherman bitten on calf muscle by a shark**

This 40-year-old male was spearfishing from a private vessel. He was swimming on the surface in approximately 5 ft (2 m) toward the boat carrying a fish he had speared when a shark bit one of his calves. A companion jumped into the water to get between the diver and the shark. The diver was assisted onto the boat and a makeshift tourniquet applied to stem the bleeding. Calls for help were quickly answered and the victim evacuated to local hospital.

The risk of shark-human conflict increases when catch is carried by or near a diver, even in shallow waters, and especially in low visibility conditions. Advanced planning on how to manage trauma is useful for divers, including specialized and surface-based devices as well as materials normally at hand.

**Case A-765: Spearfisherman bitten on thigh muscle by a shark**

This 18-year-old male was spearfishing from a private vessel moored at an offshore reef when he was bitten on the thigh by a shark. He was pulled from the water onto the boat by companions. The blood loss was severe. Efforts at CPR were unsuccessful.

See comments in cases above.

## APPENDIX B. DIVING FATALITY REPORTING IN THE ASIA-PACIFIC

John Lippmann

The Divers Alert Network Asia-Pacific (DAN AP) is a not-for-profit diving safety association based in Melbourne, Australia. DAN AP's mission is to improve the safety of recreational diving activities throughout the Asia-Pacific region (except in Japan which is under the oversight of DAN Japan).

### Australian fatalities

In Australia, the publication of diving fatality reports formally began with Bayliss<sup>1</sup> in 1969 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<sup>2</sup>, who compiled data on and reported snorkeling and compressed-air diving fatalities from 1972 to 2003. Walker's annual reports have been published in the successive journals of the South Pacific Underwater Medicine Society (SPUMS). Since 2003, John Lippmann, on behalf of DAN AP, assumed responsibility for Australian dive mortality surveillance. The subsequent fatality reports have continued to be published in *Diving and Hyperbaric Medicine*.<sup>3</sup>

Initial accident data are collected by on-scene investigators such as the police and/or workplace, health and safety officers. Autopsies are routinely conducted in diving fatalities in Australia except in rare cases where there is no familial consent or if the victim's body had not been found. This information, together with witness statements, is reviewed by respective coroners and a coroner's report is produced, with or without an inquest, as determined by the individual coroner.

The information sought and recorded include:

- Demographic and temporal data
- Medical history
- Diver training
- Diving or snorkeling experience
- Equipment used and problems found on examination
- Environmental conditions
- Autopsy report, including histology and toxicology

The Australian National Coronial Information System (NCIS) was launched in 2000 and includes all deaths reported to a State or Territory coroner since that time. 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 the State and Territory Coroners who often provide (under relevant ethics approvals) complete case files. These files generally include the full police reports, witness statements and often medical and diving histories and an equipment report. Key information from these is recorded in the DAN AP database.

Divers Alert Network Asia-Pacific (DAN AP) has constructed a database of all reported dive-related deaths in Australia since 1965.

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.

Figures 1 and 2 below show scuba related deaths in Australia and New Zealand up to 2013.

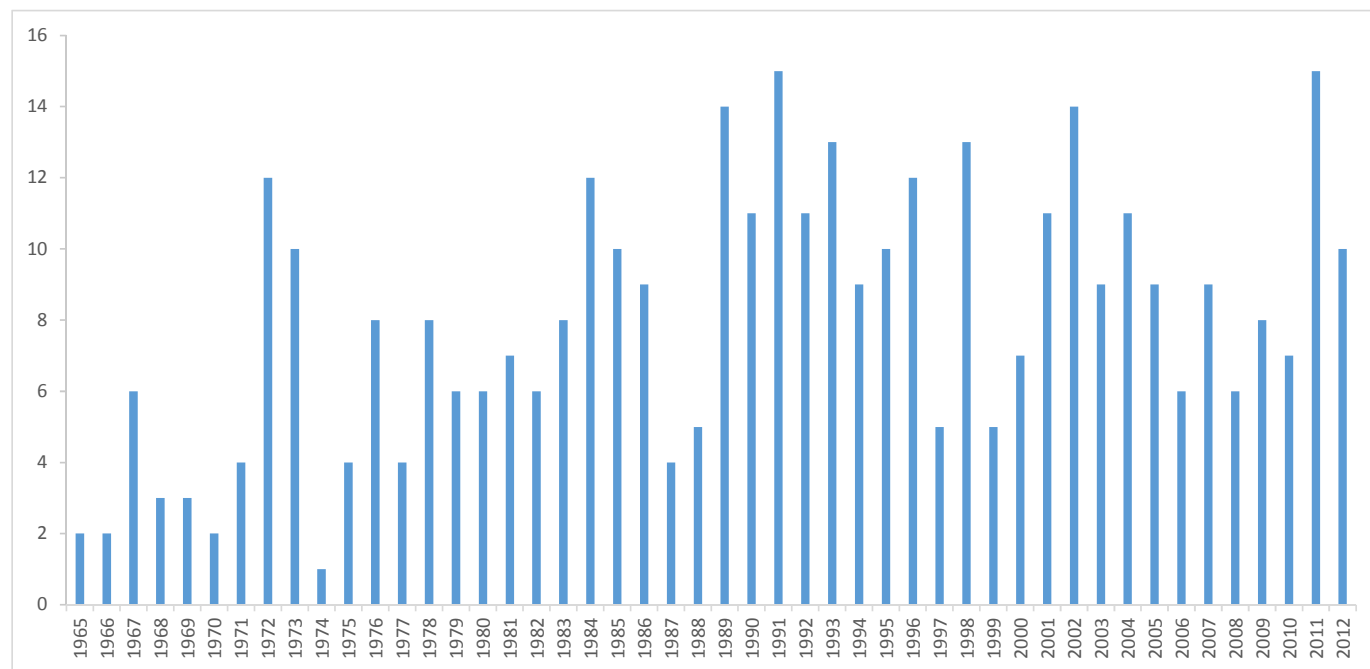


Figure 1 Recorded scuba diving fatalities in Australia from 1972-2013

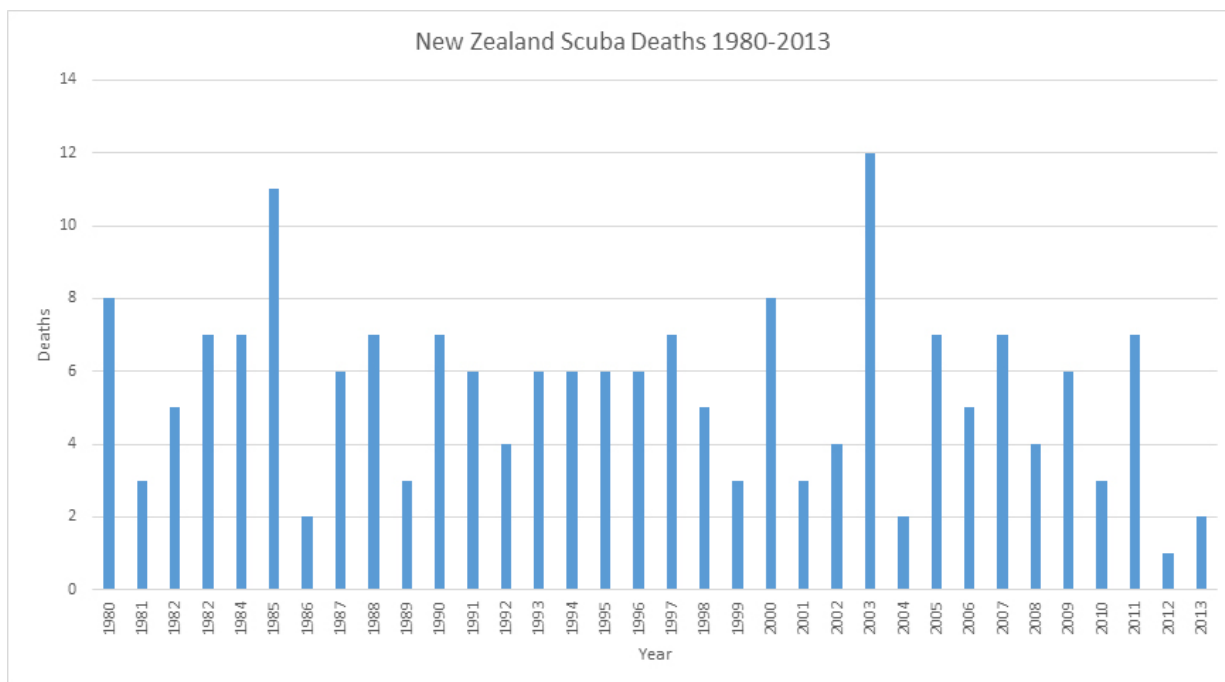


Figure 2 Recorded scuba-related deaths in New Zealand from 1980-2013

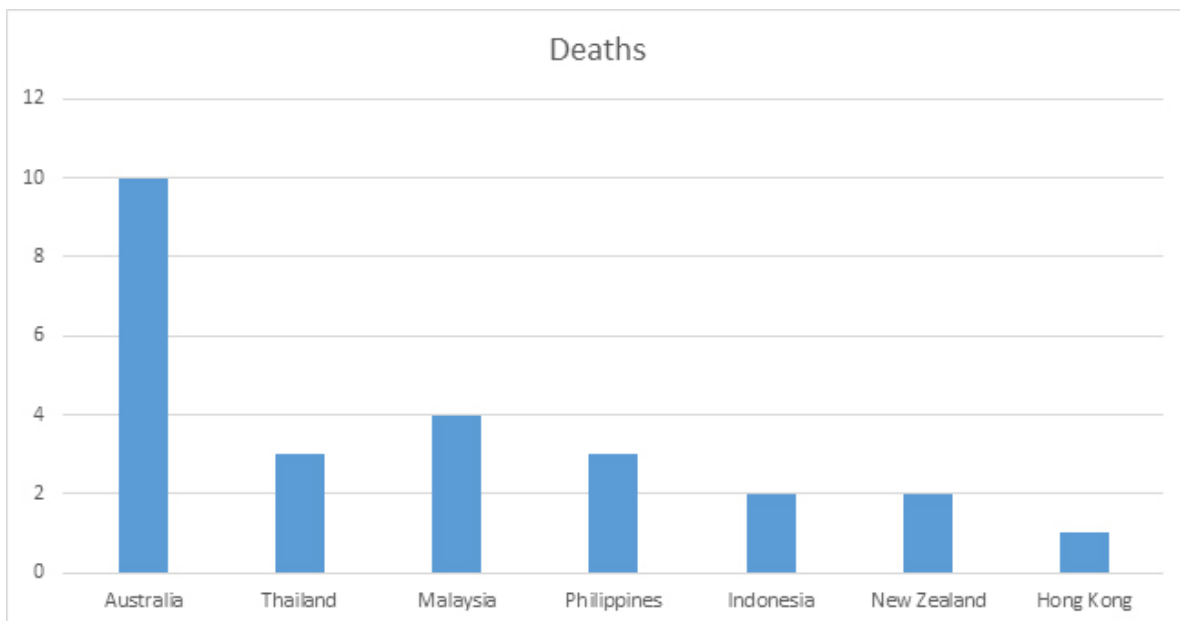


Figure 3 Scuba-related deaths of which DAN AP is aware of for the Asia-Pacific (excluding Japan) for 2013

Figure 3 shows scuba related deaths in the Asia-Pacific region that DAN AP is aware of. However, it is very likely that there were significantly more deaths in some countries that went unreported.

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## APPENDIX C. UK DIVING INCIDENTS - BRITISH SUB-AQUA CLUB

Brian Cumming

### The nature of diving in the UK

The 17,000 km coastline of the United Kingdom (UK) is highly diverse with over 1,000 islands that provide a wide range of habitats for divers to explore including wrecks, caves, reefs, walls, piers, kelp forests and inland rivers and lakes.

The nautical history of the UK, the busy shipping lanes, and many shipping casualties from two World Wars, in which the UK was heavily involved, has provided over 44,000 shipwrecks distributed around the coastline, a significant proportion of which are visited by UK divers.

Diving in the UK is available at all recreational depths (0-100 msw/328 fsw) and there is a significant body of technical divers who explore wrecks in the mixed gas range.

Water temperatures seasonally range from 5°C (41°F) in winter to 18°C (64°F) in summer in the south of the islands and 4°C (39°F) in winter to 13°C (55°F) in summer in the north.

The majority of divers in the UK use a neoprene or membrane drysuit with an additional layer of thermal insulation underneath.

The underwater visibility varies between 0 and 30 msw (98 fsw) depending on the seasonal growth of plankton that occurs during the spring and autumn seasons and the sediment load from estuaries and sediment churn during frequent windy periods.

The prevalent weather conditions in the UK mean that the surface conditions are frequently unsuitable for diving in the open sea, especially in winter. Consequently, diving in the UK is seasonal with the majority of diving taking place in the sea from April to October because conditions in the summer are generally warmer and the sea conditions are more often favorable. Some divers make use of inland sites or sheltered sea lochs to maintain diving throughout the winter months.

Tidal ranges vary between 4 and 10 meters (13 - 33 feet) and the nature of the topography means that at some sites tidal streams constrain diving to slack water only. On the other hand, divers in the UK frequently enjoy the benefits of tidal streams to facilitate exciting drift dives that can carry divers over very long distances in the course of a dive.

It has been estimated that somewhere in excess of two million person/dives are conducted annually in the UK although there is some evidence to suggest that that number has reduced in recent years.

Surveys indicate that 78% of UK divers are male and 22% are female.

It is worth noting that the average age of UK divers has been steadily increasing in recent years. The following chart illustrates the nature of that change. A key observation is the number of divers in the 'over 50' age group. At the turn of the century approximately 10% of UK divers were over 50; that number has now tripled and, as the chart shows, around 30% of our divers are now over 50. Possible explanations for this include the fact that the general UK population is aging, costs may inhibit younger divers and, with cheap travel, new divers can easily satisfy their diving aspirations in warmer climates. This increasing age profile appears to be reflected in an increased representation of 'older divers' in fatal incidents; this is an area that needs more research.

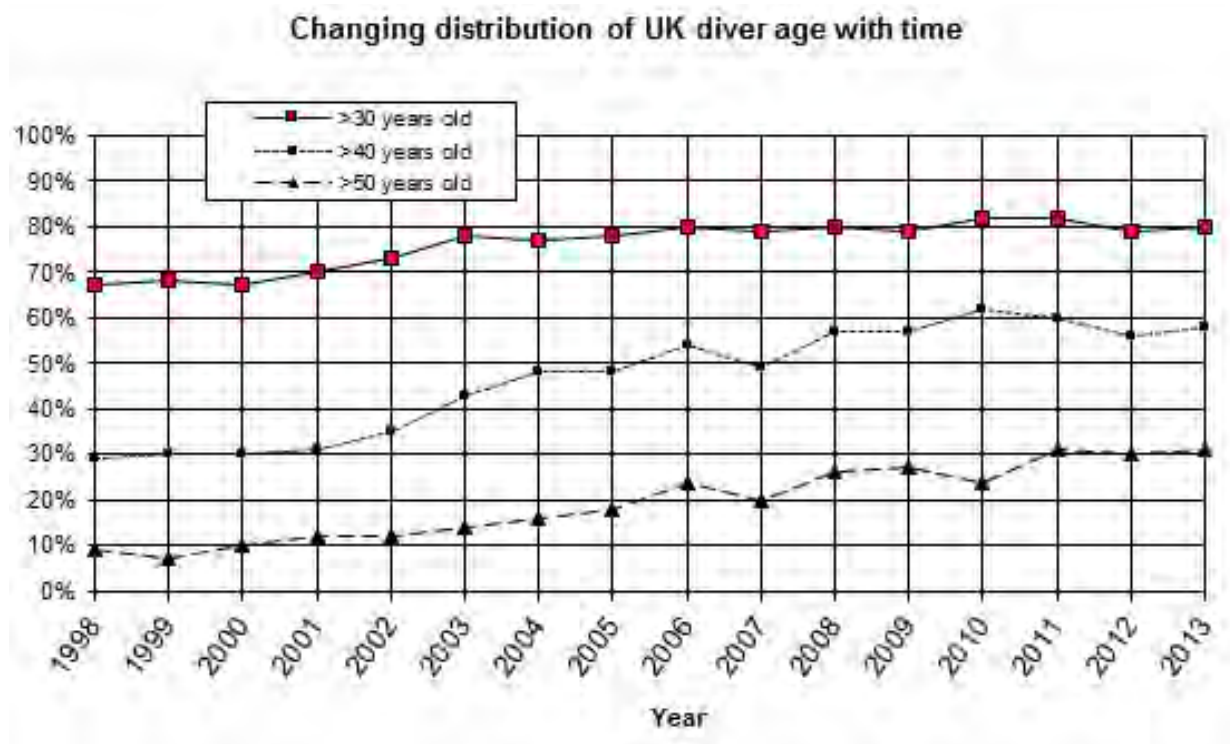


Figure 1 Distribution of divers by age over time

## Incident reporting

The British Sub-Aqua Club has, for many years, maintained a record of UK diving incidents. This record pertains to sports diving in England, Wales, Scotland and Northern Ireland. Information is obtained from reports submitted by divers, the emergency services, recompression facilities and news articles.

We believe that we capture all fatalities but we are equally sure that we only get a sample of the non-fatal incidents.

The following chart shows the number of incidents reported to us over the last 25 years.

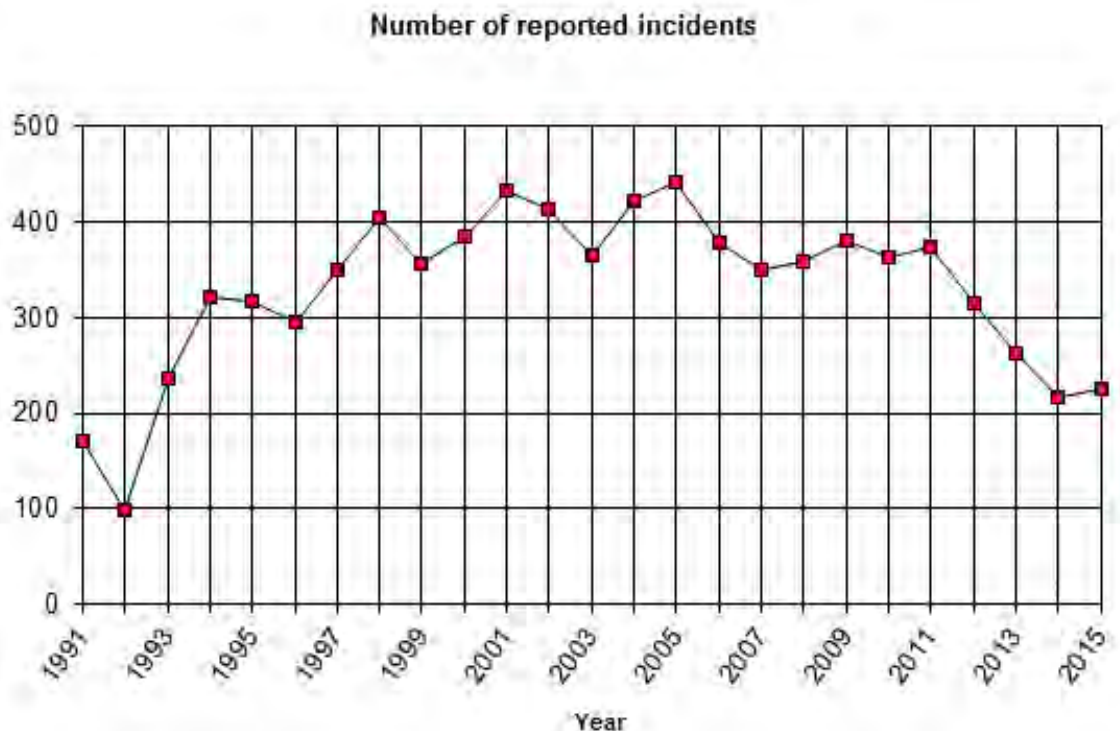


Figure 2 Reported incidents per year

As can be seen, the number of reported incidents has declined in recent years. Some of this decline is thought to be due to improved diving practice, for example, significant effort has been put into ascent training and ascent related incidents have reduced significantly. Equally, as stated earlier, it is believed that there has been a reduction in the amount of UK diving.

## Incident analysis

The BSAC categorises incident into 8 major headings:-

- Fatalities
- Decompression Illness (but not fatal)
- Abnormal ascent (but no DCI)
- Boating or surface related (e.g. engine failure, missing divers)
- Equipment failure
- Technique problem (but no adverse impact)
- Illness/Injury (other than DCI)
- Miscellaneous (e.g. false alarms)



The following chart shows the distribution of incidents into these major categories for 2015.

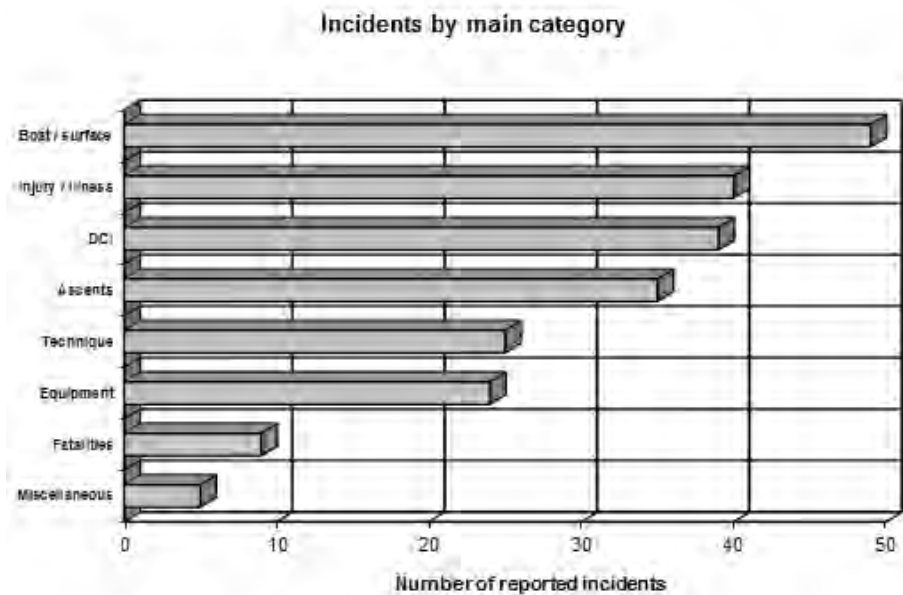


Figure 3 Main category of incidents

The trends in each of these categories are tracked on an annual basis and used to steer the development of training programmes and to develop safety advice for divers.

## Fatalities

The following chart shows the number of sports diving fatalities in the UK since 1998, the average is a little over 15 deaths per year.

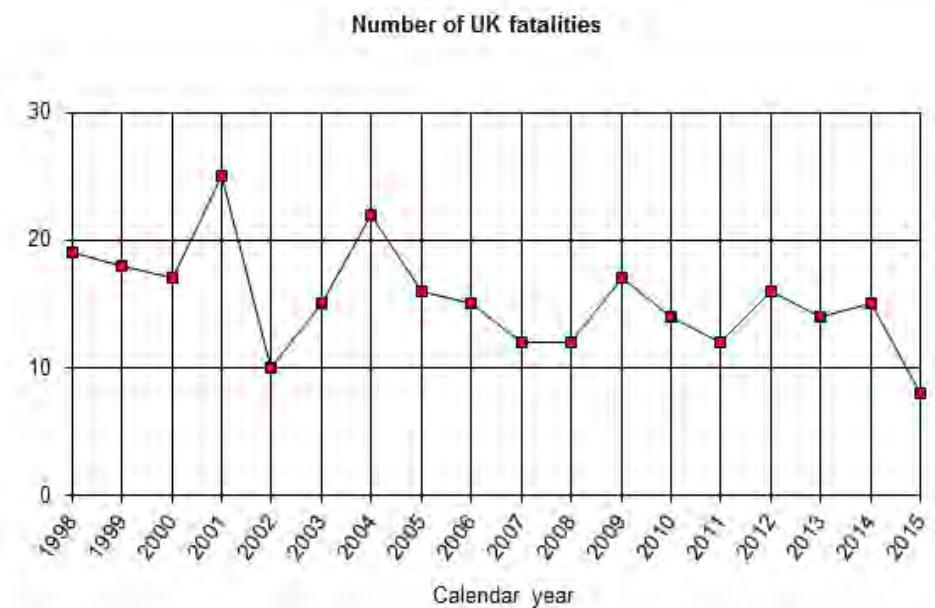


Figure 4 Sports diving fatalities in the UK since 1998

In that period there have been 277 individual deaths. In 146 of these cases there is insufficient information available to allow a full understanding of the causal factors to be determined.

However an analysis of the major causal factors, where known, reveals the following:-

41%	separation from buddy(ies)
24%	medical events, mainly heart attacks
21%	three or more divers in the group
17%	heavy/sank
14%	rapid ascent
13%	solo divers
10%	out of gas
10%	under instruction
9%	diving significantly beyond experience
9%	DCI/Pulmonary barotrauma
8%	entanglement
5%	rebreather malfunction or user error
3%	regulator free flow

In many cases one or more factors apply

### Causal factors behind the non-fatal incidents (from the 2015 Incident Report)

#### DCI

21%	involved repeat diving
19%	involved rapid ascents
19%	involved diving to deeper than 30m
11%	involved missed decompression stops
7%	involved repeat diving with a reversed profile

#### Ascents (with no subsequent ill effects)

50%	Poor buoyancy control
36%	Equipment problems
23%	Panic / anxiety / rush for surface
23%	Weighting or weight related issues
9%	Delayed SMB problems
9%	Free flows
5%	Drysuit BCD control malfunction/mis-use
5%	Out of air / gas

#### Illness/injury (other than DCI)

50%	diver ill, unwell, seasick (may include undiagnosed DCI)
24%	slips, trips, physical trauma
19%	ear problems

Plus a range of other problems such as burns, eye problem, O2 hit.

#### Equipment

24%	regulator free flow
12%	rebreather issues
12%	hose connections and failures
12%	harness issues
8%	loss of weights

Plus a range of problems such as 'O' ring failure, clip jamming, foul gas, torch failure.

### Technique

20%	poor dive control – depth/direction
16%	out of gas
16%	poor decompression planning
16%	diver separation
12%	entanglement

Plus a range of other experience related issues for example, loss of fin, mask fitting, drysuit zip left undone, swallowing water.

### Boating/surface problems

53%	involved engine problems
37%	involved lost diver(s)
18%	involved boat problems
2%	involved bad seamanship

### Summary

Apart from events resulting from latent medical problems, the great majority of incidents are avoidable. Analysis of individual incidents (where full detail is known) usually reveals one or more elements of the dive that contravene the tenets of safe diving and our annual reports' conclusions and recommendations have carried the same messages for many years. This picture only changes when new equipment or techniques are deployed, for example rebreathers, the advent of which brought a number of new problems.

A current key issue to be addressed is the aging diving population and the high number of fatalities in the UK that involve a medical event that occurs when the diver is in the water. A challenge for the medical advisors is to provide practical guidance that will help divers to mitigate this risk.

Copies of our annual report and 'Safe Diving' booklet can be downloaded, free of charge, from our website <https://www.bsac.com/>

## APPENDIX D. STATISTICS ON DIVING FATALITIES IN BRAZIL (1980 – 2015)

Eduardo Vinhaes, Irene Demetrescu, Sergio Viegas

The first known recreational diving fatality in Brazil occurred in 1980, when the activity was still incipient in the country. With the development of recreational diving, particularly after the 1990s, the number of fatalities has grown significantly. The increasing dissemination of information from the internet facilitated creating a fatalities database since 2010. However, it remains difficult to obtain detailed information on fatalities, since few cases are investigated and no official reports have been obtained.

Below is the information regarding confirmed cases of recreational scuba diving fatalities in Brazil since 1980. We are working on finding ways to access expert medical reports and autopsy results, so they can be used to accurately determine the cause of scuba diving fatalities in the country.

1. **Frequency** - Recreational scuba diving fatalities were sporadic until the late 1990s, when an annual occurrence of deaths was observed, particularly after 2010. The table below shows the occurrence of fatalities during this period under study.

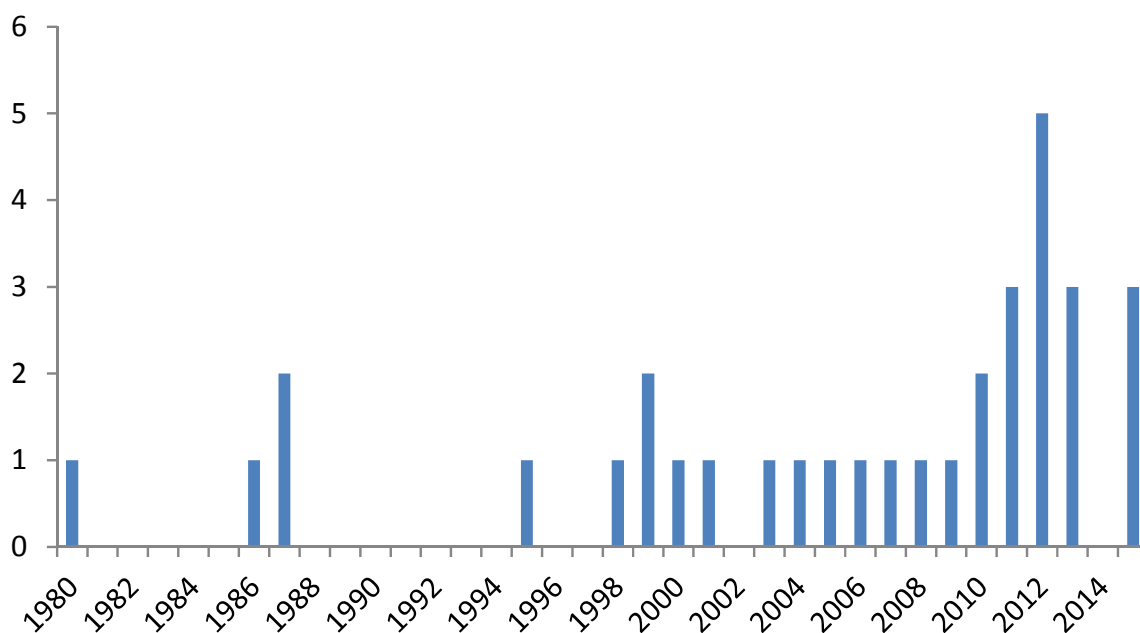


Figure 1 Yearly occurrence of fatalities involving scuba divers (n=33)

2. **Gender and age** - Although there was a total of 33 confirmed recreational scuba diving fatalities, data on the gender and age of the victims were available in 28 cases. The following chart illustrates the gender of injured divers. Most of the cases (89%) were male divers.

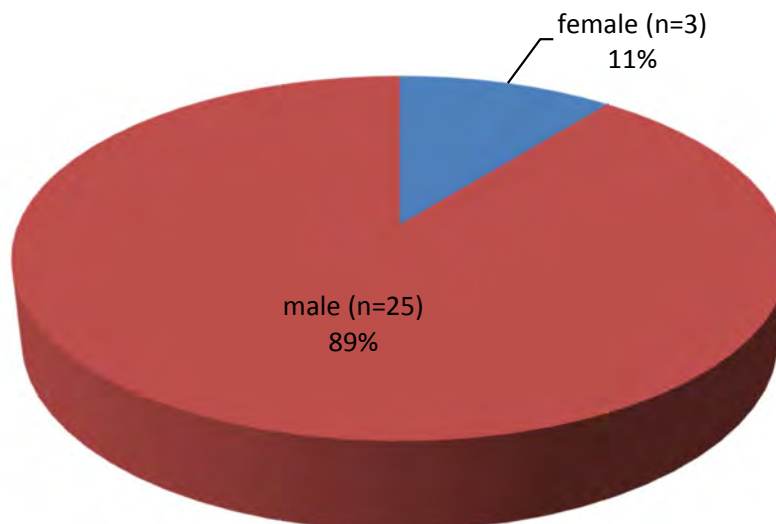


Figure 2 Number of fatalities involving scuba divers by gender (n=28)

The age of the victims ranged from 27 to 61 years old (mean=38.2 years) for men (n=10), and 34 to 60 years old (mean=47 years old) for women (n=3).

3. **Environment** where fatalities occurred - In Brazil where the coastline is 7,400 kilometers long, most of the recreational diving is performed in the ocean. However, more freshwater dive spots have been emerging, although there are no precise data on the number of recreational dives in fresh water compared with those in ocean environments. The table below shows the percentage of fatalities according to the environment where they occurred.

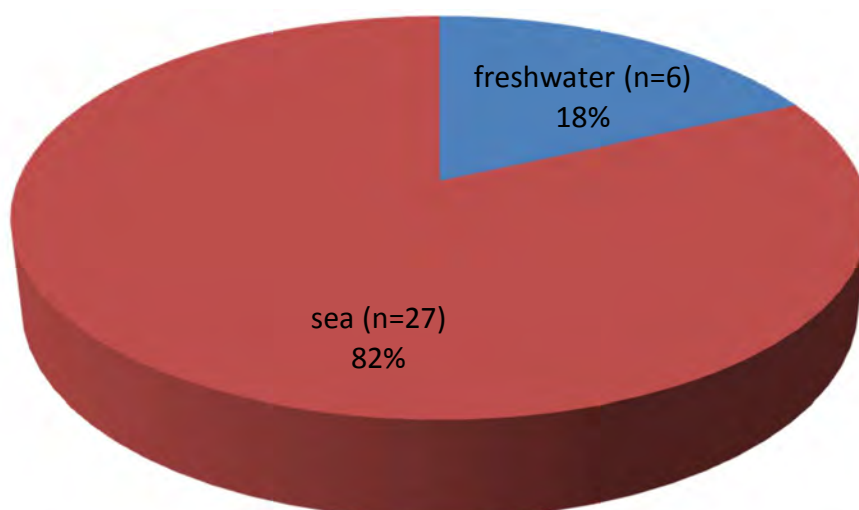


Figure 3 Environment where fatalities occurred (n=33)

Through our analysis of fatal cases involving recreational divers who were diving in the ocean (n=27), five of them (18.5%) occurred with divers who were exploring shipwrecks.

4. **Cause of death** - Medical expert reports are conducted according to state laws, which vary among states; and copies are often difficult to obtain. In 39% of the cases, the cause of death was neither identified nor confirmed. We are currently working to establish a protocol that enables more direct contact with medical experts, which should greatly facilitate gathering information in the near future. The causes of death among recreational divers are shown on the chart below:

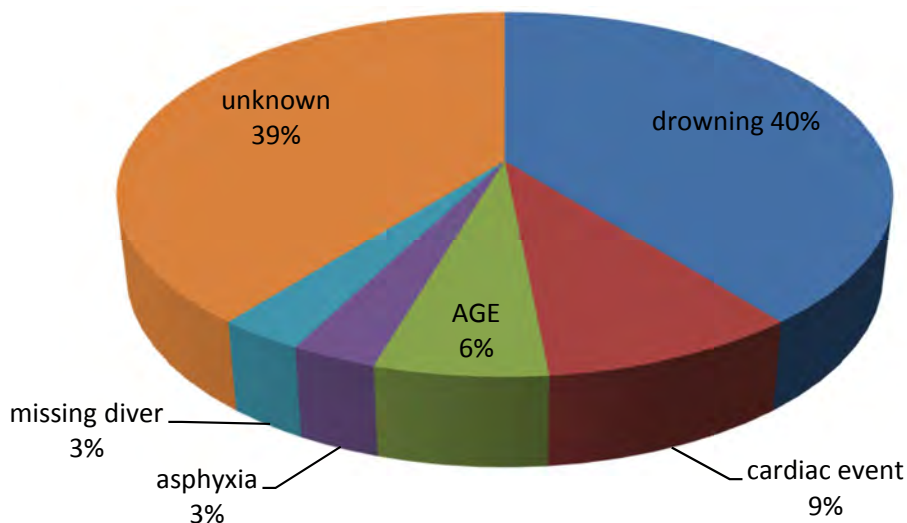


Figure 4 Cause of death among recreational divers (n=20)

The number of fatalities mentioned above excludes cave divers (n=8), professional divers (n=9) and law enforcement divers (firemen and policemen, n=4). These cases were not included in the analysis as they occurred under different conditions and had a different purpose from recreational diving.

Below are reports of some of the fatalities in an attempt to provide a better understanding of the complexity of these cases:

#### Case D-1: Low-on-air diver ascended alone and drowned

On the first day of diving, six divers (five clients and a guide) reached the maximum depth of 32 meters (105 feet). After 20 minutes at the bottom, one of the divers reached 50 bar pressure in his air cylinder, even though other members of the group had more than 50% of their air supply still available. At that time, the group guide signaled the diver to return to the surface and the dive boat. The guide and the other divers that remained watched the diver ascend from the bottom. The diver surfaced and began swimming in the reportedly correct direction. The other group members watched the diver for a few moments before resuming their diving. After a 39-minute dive, the group returned to the surface and boarded the dive boat. At this point, the guide noticed the absence of the diver who had ascended earlier. He immediately began search procedures, mobilizing other nearby boats to assist in these efforts. A diving search was conducted 50 meters (164 feet) away from the initial diving location at 35 meters (115 feet) depth on sandy bottom. From 55 feet (16 meters) they saw the diver's yellow dive tank. The victim was found facing down, with cyanosis of the face, regulator out of his mouth, deflated BCD, weight belt in place, and had a mask full of blood. Rescue procedures were performed, including bringing the victim to the surface, removing his diving equipment, clearing his obstructed nasal airway and transferring him to a speedboat to be driven to the port.

According to people in the group, the plan was to make a 3-minute safety stop during the ascent to the surface. However, the safety stop could not be made because the diver "ascended in despair". Two divers from the group reported that the victim showed agitation and inexperience, which caused increased consumption of air, and that he ascended too rapidly to the surface without performing a decompression stop. The forensic examination report indicated drowning as the cause of death.

*Comment – The victim received training in basic open-water diving but with no experience in deep diving. The excessive air consumption suggests that the diver had greatly increased ventilation probably due to anxiety, agitation, and inexperience. The ascent without the accompaniment of another diver to assist at the surface if required may have contributed to the loss of buoyancy on the surface, leading to subsequent drowning. One cannot rule out the possibility of gas arterial embolism, which could have led to the loss of consciousness on the surface, with the subsequent loss of buoyancy, as the buoyancy compensator was deflated.*

**Case D-2: Inexperienced diver ignored warning not to enter shipwreck**

A 45-year-old male scuba diver, with a basic open-water diving experience of approximately six months hired the services of local guides to accompany him on a wreck, diving to 20-meter (66 feet) depth. During the dive, the diver entered the wreck by himself, despite his low qualifications, insufficient training, and being warned not to do so. As it took longer than expected for him to return, searches were conducted on the site, and the diver was found unconscious near the hull opening through which he had entered. According to the diver's daughter, he suffered from panic disorder, had high blood pressure and was taking prescription drugs. He was taken to the Municipal Emergency Room, where he arrived showing no vital signs.

*Comment – This diver had no wreck diving training, little diving experience, and health conditions that may have contributed to his death. Diving under conditions that go beyond the training level is acknowledged as a risk factor of diving fatalities.*

**Case D-3: Diver left the group and found more than one hour later**

On the first dive of the second day in a series of dives, the dive guide led two basic open water divers. The bottom time was approximately 12 minutes, depth of approximately 5 meters (16 feet), visibility of approximately 4 meters (13 feet), and water temperature of approximately 23°C (73°F). During the dive, one of the divers separated from the group. The dive guide signaled the other diver, asking him to wait for him in the same spot. He swam away to find the diver that had separated from them. He brought him back to the group and signaled that they should stay together. After a few minutes together, the same diver separated from the group again. The dive guide then repeated the search procedure. However, after searching for one minute he returned with no success and met the diver who was waiting for him. They both ascend to the surface. They looked for bubbles that could be coming from the missing diver for another minute. Without any success, the dive guide asked the diver to return to the dive boat, inform the crew about the missing diver, and then he dived back to the bottom for another search.

At the same time, a sailor and a diving instructor were assigned to make a search on the surface with the supporting dinghy, while the boat captain sought the help of two additional boats and two instructors from another diving agency to conduct searches on the surface and underwater. After about 15 minutes of unsuccessful searches, the boat captain sent a warning sign to all boats asking for caution when navigating in the area because the diver could potentially be found adrift. After searching for approximately 1 hour and 15 minutes, the diver was found at the bottom, at a 14-meter (46 feet) depth, with the regulator out of his mouth. When brought to the surface, he was found in cardiorespiratory arrest and cyanosis. While moving the diver into the dive boat, liquid and foam came out of his mouth. The victim was found fully equipped, with the cylinder still containing 140 bar of air, mask in place, fins, octopus in position, deflated BCD, weight belt in place, and not showing any signs of despair and/or disorderly attempt to come to the surface.

*Comment - low water visibility associated with carelessness in remaining close to his partner may have contributed to the diver moving away from his group, possibly causing him to panic. Although there is not any accurate information available on this case, careful planning before diving, stating what should be done in case a diver leaves the rest of the group, may facilitate the rescue of a missing diver, thus avoiding a panic situation underwater.*



## Freediving

Freediving, particularly underwater fishing, has been practiced in various locations in Brazil since the 1970s. Due to the relatively low cost of equipment and the infrastructure necessary for its completion compared with recreational SCUBA diving costs, this type of diving has expanded throughout the country especially after the 1990s. However, there are no specific data on the population of freedivers and locations where freediving is performed.

1. **Frequency** – freediving fatalities have been occurring in Brazil since it became popular in the country. However, obtaining early data on deaths has been a difficult task since the available reports were informally completed without any documentation or supporting records. This situation has been changing significantly since the year 2000, especially due to greater disclosure of information on fatalities on the internet. The following table illustrates the significant growth of fatalities involving freedivers from 1980 to 2015.

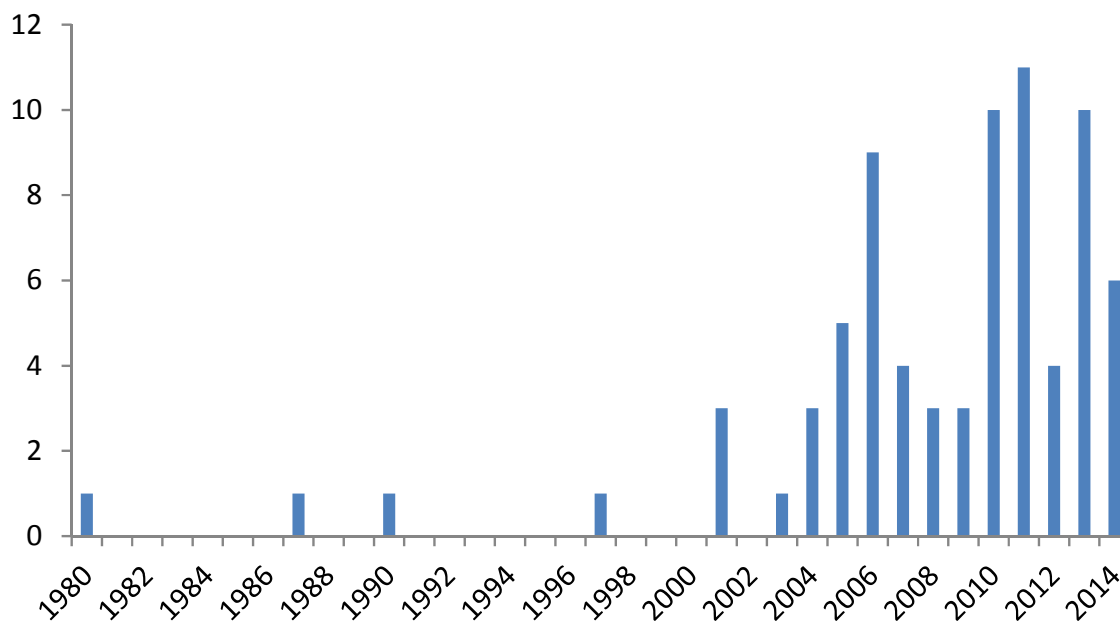


Figure 5 Number of fatal cases involving freedivers (n=76)

2. **Gender and age** - freediving fatalities (n=76) occurred mostly with male divers (n=75, 99%) from 15 to 58 years of age (mean=48 years of age). Only one case involving a female diver was registered (1%), but there was no reference to the age of the victim.
3. **Environment where the accident occurred** – the majority of freedivers in Brazil engage in spearfishing (n=56, 85%) performed mainly at sea. However, in recent years we have been informed that spearfishing has been progressively occurring in freshwater environments. There are no detailed data on locations and freshwater diver populations. The table below shows underwater fatalities in each environment.

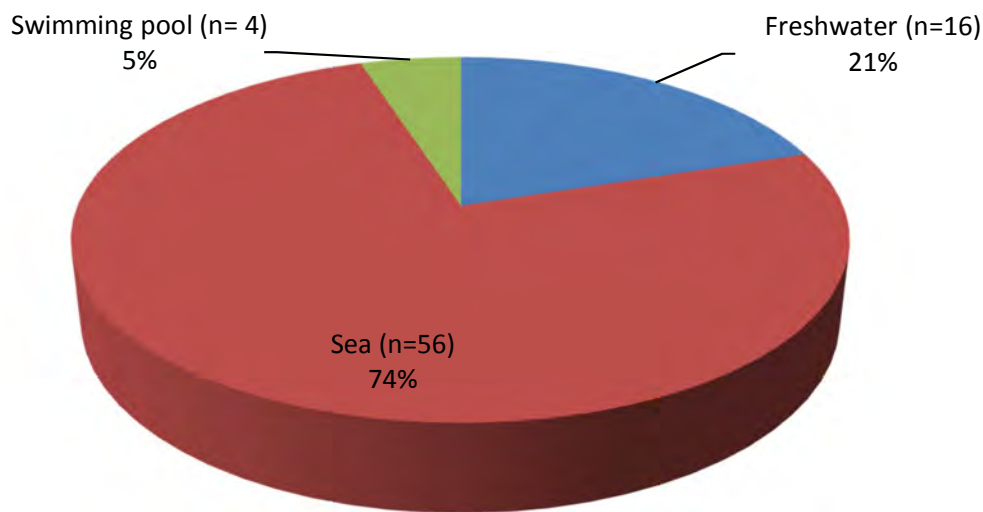


Figure 6 Environment where the accident occurred (n=76)

4. **Cause of death** - this is probably the most difficult information to obtain. In four cases, the diver's body was not found; usually we do not have access to expert medical report. However, in 9 cases (12% of total) the cause of death was trauma; in 4 cases (5%) the victims were hit by boats; and in 3 cases (4%) the victims were accidentally hit by harpoon weapons. One case (1%) occurred after the detonation of an underwater bomb used for fishing, and one case (1%) remains inconclusive.

The following are case summaries of freediving fatalities in Brazil, which may help understand the complexity of these cases.

**Case D-4: Spearfishing diver descended and did not return**

One early morning, two divers headed out for spearfishing near an oil platform. They dived in relay while a 16-year old remained on the dive boat. One of the divers, who was considered an experienced diver and had long been engaged in this kind of fishing, disappeared at around 1:45 p.m. The other fisherman immediately searched for his friend but he was unable to locate him. Then, he asked a tugboat that was supporting the platform and also the people on the platform for help. However, even after about a two-hour diving and boat search around the platform, the diver could not be found.

*Comment - Spearfishing, carried out in open-sea conditions, bottomless reference, and with little supervision from the surface, may have contributed to this death, making it impossible to find the diver's body.*

**Case D-5: Lone breath-hold diver not joking when really unconscious**

At the end of a SCUBA dive, while returning to the boat, two divers noted that a freediver without fins passed by them and ascended soon after. This freediver was the only person who had stayed on the dive boat, saying that he would not participate in that diving so the boat would not be left unattended. After the 5-meter (16 feet) safety stop, the scuba divers returned to the dive boat and found it empty. When they got out of the water, one of the divers saw the freediver afloat, almost motionless, about 50 or 60 meters (164-197 feet) away from the boat. Since they thought the diver was joking, as he usually did, they did not consider this concerning. However, after a few minutes, they brought up the subject again wondering about the freediver's behavior. Soon after, another scuba diver who was returning to the dive boat went to the site and found the freediver unconscious. First aid was provided, including the help of three doctors. Even though the diver was showing no response to the cardiopulmonary resuscitation procedures, they headed to the harbor and continued performing chest compressions and ventilation for about 30 minutes, but eventually the diver was pronounced dead.

*Comment – Even after choosing to stay on the dive boat, the victim decided to conduct freediving without a dive partner and without informing the other divers. An initial attitude of complacency in a potentially hazardous situation, thinking that the diver was “joking”, may also have contributed to the fatal outcome. The choice of diving away from the pre-established site coupled with a lack of communication with other divers can contribute, to a significant extent, to fatal cases involving freedivers.*

## APPENDIX E. SOUTHERN AFRICA DIVING MORBIDITY AND MORTALITY (2010-2015)

Cecilia J. Roberts , Laurel Reyneke and Peter Buzzacott

Founded in 1996, DAN Southern Africa (DAN SA) is a Public Benefit Organization that provides emergency medical advice and assistance for underwater diving injuries, and provides a wide range of research, education and training programs promoting safe diving. Regions of coverage include South Africa, Angola, Botswana, Comoros, Kenya, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, Swaziland, Tanzania, Zaire, Zambia, and Zimbabwe, though enquiries are also received from outside these countries.

DAN South Africa provides an emergency hotline for diving and evacuation emergencies. Response staff and diving medicine specialists are on call to assist with care coordination and evacuation. DAN SA also provides a diving medical information service. Data regarding diving fatalities in South Africa are collected whenever they occur and all medical enquiries are logged.

### Mortality

Between 2010 and 2015, DAN SA learned of 15 diving fatalities in South African waters; an average of 2.5 per year (range 0-4). The most common sites, likely reflecting their popularity with divers, were Sodwana Bay (n=4), Umkomaas (n=3) and Durban plus Miracle Waters with two each. There were fewer deaths during winter (May-October, n=4) than during summer (November to April, n=11) (Figure 1).

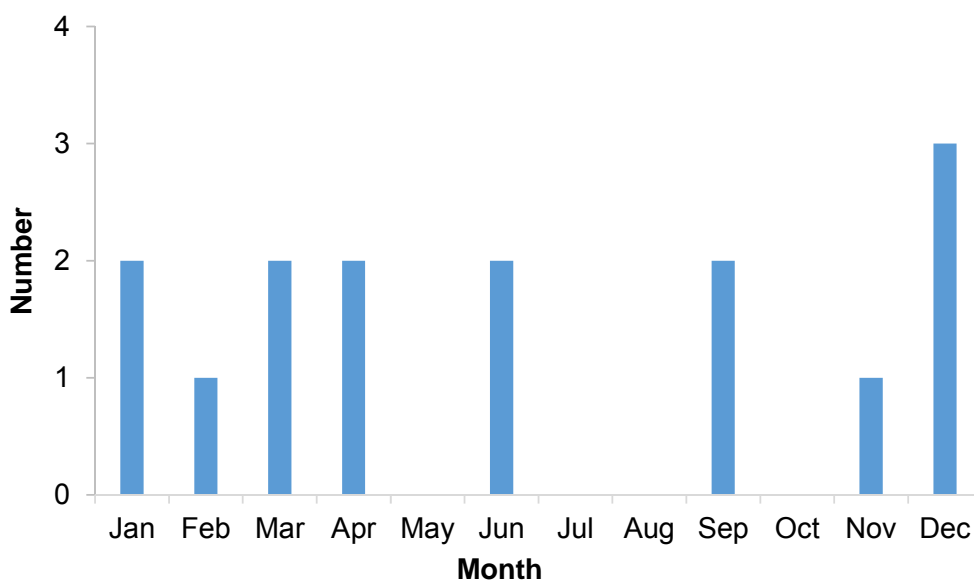


Figure 1 Monthly distribution of South African diving fatalities.

Ten fatalities were male (67%) and five were female (33%). Mean age was 43.5 years (range 21-56). The majority (n=10, 67%) died after diving from a boat, three (20%) were diving in a quarry, and one each in a pool or from the beach/shore. Maximum depths were known in ten cases (67%), comprised of a diver in a pool (n=1), four using open circuit and five using rebreathers. Average maximum depth among the four open circuit divers was 19 meters (range 17-22) whereas the average maximum depth among the rebreather divers was 67 meters (range 27-100). Four deaths (27%) occurred in freshwater and the other 11 (73%) in the sea.

The most common cause of death was cardiac arrest (n=5, 33%), followed by drowning and arterial gas embolism (n=3 each, 20%). These three causes of death represent the most common in most, if not all, recreational diving fatality studies. It should be noted, however, that of the 15 fatalities, autopsy reports were available in only two cases (13%).

Certification levels ranged from student or basic open water diver certification to technical diver and/or instructor. Nine (60%) were DAN members and six (40%) were not.

### Morbidity

Between 2010-2015 inclusive DAN SA received 613 medical enquiries, 509 diving related (83%) and 104 (17%) non-diving related. The remainder of this chapter considers the 509 diving related injuries only, which averaged 85 cases per year (range 56-175, Figure 2).

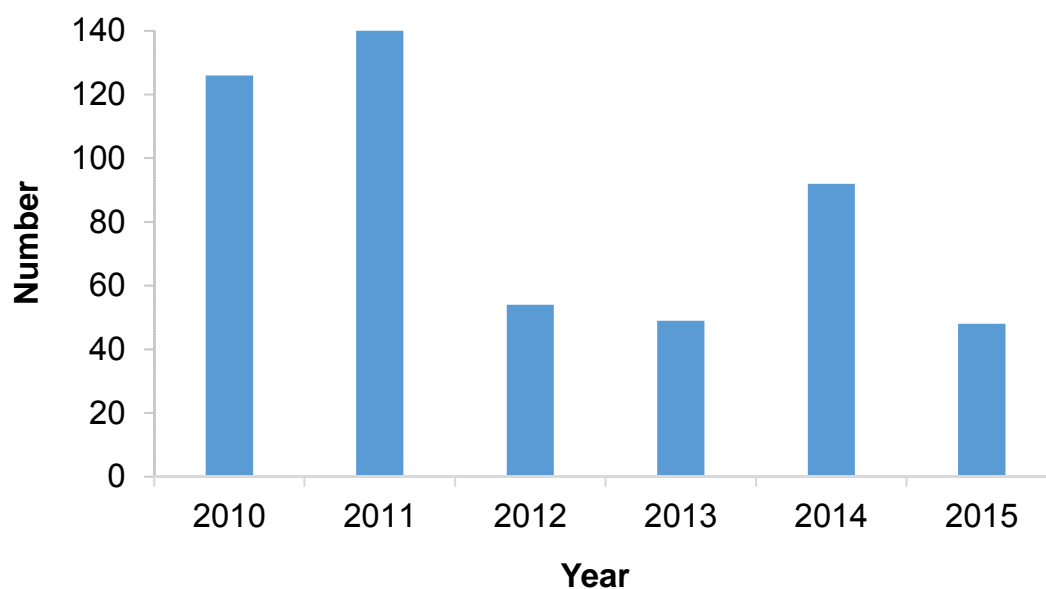


Figure 2 Number of DAN SA diving related medical enquiries by year

South Africa lies between 22° and 35° latitude in the Southern Hemisphere's subtropical zone and the monthly distribution of diving-related medical enquiries reflect this, with calls peaking over summer (November to April) and abating over winter (May to October), similar to the prevalence of diving fatalities in South Africa, as shown in Figure 3.

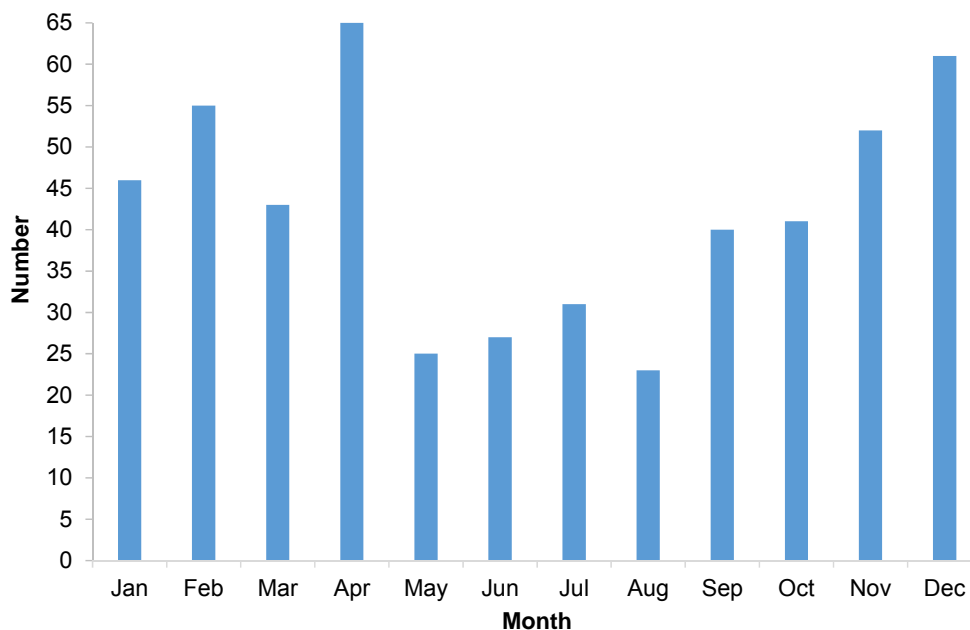


Figure 3 Monthly distribution of DAN SA diving-related medical enquiries

The country of call origin is shown in Table 1 where the number of enquiries equaled five or more. Countries where less than five enquiries originated during the six years period included Australia, Honduras, India, Indonesia, Israel, Kenya, Malawi, Maldives, Mauritius, Mexico, Micronesia, Namibia, Nigeria, Panama, Papua New Guinea, Singapore, Tanzania, Thailand and the USA.

Table 1 Country of origin where DAN SA cases  $\geq 5$  between 2010-2015

Country of origin	N (%)
South Africa	303 (60)
Mozambique	79 (16)
Zanzibar	11 (2)
Egypt	9 (2)
Seychelles	6 (1)
Angola	5 (1)
Madagascar	5 (1)
Others	26 (5)
Unknown	65 (13)
<b>Total</b>	<b>509 (100%)</b>

The majority of enquiries were from DAN members (n=319, 63%), 179 (34%) were not members and membership status in the remaining 11 (2%) was unknown.

As in many other recreational diving populations, the majority (n=314) were male (62%) and 38% were female (n=195). Where age was known (n=386 cases, range 8-67), males were a mean of 33 years (SD 12.5) and females 34 years (SD 13) of age.

Table 2 shows the frequency of evacuation by mode. The most common mode was by own means.

Table 2 Mode of transport used for medical evacuation

Mode	N (%)
Own means	193(38)
No evacuation needed	271 (53)
Ambulance	28 (6)
Fixed wing aircraft	7 (1)
Commercial flight	6 (1)
Helicopter	4 (1)
<b>Total</b>	<b>509 (100)</b>

Of the 509 enquiries, 280 (55%) were referred or received consultations as outpatients. 81 divers (16%) received recompression therapy and 62 (12%) required hospitalization. Table 3 lists the diagnoses.

Table 3 Diagnosis among 509 diving-related medical enquiries

Diagnosis	N (%)
Air Embolism	5 (1)
Barotrauma Ear	88 (17)
Barotrauma other	16 (3)
Barotrauma pulmonary	26 (5)
DCI	14 (3)
Possible DCI	3 (41)
DCS	91 (18)
Possible DCS	29 (6)
Fitness to dive enquiry	12 (2)
Hazardous marine life injury	27 (5)
Malaria	8 (2)
Musculoskeletal	1 (0)
Near drowning	1 (0)
Other	155 (30)
Trauma	33 (6)

In conclusion, DAN SA receive reports of an average of 2.5 diving fatalities per year and around 85 non-fatal diving related medical enquiries, including incidents. The summer months are the busiest. At least a quarter of all medical enquiries originate outside of South Africa and less than half of all enquiries require evacuation, most often by own means.



## APPENDIX F. PUBLICATIONS (2015)

Jeanette P. Moore

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Buzzacott P. Diving injuries are (usually) no accident. *Diving and Hyperbaric Medicine*. 2015;45(1):61.

Pollock NW. "Re: Don't dive cold when you don't have to." *Diving Hyperb Med*. 2015 Sep; 45(3): 209.

Pollock NW. "Re: Cialoni et al. Flying after diving: in-flight echocardiography after a scuba diving week." *Aerosp Med Hum Perf*. 2015; 86(5): 488.

### **Published Acknowledgment**

In: Alexiou K. PFO and diving. *X-Ray Mag*. 2015; 65: 62-3.

## Blog Posts

Denoble PJ. Sensors and Senses. The Dive Lab. Feb 2015. <https://thedivelab.wordpress.com/2015/02/09/sensors-and-senses/>

Denoble PJ. Mobile medical applications: Is Apple leading the pack or catching up? The Dive Lab. Mar 2015. <https://thedivelab.wordpress.com/2015/03/25/mobile-medical-applications/>

Denoble PJ. Bubble production in divers who have had DCS. The Dive Lab. April 2015. <https://thedivelab.wordpress.com/2015/04/20/bubble-production-in-divers-who-have-had-dcs/>

Denoble PJ. Do viagra and other PDE5 inhibitors increase the risk of DCS in humans? The Dive Lab. May 2015. <https://thedivelab.wordpress.com/2015/05/22/do-viagra-and-other-pde5-inhibitors-increase-the-risk-of-dcs-in-humans/>

Denoble PJ. Can a test identify divers who may be more susceptible to DCS. The Dive Lab. July 2015. <https://thedivelab.wordpress.com/2015/07/10/can-a-test-identify-divers-who-may-be-more-susceptible-to-dcs/>

Denoble PJ. Can a coronary calcium scan improve the prediction of heart attacks in older divers? The Dive Lab. July 2015. <https://thedivelab.wordpress.com/2015/07/16/can-a-coronary-calcium-scan-improve-the-prediction-of-heart-attacks-in-older-divers/>

Denoble PJ. Skin mottling after diving may be result of brain lesions caused by gas bubbles. The Dive Lab. July 2015. <https://thedivelab.wordpress.com/2015/07/28/skin-mottling-after-diving-may-be-result-of-brain-lesions-caused-by-gas-bubbles/>

Denoble PJ. Recompression using deep heliox tables and treatment outcomes. The Dive Lab. September 2015. <https://thedivelab.wordpress.com/2015/09/15/recompression-using-deep-heliox-tables-and-treatment-outcomes/>

Denoble PJ. Melatonin and susceptibility to CNS oxygen toxicity. The Dive Lab. October 2015. <https://thedivelab.wordpress.com/2015/10/08/melatonin-and-susceptibility-to-cns-oxygen-toxicity-2/>

Denoble PJ. Gradient factors can be used to control for depth-time exposure and alleviate the risk of decompression sickness in recreational scuba diving. The Dive Lab. December 2015. <https://thedivelab.wordpress.com/2015/12/17/gradient-factors-can-be-used-to-control-for-depth-time-exposure-and-alleviate-the-risk-of-decompression-sickness-in-recreational-scuba-diving/>

## APPENDIX G. PRESENTATIONS BY RESEARCH PERSONNEL (2015)

Jeanette P. Moore

### 2015

Foster PP, Pollock NW, Conkin J, Dervay JP, Caillot N, Chhikara RS, Vann RD, Butler BD, Gernhardt ML. Skeletal muscle microcirculation and extra-vehicular activity preparation. NASA Human Research Program Investigators' Workshop. Galveston, TX. [#0309]; January 13, 2015. Neal Pollock (presenter).

Nochetto M. Learning from the DAN Emergency Line: An Interactive Review of Cases (EN & SP). DAN Divers Day, San Cristobal Island, Galápagos, Ecuador. January 2015.

Pollock NW, Natoli MJ, Conkin J, Wessel JH III, Gernhardt ML. Ambulation increases decompression sickness in spacewalk simulations. NASA Human Research Program Investigators' Workshop. Galveston, TX. [#0068]; January 14, 2015. Neal Pollock (presenter).

Vann RD. Course introduction. In: Medicine and Physiology in Extreme Environment. CBI 206, Duke University. January 14, 2015.

Vann RD. Cosmology. In: Medicine and Physiology in Extreme Environment. CBI 206, Duke University. January 14, 2015.

Vann RD. Physics of extreme environments. In: Medicine and Physiology in Extreme Environment. CBI 206, Duke University. January 21, 2015.

Pollock NW. Managing decompression stress - beyond the algorithms. WebEx presentation, Float N' Flag Dive Centre, Burlington, Ontario. January 28, 2015.

Trout BM. The Science of the Underwater Hunt. DAN Public Lecture Series, Durham, NC. February 4, 2015.

Nochetto, M. Toxinological Aspects of Hazardous Marine Life (EN). Boston Sea Rovers, Boston, MA. February 6-7, 2015.

Pollock NW. Extreme diving and diver protection. Wilderness Medical Society Student Elective in Wilderness and Environmental Medicine, Townsend, TN. February 10-11, 2015.

Denoble PJ. Fatal Injuries in Recreational Rebreather Diving. Underwater Interventions. New Orleans, February 14, 2015.

Pollock NW. Factors in decompression stress. Rebreathers and Scientific Diving Workshop, Wrigley Marine Science Center, Catalina Island, CA. February 16-20, 2015.

Pollock NW. Diving the algorithms - reviewing dive profile. Rebreathers and Scientific Diving Workshop, Wrigley Marine Science Center, Catalina Island, CA. February 16-20, 2015.

Pollock NW. Cardiorespiratory and exercise physiology. In: Medicine and Physiology in Extreme Environment. CBI 206, Duke University. February 23, 2015.

Pollock NW. Cardiorespiratory and exercise physiology - lab experience. In: Medicine and Physiology in Extreme Environment, CBI 206, Duke University. February 25, 2015.

Nochetto M. Fundamentos del Tratamiento Hiperoxico e Hiperbárico (SP). Diplomado Internacional de Medicina Hiperbárica - Universidad Latina de Panamá Ciudad de Panamá, Panama. February 2015.

Nochetto M. Taller de Anamnesis y Pensamiento Crítico: Presentación de Casos Clínicos (SP). Diplomado Internacional de Medicina Hiperbárica - Universidad Latina de Panamá. Ciudad de Panamá, Panama. February 2015.

Nochetto M. Oxigenoterapia Normobárica: Uso de Distintos Tipos de Dispositivos de Suministro de Oxígeno (SP). Diplomado Internacional de Medicina Hiperbárica - Universidad Latina de Panamá Ciudad de Panamá, Panama. February 2015.

Nochetto M. Manejo de Accidentes Disbáricos en Operaciones Remotas (SP). Diplomado Internacional de Medicina Hiperbárica - Universidad Latina de Panamá Ciudad de Panamá, Panama. February 2015.

Nochetto M. Aspectos Toxinológicos de la Vida Marina (Parte 1) (SP). Diplomado Internacional de Medicina Hiperbárica - Universidad Latina de Panamá Ciudad de Panamá, Panama. February 2015.

Nochetto M. Aspectos Toxinológicos de la Vida Marina (Parte 2) (SP). Diplomado Internacional de Medicina Hiperbárica - Universidad Latina de Panamá Ciudad de Panamá, Panama. February 2015.

Nochetto M. Ichthyosarcotoxismos (SP). Diplomado Internacional de Medicina Hiperbárica - Universidad Latina de Panamá Ciudad de Panamá, Panama. February 2015.

Nochetto M. Learning from the DAN Emergency Line: An Interactive Review of Cases (EN). Our World Underwater, Chicago, IL. February 27-March 1, 2015.

Nochetto M. Postdive Fatigue and When to Worry (EN). Our World Underwater, Chicago, IL. February 27-March 1, 2015.

Nochetto M. Enfermedades Disbáricas. Tratamiento Definitivo (SP). Diplomado de Medicina Hiperbárica y Subacuática - Universidad Nacional Autónoma de México - Costamed, Cozumel, QR Mexico. March 2-14.

Nochetto M. Pensamiento Crítico ante la Aparición de Síntomas Post Buceo. Taller de Anamnesis (SP). Diplomado de Medicina Hiperbárica y Subacuática - Universidad Nacional Autónoma de México - Costamed, Cozumel, QR Mexico. March 2-14.

Nochetto M. Manejo del Accidente Disbárico en Operaciones Remotas (SP). Diplomado de Medicina Hiperbárica y Subacuática - Universidad Nacional Autónoma de México - Costamed, Cozumel, QR Mexico. March 2-14.

Nochetto M. Toxicidad Operativa de Gases (SP). Diplomado de Medicina Hiperbárica y Subacuática - Universidad Nacional Autónoma de México - Costamed, Cozumel, QR Mexico. March 2-14.

Nochetto M. Aspectos Toxinológicos de la Vida Marina (Parte 1) (SP). Diplomado de Medicina Hiperbárica y Subacuática - Universidad Nacional Autónoma de México - Costamed, Cozumel, QR Mexico. March 2-14.

Nochetto M. Aspectos Toxinológicos de la Vida Marina (Parte 2) (SP). Diplomado de Medicina Hiperbárica y Subacuática - Universidad Nacional Autónoma de México - Costamed, Cozumel, QR Mexico. March 2-14.

Nochetto M. Ichthyosarcotoxismos (SP). Diplomado de Medicina Hiperbárica y Subacuática - Universidad Nacional Autónoma de México - Costamed, Cozumel, QR Mexico. March 2-14.

Nochetto M. Buceo Comercial Empírico en las Americas (SP). Diplomado de Medicina Hiperbárica y Subacuática - Universidad Nacional Autónoma de México - Costamed, Cozumel, QR Mexico. March 2-14.

Pollock NW. Keynote address. Safety and leadership: collaboration of research, training and awareness. NOAA Unit Diving Supervisor Conference, Seattle, WA. March 12, 2015.

Buzzacott P. Frontiers of Decompression Research. OZTek, Sydney, Australia. March 14-15, 2015.

Pollock NW. Concerns of the aging diver. Beneath the Sea, Secaucus, NJ. March 28, 2015.

Pollock NW. Managing decompression stress. Beneath the Sea, Secaucus, NJ. March 29, 2015.

Pollock NW. Defensive dive profile planning. DAN Public Lecture series, Durham, NC. April 01, 2015.

Trout BM. Does Sex Matter in Diving? Webinar presentation with Lana Sorrell to dive group in Chicago, IL. April 10, 2015.

Pollock NW. Aviation physiology. CBI 206, Duke University, Durham, NC. April 15, 2015.

Buzzacott P. Science Day - Hillsborough Elementary School, Durham, NC. April 17, 2015.

Pollock NW. Controlling decompression stress. 1<sup>st</sup> DAN-UHMS Dive Medicine CME Program, Ambergris Caye, Belize. April 18-25, 2015.

Pollock NW. Accident case studies. 1<sup>st</sup> DAN-UHMS Dive Medicine CME Program, Ambergris Caye, Belize. April 18-25, 2015.

Pollock NW. Physical fitness and diving safety. 1<sup>st</sup> DAN-UHMS Dive Medicine CME Program, Ambergris Caye, Belize. April 18-25, 2015.

Pollock NW. Thermal physiology. 1<sup>st</sup> DAN-UHMS Dive Medicine CME Program, Ambergris Caye, Belize. April 18-25, 2015.

Pollock NW. Altitude and diving. 1<sup>st</sup> DAN-UHMS Dive Medicine CME Program, Ambergris Caye, Belize. April 18-25, 2015.

Pollock NW. Research diving in Antarctica. 1<sup>st</sup> DAN-UHMS Dive Medicine CME Program, Ambergris Caye, Belize. April 18-25, 2015.

Pollock NW. Breath-hold diving. 1<sup>st</sup> DAN-UHMS Dive Medicine CME Program, Ambergris Caye, Belize. April 18-25, 2015.

Martina S. IPE Presentation. Patriot Dive Center, Wilmington, NC. April 26, 2015.

Denoble PJ. Delay To Recompression and Outcome of DCI. IMG Meeting. Indianapolis, April 30, 2015.

Buzzacott P. Cave diving and DAN. NSS-CDS Annual Cave Diving Workshop. Lake City, FL. May 15-17, 2015.



Pollock NW. Diving and diabetes - 10 years on Breath-hold diving. South Pacific Underwater Medicine Society, Palau, Micronesia. May 17-23, 2015.

Pollock NW. The role of diabetes in captured diving accidents. South Pacific Underwater Medicine Society, Palau, Micronesia. May 17-23, 2015.

Pollock NW. Decompression stress - beyond the algorithms. South Pacific Underwater Medicine Society, Palau, Micronesia. May 17-23, 2015.

Pollock NW. Decompression-induced bubbles, the known, the unknown, and the implications. South Pacific Underwater Medicine Society, Palau, Micronesia. May 17-23, 2015.

Pollock NW. Lust4Rust diving lecture series - Truk Lagoon. May 31, 2015.

Martina S. Unraveling the Intricacies of Immersion Pulmonary Edema. DAN Public Lecture Series, Durham, NC. Jun 3, 2015.

Buzzacott P. Underwater Hunter/Harvester Diving. Scuba Show, Long Beach, CA. June 6-7, 2015.

Buzzacott P. Kelp Diving. Scuba Show, Long Beach, CA. June 6-7, 2015.

Pollock NW. Defensive dive profile planning. Hydrosports Dive and Travel Shop, Keizer, OR (webinar). Jun 10, 2015.

Pollock NW. Expanding the echo universe - decompression studies. American Society of Echocardiography, Boston, MA. June 15, 2015.

Pollock NW. Plenary speaker. Undersea and Hyperbaric Medical Society, Montreal, Quebec. June 17, 2015.

Pollock NW. Decompression stress - beyond the algorithms. Undersea and Hyperbaric Medical Society, Montreal, Quebec. June 17, 2015.

Pollock NW, Wiley JM, Kernagis DN, Clarke NW, Mackey MN, Martina SD. Field dive monitoring: bubble presentation in recreational-technical closed-circuit rebreather trimix diving. Undersea and Hyperbaric Medical Society, Montreal, Quebec. June 17, 2015. Pollock NW, presenter (oral and poster).

Trout B, Buzzacott P, Denoble PJ. Recreational diving fatalities: Harvesters versus non-harvesters. Undersea and Hyperbaric Medical Society Annual Scientific Meeting, Montreal, Canada, June 17-21, 2015. Buzzacott, P, presenter (poster).

Pollock NW. Protection against decompression sickness in US space program planning. National Academy of Sciences/Institute of Medicine meeting of the Committee to Review NASA's Evidence Reports on Human Health Risks, Washington, DC. June 22, 2015.

Buzzacott P. Diving I have enjoyed around the world. Down Under Dive Club meeting. Raleigh, NC. July 9, 2015.

Buzzacott P. Medical post-graduate research degrees (webinar). California State Polytechnic University, Pomona, CA. July 14, 2015.

Pollock NW. Editorial Process and Peer Reviewing. Wilderness Medical Society, Breckenridge, CO. July 14, 2015.

Nochetto M. Aspectos Toxinológicos da Vida Marinha (PT). Grand Rounds - Centro de Controle de Intoxicações - Universidade de Campinas, Campinas, SP, Brasil. July 2015.

Buzzacott P. Epidemiology of Scuba Diving Injury. DAN Public Lecture Series, Durham, NC . August 5, 2015.

J. Lautridou, S. Artigaud, P. Buzzacott, Q. Wang, S. Driad, A. Mazur, K. Lambrechts, C. Balestra, M. Théron, V. Pichereau, and F. Guerrero. Effect of simulated air dive and decompression sickness on the plasma proteome of rats. European Undersea Baromedical Society (EUBS) Annual Scientific Meeting, Amsterdam, The Netherlands. August 19-22, 2015. Peter Buzzacott, presenter (oral).

Pollock NW. International Conference on Ultrasound for Diving Research - Karlskrona, Sweden. Aug. 25-26, 2015

Pollock NW. Bubble pathophysiology - the importance of measuring bubbles. International Meeting on Ultrasound for Diving Research, Karlskrona, Sweden. August 25, 2015.

Møllerlækken A, Blogg L, Pollock NW, Nishi RY. Monitoring protocols for meaningful data. International Meeting on Ultrasound for Diving Research. Karlskrona, Sweden. August 25, 2015. Neal Pollock (presenter).

Pollock NW. Review of bubble scoring systems and data collection protocols. International Meeting on Ultrasound for Diving Research, Karlskrona, Sweden. August 25, 2015.

Pollock NW. Physiology and pathophysiology of immersion I and II. NOAA/UHMS Physician Training in Hyperbaric Medicine. Seattle, WA. October 05-06, 2015.

Pollock NW. Thermal considerations I and II. NOAA/UHMS Physician Training in Hyperbaric Medicine, Seattle, WA. October 05-06, 2015.

Buzzacott P. DAN Diving Incident Reporting System. DAN Cozumel Safety Seminar, Cozumel, Mexico. October 6, 2015.

Nochetto M. Delta P and Barotraumas (EN). DAN-UHMS Diving and Hyperbaric Medicine Course, Bonaire, Netherlands. October 11, 2015.

Nochetto M. Operational Gas Toxicities (EN). DAN-UHMS Diving and Hyperbaric Medicine Course, Bonaire, Netherlands. October 11, 2015.

Nochetto M. Marine Life Toxinology (EN). DAN-UHMS Diving and Hyperbaric Medicine Course, Bonaire, Netherlands. October 11, 2015.

Nochetto M. Case Studies (EN). DAN-UHMS Diving and Hyperbaric Medicine Course, Bonaire, Netherlands. October 11, 2015.

Nochetto M. Remote Operations Injury Management (EN). DAN-UHMS Diving and Hyperbaric Medicine Course, Bonaire, Netherlands. October 11, 2015.

Nochetto M. Harvesting Divers (EN). DAN-UHMS Diving and Hyperbaric Medicine Course, Bonaire, Netherlands. October 11, 2015.

Nochetto M. Diver Infection Souvenirs (EN). DAN-UHMS Diving and Hyperbaric Medicine Course, Bonaire, Netherlands. October 11, 2015.

Pollock NW. Managing decompression stress. DAN-UHMS Diving and Hyperbaric Medicine Course, Bonaire, Netherlands. October 11, 2015.

Pollock NW. Physical fitness and diving safety. DAN-UHMS Diving and Hyperbaric Medicine Course, Bonaire, Netherlands. October 12, 2015.

Pollock NW. 'Polar research diving. DAN-UHMS Diving and Hyperbaric Medicine Course, Bonaire, Netherlands. October 12, 2015.

Pollock NW. Thermal physiology. DAN-UHMS Diving and Hyperbaric Medicine Course, Bonaire, Netherlands. October 13, 2015.

Pollock NW. Managing decompression stress. CIEE Research Station Bonaire, Netherlands. October 13, 2015.

Pollock NW. Special population divers. DAN-UHMS Diving and Hyperbaric Medicine Course, Bonaire, Netherlands. October 14, 2015.

Denoble PJ. Risk of cardiac death in scuba diving. VII Brazilian Congress of Hyperbaric Medicine, Rio de Janeiro, Brazil, October 15, 2015.

Denoble PJ. Patent Foramen Ovale and Fitness to Dive Consensus Workshop. VII Brazilian Congress of Hyperbaric Medicine, Rio de Janeiro, Brazil, October 15, 2015.

Pollock NW. Altitude and diving. DAN-UHMS Diving and Hyperbaric Medicine Course, Bonaire, Netherlands. October 15, 2015.

Pollock NW. Breath-hold diving. DAN-UHMS Diving and Hyperbaric Medicine Course, Bonaire, Netherlands. October 16, 2015.

Pollock NW. Advancement and challenges in rebreather diving. UHMS Canada, Toronto, Ontario. October 25, 2015.

Pollock NW. When pressure changes are not about diving. UHMS Canada, Toronto, Ontario. October 25, 2015.

Potts L. Women in Diving - the Risk of Injury. NACD Workshop, Lake City, FL. October 10, 2015.

Buzzacott P. The "Risk" of Diving Injuries. Diving Equipment and Marketing Association, Orlando, FL. November 04 & 06, 2015.

Buzzacott P. Causes of Death in Quarries, Lakes and Dive Parks. Diving Equipment and Marketing Association, Orlando, FL. November 04 & 06, 2015.

Buzzacott P. DAN Incident Reporting System – Murphy's Law. Diving Equipment and Marketing Association, Orlando, FL. November 05 & 07, 2015.

Buzzacott P. Cave Diving Fatality Prevention. Diving Equipment and Marketing Association, Orlando, FL. November 05 & 07, 2015.

Denoble PJ. PFO and fitness to dive. DAN/UHMS consensus workshop, Diving Equipment and Marketing Association, Orlando, FL. November 04 & 06, 2015.

Martina SD. Unravelling the intricacies of immersion pulmonary edema. Diving Equipment and Marketing Association, Orlando, FL. November 04 & 05, 2015.

Martina SD. Effect of diving on the eye. Diving Equipment and Marketing Association, Orlando, FL. November 05 & 07, 2015.

Nochetto M. Infectious Souvenirs of Adventure Dive Trips: There are many more friends beyond Malaria (EN). Diving Equipment and Marketing Association, Orlando, FL. November 4-7, 2015.

Nochetto M. Undersea Hunting. Do You Know What You Are Eating? (EN). Diving Equipment and Marketing Association, Orlando, FL. November 4-7, 2015.

Nochetto M. One Does Not Just Squeeze Bubbles: Beyond Boyle's Law (EN). Diving Equipment and Marketing Association, Orlando, FL. November 4-7, 2015.

Nochetto M. Lessons from MSCC (EN). Diving Equipment and Marketing Association, Orlando, FL. November 4-7, 2015.

Nochetto M. Hazards for the Epicurean Diver (EN). Diving Equipment and Marketing Association, Orlando, FL. November 4-7, 2015.

Nochetto M. Air Has a Post-Narcotic Effect on Me (EN). Diving Equipment and Marketing Association, Orlando, FL. November 4-7, 2015.

Nochetto M. Toxinological Aspects of Hazardous Marine Life (EN). Diving Equipment and Marketing Association, Orlando, FL. November 4-7, 2015.

Nochetto M. Remote Areas Injury Management (EN). Diving Equipment and Marketing Association, Orlando, FL. November 4-7, 2015.

Nochetto M. Tailoring Your Emergency Action Plan (EN). Diving Equipment and Marketing Association, Orlando, FL. November 4-7, 2015.

Pollock NW. Defensive dive profile planning. Diving Equipment and Marketing Association, Orlando, FL. November 04 & 06, 2015.

Pollock NW. Oxygen partial pressure: hazards and safety. Diving Equipment and Marketing Association, Orlando, FL. November 04 & 06, 2015.

Pollock NW. Managing decompression stress: beyond the algorithms. Diving Equipment and Marketing Association, Orlando, FL. November 05 & 07, 2015.

Pollock NW. Concerns of aging divers. Diving Equipment and Marketing Association, Orlando, FL. November 05 & 07, 2015.

Buzzacott P. Causes of Death in Quarries, Lakes and Dive Parks. Richmond Dive Club, Richmond, VA. November 10, 2015.

Pollock NW. Diving for science in Antarctica. Durham Academy (6 pre-k and kindergarten assembly). Durham, NC. November 11, 2016.

Denoble PJ. Diving injury management for EMS. 25th Annual Surviving Trauma Conference, Pensacola, FL. November 21, 2015.

Denoble PJ. Diving Injuries Management for EMS. the 25th Annual Surviving Trauma Conference. Pensacola, FL, Nov 25, 2015.

Nochetto M. Toxicidad Operativa de Gases (SP). Cozumel Scuba Fest 2016, Cozumel, QR. Mexico. December 8-14, 2015.

Nochetto M. Vida Marina Peligrosa: Lo que los líderes de buceo deben saber sobre de toxinología marina (SP). Cozumel Scuba Fest 2016, Cozumel, QR. Mexico. December 8-14, 2015.

Nochetto M. Fundamentals on Treating DCS (EN). Saba Healthcare System, Saba, NA. December 2015.

Nochetto M. Case Studies (EN). Saba Healthcare System, Saba NA. December 2015.

## APPENDIX H - RECENT RESEARCH POSTERS

**Peter Buzzacott**

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

Trout B, Buzzacott P, Denoble PJ. Recreational diving fatalities: Harvesters versus non-harvesters. Presented at the Annual Scientific Meeting of the Undersea and Hyperbaric Medicine Society, June 17-21, 2015. Montreal, Canada.

Trout BM, Denoble PJ. Divers Alert Network fatality database review for breathing gas contamination: 2004-2012. Presented at the Annual Scientific Meeting of the Undersea and Hyperbaric Medicine Society, June 19-21, 2014. St Louis, Missouri.

Ranapurwala SI, Denoble PJ. Factors affecting adherence to pre-dive checklists: A nested study. Presented at the Annual Scientific Meeting of the Undersea and Hyperbaric Medicine Society, June 19-21, 2014. St Louis, Missouri.

Mejia E, Nochetto M, Bird N, Ranapurwala S, Denoble PJ. A case series of decompression illness in Miskito fishermen divers treated in 2010 at Clinia La Bendicion. Presented at the Annual Scientific Meeting of the Undersea and Hyperbaric Medicine Society, June 15-18, 2011. Fort Worth, Texas.

Wiley JM, Kohshi K, Penney DL, Tamaki H, Davis R, Kohshi K, Ishitake T, Morimatsu Y, Satou Y, Matsuya M and Denoble PJ. Effects of Repetitive Breath-Hold Diving on Executive Brain Function in Japanese Ama Divers Evaluated Using Digitalized Clock Drawing Test. Undersea Hyperbaric Medicine Society Scientific Annual Scientific Meeting, Las Vegas, Nevada, June 9-11, 2016.

Buzzacott P, Denoble PJ. Possible central nervous system oxygen toxicity seizures among US recreational air or enriched air nitrox open circuit diving fatalities 2004-2013. Undersea Hyperbaric Medicine Society Scientific Annual Scientific Meeting, Las Vegas, Nevada, June 9-11, 2016.



# RECREATIONAL DIVING FATALITIES: HARVESTERS VERSUS NON-HARVESTERS

Brittany M. Trout; Peter Buzzacott; Petar J. Denoble  
Divers Alert Network, Durham, NC

## Introduction

- Recreational harvesting may be defined as catching marine animals such as lobster, abalone or fish for personal use while diving within recreational diving limits.
- Harvesting marine animals for personal use is popular in Canada and the USA among mainly male recreational divers.<sup>1</sup>
- Legal harvesting occurs within designated locations and at specified times of the year.
- In Florida there is a 'sport season' which lasts just two days, ahead of the regular season, which lasts eight months.
- Additional hazards harvesters face, compared with recreational non-harvesters, remain unidentified.

## Methods

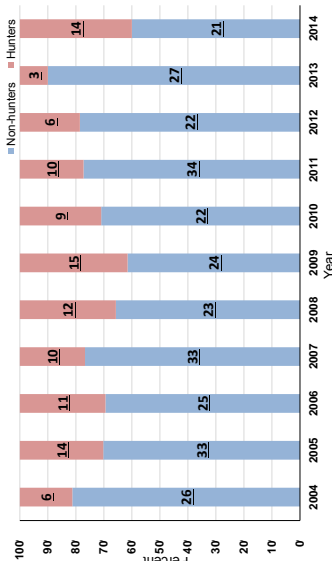
- Records for adult male divers (n=774) in the US or Canada from 2004-2014 were identified from the DAN Diving Fatality Database.
- Information is obtained from news reports, law enforcement agencies, medical examiners, witnesses and next of kin.
- Non-recreational divers and trainees were excluded, as were divers in freshwater lakes, quarries and dive parks (n=374).
- Divers engaged in harvesting (hunters, n=110, 27%) were compared with non-hunters (n=290, 73%) using SAS version 9.3.

## Results

- Of the 400 fatalities, 39 (10%) were in Canada and 361 (90%) the US.
- In the US Florida (n=51, 46%) and California (n=27, 25%) accounted for the majority of hunters (n=78, 71%).
- The two-day sport-season in Florida accounted for 22/51 (43%) of underwater hunting deaths in that state, a mean of two per year.
- There was a mean of 10 hunting fatalities per year in total (Fig 1).
- Anthropometry and dive history of hunters and non-hunters are shown in Table 1.
- At least five hunters (5%) were not certified divers, compared with two non-hunters (1%).

**Table 1. Recreational divers (n=400) anthropometry and dive history by hunting status**

	Hunters (n=110)	Non-Hunters (n=290)	Overall (n=400)
<b>Anthropometric</b>			
Age (years)	46 (13)	49 (12)	48 (12)
BMI (kg m <sup>-2</sup> )	30 (5)	29 (6)	30 (6)
Marital status	n (%) single	142 (49)	198 (50)
<b>Dive History</b>			
>61 dives experience	36 (33)	76 (26)	112 (28)
Dives in last year	16 (15)	24 (31)	22 (27)
Max depth fatal dive	67 (51)	80 (66)	76 (62)
msw (SD)	20 (16)	24 (20)	23 (19)



**Figure 1. Fatalities of non-hunters (n=290) vs. hunters (n=110) by year, with n underlined**

- Compared with non-hunters, the following were more common among hunters:
  - boat diving (n=92/110, 84% vs. n=167/290, 58%, p=0.0002)
  - solo diving (n=28/110, 25% vs. n=36/290, 12%, p=0.008)
  - night diving (n=13/110, 12% vs. n=8/290, 3%, p=0.001)
- Of the divers who were low-on or out-of breathing gas, n=20/110 (18%) were hunters and n=30/290 (10%) non-hunters (OR=1.9, p=0.04).
- Surface supply was more common among hunters (n=4, 4% vs. n=3, 1%), as was basic/open water certification (n=13, 12% vs. n=30, 10%).
- Fourteen hunters (13%) wore swim-suits or dive-skins compared with 7 (2%) non-hunters.
- Causes of death are shown in Table 2.
- As shown, hunters account for 28% of the dataset and yet they represent only 18% of cardiac deaths but 50% where the body was not recovered.

**Table 2. Cause of death by hunting status**

Cause of Death	Hunters n (Row %)	Non-Hunters n (Row %)	Overall n (Column %)
Drowning	45 (34)	87 (66)	132 (33)
Missing	44 (24)	141 (76)	185 (46)
Arterial gas embolism (AGE)	7 (32)	15 (68)	22 (6)
Body Not Recovered	6 (50)	6 (50)	12 (3)
Cardiac	5 (18)	23 (82)	28 (7)
Unknown/Unspecified	2 (15)	11 (85)	13 (3)
Propeller	1 (100)	0 (0)	1 (0)
Hypoxic Brain Injury	0 (0)	3 (100)	3 (1)
Decompression sickness	0 (0)	3 (100)	3 (1)
Lightning strike	0 (0)	1 (100)	1 (0)
<b>Overall</b>	<b>110 (28)</b>	<b>290 (72)</b>	<b>400 (100)</b>

## Discussion

- Hunters were younger on average, compared with non-hunters, and there were fewer cardiac causes of death than expected in hunters.
- Hunters more commonly ran low-on or out-of breathing gas and hunters had slightly more AGE related causes of death than expected.
- Solo diving was more common in hunters and the proportion of cases where the body was not recovered was higher than expected.
- Propeller injuries were not common among diving fatalities but such injuries may result in more hospital admissions than deaths.
- Fatalities involving hunters showed a higher prevalence of the fatal dive being at night than among non-hunting fatalities. This is the converse to what is found in other parts of the world where lobster are permitted to be hunted only during daylight hours.
- Though the numbers were small (n=8), hunters included a higher proportion of uncertified divers (5% vs. 1%), and elsewhere uncertified divers have breached more safety rules than certified divers.<sup>2</sup>

## Limitations

- This study design is retrospective and likely did not capture all fatalities in the US and Canada during the study period.
- Given the delay between death and details being obtained, many case details were not able to be subsequently confirmed.
- No denominator has yet been established in order to estimate the absolute risk of dying while hunting underwater.
- Compared with non-hunters, however, some relative risk indicators suggest possible targets for safety interventions.

## Conclusions

- Hunters and non-hunters share similar anthropometry but they differ in the circumstances of their death, therefore the act of hunting may influence cause of death.
- The hazards faced by diving hunters appear modifiable.
- Most fatalities involving hunters occurred in Florida and California, therefore safety interventions should target those two states.

## Future Work

- In addition to fatality data collection, injury data (incident reports, diver surveys, Emergency Department admissions, etc) should be collated, both to better identify hazards particular to hunting and to quantify the burden of diving injuries attributable to underwater hunting.
- Public safety information targeting hazards associated with hunting lobster should be marketed ahead of the sport-season in Florida.
- The impact of making hunting licenses valid only when accompanied by proof of certification (e.g., a C-card) should be trialed and evaluated.

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# Divers Alert Network Fatality Database Review For Breathing Gas Contamination: 2004-2012

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## Introduction

- Breathing gas contamination appears to be rare in recreational diving but is suspected to be under-reported.
- Contamination can occur due to improper compressor maintenance.
- combustion engine exhaust fumes are near the compressor intake while filling tanks.
- compressor lubricants deteriorate.
- Contaminants may be present without the diver being aware and can cause death.
- cause of death in such cases may be established if breathing gas is analyzed.
- The objective of this review was to establish how often breathing gas analysis was included in scuba fatality investigations and the implication of contaminants in dive fatality cases.

## Methods

- We reviewed fatality cases in the Divers Alert Network (DAN) fatality database from 2004-2012.
- Database includes cases involving U.S. and Canadian recreational divers. Information is obtained from news reports, law enforcement agencies, medical examiners, witnesses and the decedent's next of kin (NOK).
- Determination of contamination was based on available gas analysis results from accredited laboratories, autopsy findings investigative reports and NOK.
- Compressed breathing gas testing standards were used to confirm contamination for reported values (Table 1).

Table 1. Compressed Breathing Gas Analysis Standards

Components	CGA Grade E <sup>3</sup>	CGA-E Modified for Nitrox <sup>2,3</sup>	IANTD Oxygen Compatible Air <sup>2,4</sup>
O <sub>2</sub> (% vol)	20-22	As required	20-22
CO (ppmv)	10	10	2
CO <sub>2</sub> (ppmv)	1000	1000	1000
Volatile Hydrocarbons (ppmv)	25	25	25
Oil Particulate (mg/m <sup>3</sup> )	5	0.1	0.1
Water Content (ppmv)	24	N.S.	N.S.
Odor	N.O.	N.O.	N.O.

N.S.= Not specified N.O.=Not objectionable

## Compressed Breathing Gas Standards

- Compressed Gas Association (CGA) grade E specific to scuba industry for compressed air.
- Current version of Grade E standard is CGA G-7.1-2011.
- The US Navy and OSHA base their industrial breathing air standards on CGA G-7.1 Grade D criteria<sup>1</sup>.
- Compliance with standards is mostly self-regulated by dive industry.
- dive training and certification agencies.
- standards vary worldwide.

## Results

- 762 fatality cases were reviewed.
- 640 cases (84%) unknown if breathing gas analysis was conducted.
- 122 cases (16%) breathing gas analysis was conducted (Figure 1).

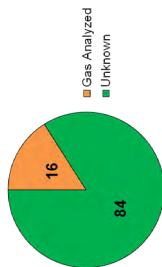


Figure 1. Breathing gas analysis conducted in fatality cases (n=762)

- Gas analysis results not available in 34 cases (28%).
- 78 cases (64%) reported no significant contaminant levels present.
- 10 cases (8%) reported positive findings including CO (n=3), odor (n=3), hypoxic gas mix with methane (n=1), CO<sub>2</sub> (n=1), oil particulate (n=1), and unidentified (n=1) (Figure 2).

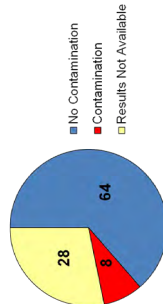


Figure 2. Contamination detected by gas analysis (n=122)

- CO contamination was likely a contributing factor to cause of death in three cases.
- Decedents used tanks from the same source (Case 2 & 3).
- Divers who obtained tanks from the same source as decedents experienced headache and nausea symptoms.
- One case of hypoxic gas mix and methane contamination (Case 4).

- Case 1** 40 yo female, certified and experienced. Maximum depth 75 fsw (23 msw). According to news reports, divemaster and dive buddy surfaced with difficulty breathing, dizziness and chest pain. CO contamination was suspected by investigators. Air testing reported lethal levels of CO according to NOK. Cause of death reported as asphyxia due to drowning.
- Case 2** 45 yo male, experienced, solo cave dive in Mexico. Body was retrieved, investigation reported tanks were contaminated with lethal doses of CO.
- Case 3** Male, unknown age, experienced. Cave diving with buddy in Mexico. Lost consciousness and brought to surface by buddy. According to news reports, gas analysis detected lethal levels of CO.
- Case 4** 16 yo male, open water certified, inexperienced. Body recovered in 72 fsw (22 msw). Nitrogen and methane exceed CGA standards according to investigative report. Hypoxic O<sub>2</sub> and CO<sub>2</sub> levels reported. Tank was not properly purged of mixed gas before filled with air.

## Discussion

- The recreational diving industry is self-regulated.
- Responsibility of dive operators, compressor operators and divers to ensure safe breathing gas.
- According to the Florida Department of Health, since 1999 no submitted breathing gas analysis reports show any evidence of contamination.<sup>5</sup>
- Evidence of contamination may exist in other locations.
- Methane is non-toxic but may be an asphyxiant where oxygen is reduced to below 16%.<sup>6</sup>

## Conclusions

- Breathing gas analysis findings are infrequently included in scuba fatality investigations.
- Causal gas contamination is rarely implied.
- Excluding contamination as a contributing factor through gas analysis increases the confidence of other established root causes.
- Breathing gas analysis findings may reveal unsafe gas mixing.
- Breathing gas contamination may be more common in non-fatal dive incidents.

## Recommendations

- Breathing gas analysis should be a routine procedure in systematic investigations of diving fatalities.
- Increase access to autopsy & investigative reports.
- Include values of gas analysis results in reports.
- Further research is needed to understand the scope of the issue in both fatal and non-fatal dive incidents.
- Maintain awareness of breathing gas quality.

## Education & Prevention Efforts

- DAN online incident reporting system.
- Articles and case summaries.
- Assist divers with breathing gas analysis testing.



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## Factors affecting adherence to pre-dive checklists: A nested study

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### BACKGROUND

- The importance of using checklists for injury prevention is well established.
- The use of pre-dive checklists in scuba diving may prevent diving-related injuries and fatalities.
- Prevalence of pre-dive checklist use in recreational diving is very low.
- For the promotion of checklists, it is vital to identify the divers who adhere and those who do not adhere to pre-dive checklist when provided.
- Identifying target groups will allow developing strategies for promoting checklist use.

### OBJECTIVE

To evaluate the factors associated with adherence to pre-dive checklist in recreational scuba divers

### DATA COLLECTION METHODS

- Nested prospective observational study
- Parent Study - cluster randomized trial to study the effect of using a pre-dive checklist (investigator developed), on the incidence of scuba diving mishaps among recreational scuba divers.
- Data was used only from the intervention group of the parent study
- Study conducted at four locations in the Atlantic and Caribbean
- Intervention group data collected over 40 location-days

### ELIGIBILITY

Minimum age – 18 years, valid diver certification, planning to dive on the day of participation, deemed fit-to-dive by the dive operator

### WHO WAS ADHERENT?

Three criteria to determine adherence; all must be met

1. Must report starting tank pressure of the first dive on the checklist
2. Must write a pre-dive plan on the checklist
3. Must check at least 10 checkboxes on the checklist

### STATISTICAL METHODS

- Descriptive statistics are reported using tables and frequencies.
- Exploratory logistic regression models to evaluate the adherence odds
- Generalized estimating equations to address the non-independence of adherence among participants diving on the same day at the same location

Table 1: Distribution of participant characteristics

Variables	Categories	Adherent	Non-adherent	Total	%
Sex	Male	291	117	408	66.1
	Female	139	70	209	33.9
Age	18-35 years	120	78	198	32.1
	> 35 years	310	109	419	67.9
Race	White	407	172	579	93.8
	Non-White*	23	15	38	6.2
Location	North Carolina	81	60	141	22.8
	Caribbean	349	127	476	77.2
Average	0-5 dives	173	91	264	42.8
	6-10 dives	81	23	104	16.9
Yearly Dives	11-15 dives	44	21	65	10.5
	16-20 dives	48	16	64	10.4
Written self-checklist No	>20 dives	84	36	120	19.4
	Yes	31	5	36	5.8
All participants		430 (69.7%)	187 (30.3%)	617	100

Table 2: Odds ratio for factors influencing adherence to pre-dive checklist

Variables	Categories	Adherence Odds ratio (95% CI)	
		Univariate	Multivariate
Self-Checklist (ref= None)	Written	2.67 (1.05, 6.74)	2.48 (0.95, 6.44)
Race (ref = White)	Non-White	0.59 (0.30, 1.11)	0.54 (0.27, 1.09)
Sex (ref=Male)	Female	0.81 (0.57, 1.15)	0.77 (0.54, 1.12)
Age (ref=18-35 years)	> 35 years	1.86 (1.31, 2.64)	1.67 (1.15, 2.42)
	6-10	1.76 (1.03, 2.99)	1.87 (1.09, 3.21)
Average yearly dives (ref=0-5 dives)	11-15	1.20 (0.67, 2.12)	1.17 (0.62, 2.20)
	16-20	1.74 (1.05, 2.89)	1.59 (0.95, 2.67)
	> 20	1.24 (0.78, 1.96)	1.14 (0.69, 1.89)
Location (ref = Caribbean)	North Carolina	0.46 (0.23, 0.91)	0.42 (0.20, 0.85)

### RESULTS

- > 30% participants were non-adherent
- Divers own pre-dive checklist use increased odds of adherence to the intervention checklist by 150%
- Older age (> 35 years) increased odds of adherence by 70%
- Odds of adherence were lower among non-white divers by 45% as compared to Whites
- Odds of adherence were lower among NC divers by 58% as compared to Caribbean divers.

### CONCLUSIONS

- Factors associated with increased odds of adhering to the intervention checklist – divers own pre-dive checklist use, older age (> 35 years), higher average annual dives (> 5 dives/ year)
- Factors associated with decreased odds of adhering to the intervention checklist – female sex, non-white race, diving location (NC vs Caribbean)

### RECOMMENDATIONS

- Importance of pre-dive checklists must be explained to divers more comprehensively
- Divers should be targeted at an early age and older divers should lead by example
- Pre-dive checklists should become an integral part of diving safety culture

### ACKNOWLEDGEMENTS

- DAN Summer 2012 interns – Patrick Dolezal, Sam Hurley, Devon Donohue, MarieClaire Joseph
- Jeanette Moore, DAN Research Specialist
- Participating dive shops in NC, Cayman Islands, and Cozumel and participating divers

### FUNDING

- Divers Alert Network
- SOPHE CDC Injury Prevention Fellowship



## A CASE SERIES OF DECOMPRESSION ILLNESS IN MISKITO FISHERMEN DIVERS TREATED IN 2010 AT CLÍNICA LA BENDICIÓN.

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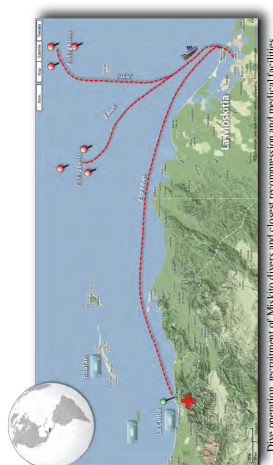
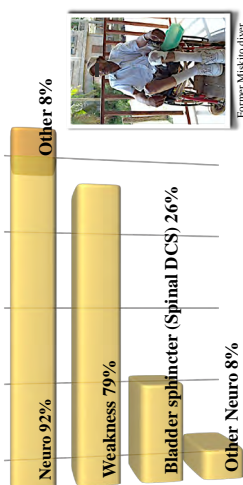
**BACKGROUND:** Miskito fishermen suffer high rates of decompression illness (DCI) while diving remotely from the nearest hyperbaric facility. Only divers with severe symptoms seek treatment. The purpose of this paper was to explore prognostic factors of outcomes in treated DCS cases.

### RESULTS:

Number of divers	123 ♂
Number of DCI cases	128
Mean age (years)	33 (20-59)
Neurological presentation	118
Motor weakness	101
Legs	65
Arms and legs	32
Arms	4
Bladder sphincter involvement	33
In-water recompression	91
Median delay to treatment	5 (1-50) days
Improvement prior to admission	57
Gross functional recovery at discharge	103
- mean HBOT	3 treatments
Residual dysfunction despite treatment	19
- mean HBOT	12 treatments
No improvement	4
Deceased	2

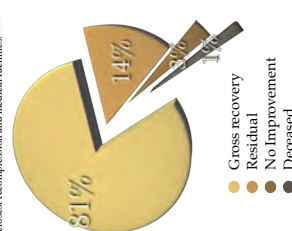


Typical houses on a Miskito village, La Modilita, Gracias a Dios, Honduras.



Former Miskito diver.

**The only significant prognostic factor of gross functional recovery at discharge was the involvement of bladder sphincter, which increased the risk of residual symptoms (OR 19, 95% CI: 7-51).**



**CONCLUSIONS:** Despite severe manifestations of DCS and long delays to standard recompression, most injured Miskito divers recovered significantly after standard HBOT. The duration of delay, the distribution of motor weakness and the natural evolution of symptoms before admission did not seem to affect the success of HBOT.



# Effects of Repetitive Breath-Hold Diving on Executive Brain Function in Japanese Ama Divers Evaluated Using Digitalized Clock Drawing Test

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## Introduction

- Traditional Ama divers have used repetitive daily breath-hold diving to harvest shellfish and seaweed off the coast of Japan and Korea for over 1,500 years. Ama divers have been reported to manifest acute neurological symptoms after a long series of breath-hold dives.
- Magnetic resonance imaging (MRI) has revealed asymptomatic cerebral lesions ("white spots") with higher prevalence in divers, including breath-hold divers, than in the general population.<sup>1,2,4</sup>
- The Montreal Cognitive Assessment (MoCA) and Clock Drawing Test (CDT) are well-tested tools used clinically to assess deficits in neurocognitive abilities.
- A digital CDT (dCDT) uses software to analyze the clocks, allowing subtle changes, such as drawing strokes and times, to be measured.
- Both a command clock and copy clock were drawn. Constructing command clock requires auditory comprehension, ability to persist in drawing, remembering task instructions and the ability to translate visuospatial information into an effective motor act. The copy clock primarily measures visuospatial perception and executive functioning.<sup>3</sup>
- Patients with less executive dysfunction (i.e. Alzheimer's disease) will improve from command to copy whereas patients with frontal system deficits (i.e. Parkinson's, Huntington's) usually have poor performance on both.
- The objective of this study was to use these clinically-developed neurological tools to test Ama divers for possible subclinical deficits in executive functioning.

## Materials and Methods

- 12 male Ama divers were tested before and after a workday of breath-hold dives using the MoCA and dCDT.
- Dives were assisted with weights.
- The dCDT consisted of a digital pen that recorded the clock drawing as it happened and stored the recordings for computer-assisted analysis.
- Clock test administration involved first commanding patients to draw the face of a clock with all numbers and set the two hands to 10 after 11. Separately, the subject then copies a pre-drawn clock model.
- Pre- and post-diving dCDT results were assessed and compared to the MoCA results.
- Due to the small sample size, repeated measures t-tests were used to analyze the data.

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## Results

- Subjects were 12 males, mean age 54 (32-65) years
- 3 subjects had medical history significant for DCI
- All 10 subjects imaged with MRI had lesions in their brain
- 6 subjects had cortical lesions
- 3 subjects had white matter lesions
- 2 subjects did not have MRI done
- The median pre-dive MoCA score was 25 (20-28) and post-dive 26.5 (21-30)
- The score was lower in older divers

Fig 2. Mean Total Drawing Time

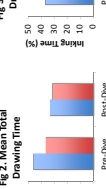


Fig 3. Mean Actual Drawing Time

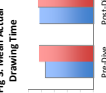


Fig 4. Mean Total Number of Strokes

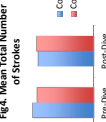
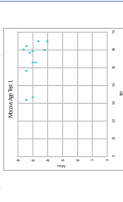


Fig 1. Mean MoCA Score vs. Age of Diver



- Divers took longer to draw the command clock than the copy clock both pre- and post-diving
- They took less time to draw both command and copy clocks on the 2<sup>nd</sup> administration (after diving)
- Total number of strokes used to draw the clock did not differ between command and copy clock pre- or post-diving

Fig 5. Pen Speed

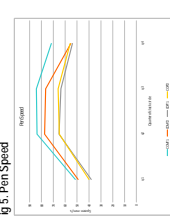
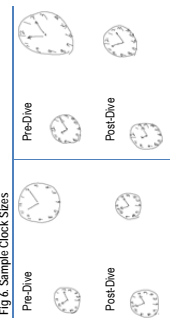


Fig 6. Sample Clock Sizes



- There was a decline in pen speed in the post-diving command clocks while copy clocks did not.

## Discussion

- MoCA:** There were significant differences for baseline MoCA score and age. Further analysis with a larger study sample will help understand age effects with diving.
- Time:** The faster total drawing time of both the command and copy clocks after diving could be due to practice effects and need to be looked at with a control group.
- Inking% = Thinking% = 100% Total Clock Drawing Time**
  - For the command clocks only, divers spent proportionately more time "inking" rather than "thinking" after diving.
  - Could be due to a reduction in thinking time due to practice effects or a slower ink speed or a combination. This is not due to drawing more since the command clocks were smaller in size and there was no difference in total strokes.
- Size:** Because copy clocks often are similar to the model in size, size effects for neurological disorders are most often noted on the command clocks, which became smaller after diving, whereas copy clocks did not. This suggests a similarity to insidiously progressive neurocognitive disorders such as Alzheimer's.
- Speed:** There was a decline in pen speed (including slower maximum speed) for post-diving command clocks with significance for Q4 ("deceleration").
  - Change in the speed of the command clocks post-dive with no change in the copy clock speed suggests that it is highly unlikely due to a simple motor speed change due to fatigue or some other general motor slowing.
  - May reflect the effect of increased cognitive demands (language and memory in addition to visuospatial and executive function) on motor speed as compared to the comparatively simpler copy task (visuospatial perception and executive function).

## Conclusions

- The cognitive changes we found on the dCDT reflect similar changes as seen in insidiously progressive neurocognitive disorders. When combined with low MoCA scores in older divers, this raises the possibility that commercial breath-hold divers may be at risk for long-term cognitive damage.
- The small sample size limits the significance of the findings but the consistency of changes indicates that the dCDT could be a useful tool to study this issue.
- With a larger study size and normal comparison group, we could look at additional measures such as decision-making, information processing, cognitive efficiency and simple/complex motor speed and could look at specific MoCA functions with respect to clock performance.
- We plan to expand the study to include a larger number of subjects and a proper control group of non-divers.



# Possible central nervous system oxygen toxicity seizures among US recreational air or enriched air nitrox open circuit diving fatalities 2004-2013

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## Introduction

- Oxygen enriched air, popularly known as "enriched air nitrox" (EAN) includes blends of nitrogen and oxygen that contain up to 40% oxygen.
- At any given depth the partial pressure of oxygen is higher when breathing EAN rather than air and increased partial pressures of oxygen are a cause of central nervous system (CNS) oxygen toxicity seizures in both scuba divers and patients undergoing hyperbaric oxygen therapy.
- Susceptibility varies between and within individuals and is increased with immersion, exercise, low temperature or when carbon-dioxide is elevated.
- The National Oceanic and Atmospheric Administration (NOAA) adopted EAN use for scientific diving in 1978 and the first NOAA EAN decompression tables were published in the following year.
- The first diver certification program for recreational EAN diving was released in 1985. At that time concerns were expressed that many EAN divers might suffer CNS oxygen toxicity seizures and drown.
- In 1995/96, ten years after recreational EAN diving first appeared, two large recreational diver training agencies, the Professional Association of Diving Instructors (PADI) and the British Sub-Aqua Club (BSAC) both commenced EAN diver training.
- By the year 2000 US recreational diver training agencies had certified more than 30,000 EAN instructors, over 230,000 divers and more than two and a half million EAN dive cylinder fills had been sold.
- Among 46,801 recreational open circuit dives recorded by the Divers Alert Network (DAN) between 1994-2004, 9,935 (21%) were made breathing EAN.
- Latest figures from the Sports & Fitness Industry Association (SFIA) suggest more than three million Americans participated in scuba diving once or more in 2014.
- Without knowing what proportion of their dives were made with EAN as the primary breathing gas, it is now likely of the order of hundreds of thousands of dives each year.

## Methods

- The DAN diving fatality database was searched for possible oxygen toxicity cases. US fatalities on open-circuit occurring between 2004-2013, where the breathing gas was either air or EAN, were identified.
- Causes of death and the preceding circumstances were examined by a medical examiner trained and experienced in diving autopsies.
- Case notes were searched for the words "seizure" or "toxicity" and identified cases were reviewed for witnessed seizures at elevated partial pressures of oxygen.
- Our primary research question was: did the predictions of widespread CNS oxygen toxicity seizures among recreational divers come to pass? We also looked for differences between EAN or air diving fatalities.
- Logistic regression with breathing gas as the outcome variable was used to test differences for significance which was accepted at  $p < 0.05$ .

## Results

- The dataset comprised 344 air divers (86%) and 55 divers breathing EAN (14%).
- Age in years ranged from 14-78 among air divers and 20-66 for EAN.
- Body mass index (BMI) ranged from 14-50 in air divers and 18-43 for EAN divers.
- Anthropometry and dive factors are presented in Table 1.

**Table 1. Anthropometry and dive factors, by gas breathed**

Anthropometry	Air n=344	EAN n=55	Overall n=399	Significance (P-value)
Age (yrs)	x (SD) 47 (13)	50 (10)	47 (13)	0.14
Number male	n (%) 279 (81)	44 (80%)	323 (81)	0.85
BMI* kg.m <sup>-2</sup>	x (SD) 29 (6)	28 (5)	29 (6)	0.44
Diving Characteristics				
Number days diving	x (SD) 1.2 (0.5)	1.1 (0.4)	1.2 (0.5)	0.40
Number dives that day	x (SD) 1.6 (1.2)	1.7 (1.3)	1.6 (1.2)	0.71
Max depth fatal dive	x (SD) 18 (15)	28 (12)	20 (15)	<0.0001
Environment				0.39
Ocean/Sea	n (%) 247 (72)	45 (82)	292 (73)	-
Lake/Quarry	n (%) 61 (18)	5 (9)	66 (17)	-
River/Spring/Cave	n (%) 22 (6)	5 (9)	27 (7)	-
Dive Platform				0.001
Boat	n (%) 183 (53)	43 (78)	226 (56)	-
Shore	n (%) 150 (44)	6 (16)	159 (40)	-
Pier	n (%) 11 (3)	0 (0)	14 (4)	-

## Results continued...

- EAN divers were neither more nor less likely ( $p=0.23$ ) than air divers to have been diving in colder or warmer water.
- The source of the diving equipment was known in 255 cases. The equipment was personally owned in 130/207 (63%) of cases where the breathing gas was air and 36/43 (84%) of EAN cases ( $p=0.006$ ).
- The most common causes of death were drowning ( $n=179$ , 45%), cardiac causes ( $n=28$ , 7%) and arterial gas embolism ( $n=25$ , 6%).
- The mean oxygen content in EAN was 31% (SD 3%, range 24-40%).
- EAN divers' fatal dives were deeper than air divers', (28 msw vs. 18 msw,  $p<0.0001$ ).
- Of the 249 cases where a cause of death was established, 218 (88%) breathing air and 31 (12%) breathing EAN, only three EAN divers were considered to have possibly died following CNS oxygen toxicity seizures at depth (ppO<sub>2</sub> 132, 142 and 193 kPa), and only one of those was considered likely (ppO<sub>2</sub>=193 kPa).

## Case #1

- An experienced diving instructor had filled his primary tanks with EANX32 (EAN containing 32% oxygen) for a planned dive which then did not take place. Weeks later an opportunity presented to dive to 49 msw where the partial pressure of oxygen breathed would have been 193 kPa. The diver's computer recorded his descent to 49 msw, a slow ascent to 40 msw depth and he was then observed by his two students to suffer a seizure and fall back down to 49 msw depth, also recorded by the diving computer. The investigation concluded the diver, a certified and very experienced technical diver, may have forgotten the contents of his primary cylinders and dived assuming he was breathing air.

## Discussion

- Diving fatalities where the primary breathing gas was EAN were of the same mean age, sex and BMI as fatalities where the divers were breathing air. They had been diving for the same number of consecutive days, made the same number of dives on the fatality day but EAN divers dove significantly deeper than air divers during their last dive, 28 msw vs 18 msw,  $p<0.0001$ .
- There was no difference between air and EAN diving fatalities in the environment dived in, nor in the temperature of the water, but EAN divers were more likely to have been diving from a boat and less likely than air divers to have been diving from shore ( $p=0.001$ , Table 1).
- Compared with air divers, EAN divers were also more likely to have been diving in equipment they personally owned ( $p=0.006$ ).
- We may speculate that divers with higher ownership of dive equipment and greater access to diving from boats might have higher socioeconomic status (SES) but we may never know with any degree of certainty if this is the case.

## Limitations

- There is no diagnostic test with high specificity for having suffered a CNS oxygen toxicity seizure. The diagnosis usually relies upon a witnessed seizure while (or soon after) breathing a partial pressure of oxygen above 142 kPa.

## Conclusions

- Despite wariness of EAN three decades ago, our analysis of recreational diving fatalities in the US over 10 years found just one death likely from CNS oxygen toxicity among EAN divers.
- A further two possible, though unlikely, cases were also found.
- Determining causes of death among divers often involves a degree of uncertainty and 150 cases in this study had no cause of death available.
- Even so, fears of commonplace CNS oxygen toxicity seizures while EAN diving have not apparently been realized.

## APPENDIX I. GLOSSARY

Neal W. Pollock

### Absorbent (rebreather)

Chemical compound used to remove carbon dioxide from breathing gas. See “Scrubber.”

### Acetaminophen

Tylenol, paracetamol, N-acetyl-p-aminophenol, APAP. A non-prescription drug that is used as an alternative to aspirin to relieve mild pain and to reduce fever.

### Adult Respiratory Distress Syndrome (ARDS)

Severe inflammation of the alveoli (air sacs) of the lungs, inhibiting gas exchange, and carrying a high threat to life.

### Advair

Prescription drug that prevents the release of substances in the body that cause inflammation. It is common used to prevent asthma attacks and flare-ups or worsening of chronic obstructive pulmonary disease (COPD) associated with chronic bronchitis and/or emphysema. Advair contains the steroid fluticasone and the bronchodilator salmeterol. Salmeterol works by relaxing muscles in the airways to improve breathing.

### Aerobic Capacity ( $\text{VO}_2 \text{ max}$ )

The maximal amount of oxygen that can be consumed per unit of time. Determined through a short, graduated test to exhaustion while expired gases are captured and analyzed. Often reported in weight-indexed units of milliliters of oxygen consumed per kilogram body weight per unit time ( $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ).

### Agonal Breathing

An abnormal pattern of breathing characterized by sporadic gasps with audible effort. Possible causes include cerebral ischemia and severe hypoxia. Agonal breathing often progresses to complete apnea and death.

### Albuterol

A prescription drug (also known as salbutamol) used to prevent and treat wheezing and shortness of breath caused by breathing problems (e.g., asthma, chronic obstructive pulmonary disease). It is also used to prevent asthma brought on by exercise. Albuterol belongs to a class of drugs known as bronchodilators. It works in the airways by opening breathing passages and relaxing muscles. Nervousness, shaking (tremor), mouth/throat dryness or irritation, cough, dizziness, headache, trouble sleeping, or nausea may occur. Serious side effects include fast/pounding heartbeat, muscle cramps/weakness. Rare but very serious side effects include chest pain and irregular heartbeat. Rarely, this medication has caused severe, sudden worsening of breathing problems/asthma (paradoxical bronchospasm).

### Alternobaric Vertigo

Dizziness and disorientation resulting from unequal pressures in the two middle ears. Usually transient.

### Ambiguous DCS

A case where the diagnosis of DCS is not certain; for example, a case with sufficient decompression exposure but minimal, atypical symptoms or symptoms of short duration that spontaneously resolve.

### Antiemetic

A drug that prevents or treats nausea and vomiting, typically used to treat motion sickness.

### Antihistamine

Drug that may be part of some over-the-counter (OTC) medicines for allergies and colds. Some antihistamines cause drowsiness. See “Over-the-Counter.”

**Annual Fatality Rate (AFR)**

The annual fatality rate is a count of deaths occurring within one year in a specified population (incidence) divided by the number of persons in the specified population (the denominator). AFR is usually expressed as the number of deaths per 10,000 persons or per 100,000 dives.

**Arterial Gas Embolism (AGE)**

Gas in the arterial circulation. In divers this may be caused by a sudden reduction in ambient pressure, such as a rapid ascent without exhalation that causes over-pressurization of the lung and pulmonary barotrauma. The most common target organ is the brain, and the usual signs and symptoms include the rapid (<15 min) onset of stroke-like symptoms after reaching the surface.

**Arterionephrosclerosis**

Patchy, wasting scarring of the kidney due to narrowing of the lumen (cavity) of the large branches of the renal artery.

**Aspiration**

The drawing of a foreign substance, such as water or gastric (stomach) contents, into the respiratory tract during inhalation.

**Ataxia**

A gross lack of coordination of muscle movements. Examples include: unsteady gait (walk), tendency to stumble, slurred speech, difficulty with fine-motor tasks (e.g., buttoning a shirt), slow eye movements, and difficulty swallowing.

**Atherosclerosis**

Thickening and hardening of the arteries caused by the accumulation of plaque.

**Atmosphere (atm)**

Measure of atmospheric pressure indexed to the normal conditions at sea level. Normal sea level pressure is 1.0 atm, 1.013 bar, 14.695 pounds per square inch, 101.3 kilopascals or 760 mm Hg.

**Atmosphere Absolute (ATA)**

Ambient pressure, including the barometric pressure of the air above the water.

**Auscultation**

The act of listening for sounds made by internal organs, for example, the heart and lungs, to aid in diagnosis.

**Automated External Defibrillator (AED)**

A portable electronic device that automatically assesses patients for life-threatening cardiac arrhythmias (dysrhythmias) of ventricular fibrillation and ventricular tachycardia. If identified, the device can be activated to provide a shock to interrupt the dysrhythmia and allow the heart to reestablish an effective rhythm. The device will not recommend a shock in the absence of a target dysrhythmia.

**Barotrauma (BT)**

A condition caused by a change in ambient pressure in a gas-filled space due to the effects of Boyle's law. When gas is trapped in a closed space within the body, the gas will be compressed if the depth increases and will expand if the depth decreases. Barotrauma injuries of descent include ear squeeze, tympanic membrane rupture or sinus squeeze. Injuries of ascent include pulmonary barotrauma, which can result in air embolism, pneumothorax or pneumomediastinum. See "Boyle's Law."

**Benzodiazepine**

A class of drugs that act on the central nervous system as tranquilizers, such as Librium and Valium.

**Body Mass Index (BMI)**

BMI is measure of body weight:height proportionality used to predict body composition. It is computed by dividing body weight in kilograms by the squared height in meters. BMI is often used as a convenient surrogate for actual body composition measures. Categorization by BMI (in kg·m<sup>-2</sup>): <18.5 = underweight; 18.5 to <25.0 = normal; 25.0 to <30.0 = overweight; 30.0 to <35.0 = grade 1 obesity; 35.0 to <40.0 = grade 2 obesity; and ≥40.0 = morbid obesity.

**Bounce Dive**

Any dive where the diver returns to the surface with little or no decompression. This is opposed to a saturation dive, where decompression can require many days, depending on the depth.

**Boyle's Law**

Under conditions of constant temperature and quantity, there is an inverse relationship between the volume and pressure for an ideal gas. Volume increases as pressure decreases and vice versa.

**Bradycardia**

Unusually slow heart rate.



**Breathing Bag**

See "Counterlung."

**British Sub-Aqua Club (BSAC)**

The club-based organization that serves as the governing body of sport diving in the United Kingdom.

**Buoyancy Compensator (BC)**

Device used to regulate buoyancy during diving activity. Necessary given the buoyant changes associated with gas compression and expansion.

**Carbon Monoxide (CO) Poisoning**

Carbon monoxide binds to hemoglobin 200-250 times more effectively than oxygen, effectively reducing the oxygen carrying capacity of the blood.

**Cardiomegaly**

Enlargement of the heart, either due to thickened heart muscle or an enlarged chamber.

**Cardiopulmonary Resuscitation (CPR)**

Treatment protocols employed when a person's heart and/or breathing stops.

**Catalina Oxygen Treatment Table**

An 11:52 h:min therapeutic recompression protocol that employs oxygen breathing with air breaks to treat severe decompression sickness. The protocol employs a maximum pressure equivalent to a depth of 60 fsw (18 msw), with a second step at 30 fsw (9 msw). Conceptually, it is a super-extended US Navy Treatment Table 6.

**Cause of Death (COD)**

The medically determined reason for death. This is often distinct from the factors leading to the situation in which death occurred.

**Cerebrovascular**

Pertaining to the blood vessels of the brain.

**Channeling (rebreather)**

Improper operation of a scrubber bed that allows passage of gas without effective removal of carbon dioxide. May be caused by scrubber material compression or inadequate packing.

**Chi Square (statistics)**

A non-parametric statistical test that compares outcome patterns expected by chance with outcome patterns that are observed.

**Chokes**

Pulmonary decompression sickness. Respiratory distress after a dive characterized by sore throat, shortness of breath, and/or the production of pink, frothy sputum. The cause of chokes is poorly understood but may result from low-pressure pulmonary edema resulting from large quantities of bubbles in the venous circulation that damage the cells of the blood vessel wall leading to pulmonary capillary leakage, circulatory blockage and respiratory dysfunction due to impaired gas exchange.

**Cholelithiasis**

Formation of gallstones.

**Cholesterolosis**

An intracellular accumulation of lipids (cholesterol). Sometimes associated with inflammation of the gallbladder (cholecystitis) and gallstones (cholelithiasis). At gross examination, 1-2 mm yellow micropolyps contrast the red aspect of the surrounding mucosa, explaining the term "strawberry gallbladder."

**Ciguatera**

Poisoning caused by the ingestion of marine fish with flesh contaminated by dinoflagellate neurotoxins.

**Clonus**

An abnormal form of movement marked by rapid succession of contractions and relaxations of a muscle.

**Closed-Circuit Rebreather (CCR)**

A breathing set that delivers oxygen and recycled gas from which carbon dioxide has been chemically removed from the expired breath.

**Computed Tomography (CT)**

Medical imaging technique that uses a large series of two-dimensional X-ray scans to generate detailed three-dimensional images.

**Coronary Artery Disease (CAD)**

A disease with many causes resulting in the thickening, hardening and narrowing of the medium to large-sized arteries of the heart.

**Counterlung (rebreather)**

The flexible compartment of a rebreather that serves as a volume reservoir for the breathing diver.

**Cyanosis**

Appearance of a blue or purple coloration of the skin or mucous membranes due to the tissues near the skin surface having low oxygen saturation.

### **Decompression Dive**

A dive that requires decompression stops during ascent; limits vary with the dive tables or computer model used.

### **Decompression Illness (DCI)**

The broad term that encompasses both decompression sickness (DCS) and arterial gas embolism (AGE). DCI is commonly used to describe any disease caused by a reduction in ambient pressure. It is used because the signs and symptoms of DCS and AGE can be similar and because recompression is the treatment for both.

### **Decompression Sickness (DCS)**

A disease caused when the total dissolved gas tension in a diver's tissue exceeds ambient hydrostatic pressure and gas bubble formation occurs and promotes biochemical effects/reactions. Symptoms may include itching, rash, joint pain, muscle aches or sensory changes such as numbness and tingling. More serious symptoms include muscle weakness, paralysis or disorders of higher cerebral function, including memory and personality changes. Death can occur from DCS, although very rarely in modern times. See "Type I DCS," "Type II DCS" and "Type III DCS."

### **Decompression Stop**

An obligatory stop in the ascent from a dive required by a decompression model. The duration and depth can vary by model. Stops are mathematically determined and may not reflect the actual decompression stress experienced by the diver. See "Safety Stop."

### **Depth-Time Profile**

See "Dive Profile."

### **Diabetes**

A disease characterized by improper production or improper use of insulin in the body. Most common form is Type II (non-insulin-dependent diabetes mellitus; NRDM), largely controllable by diet and exercise. Less common is Type I (insulin-requiring diabetes mellitus; IRDM), which demands insulin therapy.

### **Diaphoresis**

The state of sweating profusely.

### **Diluent**

Gas used in a rebreather to reduce (dilute) the fraction of oxygen in the breathing gas. See "Mixed Gas."

### **Diphenhydramine**

An antihistamine compound used for the symptomatic relief of allergies.

### **Disabling Injury**

In diving, an injury that renders a diver unable to survive in a subaquatic environment or that directly causes death.

### **Diuretic**

Agent that stimulates urine production and subsequent reduction in the body fluid volume.

### **Dive Computer**

Personal electronic device that continually measures time and pressure during a dive, calculates remaining no-decompression time according to the embedded mathematical algorithm and provides instructions for decompression as applicable. Dive computers may employ one or more of a number of mathematical models to compute decompression status. Some dive computers integrate breathing cylinder pressure to estimate time remaining for the gas supply.

### **Dive Log**

The dive log is a document maintained by divers in which relevant information about dives is recorded. The amount of information depends on personal interest of divers. See "Dive Log-7" for the computerized dive log information collected by DAN for studies of decompression safety.

### **Dive Log-7 (DL-7)**

A standard computer format for recording dive profile information that can be uploaded directly to DAN.

### **Dive Profile**

A set of depth-time-gas points describing the dive. The number of points depends on the minimal recording interval of the dive recorder and can vary from one second to one minute. A recording interval of five seconds or less provides sufficient detail for DAN studies of decompression safety.

### **Dive Recorder**

An electronic device that records depth and time during the dive. The recorder does not calculate saturation of the body with inert gas and does not provide any instruction for decompression. Some recorders are designed as "black boxes," with no visible display, while others have a display to indicate current depth and time of dive.

**Dive Safety Lab (DSL)**

A project to collect computerized dive profiles and dive outcome information, developed and conducted by DAN Europe, designed to share goals and methodology with DAN's Project Dive Exploration. See "Project Dive Exploration."

**Dive Series**

Dives conducted in rapid enough succession that they are not independent. Project Dive Exploration (PDE) defines a series as all dives not followed by 48 hours without diving or flying exposure.

**Diving Accident Report Form (DARF)**

A form used by DAN from 1987 through 1997 to collect information about injured divers treated in recompression chambers.

**Diving Injury Report Form (DIRF)**

A form used by DAN from 1998 through 2004 to collect information about injured divers treated in recompression chambers.

**Dwell Time (rebreather)**

The length of time expired gas in a rebreather remains in the carbon dioxide scrubber.

**Dysarthria**

A motor speech disorder resulting from neurological injury of the motor component of the motor-speech system. It is a condition in which the muscles that help produce speech are effectively impaired, making it very difficult to pronounce words.

**Dyspnea**

Difficulty breathing, often described as unpleasant or uncomfortable; often referred to as air hunger.

**Emergency Medical Services (EMS)**

System responsible for providing pre-hospital or out-of-hospital care by paramedics, emergency personnel, emergency medical technicians, and medical first aid responders.

**Enriched-Air Nitrox (EAN; Nitrox; Oxygen-Enriched Air)**

A nitrogen/oxygen breathing gas mixture containing more than 21% oxygen, usually made by mixing air and oxygen. The most commonly used mixture contains 32% oxygen.

**Epistaxis**

Nosebleed.

**Equivalent Air Depth (EAD)**

The underwater depth at which air would provide a similar absolute content of nitrogen to that found in a given enriched-air nitrox breathing mixture.

**Facial Baroparesis (Alternobaric Facial Nerve Palsy)**

A reversible paralysis of the facial (seventh cranial) nerve resulting from pressure introduced through the middle ear.

**Feet of Freshwater (ffw)**

A unit of pressure synonymous with depth in freshwater. Thirty-four feet of freshwater is equal to approximately 1.0 atmosphere, 1.0 bar, 14.685 pounds per square inch, or 0.01 kilopascals of pressure. The differences in density of seawater and freshwater result in small pressure differences at the same absolute depth.

**Feet of Seawater (fsw)**

A unit of pressure synonymous with depth in seawater. Thirty-three feet of seawater is equal to approximately one atmosphere, 1.0 bar, 14.685 pounds per square inch, or 0.01 kilopascals of pressure. The differences in density of sea- water and freshwater result in small pressure differences at the same depth. The fsw term is commonly used by the dive industry. For metric users, the reference is meters of sea- water (msw); 1.0 fsw = 0.3048 msw (arithmetic conversion).

**Field Research Coordinator (FRC)**

A trained volunteer who helps DAN collect data for Project Dive Exploration (PDE).

**First Aid Oxygen (FAO )**

See "Surface Oxygen Treatment"

**Fisher Exact Test (statistics)**

A non-parametric statistical test similar to Chi Square except that it calculates an exact p value; useful if the marginal is very uneven or if the value in a single cell is a very small value. Exact p values tend to be more conservative than most approximate estimates such as Chi Square or t-test.

**Flying After Diving (FAD)**

Flying after diving involves exposure of divers to a secondary decompression stress. Pressurized commercial airliners are required by law to be able to maintain the cabin altitude at 8,000 ft (2,438 m). The actual cabin pressure is typically greater than this. In one study the average was around 6,000 ft (1,800 m), approximately 80% of the atmospheric pressure at sea level. Unpressurized aircraft may reach altitudes in excess of 8,000 ft. Following diving, there can be enough residual nitrogen dissolved in the body for the secondary decompression stress of flying to cause decompression sickness. For this report, all flights within 48 hours after diving are considered “flying after diving.” Practically, divers can also be exposed to secondary decompression stress post-dive by driving to altitude.

**Freediving**

Breath-hold diving conducted while wearing a mask and some form of fin or fins. Freedivers generally dive to depth and train to increase their range. Freediving is typically conducted in open water settings. See also “Breath-Hold Diving” and “Snorkeling.”

**Gradient Factors**

Used to mathematically adjust decompression limits to a chosen degree of conservatism. They are typically applied to the Buhlmann algorithm. Gradient factors limit the fraction of M-value achieved during ascent. M-values represent the theoretical maximum allowable gas pressure computed for tissues intended to avoid bubble formation, although it is now known that bubbles commonly form below M-value. Gradient factors are assigned in two parts. For example, a 30/70 setting would require a first stop at 0.3 (or 30%) of the M-value, and then control the ascent to bring the diver to the surface at 0.7 (or 70%) of the M-value.

**Hart-Kindwall Oxygen Recompression Treatment Table**

A 2:30 h:min recompression protocol used to treat decompression sickness. Oxygen is breathed throughout, typically in a monoplace chamber. The protocol employs a maximum pressure equivalent to a depth of 60 fsw (18 msw). Decompression travel is at 1 ft·min<sup>-1</sup> (2 ft·min<sup>-1</sup> if all symptoms were mild and cleared within the first 10 min of reaching 60 fsw).

**Hazard**

A condition, event or circumstance that could lead to or contribute to an unplanned or undesirable event and cause injury or material damage.

**Health Insurance Portability and Accountability Act (HIPAA)**

US Federal legislation designed to protect the privacy and interests of individuals and their families. DAN collects dive injury and fatality information in compliance with HIPAA.

**Heliox**

See “Mixed-Gas.”

**Hematocrit**

A measure of red blood cell volume in a sample volume of blood. Normal ranges are 40-53% for males and 35-46% for females.

**Hemoptysis**

The coughing up of blood or bloody sputum from the lungs or airway.

**Hyperbaric Oxygen (HBO)**

The therapeutic administration of oxygen under conditions of substantially increased atmospheric pressure. See also “Hart-Kindwall Oxygen Recompression Treatment Table” and “US Navy Treatment Table.”

**Hypercapnia**

Condition in which the level of carbon dioxide in the blood is higher than normal.

**Hyperglycemia**

Condition in which blood glucose (sugar) is higher than normal.

**Hyperoxia**

Condition of higher-than-normal partial pressure of oxygen. In medicine, it refers to excess oxygen in the lungs or other body tissues, which can be caused by breathing air or oxygen at pressures greater than normal atmospheric pressure.

**Hyperreflexia**

A condition in which the deep tendon reflexes are exaggerated.

**Hypertension**

High blood pressure. A medical condition associated with the development of heart disease and stroke.

**Hyperventilation**

Voluntary ventilation of the lungs in excess of metabolic need (achieved by increasing depth of breaths and/or rate of breathing). Often used to lower carbon dioxide content of the bloodstream and increase breath-hold time. Excessive hyperventilation will increase the risk of loss of consciousness due to hypoxia. See “Hypoxia of Ascent.”

**Hypocapnia**

Condition in which the level of carbon dioxide of the blood is lower than normal. This state is typically produced by hyperventilation.

**Hypoglycemia**

Condition in which blood glucose (sugar) is lower than normal.

**Hypoventilation**

Ventilation of the lungs at an abnormally slow rate, not meeting metabolic needs, resulting in a net accumulation of carbon dioxide in the blood, which will drive the urge to breathe in a healthy person.

**Hypoxemia**

Condition of lower-than-normal partial pressure of oxygen in the blood. See “Hypoxia of Ascent.”

**Hypoxia**

Condition of lower-than-normal partial pressure of oxygen. May be experienced by breathing a gas mixture at the surface that was intended for a deep bottom. See “Hypoxemia” and “Hypoxia of Ascent.”

**Hypoxia of Ascent**

Unconsciousness resulting from hypoxia compounded by surfacing at the end of a breath-hold dive. The reduction in pressure associated with returning to the surface causes the oxygen partial pressure to fall faster than through metabolism of the gas alone. This condition is commonly called shallow water blackout in North America, but this term was previously used in the UK to describe a different problem. See also “Hyperventilation,” “Hypoxia,” and “Hypoxic Loss of Consciousness.”

**Hypoxic Loss of Consciousness (HLOC)**

Loss of consciousness resulting from an acute state of hypoxia.

**Immersion Pulmonary Edema (IPE)**

A shift of fluid into the alveolar space of the lung, secondary to water immersion. The cause is multifactorial;

factors that may play a role in addition to immersion include fluid loading, cold stress, suit and breathing system resistance, exercise and high gas density. The net effect is an increase in pulmonary pressure and membrane permeability, which drives fluid out of the bloodstream.

**Incidence Rate**

The number of new cases in a defined population in a given time period.

**Incident**

An event or occurrence.

**Inner Ear Barotrauma (IEBT)**

Trauma to inner ear frequently caused by a rapid rise of middle ear pressure causing an inward bulge of the round window and an outward bulge of the stapes foot plate. Implosion of the round window is possible. IEBT is usually associated with significant middle ear barotrauma.

**International Association for the Development of Apnea (AIDA)**

The Worldwide Federation for breath-hold diving, established in 1992. AIDA manages and oversees the recognition of records, organizes competitions, and promotes standards for freediving education.

**In-Water Recompression**

Practice of returning a diver back underwater as an emergency treatment of decompression sickness. Logistical and safety issues make therapeutic treatment in a recompression chamber the standard of care for decompression sickness symptoms.

**Infiltrates**

Abnormal regions of opacity (non-transparency) with poorly defined margins visible in the lung (typically seen in X-rays).

**Intracardiac**

Within the heart.

**Ischemia**

Inadequate delivery of blood to a local area due to a blockage of blood vessels in the area.



**Kruskal-Wallis (statistics)**

A nonparametric statistic used to compare three or more samples. The null hypothesis is that the groups have comparable distributions; the alternative hypothesis is that at least two of the samples differ (with respect to median). It is analogous to the F-test used in analysis of variance (parametric). While analysis of variance tests depend on the assumption of normal distribution, the Kruskal-Wallis test is not so restricted.

**Lasix**

A prescription medication, furosemide (trade name Lasix) is a commonly used as a diuretic to treat hypertension and edema.

**Lung Barotrauma**

See "Pulmonary Barotrauma."

**Mean (statistics)**

The arithmetic average calculated by taking the sum of a group of measurements and dividing by the number of measurements. See "Median."

**Median (statistics)**

The middle value in a range of numbers. Half the numbers are higher than the middle value and half are lower. The mean and median will be extremely similar if the group of numbers is normally distributed. See "Mean."

**Mediastinal Emphysema (Pneumomediastinum)**

Air that surrounds the heart (not within the heart or blood vessels). This is usually the result of pulmonary barotrauma.

**Medical Services Call Center (MSCC)**

The computerized logging system, introduced in 2006, that captures all calls, emergency and information, and emails received by the DAN Medical Services Department.

**Meniere's Disease**

A disorder of the inner ear that can affect hearing and balance. It is characterized by spontaneous episodes of vertigo, tinnitus (perception of roaring, buzzing or ringing in the ears) and hearing loss.

**Metabolic Demand**

The energetic requirement of the body; typically measured indirectly by the amount of oxygen consumed in respiration.

**Meters of Seawater (msw)**

Metric unit of length or depth; 1.0 msw = 3.28084 fsw (arithmetic conversion). See "Feet of Seawater."

**Middle Ear Barotrauma (MEBT)**

Caused by an inability to equalize middle ear pressure with that of the ambient (surrounding) pressure. The insult may occur on compression ('squeeze') or ambient pressure reduction ('reverse block'). See "Otitis Media."

**Mixed-Gas**

Any breathing gas made by mixing oxygen with other gases. Mixed-gas usually consists of oxygen plus nitrogen and/or helium. Heliox refers to helium and oxygen mixtures, nitrox to nitrogen and oxygen mixtures. Trimix refers to mixtures containing helium, nitrogen, and oxygen.

**Multi-Day Diving**

Dives spread out over a period longer than 24 hours but where the surface interval between successive dives is less than 24 hours.

**Multi-Level Dive**

A dive where the diver spends time at several different depths before beginning his or her final ascent to the surface. Usually associated with dive computers that allow a diver to ascend gradually from maximum depth while tracking the decompression status.

**Myocardial Infarction**

Heart attack. Death of some of the cells of the heart from lack of adequate blood supply resulting from constriction or obstruction of the coronary arteries.

**Myxoid Tumor**

A connective tissue tumor with a 'myxoid' background, composed of clear, mucoid substance.

**Nitrogen Narcosis**

Euphoric and anesthetic effect of breathing nitrogen at greater than sea level pressure. All gases except helium have an anesthetic effect when their partial pressure is increased. Because nitrogen is the principal component of air, its anesthetic effect is the most pronounced in divers at depth and may cause serious impairment of mental abilities. Nitrogen narcosis is often first noticed when breathing air at depths beyond 60-100 fsw (18-30 msw).

**Nitrox**

See “Enriched-Air Nitrox” and “Mixed-Gas.”

**No-Decompression Dive or No-Stop Dive**

A dive where direct ascent to the surface is allowed at any time during the dive without an obligatory decompression stop.

**Non-Steroidal Anti-Inflammatory Drug (NSAID)**

Medications used primarily to treat inflammation, mild to moderate pain, and fever.

**Normal Distribution (statistics)**

A group of numbers is normally distributed when the majority is clustered in the middle of the range with progressively fewer moving out to both extremes. The frequency plot of a normal distribution appears as the classic bell-shaped curve.

**Nystagmus**

A rapid, involuntary, and oscillatory movement of the eyeball, usually from side to side.

**Obesity**

See “Body Mass Index.”

**Otitis Externa**

Inflammation of the outer ear and ear canal. May be caused by active bacterial or fungal infection or secondary to dermatitis only with no infection. Also known as swimmer’s ear.

**Otitis Media**

Inflammation of the middle ear, in diving frequently caused by difficulties in equalizing middle ear pressure. See “Middle Ear Barotrauma.”

**Over-the-Counter (OTC)**

Medications/Drugs purchased legally without a prescription.

**Oxygen-Enriched Air**

See “Enriched-Air Nitrox.”

**Oxygen Sensor (rebreather)**

A sensor used to measure the partial pressure of oxygen in the closed-circuit.

**Oxygen Toxicity**

Syndrome caused by breathing oxygen at greater than sea level pressure. Primarily affects the central nervous system (CNS) and lungs. CNS oxygen toxicity may

come on immediately and be manifested by seizures, twitching, nausea and visual or auditory disturbances. It may occur in a highly unpredictable manner at partial pressures greater than 1.4 to 1.6 atm in an exercising diver. Pulmonary oxygen toxicity can take much longer to develop (hours) but may occur at lower partial pressures of oxygen (>0.50 atm). Pulmonary oxygen toxicity is caused by inflammation of the lung tissue, resulting in shortness of breath, cough and a reduced exercise capacity.

**p Value (statistics)**

Level of significance established to denote a significant difference in statistical tests; also known as alpha. Often set at  $p < 0.05$ .

**Paraparesis**

Partial paralysis of the lower limbs.

**Paresthesia**

Numbness or tingling of the skin; a common symptom of DCS in recreational divers.

**Partial Pressure**

The pressure exerted by a single component gas, typically in a mixture of gases.

**Patent Foramen Ovale (PFO)**

An opening between the right and left atria of the heart. Normally closed and sealed by tissue growth after birth, almost 30% of the adult population retain some degree of patency (openness). ‘Probe patency’ describes the ability to work a blunt probe through the opening during autopsy. Such openings may be small and functionally irrelevant.

‘Physiologic patency’ describes an opening large enough to allow meaningful flow of blood directly between the two chambers. A small portion of those with a PFO will have the highest degree of patency. Blood passing from right to left through a PFO bypasses lung filtration. Any bubbles present in such blood would be distributed throughout the body, potentially increasing the risk of serious decompression sickness if the bubbles impinged upon sensitive tissues. Some divers investigate the option of medical closure of PFOs. The risk of PFO in divers can also be mitigated by conservative dive profiles that do not produce bubbles.

**Paua**

A large, edible abalone found in New Zealand.



### **Perceived Severity Index (PSI)**

A measure of the severity of decompression injury.

### **Pleural Space**

The small potential space between the parietal and visceral layers of the pleura that lines the thoracic cavity. It is a potential space since there is no actual space, instead it is filled with a lubricating fluid that reduces the friction between the pleural layers as the lungs expand and contract.

### **Pneumomediastinum**

See “Mediastinal Emphysema.”

### **Pneumothorax**

A collection of gas in the pleural space (the fluid-filled potential space surrounding the lungs), which results in the collapse of the lung on the affected side.

### **Project Dive Exploration (PDE)**

A long-term study developed by DAN to collect computerized profiles of diving exposures and information on the health outcome (symptomatic or asymptomatic). The accumulated data can be useful to model decompression risk.

### **Protected Health Information (PHI)**

Information that could disclose the identity of a research subject, patient or decedent according to the Health Insurance Portability and Accountability Act (HIPAA). PHI includes names, address, birthdate, social security numbers, etc. DAN does not disclose PHI to any party other than employees, representatives and agents of DAN who have a need to know.

### **Pulmonary Barotrauma (PBT)**

Damage to lungs from expanding gas. See “Barotrauma.”

### **Pulmonary Emphysema**

A medical condition commonly caused by smoking that leads to abnormal distension of the lungs resulting from the destruction of its supporting and elastic internal structure.

### **Pulmonary Overinflation Syndrome (POIS)**

A group of barotrauma-related diseases caused by the expansion of gas trapped in the lung, or over-pressurization of the lung with subsequent over-expansion and rupture of the alveolar air sacs. It includes arterial gas embolism, tension pneumothorax, mediastinal emphysema, subcutaneous emphysema and rarely pneumopericardium.

### **Pulmonary Overexpansion**

Abnormal distension of the lungs. In divers, pulmonary over-expansion usually results from the effects of Boyle's law. It can cause rupture of alveoli and penetration of gas into various surrounding spaces, causing mediastinal emphysema, pneumothorax or arterial gas embolism. See “Pulmonary barotrauma.”

### **Rales**

Wet, clicking, rattling or crackly lung noises heard on auscultation of (listening to) the lung during inspiration. The sounds are caused by the opening of small airways and alveoli collapsed by fluid in the air spaces.

### **Rapid Ascent**

An ascent rate fast enough to put a diver at increased risk of decompression illness (DCI), usually at rates in excess of 60 fsw (18 msw) per minute.

### **Rebreather**

Self-contained breathing device that recirculates some or all of the expired gas to increase efficiency. Systems may be semiclosed or fully-closed-circuit.

### **Recompression Treatment**

Treatment involving a return to pressure. Typically completed in a recompression chamber but, in some cases, may involve an in-water return to pressure. Well-established, standard treatment tables exist for recompression chamber therapy. See “United States Navy Treatment Tables 5 and 6 (USN TT5 and TT6)” and “Hart-Kindwall.”

### **Repetitive Dive**

A dive in which residual nitrogen remaining from a previous dive affects the decompression requirements of the subsequent dive. Some decompression computers carry over information from previous dives for 24 hours or longer, depending on the decompression model used. For the purposes of DAN's injury reporting, a repetitive dive is any dive occurring within 24 hours of a previous dive. See “Residual Nitrogen.”

**Representative Sample (statistics)**

A group selected from a population for testing that reasonably represents the characteristics of the population.

**Residual Nitrogen**

Nitrogen content in excess of the ambient levels as a result of recent diving exposure. See “Repetitive Dive.”

**Residual Symptoms**

Symptoms remaining at the conclusion of treatment. May respond to additional treatments, be refractory to further treatment but eventually resolve spontaneously, or remain permanently.

**Resolution of Symptoms**

Symptoms resolving (disappearing) at some point after appearance. Resolution may be spontaneous or in response to treatment and partial or complete.

**Reverse Block**

Overpressure developing in a blocked middle ear space during ascent as ambient pressure falls and internal pressure cannot be equalized. Symptoms include pain and dizziness; tympanic membrane rupture may result if equalization of space is not possible.

**Rhomberg (Sharpened)**

The Sharpened Rhomberg test is intended to detect ataxia, commonly used for diver assessment. The subject stands erect on a firm, level surface with feet aligned in a tandem (heel-to-toe) position. The arms are then folded across the chest. Once stable, the subject is instructed to close his or her eyes and to maintain the position for 60 seconds. The measured score is the time in seconds the position is held. The end is marked by opening of the eyes or movement of the hands or feet to maintain balance.

**Risk**

The chance or probability that a person will be harmed or experience an adverse health effect if exposed to a hazard. It may also apply to situations with property or equipment loss.

**Safety Stop**

A recommended halt in the planned ascent to the surface (usually for 3-5 min at 10-20 ft [3-6 m]) intended to reduce the risk of decompression injury. A safety stop is not an obligatory decompression stop required by tables or a dive computer. See “Decompression Stop.”

**Sarcoidosis**

A chronic disease of unknown cause characterized by the enlargement of lymph nodes in many parts of the body and the widespread appearance of granulation tissue (granulomas, typically produced in response to infection) derived from the reticuloendothelial (macrophage) portion of the immune system.

**Scrubber (rebreather)**

Refers to the chemical compound (absorbent) used to remove carbon dioxide from breathing gas.

**Scuba**

Self-contained underwater breathing apparatus.

**Scuba Epidemiological Reporting Form (SERF)**

An injury recording system for DAN that replaced the DIRF. It emphasizes collection of recorded dive profiles.

**Semiclosed-Circuit Rebreather (SCR)**

A type of rebreather that injects a mixture of nitrox or mixed gas into a breathing loop to replace that which is used by the diver for metabolic needs; excess gas is periodically vented into the surrounding water in the form of bubbles.

**Sequelae**

A pathological condition that is a consequence of a previous disease or injury.

**Setpoint (rebreather)**

The oxygen partial pressure to be maintained by the de-vice. Oxygen is added to the circuit when the oxygen partial pressure falls below the setpoint. Often user-adjustable within a limited range. See “Solenoid.”

**Shallow-Water Blackout**

The term was initially coined to describe impaired consciousness associated with the use of closed-circuit oxygen rebreathers, likely due to inadequate carbon dioxide scrubbing. It was subsequently usurped to describe hypoxia of ascent in breath-hold divers. The ambiguity of usage makes it an out-of-favor name, particularly for the breath-hold application, where hypoxia of ascent is recommended. See “Hypoxia of Ascent.”

**Snorkeling**

Swimming with mask, snorkel and fins. Snorkelers may remain at the surface or conduct breath-hold dives. See also “Breath-Hold Diving” and “Freediving.”

**Solenoid (rebreather)**

Electromagnetic valve that opens to inject oxygen into mixed-gas closed-circuit rebreathers. Activated automatically or manually to maintain the setpoint.

**Spearman Rank Coefficient (statistics)**

Statistical test that measures the relationship between two variables when data are in the form of ranked orders.

**Square Dive**

A dive in which the descent is made to a given depth and where the diver remains for the entire dive before ascending to the surface or stop depth.

**Standard Deviation (SD) (statistics)**

A measure of the variability within a group of numbers reported with discussion of means, appropriate for a close to normally distributed sample. Approximately 68% of the values will be within one SD of the mean (half above the mean and half below), approximately 95% within two SD, and approximately 99% within three SD. Outlier values, deviants from the norm, are conservatively identified as those more than two SD from the mean.

**Steatosis**

A process resulting in the abnormal retention of lipids within cells. Also known as fatty or adipose degeneration.

**Subcutaneous Air (Subcutaneous Emphysema)**

Air under the skin after pulmonary barotrauma. The most frequent location is around the neck and above the collarbones where the gas may migrate after pulmonary overexpansion.

**Sudden Hearing Loss (SHL)**

Sudden hearing loss (SHL) is defined as a hearing loss of at least 30 dB over three or more contiguous frequencies, occurring over a period of 72 hours or less. The cause is variable and often cannot be confirmed. It is frequently accompanied by tinnitus and may or may not resolve spontaneously.

**Surface Interval Time (SIT)**

Time spent on surface between sequential dives.

**Surface Oxygen Treatment (SOT)**

Oxygen delivered at the surface with a therapeutic intent. Gas may flow from the supply system in a continuous mode or through a demand valve upon inspiration of the conscious, spontaneously breathing injured person. The breathing circuit may be open (releasing exhaled gas to the environment) or closed (reusing exhaled gas after

carbon dioxide is removed). The delivery interface may be some form of simple non-rebreathing facemask, a partial rebreathing facemask or a nasal cannula. The fraction of oxygen delivered to the injured person and the oxygen flow rate required will vary dramatically depending on system configuration and use.

**Tachycardia**

Abnormally rapid heart rate.

**t-test (statistics)**

A statistical test used to determine if there is a significant difference between the means of two different groups.

**Thrombocythemia**

A blood disorder of excess cell proliferation. It is characterized by the production of too many platelets in the bone marrow.

**Tinnitus**

The perception of sound within the ear in the absence of corresponding external sound. Frequently described as a ringing noise, but a variety of presentations are reported. May be unilateral or bilateral and intermittent or continuous.

**Travel Assist**

Travel assistance plan available from DAN that covers necessary medical evacuation.

**Triggering Event**

A tangible or intangible barrier or occurrence that, once breached or met, causes another event to occur. In other words, the pivotal event leading to the ultimate outcome.

**Trimix**

See "Mixed-Gas."

**Type I DCS (DCS I, Musculoskeletal DCS)**

Decompression sickness where the symptoms are felt to be non-neurological in origin such as itching, rash, joint or muscle pain.

**Type II DCS (DCS II, Neurological or Cardiopulmonary (DCS))**

Decompression sickness where there is any symptom referable to the nervous or cardiovascular system.

**Type III DCS (DCS III)**

A serious form of DCS sometimes seen after long deep dives with a rapid ascent. Type III DCS is thought to be caused by arterial gas embolization after a dive where

a large quantity of inert gas has been absorbed by the tissues. Presumably the arterial bubbles continue to take up inert gas and grow, causing a rapidly deteriorating clinical picture.

#### **United States Navy Treatment Table 5 (USN TT5)**

A 2:15 h:min therapeutic recompression protocol that employs oxygen breathing with air breaks to treat decompression sickness. The protocol employs a maximum pressure equivalent to a depth of 60 fsw (18 msw). Extensions can increase the duration at 30 fsw (9 msw).

#### **United States Navy Treatment Table 6 (USN TT6)**

A 4:45 h:min therapeutic recompression protocol that employs oxygen breathing with air breaks to treat decompression sickness. Commonly used. The protocol employs a maximum pressure equivalent to a depth of 60 fsw (18 msw), with a second step at 30 fsw (9 msw). Extensions can increase the duration at either 60 fsw or 30 fsw (9 msw). Extremely similar to Royal Navy Treatment Table 62.

#### **United States Navy Treatment Table 9 (USN TT9)**

A 1:02 h:min therapeutic recompression protocol that employs oxygen breathing with air breaks. The protocol employs a maximum pressure equivalent to a depth of 45 fsw (14 msw).

#### **Upper Respiratory Infection (URI; 'cold')**

The most frequently reported acute health problem from the DAN sample of injured divers.

#### **Vasovagal Syncope**

Transient loss of consciousness (fainting) resulting from a sudden drop in heart rate and blood pressure and subsequent reduction in brain blood flow. It may be triggered by a variety of stressful conditions.

#### **Venous Gas Emboli (VGE)**

Gas phase, also known as bubbles, located in the veins returning blood to the right side of the heart or in the pulmonary artery, delivering blood from the right heart to the lungs where bubbles are filtered out of circulation. See "Patent Foramen Ovale."

#### **Vertigo**

Sensation of irregular or whirling motion, either of oneself (subjective) or of external objectives (objective).

#### **Waist-to-Hip Ratio (WHR)**

Used to assess for disproportionate accumulation of tissue in the abdominal region, such accumulation being associated with increased health risk. WHR is computed by dividing the circumferences of the waist at the narrowest point by the circumference of the hips at the widest point. Optimal scores are  $\leq 0.8$  for men and  $\leq 0.7$  for women.



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