



2019 ANNUAL DIVING REPORT

2017 Diving Fatalities, Injuries and Incidents



DAN ANNUAL DIVING REPORT

2019 Edition

A report on 2017 diving fatalities, injuries, and incidents

PETAR J. DENOBLE, MD, DSC

Editor

DIVERS ALERT NETWORK
DURHAM, NC

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TABLE OF CONTENTS

Acknowledgments	4
Introduction	5
In Memoriam	7
Project Dive Exploration (PDE)	9
Section 1. Diving Fatalities	11
Section 2. DAN Incident Mapping	33
Section 3. Diving Injuries	41
Section 4. The Diving Incident Reporting System (DIRS)	49
Section 5. Breath-hold Diving	68
Section 6. Training and Education	76
Section 7. The DAN HIRA Initiative	84
Section 8. International Data	92
Diving Accidents In Australia	93
Scuba Diving Fatalities In Japan, 2017	97
Sri Lanka Case Studies	102
Appendix A. Publications	107
Appendix B. Presentations	110

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INTRODUCTION

William Ziefle, DAN President and CEO

Every year DAN Research works diligently to collect dive incident data, analyze it and present it in a useful, educational format. Over the years we have continually refined this effort.

The collection and analysis of this data is done by four diving medicine physicians. DAN vice president of research Dr. Petar Denoble has led the team for more than two decades. Medical examiner Dr. Jim Caruso has been an instrumental contributor for just as long. Five years ago we added medical examiner Dr. Craig Nelson and DAN medical director Dr. Jim Chimiak to the team.

The format of Edition 2019 is similar to that of previous editions. In Section One, we present 2017 fatality data. At the beginning of this section are summary statistics for fatalities in the U.S. and Canada followed by a series of case studies that offer further insight into causes.

This year's report features enhanced spatial/geographic data. Section Two includes a series of maps of fatal and nonfatal dive-related injuries around the U.S. and the world. For the

first time, we have county-level data in Florida and California, the states with the most diving. These popular dive destinations accommodate various scuba diving activities, including wreck diving and underwater harvesting. We are pleased to have reached this level of geospatial analysis and will continue to work with public health officials in these counties for the next 10 years.

In Section Three we present the summary statistics of nonfatal injuries, based on data from the DAN Medical Services Call Center, as well as an in-depth review of select cases. Section Four focuses on incident reports, most of which did not involve any injury, provided voluntarily by divers. The breath-hold diving portion of the report follows in Section Five. DAN employs various injury and fatality prevention strategies, so we added a section, Section Six, about training programs, which target individual divers, and hazard identification and risk assessment (HIRA) programs, which promote operational safety.

The addition of enhanced geographic data is a step forward for the report, but there is always more to do. Among the improvements

we are considering for the coming years are interactive digital maps of injuries and fatalities, a revamping of the dive incident reporting system, an enhanced coding system for increased granularity, inclusion of diving-adjacent activities (such as topside accidents involving scuba cylinders) and greater coordination with training agencies and other organizations to standardize reporting and capture even more incidents.

Our data revealed some interesting themes. For one, cardiovascular disease was present in many of the available autopsy reports. We also noted that fatalities occurred in people of various certification levels and participation frequency and that a significant number of deaths occur at shallow depths. Analysis by DAN experts revealed that a better understanding of cardiovascular disease and the buddy system's role in dive fatalities is crucial.

Dive fatalities are complex and poorly understood. If similar medical conditions and circumstances were to appear in a person outside of the water, death might be attributed to a chronic disease. Because symptoms presented in the water, however, the fatality is often attributed to diving. It is this complexity that makes it so challenging for scientists to decipher the risk factors and spurious associations in fatal and nonfatal dive accidents.

It is not surprising that nonfatal scuba injuries occur with greater frequency than fatalities. The challenge in analyzing the trends and distribution of scuba injuries is identifying who is diving and how frequently.

The analysis of the data on fatal and nonfatal breath-hold diving injuries yielded several insights. Notably, men were more often involved in breath-hold incidents than women, and people in their twenties and thirties were more often involved than people in other age groups. Divers over forty years of age, however, were more often involved in breath-

hold fatalities. Breath-hold diving activities range from what could be described as child's play to competitive freediving involving highly trained divers that push the limits of the human body. No matter the dive depth, it is vital that breath-hold divers understand the body's reaction to diving. While chronic disease may have played a role in some of the analyzed cases, there is also reason to believe that some deaths were due to miscalculations of the individuals' ability to hold their breath long enough to return to the surface.

To prevent injury and loss of life, change must happen at various levels. We continue to expand our outreach to divers and dive professionals through training and risk management programs. DAN's first aid and HIRA programs are the most relevant, detailed and comprehensive such programs in the industry.

This report has pages of detailed case analysis. Some of you will read through each in detail, while others will give them a passing glance. Perhaps the most important message to take away is that divers must continue to help divers stay safe. If you know of a dive injury, report it to DAN. If you have a chronic medical condition or are over 50 years old, talk to your primary care doctor about your intention to dive. If your doctor is unfamiliar with dive medicine, have them contact DAN; we can help.

I'd like to thank our partners at DAN Europe, DAN Japan, DAN Brazil and in Australia as well as collaborators in Sri Lanka and at the British Sub-Aqua Club. Their contributions to this report are invaluable in providing a better understanding of fatal and nonfatal scuba injuries around the world.

Ultimately, no matter your experience or level of training, remember the basics, and stick with your buddy. We hope you find this report useful in staying safe while diving.

IN MEMORIAM

Bobby Forbes
1957- 2015



Bobby Forbes was a marine biology graduate from Heriott-Watt University. During his rich and diverse career, Bobby was involved in commercial diving in various leadership roles, and with university programs as a diving officer and faculty at the International Centre for Island Technology (ICIT) in Orkney, Scotland.

In 1990, he was responsible for establishing the new unit and the associated hyperbaric facility which was jointly operated by the Orkney Health Board and the Stromness Medical Practice. This was, and still is, the only hyperbaric chamber at the popular Scapa Flow dive sites which are visited by thousands of divers each year. Injured divers are treated in the hyperbaric facility that today carries Bobby Forbes' name.

Bobby and his dive team maintained the oil terminal at the small island of Flotta and taught students and assisted with hyperbaric treatment of injured divers.

He was the Manager of the Scientific Underwater Logistics (SULA) Diving Limited. As an avid diver and scientist, he was interested in submerged cultural heritage. He engaged in mapping of the

famous cemetery of the WWI fleet through the ScapaMAP project; and the less famous crannogs, small artificial islands in many of Scotland lochs. He was one of the founders of the Orkney Research Center for Archeology (ORCA) and the Aviation Research Group of Orkney & Shetland (ORCAS). Bobby was also the Diving Advisor for Marine Scotland, undertaking audits of diving contractors working for Marine Scotland, and a consultant for Police Scotland in the investigation of diving fatalities.

Bobby Forbes was a big supporter of Divers Alert Network. He was one of the first Field Research Coordinators for Project Dive Exploration and single-handedly collected most of the dive profiles from Scapa Flow. He was a mentor to DAN summer interns who helped him with data collection. The PDE paper includes 15,067 dives under the Scapa Flow group, all collected by Bobby Forbes or under his supervision. The DAN research staff and DAN interns are grateful for his contributions.

Besides his professional diving credentials, his recreational diving qualifications include:

1984 - Health & Safety Executive Surface Supplied Diver (III/769/84)

1991 - Assistant Life Support Technician

1994 - PADI Master SCUBA Diver Trainer (54572)

1995 - PADI Speciality Instructor (10 Specialities)

1995 - IANTD Advanced Nitrox Instructor (1071)

1998 - IANTD TriMix Diver (11188)

2000 - IANTD Gas Blender Instructor (11188)

2000 - Advanced European Scientific Diver (GB311359)

2001 - PADI Medic First Aid Instructor (54572)

2001 - DAN First Aid Oxygen Instructor (93058)

2001 - Nautical Archaeology Society Tutor

2008 - IANTD Rebreather Diver



PROJECT DIVE EXPLORATION (PDE)

In 1995, DAN started a project to prospectively collect data about how recreational divers dive and how often they get decompression sickness. For the first time, dive exposures were described in detail thanks to the availability of dive computers with recording capability. Dive profile details - depth changes over time - were collected from volunteers using commercially available dive computer/recorders that also reported the presence or absence of suspected decompression sickness symptoms after a dive. The objectives were to collect open-water free-range dive profile data, explore how probabilistic models perform on recreational dive data, and correlate the observed and the predicted incidence of DCS.

The enrollment of volunteers began in 1995 and continued until 2008. The study was possible thanks to dive computer manufacturers who adopted a standard format for data exported from their dive computers. By the end of the study, there were 11 manufacturers participating.

In the beginning, due to the complex nature and limited use of dive computers at the time, DAN trained volunteers to act as field data coordinators to assist with field data

collection. Later on, dive computers became more user-friendly and any diver with some basic technical skill could participate on their own. By the end of the study, more than ten thousand divers have participated and collected nearly 200,000 dives. Unfortunately, not all records were usable because either they did not fit the definition of a dive (deeper than 10 ft, longer than 3 minutes), or there were errors in the recordings, or incomplete reporting of the outcomes.

After thorough data cleaning and verification, 122,129 dives were retained for the final analysis. The outcome was classified as DCS in only 38 of these dives. The overall incidence of DCS was 3.1 cases per 10,000 dives, but it varied significantly among different groups of divers. The lowest was among basic recreational divers (0.7/10,000) and higher among Cozumel dive guides and cold-water wreck divers in Scapa Flow. A small number of DCS cases limited the analysis which was detailed in the report which was published in the *Undersea and Hyperbaric Medicine Journal*. With permission from the UHMS, a reprint of the abstract follows.

The lessons learned from this crowd-sourced study are many and hopefully will help with similar studies in the future. Besides technical issues, the major problem was reporting of additional data not recorded by dive computers and a prompt post-dive health

status report. With advances in dive computer technology widespread use of mobile devices, and popularity of crowd sourcing, another study of dive exposure and outcomes is probably already somewhere in the making by enthusiastic researchers.

A STUDY OF DECOMPRESSION SICKNESS USING RECORDED DEPTH-TIME PROFILES

Dunford RG, Denoble PD, Forbes R, Pieper CF, Howle LE, Vann RD. Undersea Hyperb Med. 2020;47(1): 85-100.

Introduction: 122,129 dives by 10,358 recreational divers were recorded by dive computers from 11 manufacturers in an exploratory study of how dive profile, breathing gas (air or nitrox [N₂/O₂] mixes), repetitive diving, gender, age, and dive site conditions influenced observed decompression sickness (DCS_{obs}). Thirty-eight reports were judged as DCS. Overall DCS_{obs} was 3.1 cases/10⁴ dives.

Methods: Three dive groups were studied: Basic (live-aboard and shore/dayboat), Cozumel Dive Guides, and Scapa Flow wreck divers. A probabilistic decompression model, BVM(3), controlled dive profile variability. Chi-squared test, t-test, logistic regression, and log-rank tests evaluated statistical associations.

Results: (a) DCS_{obs} was 0.7/10⁴ (Basic), 7.6/10⁴ (Guides), and 17.3/10⁴ (Scapa) and differed after control for dive variability ($p < 0.0001$). (b) DCS_{obs} was greater for 22%-29% nitrox (12.6/10⁴) than for 30%-50% nitrox (2.04/10⁴) ($p \leq 0.0064$) which did not differ from air (2.97/10⁴). (c) For daily repetitive dives (<12-hour surface intervals (SI)), DCS occurred only following one or two dives (4.3/10⁴ DCS_{obs}; $p < 0.0001$) where SIs were shorter than after three or more dives. (d) For multiday repetitive dives (SIs < 48 hours), DCS was associated with high multiday repetitive dive counts only for Guides ($p = 0.0018$). (e) DCS_{obs} decreased with age at 3%/year ($p \leq 0.0144$). (f) Males dived deeper ($p < 0.0001$) but for shorter times than females ($p < 0.0001$).

Conclusions: Collecting dive profiles with dive computers and controlling for profile variability by probabilistic modeling was feasible, but analytical results require independent confirmation due to limited observed DCS. Future studies appear promising if more DCS cases are gathered, stakeholders cooperate, and identified data collection problems are corrected.

SECTION 1. DIVING FATALITIES

Petar J. Denoble, James Chimiak, Asienne Moore, James L. Caruso, Craig Nelson

INTRODUCTION

The 2019 DAN Annual Diving Report presents descriptive statistics and selected case summaries of recreational diving fatalities collected in 2017. We are also showing a comparison with the last ten years where possible. The most notable trend in 2017 data is the increase in the average age of victims. The age in itself is not a direct risk for diving, but it may affect health and physical fitness in a way that diving becomes risky. Still, for most people, recreational scuba diving may be safe if practiced responsibly, and if we could identify those who may be at an increased risk of dying while diving. (Note that Section One covers fatalities associated with scuba diving while Section Four covers injuries and fatalities associated with breath-hold diving.)

THE DATA COLLECTION PROCESS

INITIAL NOTIFICATION AND CASE QUALIFICATION

The data collection process has not changed since 2016. It begins with an initial notification that may come as voluntary reports from affiliated organizations and individuals, active internet search, and automated internet alerts.

Online news media outlets are monitored for keywords involving breath-hold diving and scuba deaths. Sorting through the media alerts is especially tedious work. Regardless of how refined the criteria are, the by-catch of redundant and useless reports far exceeds the number of unique accident cases. Other sources of notifications regarding fatalities include families of DAN members and friends and acquaintances of decedents who are aware of DAN's fatality data collection efforts. The DAN Medical Services Call Center (MSCC) is the most valuable single resource since the DAN Medical Services Department assists with the management of any diving incident that is called in, whether or not the victim is a DAN member.

Table 1-1. Number of collected fatalities worldwide (n=228)

Diver Classification	USA & Canada citizens	Foreign	Not Recreational	Breath-hold	Total
Recreational	65	59	0	0	124
Technical	2	10	1	0	13
Uncertified	1	3	0	0	4
Military	0	2	1	0	3
Student	1	1	0	0	2
Task	0	0	1	0	1
Public Safety	0	0	1	0	1
Unknown	1	17	5	0	23
Breathhold	0	0	0	57	57
Total	70	92	9	57	228

Each death is classified as to whether or not it should be followed up on. All recreational diving fatalities that occur in the U.S. or Canada and all deaths of U.S. or Canadian citizens, no matter where they occur, are marked for follow-up. Any fatalities that occur outside the U.S. or Canada and involve citizens of other countries are classified as foreign and are not followed-up on due to logistic issues. Cases that occur during non-recreational dives (e.g., military dives) are classed as non-recreational, and they are not followed up on either. Breath-hold fatalities are classified as a distinctive group, and the follow up is attempted when the contact information is available.

INVESTIGATOR AND MEDICAL EXAMINER REPORTS

DAN does not conduct investigations of diving fatalities. However, local law enforcement agencies or the U.S. Coast Guard (USCG) frequently investigate diving-related deaths in the U.S. A proportion of victims are subject to autopsies. Sometimes it takes over a year to complete the investigation and produce the reports. DAN tries to obtain all available reports, but there are often administrative hurdles to overcome. In many cases, these reports could not be collected, which impedes our ability to conduct analysis.

REPORTS FROM WITNESSES AND NEXT OF KIN

DAN uses its Fatality Reporting Form to collect fatality data from witnesses and family members. The form may be downloaded from the DAN website (<https://www.diversalernetnetwork.org/files/DivingFatalityReportingForm.pdf>) or requested from the DAN Research or Medical Services departments. When necessary, a family member of the decedent may be contacted to assist in the data-collection process. Family members may complete the Fatality Reporting Form and/or provide authorization for the release of the decedent's autopsy report. The incident reporting form on the DAN website (<https://www.diversalernetnetwork.org/research/incidentReport/>) can also be used by family members and witnesses to report diving fatalities or to provide additional details regarding already reported fatalities.

DATA ENTRY AND ANALYSIS

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

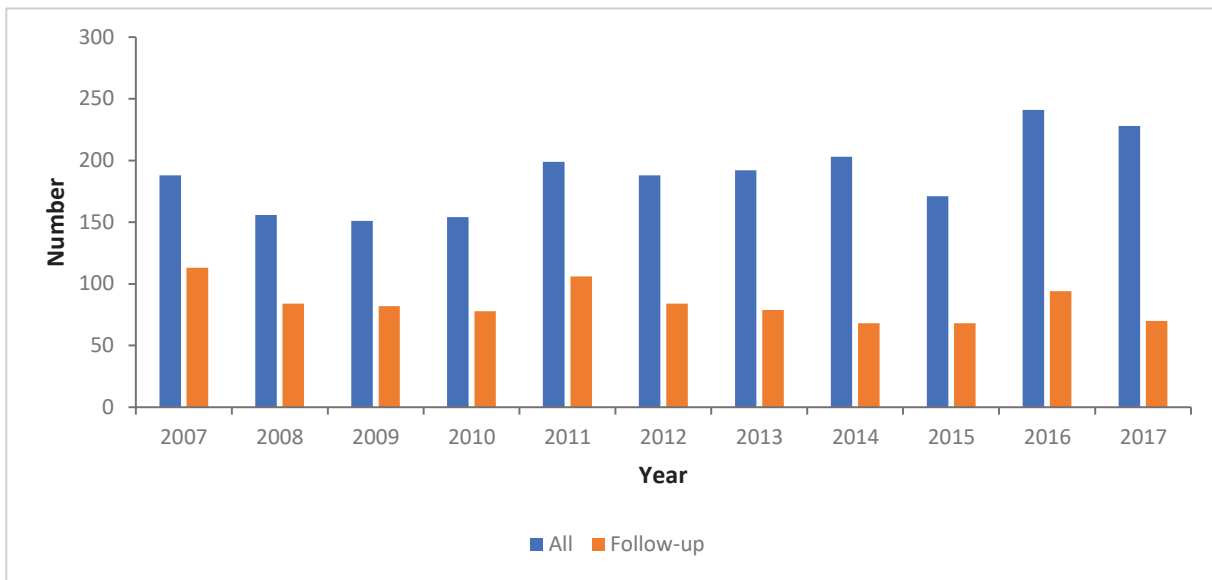


Figure 1-1. Total number of reports collected and the number of follow up reports in 2007-2017

DATA

NUMBER OF FATALITIES COLLECTED

Worldwide, DAN received notification of 228 deaths involving underwater diving during 2017. A breakdown of this total is shown in Table 1-1.

Only 162 pertained to recreational scuba divers, 70 of which occurred in the U.S. or Canada or involved U.S. or Canadian citizens (follow-up cases) and thus were actively investigated by DAN. DAN also received word of 9 scuba-related fatalities that did not involve recreational divers and 57 fatalities associated with breath-hold diving. The total numbers of received notification and follow-up cases for 2007 to 2017 by year are shown in Figure 1-1 along with the data for the same periods average.

Autopsies were available for 20 of the 70 U.S. and Canadian cases (30%) and nine of the 57 breath-hold cases (10%).

GEOGRAPHIC AND SEASONAL DISTRIBUTION OF FATALITIES

The number of fatalities by country of death for 2017 is shown in Table 1-2.

Table 1-2 does not necessarily reflect the true numbers of cases worldwide. Rather, it reflects the DAN data collection process, which is focused on the scuba death of U.S. and Canadian citizens worldwide and all deaths in the U.S., Canada, Mexico, Caribbean. The country with the largest number of recreational scuba diver deaths in our dataset is the United States of America (42) followed by South Africa (9), Australia, Canada, and Pacifica (8 each), Scotland and Italy (7), UK and Mexico (6). The total number of recreational scuba deaths for the ten years is shown in Table 1-3. For numbers of fatality among DAN Europe members, see page 92.

The state that consistently reports the largest number of scuba deaths is Florida with 14 and 205 cases in 2017 and preceding 10 years, respectively. California follows on this list with 6 and 110 cases in the same time frames. See Figure 1-2.

Table 1-2. The number of fatalities by country of death in 2017

Country by ISO Region	n	Country by ISO Region	n
ASIA		NORTHERN AFRICA	
China	3	Egypt	3
Indonesia	6	NORTHERN AMERICA	
Malaysia	3	Canada	8
Maldives	1	United States	71
Myanmar	1	OCEANIA	
Philippines	5	Australia	7
Thailand	6	Fiji	2
Vietnam	2	French Polynesia	3
CENTRAL AMERICA		Guam	2
Belize	1	New Zealand (Aotearoa)	8
Costa Rica	2	Solomon Islands	2
Honduras	1	SOUTHERN AFRICA	
Mexico	6	South Africa	13
EUROPE		THE CARIBBEAN	
Turkey	1	Bahamas	2
EUROPEAN UNION		Barbados	1
Finland	1	Cayman Islands	4
France	2	Dominican Republic	1
Greece	3	Jamaica	1
Italy	7	Netherlands Antilles	2
Malta	3	Saint Kitts and Nevis	1
Netherlands	1	Saint Lucia	1
Spain	4	TOTAL	
UNITED KINGDOM		208	
Great Britain	6		
Ireland	2		
Scotland	7		
MIDDLE EAST			
United Arab Emirates	2		

Table 1-3. The 10-year total number of scuba fatalities by country

Country By ISO Region	n	Country By ISO Region	n
ASIA	43	Canada	57
China	1	Greenland	1
India	1	United States	707
Indonesia	12		
Japan	3	OCEANIA	51
Malaysia	3	Australia	20
Maldives	5	Fiji	8
Philippines	7	Guam	6
Thailand	10	Micronesia, Federated States Of	3
Việt Nam	1	New Zealand	13
		Vanuatu	1
CENTRAL AMERICA	79	SOUTH AMERICA	4
Belize	16	Brazil	1
Costa Rica	2	Ecuador	3
Honduras	9		
Mexico	52	SOUTHERN AFRICA	5
		South Africa	5
EASTERN AFRICA	1	THE CARIBBEAN	96
Tanzania	1	Antigua And Barbuda	1
		Aruba	1
EUROPE	1	Bahamas	12
Iceland	1	Barbados	2
		British Virgin Islands	5
EUROPEAN UNION	11	Cayman Islands	46
France	1	Cuba	4
Greece	1	Dominican Republic	3
Ireland	2	Grenada	1
Malta	3	Jamaica	3
Spain	2	Puerto Rico	2
United Kingdom	2	Saint Kitts And Nevis	2
		Saint Lucia	1
MIDDLE EAST	3	Saint Martin	2
United Arab Emirates	3	Turks And Caicos Islands	9
		U.s. Virgin Islands	2
NORTHERN AFRICA	3		
Egypt	3	Total	1,067
NORTHERN AMERICA	770		
Bermuda	5		

Table 1-4. Number of follow-up cases by state/province for 2017

State/Province	N
Florida	14
California	6
Hawaii	4
Massachusetts	2
Ontario	2
South Carolina	2
Washington	2
Alberta	1
British Columbia	1
Louisiana	1
Manitoba	1
Minnesota	1
North Carolina	1
New Jersey	1
Newfoundland And Labrador	1
New Mexico	1
Nevada	1
New York	1
Ohio	1
Pennsylvania	1
Quebec	1
Rhode Island	1
South Dakota	1
Saskatchewan	1
Texas	1
N/A	1

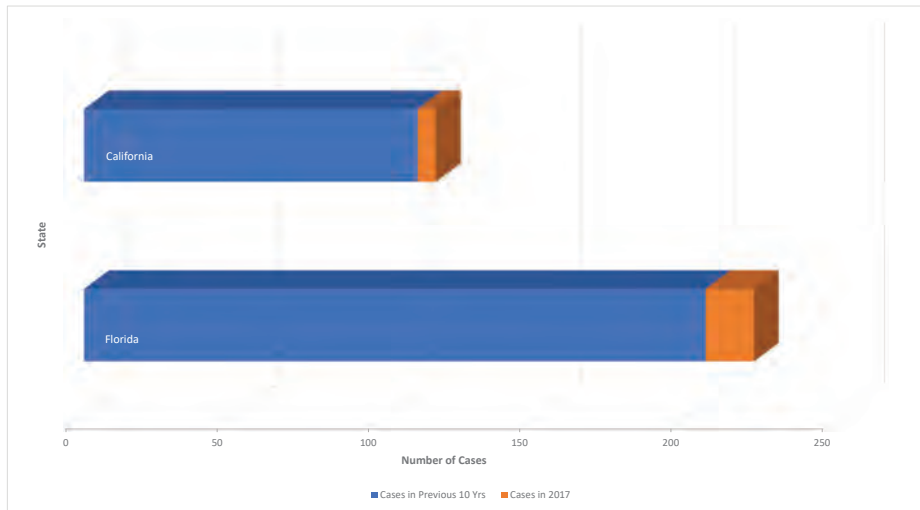


Figure 1-2. Total number of cases in California and Florida in 2017 and the preceding 10 years

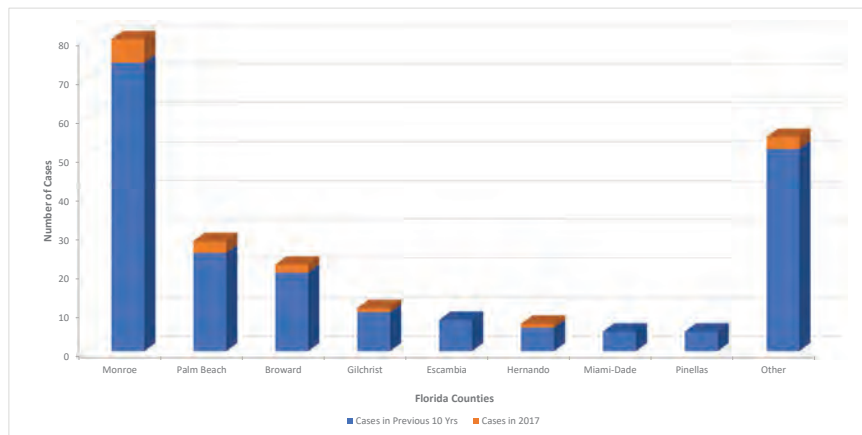


Figure 1-3. Florida fatalities by county 2017 and the preceding 10 years

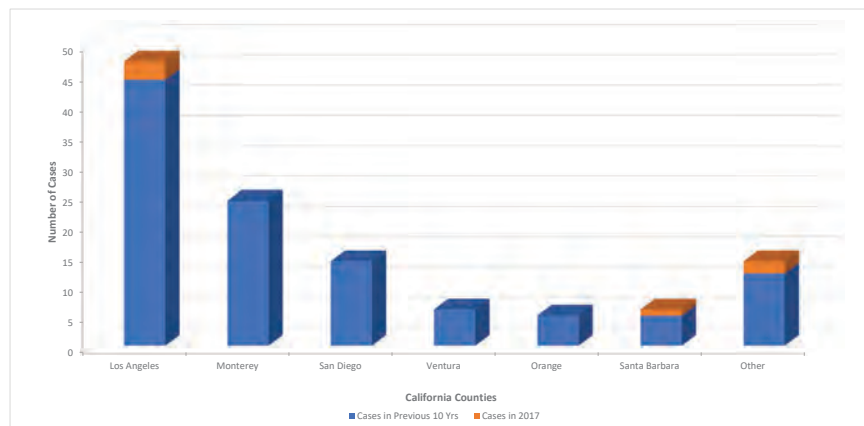


Figure 1-4. California fatalities by county in 2017 and the preceding 10 years

While we do not know the numbers of dives by states, Florida and California are the two most popular dive destinations. We looked at the number of fatalities by county in Florida and California. The results are shown in Figure 1-3 for Florida and Figure 1-4 for California.

The Number of scuba deaths in Monroe County, Florida (74 for the ten years and 6 for 2017), far exceeds Palm Beach (25 cases) and Broward (20 cases) counties in the ten years. The Monroe county includes attractions like wrecks of USS Oriskany, Spiegel Grove and USAFS General Hoyt S. Vandenberg.

In California, the county with the largest number of scuba fatalities in Los Angeles county with 44 in ten years and three in 2017. The second largest is Monterey, with 24 and San Diego with 14 in ten years.¹

AGE AND HEALTH OF DECEDENTS

Figure 1-5 shows the distribution by age and sex of the 67 cases for which that information is known. In 79% of the 70 cases, the victims were male (n=55), and in 21% of cases, the victims were female (n=15). The age of the victim was unknown in three cases. More than two-thirds of the 67 victims whose age is known (66%) were 50 years of age or older, and more than four-fifth (80%) were 40 years or older.

The victim's medical history was, in most cases, incomplete or unknown.

DIVING CERTIFICATION AND EXPERIENCE

Information about decedents' diving certification level was missing in most cases. Decedents' years of diving experience since their initial certification was known in only four cases.

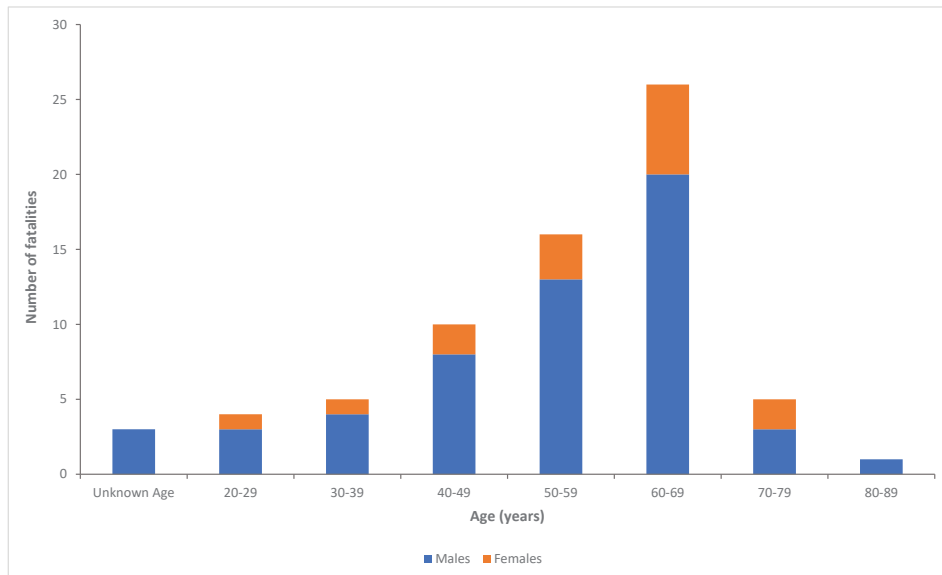


Figure 1-5. Age and sex distribution

CHARACTERISTICS OF DIVES

Figure 1-6 shows the type of diving activity undertaken during the fatal dive. Information was available for 48 of the 70 cases (69%). At least 35 cases (50%) involved leisure or sightseeing, 7 (10%) involved spearfishing, hunting, or collecting game, 3 (9%) were training dives, one instructing, and one photographing.

For examples, see cases 1-2, 1-4, 1-5, 1-14, 1-15, and 1-24 in the Fatality Case Summaries section, page 25.

The **dive platforms** from which fatal dives began was reported in 55 cases (76%). In 32 of those 55 cases, the dive began from a vessel, and in 23 cases, it began from shore. See Figure 1-7.

Environment: The majority of fatal dives occurred in an ocean/sea environment (n=50, 71%), with the rest occurring in freshwater (n=12, 17%, two of which in a cave) or in rivers or springs (n=4, 6%). In one case, a description of the environment was missing. See Figure 1-8.

For examples, see cases 1-7, 1-10, 1-16, and 1-17 in Fatality Case Summaries section on page 25.

Visibility: Only 5 cases (7%) included information on visibility, this serves as an example of the challenges of gathering complete data on diving fatalities.

A similar lack of data is seen with sea conditions, current, protective suits, breathing apparatus (4 used a rebreather), breathing gas, and the dive profile details.

Buddy status: At least two dives were intended as solo dives. For most dives, the buddy status at the beginning was not known. Of those who started with a buddy, six ended up separated, but there is no evidence that it was intentional. In some cases, the disappearance of the victim was not noticed immediately, and in other victims left the group and did a rapid ascent to the surface. In several cases, buddies stayed with the victim for the entirety of the dive, brought the victim to the surface, or accompanies them during the emergency ascent, but the outcome still was fatal.

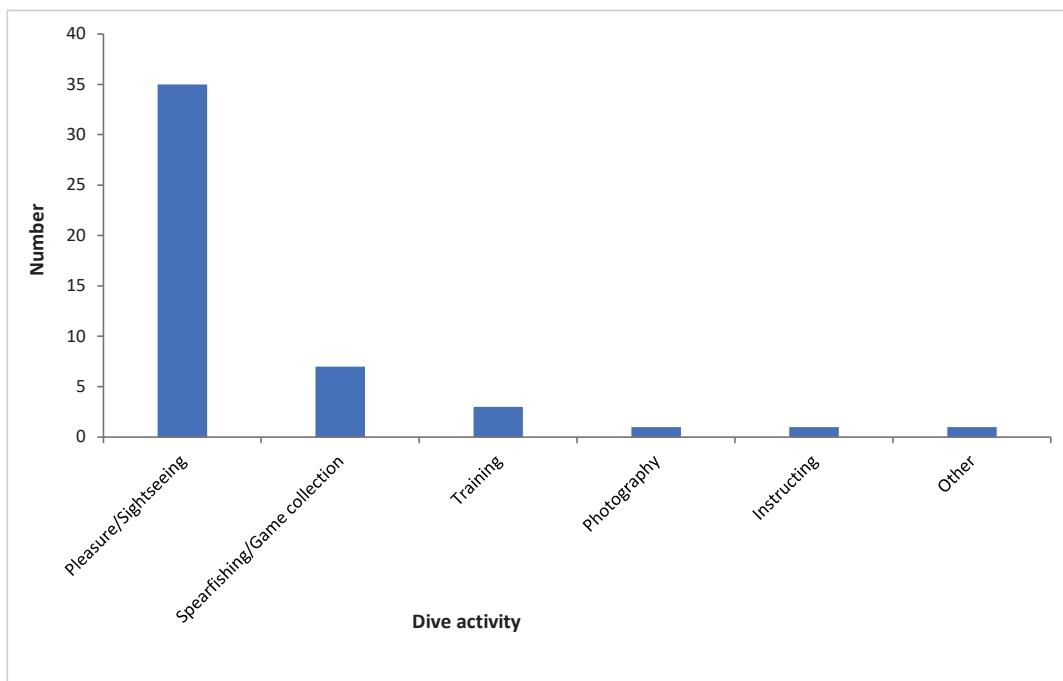


Figure 1-6. Diving activity during the fatal dive (n=48)

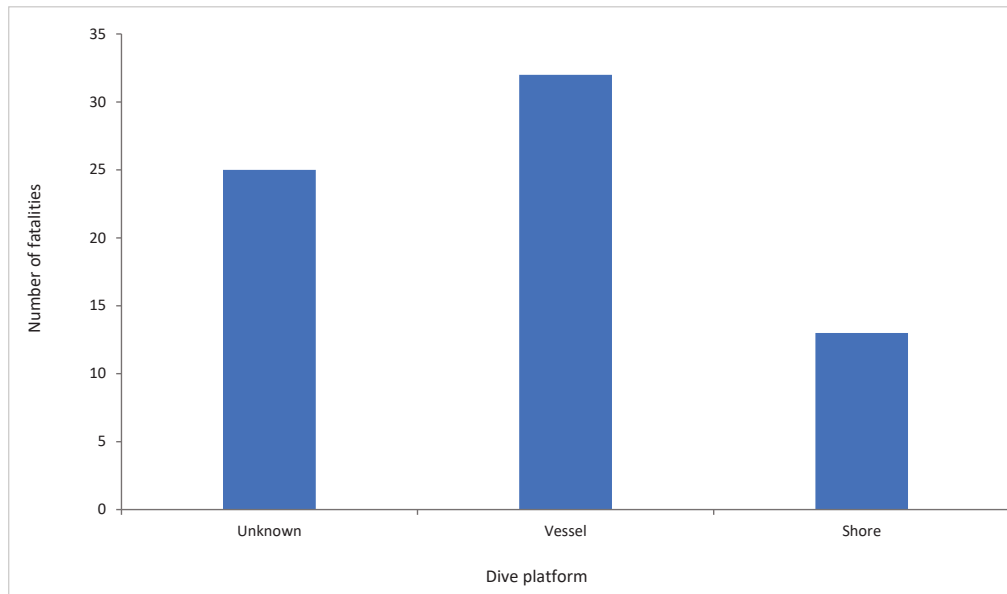


Figure 1-7. Dive platform during the fatal dive (n=55)

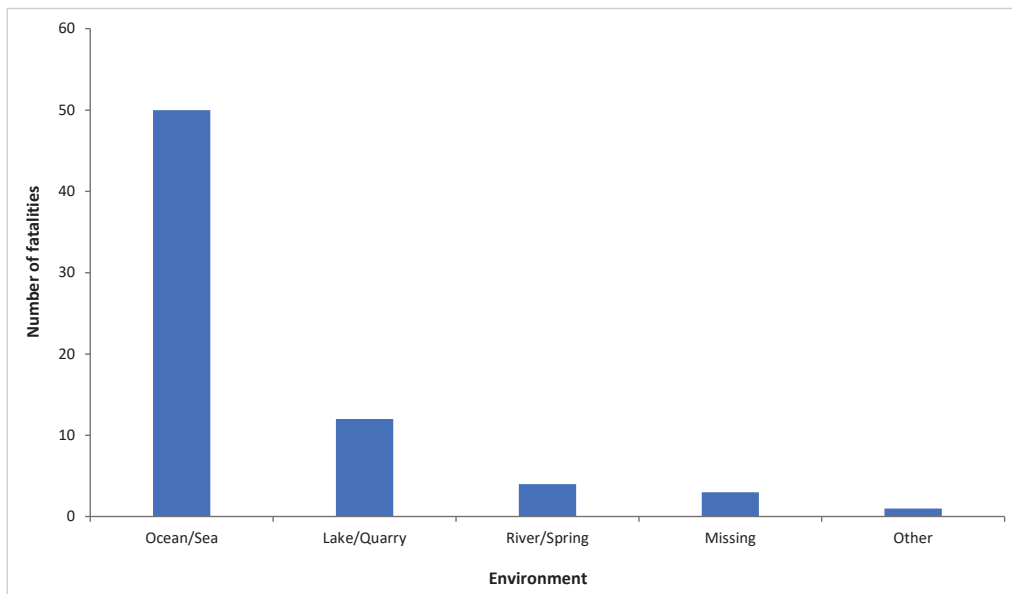


Figure 1-8. Dive environment during the fatal dive (n=50)

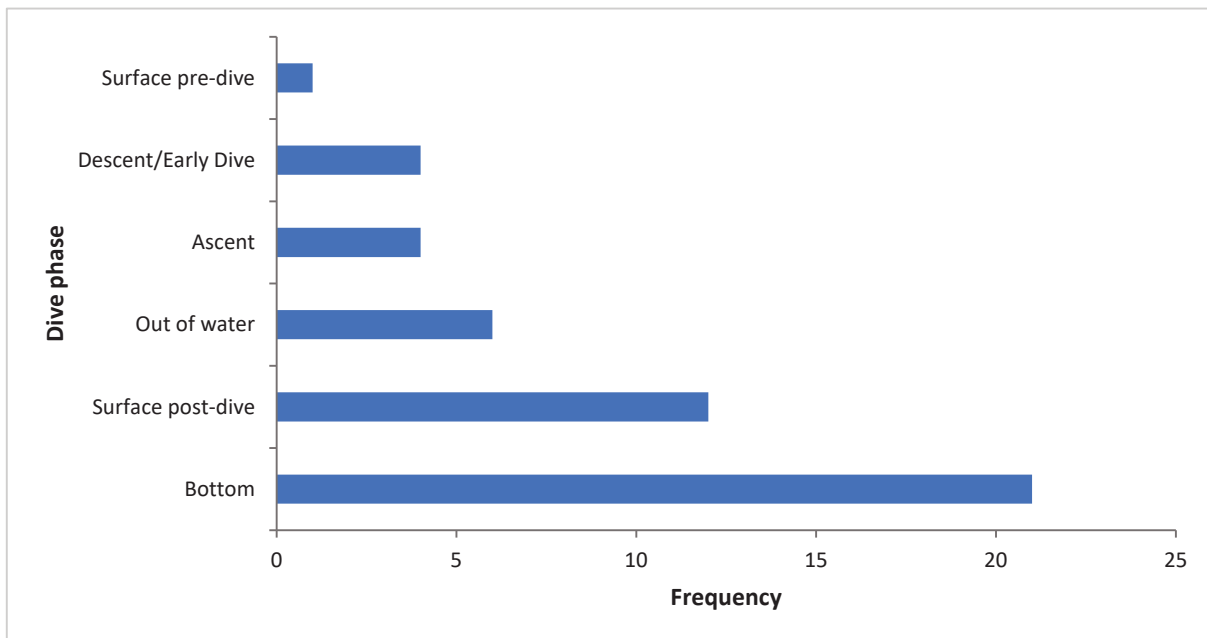


Figure 1-9. Phase of dive when diver lost consciousness (n=48)

ANALYSIS OF SITUATIONS AND HAZARDS

FATALITIES BY DIVE PHASE

We use the following dive-phase categories: a) on the surface before diving, b) underwater, c) on the surface after diving, and d) exiting the water. Dive-phase information was available in 48 of the 70 cases (66%).

Figure 1-9 shows the distribution of this information. In the majority of the 48 cases where the information was known, the diver lost consciousness underwater at the bottom (n=21), or on the surface following the dive (n=12), out of the water (n=6), during descent early in dive (n=4), during ascent (n=4), or at the surface before the dive (n=1).

It appears that the problem that led to fatality became critical underwater in 41 cases and seven at the surface. For the remainder of the cases, it was not possible to establish.

CAUSES OF INJURIES AND DEATHS

The available data limit the analysis of the causes of injuries and deaths. The most reliable source in this dataset was the autopsy report, which was available in 20 scuba and 9 breath-hold cases. While the pre-existing cardiac conditions were often present, direct causality was difficult to establish. However, it is of note to report that in 7 autopsies, significant cardiomegaly was found.

The cause of death, as established by the medical examiner, is shown in Table 1-5.

Table 1-5. Cause of death by medical examiner

Cause of Death	n
Drowning	11
Heart Disease	5
AGE	2
Severe DCS	1
Unknown	1

The most common cause of death (COD) was drowning, which is expected as any condition that disables a diver while in the water may result in drowning. Heart disease or acute cardiac events were established in five cases. It appears that medical examiners assigned heart disease as the cause of death based on significant pathological substrates found, known as the history of heart disease and sometimes the description of the course of events. The pathological substrates included cardiomegaly, LVH, pulmonary edema, extensive CAD, and pacemaker. For details, see cases 2, 6, 7, and 8 in Fatality Case Summaries. Arterial gas embolism (AGE) was a circumstantial diagnosis without a specific pathological substrate. The case of the death due to DCS occurred in a 70-year-old diver after diving to 122 msw (400 fsw) and omitted most of the decompression.

DISABLING INJURIES

The most common disabling injury that rendered the victim incapable of using protective equipment underwater or of reaching surface alive was an acute heart disfunction in all five cases with the cause of death attributed to heart disease. Besides, there were four cases with drowning as the causes of death, where the disabling factor was an acute heart event. See cases 1,3, and 5.

Table 1-6. Disabling injury

Disabling Injury	n
Heart problem	9
Unknown	3
Loss of consciousness	1
Respiratory distress	1
Gastrointestinal bleeding	1
AGE	1
Severe DCS	1
Panic	1
Asphyxia	1

DISABLING AGENT

Disabling agents or mechanisms of injury are shown in Table 1-7. The disease was the most likely disabling agent in ten cases, nine of which pertain to disabling heart conditions and one to the upper gastrointestinal bleeding. In three cases, the injury was caused by rapid ascent while holding breath, in three cases it was unknown, and omitted decompression, out-of-gas, uncontrolled sinking, and saltwater aspiration were suspected in one case each.

Table 1-7. Disabling agent

Mechanisms (Disabling Agent)	n
Disease	10
Rapid ascent, lung overinflation	3
Unknown	3
Omitted decompression	1
Out of gas at depth	1
Uncontrolled sinking	1
Saltwater aspiration	1

TRIGGERS

Triggers that initiated a chain of events leading to fatality, as shown in Table 1-8, were not identified in most cases.

Table 1-8. Triggers

Triggers	n
Unknown	10
Buoyancy problem	4
Intrinsic cardiac event	2
Entanglement	1
Panic	1
Equipment problem	1

Most cardiac-related accidents occurred apparently without any obvious external cause. In a few cases, the cardiac-related death was associated with exertion caused by negative buoyancy. The entanglement and equipment problem was the trigger for two other fatalities. In one case, the panic, which usually needs a trigger, was considered the trigger itself. It occurred in a student on his first dive, without an obvious cause.

LESSONS LEARNED

DIVING WITH MULTIPLE CARDIOVASCULAR RISK FACTORS AND PRE-EXISTING CONDITIONS

In 2017, among the 29 cases where autopsy was available (20 scuba and 9 breath-hold), in ten scuba cases and six breath-hold cases, the cause of death or disabling condition was an acute cardiac event. There were often multiple pre-existing conditions among the victims. While the presence of any of those conditions alone may not be critical, when presenting together, they should be judged as disqualifying for diving in retrospect.

Fatality Case Summaries 1-1 through 1-4 (Page 25) have multiple health conditions and risk factors that increase the probability of premature death due to cardiovascular disease in common. Cardiovascular diseases (CVD), including stroke and heart attack, are the most common causes of death. According to the CDC National Vital Statistics Report for 2017, among the general population of the USA, heart attack causes one out of four deaths while stroke causes one out of 20 deaths.^{1,2} The annual incidence of heart attack is 805,000 and of stroke is 795,000.^{3,4} Thus, it is not unexpected that some CVD related deaths occur in scuba divers while diving. Both heart attack and stroke are disabling conditions which, in scuba diving may be lethal more often than in other conditions since it occurs underwater and may involve considerable delay to immediate CPR. In 2017, among 25 cases with available autopsy, there were nine cases with probable cardiac causes and no cases with suspected stroke.

Sudden cardiac death (SCD) may be caused by an acute blockage of heart arteries (myocardial infarction), undiagnosed coronary heart disease, enlarged heart (cardiomyopathy), or thickened walls of the left ventricle (left ventricular hypertrophy, LVH), valvular heart disease, heart failure, and arrhythmias. Known risk factors for SCD are the same as risk factors for coronary artery disease: a family history of coronary artery disease, smoking, high blood pressure, high blood cholesterol, obesity, diabetes, and a sedentary lifestyle. Among

other factors that increase risk are age, being male, use of cocaine or amphetamines, low potassium or magnesium levels, obstructive sleep apnea, and chronic kidney disease. Stress and strenuous exercise to which subject is not accustomed may precipitate the SCD in people with pre-existing conditions as reported for skiers and mountaineers.⁵

The prevalence of CVD conditions among scuba divers is not known. Surveys show that many divers continue diving after being diagnosed with heart disease or arrhythmias.^{6,7} Indeed, not all heart conditions are necessarily contraindications for diving, which is considered a leisurely activity. However, sometimes diving may be strenuous, and thus, when multiple risks or heart conditions are present, medical fitness for diving should be scrutinized.

It is of note that two-thirds of the reported fatalities in 2017 were between 50 and 80 years of age. Out of 30 witnessed fatalities, 15 fit the description of SCD, and in ten out of 20 with an available autopsy, SCD was found to be the probable cause of the scuba fatality. Some form of heart disease was present in many cases, but in the four described in the Fatality Case Summaries (Cases 1-1 to 1-4), multiple conditions were present: hypertensive heart disease, cardiomegaly, diabetes, obesity, in addition to advanced age and other risk factors like smoking.

Cardiomegaly was often found in this small case series. The causes of cardiomegaly are many like hypertension and others that increase with age. During the early stages, subjects are asymptomatic and tolerate exercise. Others are asymptomatic at rest but experience shortness of breath with exercise. Even in asymptomatic subjects, cardiomegaly increases the risks of arrhythmias and SCD. The prevalence of asymptomatic cardiomegaly is not known. An indication of what it could be is the prevalence of symptomatic heart failure (HF) in the USA, which is about 6 million.³ While people with HF are not likely to dive, it is important to screen for asymptomatic cardiomegaly in divers with risk factors.

We had no information if these victims underwent a medical evaluation before diving, whether the examination was thorough, and what advice they have received, but one link in this chain failed. Let us be reminded:

- Men over 45 and women over 50 should have periodic medical examinations
- Divers with multiple cardiovascular risk factors should be evaluated periodically
- Divers with a diagnosed heart condition should be thoroughly tested for exercise tolerance before being cleared for diving
- Divers with multiple manifestations of CVD, especially if metabolic syndrome (diabetes, obesity) is present, should be advised not to dive

ATRIAL FIBRILLATION

Atrial Fibrillation (AF) is characterized by irregular electric impulses coming from aberrant sites in the left atrium and may decrease heart output. Some people get AF from time to time and, after a brief episode, revert spontaneously or under medication back to a normal rhythm. Some people must take medication all the time to maintain a normal rhythm. An alternative to medication is to treat AF with ablation, a type of surgery that removes sources of irregular electric activity, like in Case 1-7. However, some people are permanently in atrial fibrillation, like Case 1-8, and they usually receive chronic medication to keep their heart rate under control. While the participation of people with periodic AF may be disputable, in the case of permanent AF, under the current guidelines for fitness to dive evaluation, the diver should be considered unfit. Return to diving after ablation should be discussed with a cardiologist. Even after cardiology consultation, the risk of sudden debilitating arrhythmia is always looming above patients with AF. Thus, if a diver with AF decides to continue diving, he should carefully choose his diving opportunities and should disclose his condition to his buddy and dive operator. They should strictly adhere to safe buddy diving practices, including always returning to the surface together.

BUDDY DIVING

Buddy diving is a potentially life-saving practice for scuba divers. Properly implemented, it helps to prevent accidents and to avert bad outcomes of possible incidents. Buddy diving starts with sharing the dive plan, getting familiar with each other's equipment, pre-dive buddy check, keeping an eye on each other during the dive, sticking to the plan, returning to the surface together, and conducting a post-dive debrief. Every year, we see many cases illustrating the failure of a buddy system, as well as cases where the buddy system could not help despite the proper conduct of both partners (Cases 1-9, 1-10, 1-11).

Buddy assistance is probably most valuable when one buddy suddenly has issues with a gas supply, but it may help in other situations too. For the buddy assistance to be of value, buddies should stay close to each other and check each other often. The classic buddy system means two divers diving together dedicated to each other's safety. In a group of three or more divers, it is unlikely to expect the same level of dedication and attention to the needs of others.

In real life, buddies often separate but this is rarely intentional. Without strong discipline, it is easy to lose sight of a buddy. It seems that the separation has become common and that buddies rarely abort their dive and go to the surface to wait there to re-establish contact. Even without separation, one diver may become unconscious and sink to the bottom without his preoccupied buddy noticing it. Thus, it is wrong to assume that an out-of-sight buddy has intentionally separated and to continue to dive without attempting to find him.

In guided diving, there is often one diver in the lead and one following the group with the task to herd all divers together. Despite this attempt, divers often get lost or drown unnoticed. Maybe it would help if each diver in a group had an assigned buddy.

In some cases, the affected divers alert the buddies of their intention to surface. Their distress may not always be obvious to their buddy, and they may not have time

for explanations. Since their buddy did not comprehend the problem, the distressed diver's main priority is to reach the surface. For buddy diving, the rule is for both divers to return to the surface at the same time. It is even more important to follow this rule when one buddy decides to ascend sooner than originally planned. A special situation is in case the instructor has two or more students, and one gets in distress. Taking just one student to the surface may be fatal for the inexperienced diver left at depth.

As a final note, Case 1-11 should be a warning to experienced divers who may feel that the buddy system is only for novice divers.

There remains a lot to learn about why divers separate, what is the best and most efficient practice of buddy diving, how to monitor divers in the group, and how to make the buddy system more reliable in general.

FATALITY CASE SUMMARIES

Case 1-1: Hypertensive heart disease, cardiomegaly with LVH, and morbid obesity

This is a 60-year-old male scuba diver with a significant history of hypertension, morbid obesity (BMI = 37 kg/m²), known coronary artery disease, diabetes, who was diving under ideal conditions in shallow water checking out his gear. He had trouble descending, so he added extra weights. He silently disappeared from his buddy, and nobody witnessed his last moments. A swimmer passing by found his body and required assistance to bring him to the surface. EMS happened to be nearby and they administered CPR/ACLS (advanced cardiovascular life support) without success.

The autopsy findings, based on the coroner's summary, did not provide an explicit cause of death, but the major findings included critical coronary atherosclerosis, cardiomegaly (heart weight = 600 grams) with left ventricular hypertrophy. The final cause of death was drowning, but there was no evidence to establish the disabling condition that rendered him unable to protect his airways underwater. The fluid in his sinuses may indicate that he was already unconscious and not able to equalize pressure while sinking to the bottom.

Based on the autopsy findings, lack of fitness, his struggle with buoyancy, and silent disappearance, it is quite likely that he developed a dysrhythmia and cardiac arrest.

Case 1-2 Hypertensive heart disease, cardiomegaly, hepatosplenomegaly, obesity, and implanted pacemaker

A 57-year-old male [180 centimeters (71 inches), 102 kilograms (224 lbs), BMI = 31.2 kg/m²] had a known hypertensive heart disease and an implanted pacemaker rated for 10 msw (33 fsw). His physician advised no diving deeper than 6-8 msw (20-25 fsw). Shortly after diving to 12 msw (40 fsw), he began experiencing trouble and came to the surface where he lost consciousness. He was brought to the boat, and CPR was promptly started without success.

The autopsy report lists an abnormally enlarged heart (cardiomegaly; heart weight = 600 grams), enlarged liver and spleen (hepatosplenomegaly), severe damage of the kidney (bilateral arteriolo-nephrosclerosis), and an implanted pacemaker.

This diver had a history of hypertension and troubling arrhythmia that required an implanted defibrillator. In such cases, the fitness to dive could not be judged solely on whether the implanted pacemaker would withstand the pressure but also the indication. Screening for cardiomegaly should be considered, and tests like chest x-ray, electrocardiogram (ECG), or echocardiography should be used.

The ability of the implanted device to withstand the ambient pressure for the depth of the dive site is paramount to the device's successful operation. An implantable pacemaker rated for 10 msw (33 fsw) is not suitable for diving. However, even with a pacemaker rated for greater depth, patients who need it require greater scrutiny, including a physical exam, specialty consultation and reviewed with a diving medical physician. Any depth limitations must be conveyed to the patient and his dive partners. The dive operator must fully understand the restrictions and be able to safely accommodate such a diver.

Case 1-3 Hypertensive heart disease, cardiomegaly with concentric LVH, morbid obesity, smoker

The diver is a 50-year-old, morbidly obese (BMI = 36.2 kg/m²) male, who was a smoker with a history of hypertension indicated that he was experiencing difficulty breathing (or chest discomfort) toward the end of his planned dive. Other divers proceeded to the surface to assist him, but before reaching the surface, they observed that he suddenly stopped his controlled ascent (he probably became unconscious at that point) and sunk to the bottom without struggle. He never dropped his weight belt. He was retrieved and brought back to the boat, where resuscitative efforts were unsuccessful.

Autopsy revealed pulmonary edema, cardiomegaly (heart weight = 558 grams) with concentrically symmetrical left ventricular hypertrophy, chronic nephrolithiasis, and moderate hepatic steatosis. Chemistry tests were positive for alprazolam (benzodiazepine), citalopram, and bupropion, all of which are anti-depressive but also may be used for other indications. The medical examiner ruled that the cause of death was drowning, but the disabling condition may be an acute cardiac event. The reported shortness of breath may have been due to pulmonary edema or cardiac dysrhythmia, which has been associated with cardiomegaly, LVH, and polypharmacy.

Case 1-4 Hypertension, coronary artery disease, cardiomegaly, diabetes, and obesity

This 63-year-old, obese (BMI = 34.5 kg/m²) male, dived to 27 msw (90 fsw) with two buddies on a team. At depth, he signaled that he was having difficulties, aborted the dive, and made an emergency ascent before the two buddies could get to him. Upon reaching the surface, he appeared to be in distress and panicked. He was assisted to the boat, where he collapsed upon exiting the water. The boat crew started CPR and took him to the nearest ER, where he was declared dead.

He had a history of hypertension and diabetes. His autopsy revealed an enlarged heart with LVH, conspicuous pulmonary edema, serum positive for B-blocker, and significant coronary artery disease. Gas bubbles were present in the left heart but not in the right heart.

The likely disabling condition, in this case, is dysrhythmia, which led to cardiac arrest and death. Pulmonary edema did not appear significant, and clinical correlates for immersion pulmonary edema (IPE), cough, frothy, blood-tinged sputum, were not reported.

Case 1-5 Atherosclerotic coronary disease, obesity, smoking and lack of fitness

A 59-year-old obese (BMI = 33.1 kg/m²) male who was a smoker lost consciousness while diving at 24 msw (80 fsw) and drowned. He had trouble maintaining his buoyancy in an earlier dive and needed a guide's assistance. He was seen struggling against the current and even trying to hold on to coral, but he did not appear to be in distress. He was found unconscious at the bottom with the regulator out of his mouth. Other divers in the area brought him to the surface and aboard where the crew began CPR. He was transported ashore and later declared dead. An autopsy revealed significant coronary artery disease, dilated heart, evidence of pulmonary barotrauma (bilateral pneumothorax, subcutaneous emphysema). His dive computer recorded a heart rate of 210 when he went into distress.

The probable disabling condition, in this case, was an acute coronary syndrome with arrhythmia. Contributing factors may have been exertion, stress, and the possible onset of pulmonary edema. The pulmonary barotrauma occurred on the ascent while the victim was already unconscious. This diver was probably not exercising regularly nor received formal exercise stress testing. Otherwise, he would have been aware of his poor fitness, and he may not have elected to dive in a strong current that required significant sustained effort.

Case 1-6 Severe left ventricular hypertrophy and depression

A 60-year-old scuba diver collapsed upon boarding the boat after a 29 msw (95 fsw) dive. He had a history of hypertension, smoking, and was treated for depression. His medications included beta-blockers metoprolol, and anti-depressants Lamotrigine and Sertraline. The autopsy revealed severe left ventricular hypertrophy, moderate cardiomegaly, moderate coronary artery disease, and pulmonary edema.

The cause of sudden cardiac death in this case with LVH and cardiomegaly could have been an arrhythmia with a contribution of immersion pulmonary edema.

Case 1-7 Persistent atrial fibrillation

A 65-year-old female, experienced scuba diver, with a history of persistent atrial fibrillation, went into distress while spearfishing and lobster harvesting at about 23-26 msw (75-85 fsw). The water temperature was comfortable and the sea was calm. While adequately hydrated, she was wearing a tight-fitting wetsuit and indicated that she felt poorly 40 minutes into a dive that she had planned to last for one hour. She returned to the surface alone. At the surface, she was extremely dyspneic and weak. An alert crew identified that she required assistance to get aboard the boat. Unable to catch her breath, uncontrollably coughing up blood-tinged sputum, she eventually lost consciousness and pulse. CPR was initiated without success, and she was later declared dead.

We couldn't obtain the autopsy report for this case. The victim used Xarelto, Metoprolol, Xanax, Amiodarone, Digoxin for her condition. She was a smoker. Her symptoms indicate immersion pulmonary edema. Her medications indicate significant cardiac problems and certainly could have contributed to its development.

Case 1-8 Diving with atrial fibrillation after ablation

A 62-year-old male diver was hunting for lobsters with his son. This was their third dive of the day, and the maximum depth was 27 msw (90 fsw). At some point, after they had reached 12 msw (40 fsw), the father gave a sign that he is going to the surface. His son did not notice any sign of distress, and he did not find it unusual because his father often finishes his dives without a dive buddy. The son did not surface with his dive buddy and instead joined another group for more lobster hunting. The victim appeared on the surface in distress alone and was recovered by alert boat crew and CPR initiated. He was evacuated to a recompression chamber, did not regain consciousness, and later died from a cardiac event. He had a history of atrial fibrillation that he reportedly had under control with an ablation two months before the accident, and was on medications. Autopsy revealed moderate to mild coronary artery disease and pulmonary edema, and no signs of pulmonary over inflation.

Case 1-9 The death of an adhoc buddy not noticed by two others

A 48-year-old male who was diving at a depth of less than 9 msw (30 fsw) drowned under ideal diving conditions. He was an experienced diver and felt that forming a three-person buddy team was adequate. The shallow depth, ideal conditions, and over three dozen other divers in the water gave further confidence to the decision. The other two divers in his team may have determined his professed experience did not warrant the usual vigilance and lost track of his whereabouts as he explored the reef. When they surfaced, they couldn't find him. The crew started lost diver procedures, but they could not find the diver. His body was discovered many hours later, at the bottom not far from the entry site. There were no witnesses of his last minutes and no one saw him surface at any time. His dive gear appeared functional. The autopsy had no significant findings.

Most likely, he lost consciousness suddenly and sunk. A recording from his computer could have helped to establish if he attempted an ascent at any time. In the absence of known health history and unremarkable autopsy findings, it is not possible to establish what was the disabling factor in this case. It is also not clear whether his buddies lost sight of him when he sunk unconscious to the bottom, or he intentionally separated before getting in trouble.

Case 1-10 Entangled in a fishing net at depth diver drowned before her informal buddies realized she was missing

A 56-year-old, experienced female diver was found unconscious and entangled in a fishing net at 58 msw (190 fsw) by a small group of divers diving together (loosely serving as buddy team). They found her with the regulator out of her mouth, tangled in fishing net upside down. They untangled her and, in a rapid uncontrolled ascent, got her to the surface. She remained unconscious since her discovery on the bottom despite receiving CPR. She was evacuated and treated unsuccessfully in a recompression chamber and was later declared dead. She had additional tanks of 50% and 100% oxygen for decompression. Her primary was air. The autopsy revealed minimal coronary artery disease, tympanic membrane perforation, subcutaneous emphysema, and cortical and brainstem hemorrhagic microinfarcts.

The disabling agent in this accident is the entanglement, while the disabling injury may have been asphyxia or hyperoxic toxicity. The ensnaring net may have pulled her regulator away and she either could not get to her secondary regulator and drown or mistakenly used either of her hyperoxic deco mixes. In her struggle, she may have inflated her legs, flipping her and further adding to her confusion. At this depth, nitrogen narcosis impairs the ability to handle emergency procedures as well as the efficacy of the buddy system. Despite it, buddies probably found the victim quite soon after she disappeared while she still may have been alive. In an attempt to take her to the surface, buddies at first failed to realize that her regulator was still entangled by the net.

They added gas to her BC, but she was not ascending until they finally freed her regulator. Now, with excessive positive buoyancy, she went emergently to the surface, which resulted in the rupture of her eardrum. It is not clear if she had arrived at the hyperbaric chamber alive, but she was recompressed to 50 msw (165 fsw) in an attempt to treat possible AGE and DCS. Five days later, the autopsy found subcutaneous emphysema and signs of micro-bleeding in the brain.

Diving at 58 msw (190 fsw) breathing air is risky, and the divers' ability to cope with problems is diminished. Buddy diving may not be sufficient to mitigate the risks faced at this depth.

Case 1-11 Buddy Check before Diving Important for all Divers.

A 57-year-old male diver was on his third dive when he switched to another dive buddy as the teams entered the water. Both were experienced divers and they decided that buddy checks were not needed. They arrived at 40 msw (130 fsw) when the buddy noticed that the victim was not moving and regulator was out of his mouth. The buddy replaced the regulator and purged it twice without success. He attempted to drop the victim's weights and inflate his BC when he lost hold of the victim who sank. His body was found and recovered by a remotely operated vehicle (ROV) in 91 msw (300 fsw) about three days later.

There were no problems before this last dive. The diver was carrying 30% nitrox in his main tank and possibly 40% nitrox in his pony bottle (empty, unable to analyze). The electronic gauge later determined that he used his main tank only for adding gas to his drysuit while he inadvertently was breathing from the pony bottle. This exposed him to the partial pressure of oxygen greater than 20 psi (1.4 bars), which is generally considered a safe limit.

Autopsy revealed left ventricular hypertrophy and significant coronary artery disease. Possible disabling conditions, in this case, are sudden cardiac death, running out of gas and drowning, and oxygen toxicity. His buddy was in the vicinity, and the fact that he was not alerted may indicate

that unconsciousness was sudden likely in SCD. On the other hand, the running out of gas may have evoked a stress response, which, coupled with his significant coronary artery disease, may have led to dysrhythmia and unconsciousness. Nitrogen narcosis may have contributed and impaired his response to the emergency.

Case 1-12 Gear malfunction triggered a fatal event in a diver with cardiomegaly

A 72-year-old obese male drowned while diving. He made a dive to 13 msw (43 fsw), and after a long surface interval began a second dive when his dive buddy noticed a hole in his BC and developed a leak. The buddy inflated her BC and brought him to the surface. He subsequently appeared panicked and confused and swam frantically away from the boat before losing his mouthpiece. His buddy swam up and noticed he was not breathing or had a pulse. She was unable to bring him back to the boat and recover him. She waved down a passing boat. Resuscitation efforts were unsuccessful. A medical examiner found cardiomegaly, mild to moderate coronary artery disease, and pulmonary edema.

Difficulty with his buoyancy vest throughout the dive with eventual leak and an uncontrolled emergency ascent is possible triggers in this accident, which resulted in arrhythmia and cardiac arrest. The autopsy found evidence of lung barotrauma or cerebral arterial gas embolism.

Case 1-13 Buoyancy Compensator not connected to the gas source led to drowning

A 63-year-old female scuba diver experienced difficulties shortly upon entering the water. Before entering the water, her new buddy warned her that her BC hose was not connected. She said she would connect it. She entered the water with two buddies. One of the staff noticed her at the surface, shortly after the beginning of dive, with the regulator and mask in place, raising a hand. He asked if she needed more weight, but she did not answer, and she soon slipped underwater. One diver said she saw her weight belt sinking past her. It is not clear when the weight belt was dropped and who did it. When she looked

up, she saw the victim ascending, but soon the victim started descending headfirst until reaching the bottom and did not interact with anyone around her. At one point, her buddies noticed her 6 meters (20 feet) away flailing. One diver who tried to assist her saw that the victim's BC was not connected, and one rescuer attempted to inflate it manually. Divers brought the victim to the surface and within a few minutes staff got her out of the water and initiated CPR. Later, she was taken to the ER, where she was declared dead.

Failure to connect BC hose and negative buoyancy probably led to the drowning of this diver. Her brief appearance at the surface was classic for a drowning victim, unresponsive, hyper-focused, minimal activity, and eventual sinking. Her struggle with the buoyancy may have caused other disabling conditions like arrhythmia or immersion pulmonary edema.

Case 1-14 Rapid development of coma after an emergency ascent from depth

A 66-year-old male instructor teaching an open circuit trimix course dived to 70 msw (230 fsw) with two students. The last dive was planned for about 19 min and 40 minutes of planned decompression. However, after about 6-7 minutes at the bottom, the victim left his student at depth and ascended rapidly. The victim surfaced in a panicked and confused state, was able to board the boat, and requested oxygen. He was assisted out of his dive gear and was provided high flow oxygen via a face mask. There was a 5 minutes ride back to shore, and he started to struggle with or reject the oxygen mask. His respiratory pattern appeared shallow and rapid and repeatedly made "Ahh" sounds as if in severe pain. He was confused and unable to focus. During the 10 minute wait for an ambulance at the dock, his level of consciousness began to decrease, and the muscles in his hands and arms began to contract. He became unresponsive and was believed to be in respiratory arrest while being loaded into the ambulance. He was transferred to a local hospital.

His bottom mix was 17/57 and had a travel gas of 30/35 down to 30 msw (98 fsw). He also had 50% and 100% deco gases.

He was transferred to a hospital with hyperbaric treatment ability and was given 4-5 treatments but remained in a comatose state. The victim was flown back to his home country (U.S.) in a comatose but stable state. An MRI revealed extensive swelling of the cervical spinal cord with diffuse bihemispheric white matter lesions and areas of restricted perfusion. Twelve days after the initial incident, he died due to cardiac arrest.

It is not known what triggered the emergency ascent in this case, but the dominant symptoms upon exiting the water were of severe decompression illness, which occurs after a rapid ascent from great depth and omitted decompression. The MRI findings may support the diagnosis of DCI. Fortunately, his two students were reportedly able to decompress properly and made it aboard without a problem.

Case 1-15 Deep wreck diving went bad

A 71-year-old male diver was on a wreck dive to 58 msw (190 fsw). He became entangled and then freed. He then lost contact with the ascent line. He floated to the surface and collapsed on the ladder of the boat and was brought on board. He was given CPR for 90 minutes to no avail. There is speculation that he died of a heart attack. However, this was a severe decompression accident, and severe decompression sickness was very likely, not excluding the possibility of arterial gas embolism or heart attack.

Case 1-16 Diver in distress at depth did a rapid ascent and became unresponsive

A 46-year-old male diver was pulled from the water unresponsive after a deep wreck dive to 55-76 msw (180 - 250 fsw). His buddy noticed that he was struggling underwater, but the two of them could not locate the ascent line, and the victim did a rapid ascent. CPR was performed for two hours while waiting for the USCG. The USCG did not evacuate via helicopter due to the length of CPR.

The cause of the victim's struggle at the bottom is not known. He may have died while ascending, from the condition causing him distress at depth. However, this was a severe decompression accident, sufficient to be the primary cause of death.

Case 1-17 Experienced divers failed to recognize the need for refresher course despite a series of near-misses when they resumed diving after long absence

A 62-year-old female, experienced diver, lost consciousness while trapped and inverted at 20 msw (65 fsw).

She and her buddy were both experienced divers with hundreds of dives, but this was their first dive trip after a ten year hiatus. They reported to the dive operator that they were probably more experienced than most instructors. However, on day one, she discovered her drysuit no longer fit. She had considerable trouble with inflation/buoyancy on her first dive, required maximum assistance of the crew, and was overwhelmed to the point that she opted not to dive the rest of that day.

Subsequent dives were plagued by the inability to control her drysuit. At one point, she overinflated her drysuit due to difficulty overcoming the current and trapped her inflation bottle in the rocks. After freeing her, her buddy signaled that he was out of the air and was forced to make an emergency ascent without her despite making his situation known. Not finding his buddy on the surface, the out of air buddy felt he had to descend only to find her on the bottom signaling to him. He recovered her from the bottom but ran out of the air and was going to rely on his pony bottle to ascend.

Unfortunately, the buddy had turned off his emergency pony bottle. He signaled to her his urgent need for air, but she again failed to recognize the emergency or assist, and he made an emergent ascent almost losing consciousness himself. She finally recognized his plight and aided him on the surface. The boat crew made an emergent rescue and brought him safely aboard. The buddy pair did no further dives that day.

After two days of near-miss underwater incidents, they planned their next dive and decided to add the additional task of photography. Shortly after reaching the bottom, she was found inverted when her drysuit legs overinflated but remained at depth due to her weighting. She was unresponsive and not breathing. She was brought rapidly to surface by her dive buddy, who inflated her BC, dropped her weights [about 9 kilograms (20 pounds)], and kept her regulator in her mouth. She was not breathing from the time she left the bottom and had no pulse when checked onboard with an estimated 10 minutes from depth to boat. No rescue breaths were administered in the water. Blood tinged sputum was seen coming from her mouth. A crew administered CPR and attempted defibrillation three times during the initial 20 minutes of resuscitation without success. She was hoisted aboard the rescue helicopter that happened to be training nearby where ACLS continued with persistent asystole by monitor. The hoist was estimated to be 2 minutes in duration. She was taken to a recompression chamber and recompressed to 50 msw (165 fsw) without change and later declared dead. The autopsy revealed extensive lung barotrauma, bleeding in the petrous bones of the ears, and bilateral parietal subarachnoid bleeding. There was an insignificant coronary artery disease.

It is important to recognize deficiencies in training, physical fitness, and equipment. Even experienced divers who take an extended period away from diving, benefit from refresher dives. Even if the gear is in good working order, consider a replacement if it no longer fits or works effectively for you. Opting out of diving is the right decision when issues such as health, equipment, environment, etc. is a concern.

Avoid task loading until comfortable in the water. The multiple red flags should prompt one to put the camera away during this dive trip and concentrate on the basic skills. Drysuit diving requires proper equipment and training to use safely.

Possible causes for the loss of consciousness underwater:

- **Pulmonary edema** - high catecholamine surge when inverted by drysuit mishap, perhaps overhydrated, age, inversion with a hydrostatic elevation of central vascular pressure; copious blood-tinged sputum observed
- **Subarachnoid hemorrhage** noted on autopsy after an inverted position. Several episodes of lack of awareness/comprehension noted on previous dives.

Clear indications of the pulmonary over-inflation syndrome were evident on autopsy and may have impacted resuscitation, but they were not the primary cause of this fatality.

Case 1-18 Panic upon entry and drowning of an apparently healthy woman

A 65-year-old, obese (BMI = 39 kg/m²) female, experienced diver, entered the water and began to panic as she descended, and attempted to remove her face mask. A fellow diver assisted her to the surface and struggled to keep the woman's regulator in place. CPR was unsuccessful, and she was later pronounced dead.

She had no history of cardiac disease, medications, or recreational drug use. The autopsy found no significant atherosclerosis. Lungs were moderately edematous, which is compatible with drowning. The equipment appeared to be in good condition. We do not know if her tank valve was open when she entered the water and began sinking. The cause of death ruled by the medical examiner was drowning. We do not know what triggered a panic when she entered the water. The attempt to take off the mask underwater may be that the regulator did not provide air (tank valve closed) or that she experienced shortness of breath due to other causes.

Case 1-19 Acute stomach bleeding while diving

A 63-year-old female scuba diver joined two others on a dive where she lost consciousness at depth over 30 minutes into her dive. She was brought to the dive boat, and later received CPR. The victim had a significant history of hemorrhage and hypertension. An autopsy showed a significant GI ulcer with chronic inflammation that resulted in over one liter bleed into her stomach.

Dramatic acute medical conditions like stomach bleeding may not always be predictable. They may occur unrelated to diving, but if they occur underwater and in a remote location that hampers timely evacuation, they are more likely to be fatal.

Case 1-20 Fatal outcome in saltwater aspiration

A 64-year-old male, novice diver, panicked while underwater. Upon reaching the surface, he struggled with buoyancy and removed his regulator. Due to the sea state and difficulty staying afloat, he eventually aspirated seawater before retrieval by the boat. The crew provided first aid oxygen and he remained conscious without signs of focal neurologic deficit or evidence of pulmonary barotrauma. He later developed a cough while his oxygen saturations remained low despite supplemental oxygen. His respiratory status quickly degraded despite intense respiratory support in the ICU, including mechanical ventilation. He eventually died.

REFERENCES

1. CDC. Heart disease facts. <https://www.cdc.gov/heartdisease/facts.htm>. Accessed February 25, 2020.
2. Heron, M. Deaths: Leading causes for 2017. *National Vital Statistics Reports*;68(6).
3. Benjamin EJ, Muntner P, Alonso A, Bittencourt MS, Callaway CW, Carson AP, et al. Heart disease and stroke statistics—2019 update: a report from the American Heart Association. *Circulation*. 2019;139(10):e56–528.
4. Fryar CD, Chen T-C, Li X. Prevalence of uncontrolled risk factors for cardiovascular disease: United States, 1999–2010. *NCHS data brief*. 2012 Aug;(103):1-8.
5. Windsor SJ, Firth PG, Grocott MP, Rodway GW, Montgomery HE. Mountain mortality: a review of deaths that occur during recreational activities in the mountains. *Postgrad Med J*. 2009;85:316–321. doi:10.1136/pgmj.2009.078824
6. Lippmann J, Taylor D, Stevenson C, Williams J, Mitchell SJ. Diving with pre-existing conditions. *Diving Hyperb Med*. 2017;47(3):180-190.
7. Ranapurwala SI, Kucera KL, Denoble PJ. The healthy diver: A cross-sectional survey to evaluate the health status of recreational scuba diver members of Divers Alert Network (DAN). *PLOS One*, Published online March 22, 2018. <https://doi.org/10.1371/journal.pone.0194380>

SECTION 2. DAN INCIDENT MAPPING

Andrea Filozof, Asienne Moore, Allan Uribe

OVERVIEW

Divers Alert Network maintains data on scuba diving accidents and injuries reported to the Medical Services Call Center (MSCC) as well as those reported through internet and media outlets. Mapping this data provides DAN and the scuba community with a quick way to visualize the de-identified data and identify trends. This visual data can also be used to help DAN allocate resources or focus on a particular area to determine why accidents and/or fatalities are occurring there. As the data collection becomes more refined, the aim is to identify the specific factors behind these trends, ranging from diver age, to injury type, to water temperatures. Ultimately, however, reliance is on the scuba community to help accurately report these incidents when they occur. Understanding where, why, and how diving incidents occur helps DAN determine how to prevent future injuries - and may save the life of a fellow diver.

DATA COLLECTION

Data collection at DAN begins with certified dive medics and physicians at the Medical Services Call Center (MSCC). The MSCC operates 24/7 and accepts both emergency and non-emergency calls. The emergency call line assists divers who have suffered a diving injury by providing evacuation assistance, referrals to physicians with dive medicine experience, and insurance coverage of dive-related injuries. The non-emergency line answers general questions about diving with known health issues or medical conditions, human physiology and diving, environmental conditions and diving, and travel questions. These calls are recorded as either cases (emergency calls) or information requests (non-emergency) in a secure database. With proper institutional review board approval, DAN researchers may then use de-identified data to study specific topics and map relevant data. Recent study topics include children in diving, women in diving, and breath-hold injuries and fatalities.

MAPPING

In order to create the maps in this report, we built a series of database queries to select the specific information we wished to visualize geospatially. Query examples included all scuba diving cases handled by MSCC, scuba diving fatalities, and breath hold incidents (both fatal and non-fatal). No personally identifying data, such as names or member ID numbers, were used in our mapping queries. Based on the level of detail provided for the incidents in each query, the location data can be joined with geographic boundaries within mapping programs to give a count of how many incident types have occurred in a particular country or state. The research team relied on the open-source geographic information system (QGIS) to join the data and build the maps displayed here.

LIMITATIONS

The data depicted in each map represents the total raw count of each type of incident. Regions that contain greater numbers of scuba divers therefore generally reflect a greater number of scuba diving incidents; it does not necessarily mean that those regions are more dangerous diving destinations. The U.S. states of California and Florida, for example, routinely boast the highest number of certified scuba divers in the country (around 14% and 10% respectively, according to the Diving Equipment and Marketing Association's 2019 State Certification Census). As a result, California and Florida also show the greatest density of scuba diving incidents in nearly every category. Incident density serves here as a tool for allocating resources rather than flagging an area as unsafe. DAN does not seek to discourage travel from any location based on the mapping data provided.

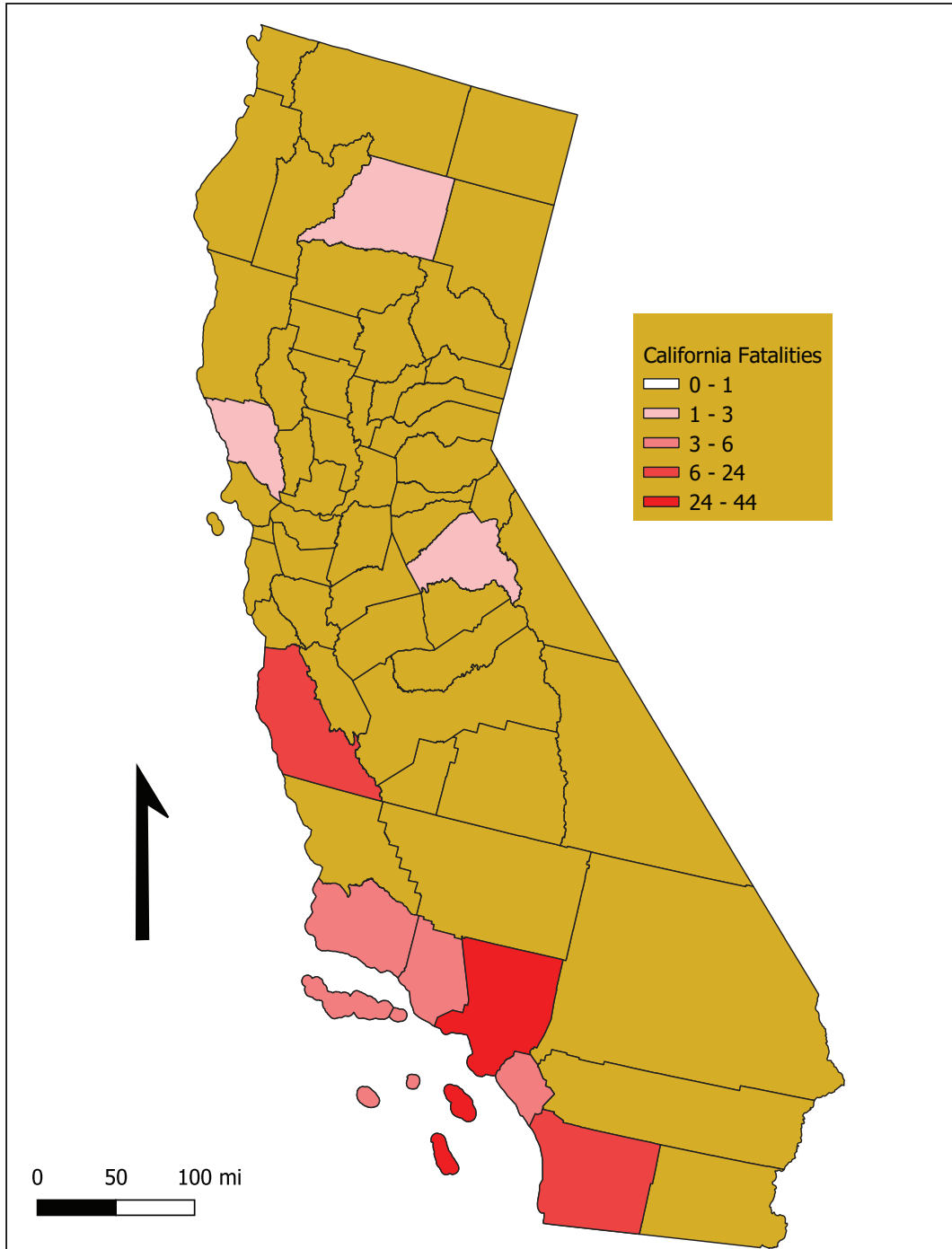
The maps currently reflect incidents down to the smallest geographic boundary listed for the majority of cases within the database. For this reason, the maps only display incident density at the state level within the United States and at the country level for international cases. As DAN continues to expand globally and refine data collection techniques, we aim

to capture incident data down to the city level both within the U.S. and abroad.

CONCLUSION

Effective data collection and management serve as the foundation of DAN's mission to build a culture of dive safety. By capturing and reviewing these lessons learned, we are better able to shape training and risk management techniques that prevent diving accidents from happening in the first place. While DAN ultimately aims to bring the number of incidents as close to zero as possible, DAN research works to guarantee that we, as a dive community, learn as much as possible from every incident that does occur. From exploring new frontiers in diving physiology to formulating new training programs, DAN relies on the input of fellow divers to ensure that everyone exits the water safely.

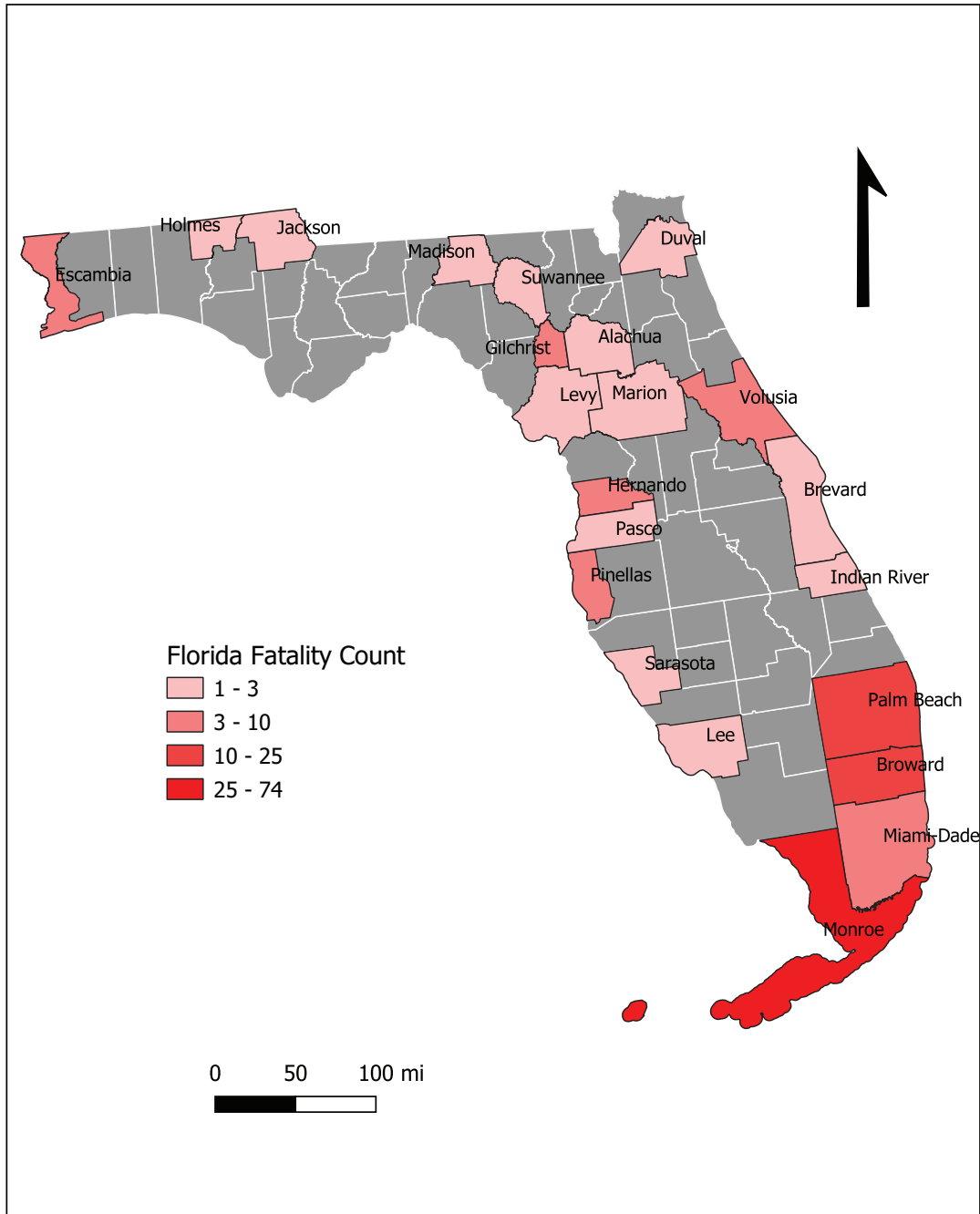
Deaths in California by County 2007 - 2017



Created by: Allan Uribe
Date: January 23, 2020

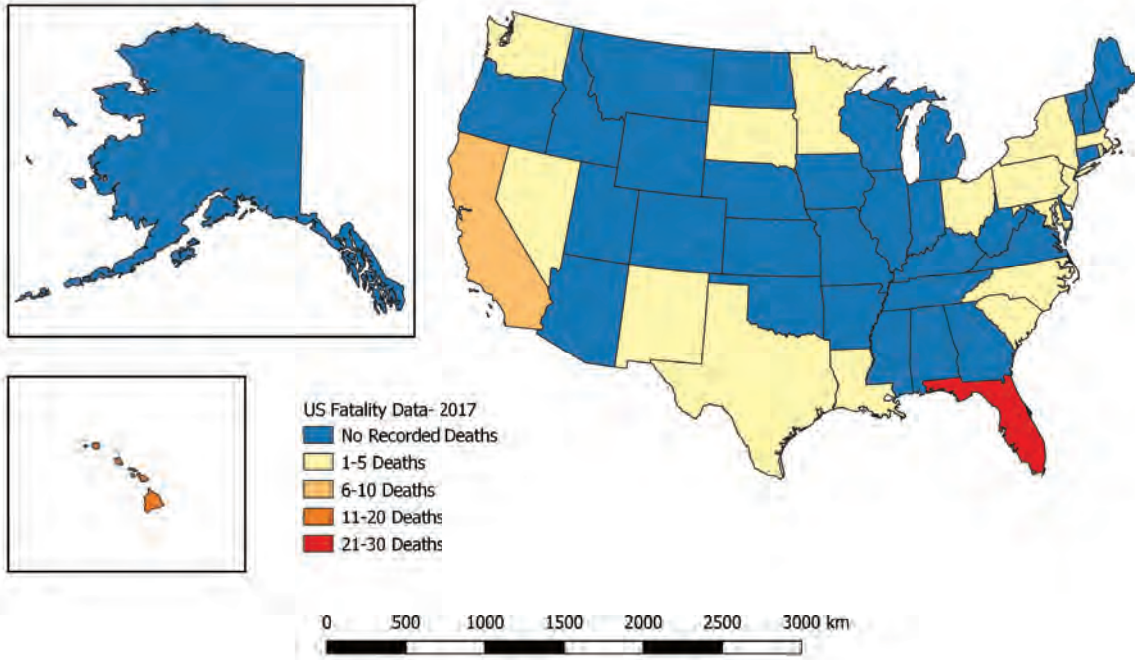
Data: DAN fatalities data

Deaths in Florida by County - 2007 - 2017

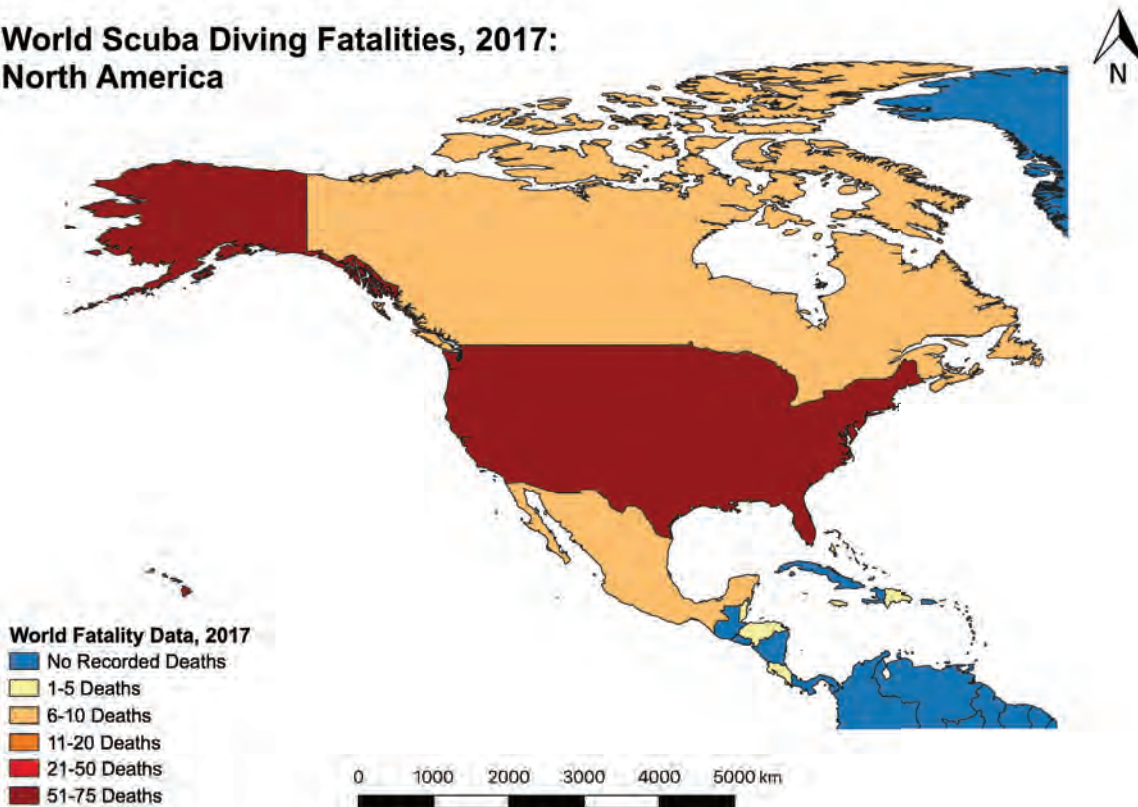


Created by: Allan Uribe Data: DAN fatalities data
Date: January 23, 2020 Updated: March 3, 2020

US Scuba Diving Fatality Data, 2017



World Scuba Diving Fatalities, 2017: North America



World Scuba Diving Fatalities, 2017: South America and the Carribean

World Fatality Data, 2017

- No Recorded Deaths
- 1-5 Deaths
- 6-10 Deaths
- 11-20 Deaths
- 21-50 Deaths
- 51-75 Deaths

0 1000 2000 3000 4000 5000 km

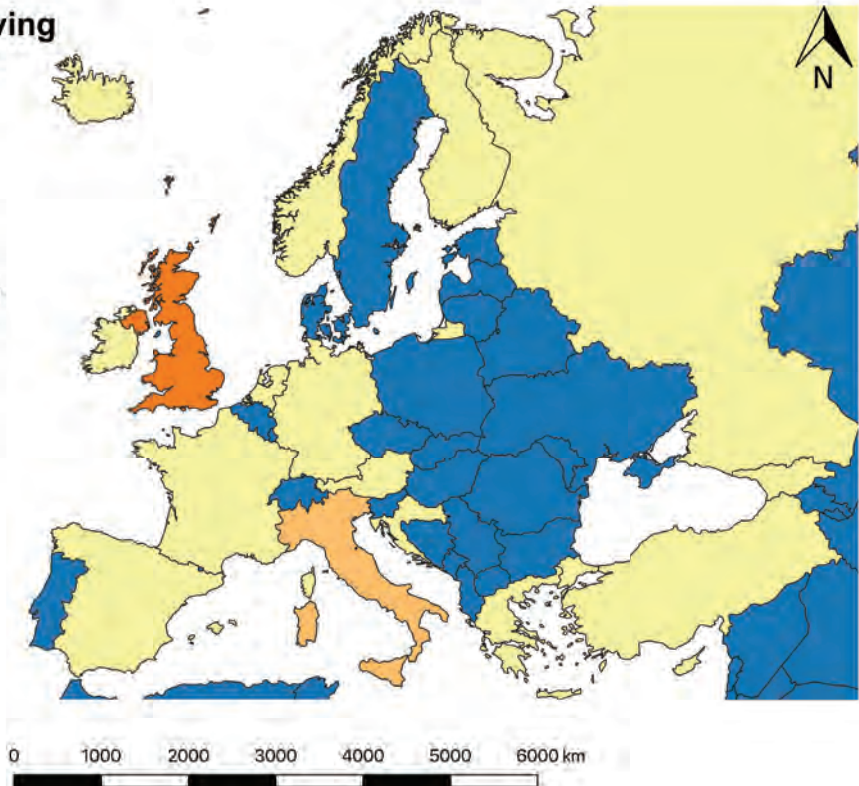


World Scuba Diving Fatalities, 2017: Europe

World Fatality Data, 2017

- No Recorded Deaths
- 1-5 Deaths
- 6-10 Deaths
- 11-20 Deaths
- 21-50 Deaths
- 51-75 Deaths

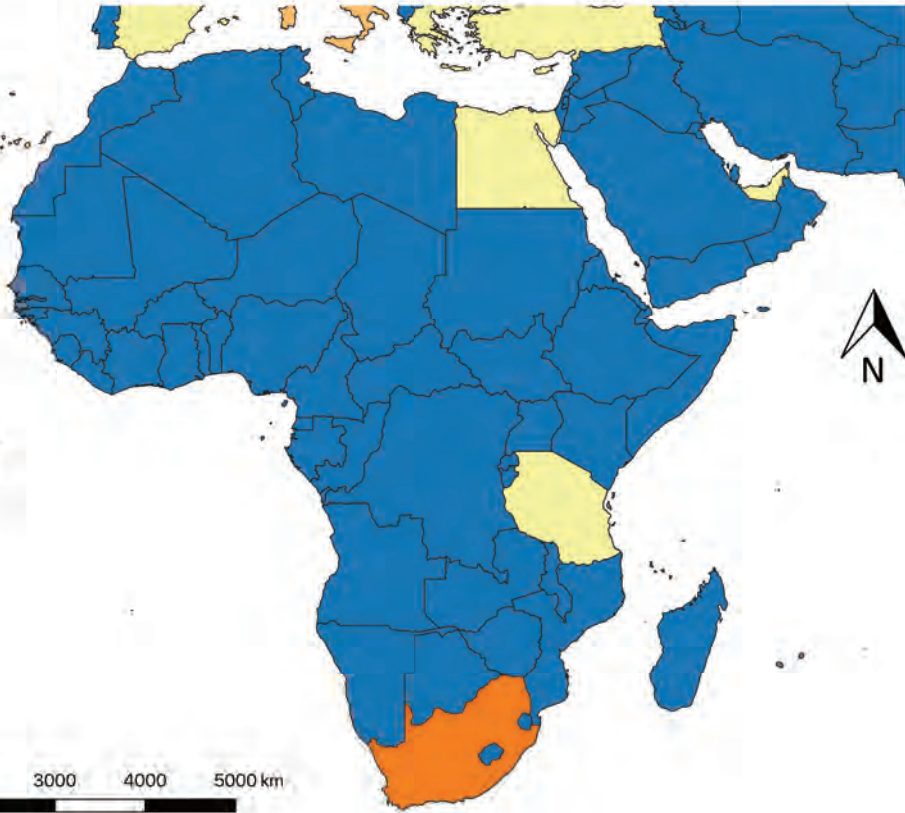
0 1000 2000 3000 4000 5000 6000 km



World Scuba Diving Fatalities, 2017: Africa and the Middle East

World Fatality Data, 2017

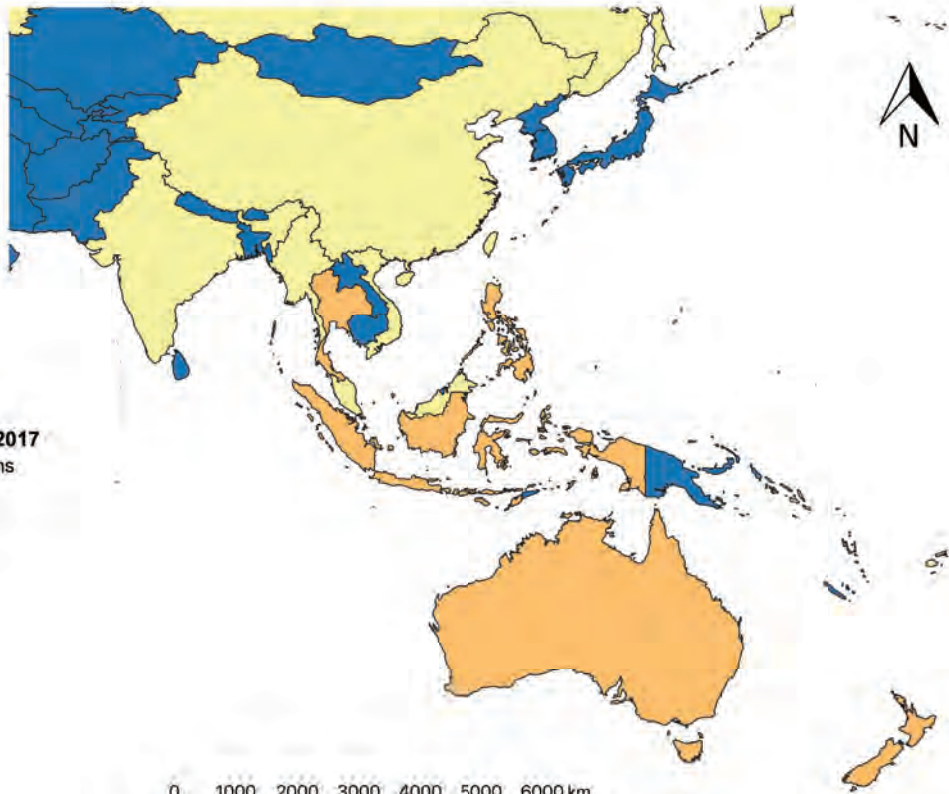
- No Recorded Deaths
- 1-5 Deaths
- 6-10 Deaths
- 11-20 Deaths
- 21-50 Deaths
- 51-75 Deaths



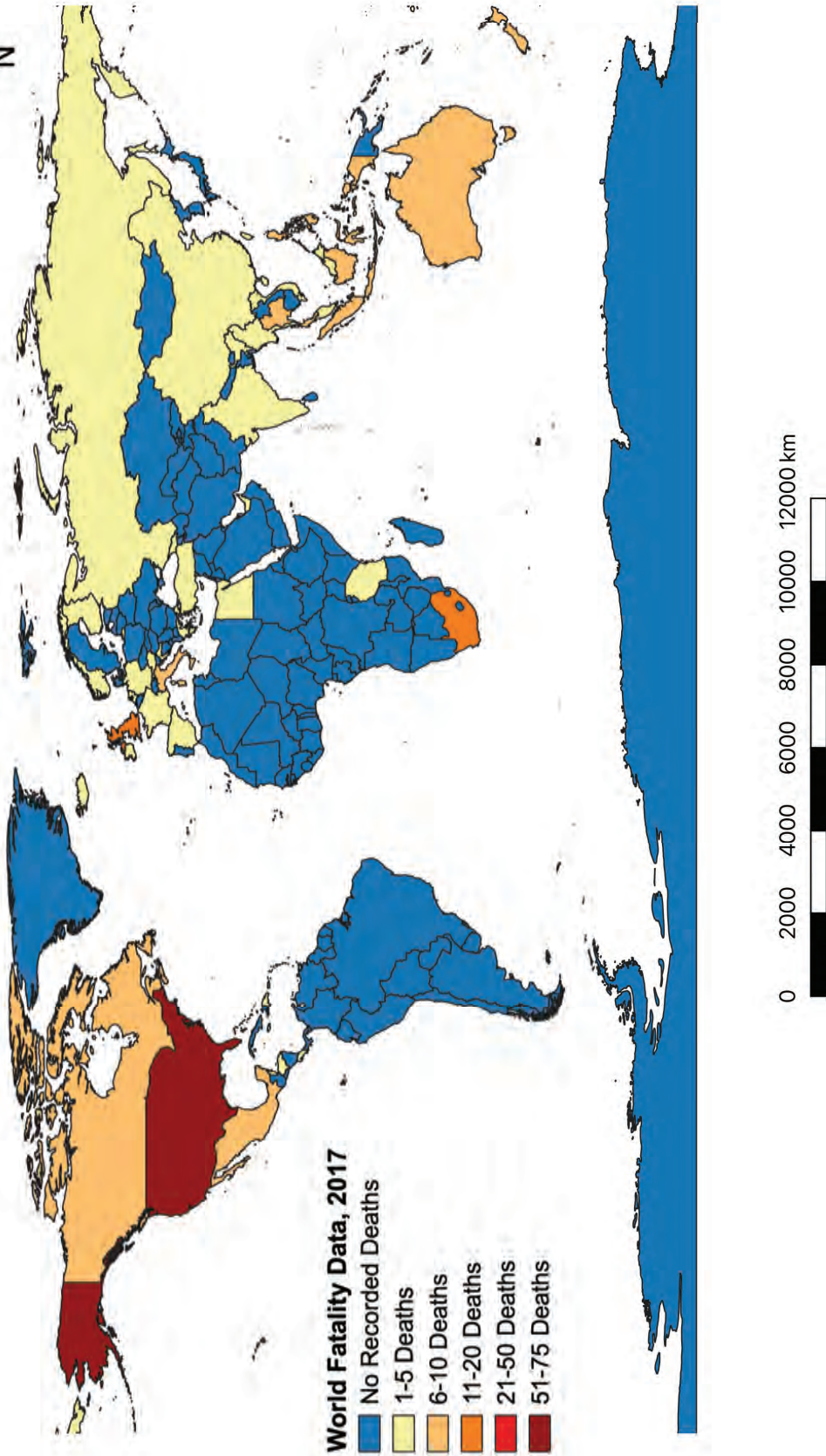
World Scuba Diving Fatalities, 2017: Asia-Pacific

World Fatality Data, 2017

- No Recorded Deaths
- 1-5 Deaths
- 6-10 Deaths
- 11-20 Deaths
- 21-50 Deaths
- 51-75 Deaths



World Scuba Diving Fatalities, 2017



SECTION 3. DIVING INJURIES

Matias Nochetto, Daniel Nord, Camilo Saraiva, James Chimiak

MEDICAL SERVICES CALL CENTER (MSCC)

DAN was originally established in 1982 to assist injured divers. It began as one medic receiving phone calls and engaging volunteer physicians as needed. Since 2019, DAN staffs a team of medics, nurses, and physicians operating full time at a call center in two strategic locations to provide adequate coverage to DAN members and divers in need around the world.

CALLS TO MSCC

The DAN Medical Services Call Center (MSCC) is a great resource for recreational scuba divers, dive professionals and medical professionals that take care of divers. One of the metrics we use to quantify the services DAN provides through the MSCC is the number of interactions with divers and other individuals who contact us through phone calls or emails both for emergency medical and travel assistance and for non-emergency medical information.

An 'interaction' is every contact of our medics with an external party, member or non-member, diver or non-diver, involved dive professional, referral physician or medical facility, treating medical professional, local authorities or EMS, travel assistance agents and insurance personnel.

Interactions are divided into three main groups:

Cases – initial inbound contact for emergency medical and travel assistance, related or not to diving;

Inquiries – initial inbound contact for non-emergency medical information, mostly related to travel and diving;

Follow-ups – sequential inbound or outbound contacts for both emergency medical assistance or non-emergency medical information.

Out of all 20,931 Interactions in 2017 there were:

- 48% Follow-ups (10,032);
- 34% Inquiries (7,091);
- 18% Cases (3,808).

Among 7,091 Inquiries the leading topics were:

- Diving Physician Referrals -1,196 (17%);
- Diving Physics and Physiology information - 951 (14%).

Table 3-1. Emergency cases and information requests

YEAR	CASES	INQUIRIES	TOTAL
2014	3,167	6,360	9,527
2015	3,487	6,636	10,123
2016	3,594	6,728	10,322
2017	3,808	7,091	10,899
TOTAL	17,259	34,233	51,492

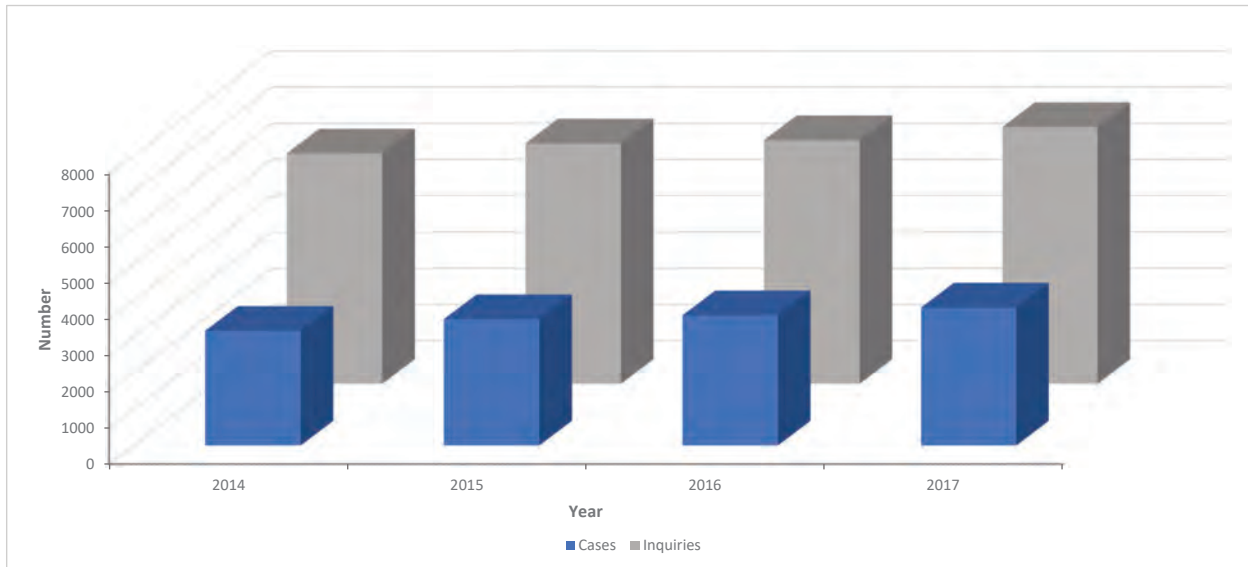


Figure 3-1. Number of cases and inquiries in 2014-2017

The number of emergency cases and information requests is steadily growing, as shown in Table 3-1 and Figure 3-1.

In 2017, compared to the average of the previous three years (2014-2016) there were:

- 11% more Cases (3,808 vs. 3,416);
- 8% more Inquiries (7,091 vs. 6,575);
- 15% more Follow-ups (10,032 vs. 8,711).

Table 3-2. Diving and non-diving related injuries in 2017.

ILLNESS/INJURY	2014	2015	2016	2017	TOTAL
Diving Related	2,046	2,117	2,236	2,069	8,468
Non-Diving Related	1,227	1,474	1,645	1,660	6,006
Total	3,273	3,591	3,881	3,729	14,474
% Non-Diving	37.5%	41.0%	42.4%	44.5%	41.5%

Most cases were diving related, as shown in Table 3-2, but the percentage of non-diving related cases increased from 37.5% in 2014 to 44.5% in 2017.

The distribution of diving related cases according to a suspected health problem category is shown in the Table 3-3.

Table 3-3. Distribution of diving related cases

DIVING RELATED	2014	2015	2016	2017	TOTAL
Barotrauma	897	1,026	1,071	1,037	4,031
Decompression Sickness	534	618	695	576	2,423
Marine Envenomation	244	250	229	214	937
Pulmonary Edema - IPE	48	36	45	55	184
Arterial Gas Embolism / AGE	36	41	47	34	158
Fatality	30	28	48	58	164
Non-Fatal Drowning	15	34	24	17	90
Gas Contamination	13	22	32	19	86
Finfoot	24	20	16	13	73
Motion Sickness	14	18	17	7	56
Mask Squeeze	15	10	17	18	60
Loss of Consciousness	14	8	14	8	44
Cardiac Arrhythmia	5	9	12	3	29
Nitrogen Narcosis	4	2	2	5	13

As in the past, the most common diving injury is barotrauma followed by decompression illness and marine envenomations. Cases with suspected IPE exceed cases suspected of AGE.

The type of symptoms in suspected DCS cases is shown in Table 3-4.

Table 3-4. The distribution of DCS cases by type of symptoms

DECOMPRESSION SICKNESS	2014	2015	2016	2017	TOTAL
DCS Type 2	207	279	339	254	1,079
Cutaneous	122	174	163	176	635
DCS Type 1 (Pain only)	141	140	152	124	557
Pulmonary / Chokes	10	9	14	1	34

Table 3-5. Evacuations in 2017

Geographic Region	Air Ambulance	Commercial	Ground or Fast Boat	Grand Total
Caribbean Basin	13	15	0	28
SE Asia	5	9	1	15
Central America	3	4	5	12
Mexico	1	10	0	11
Pacific	8	3	0	11
North America	2	2	0	4
Europe	0	2	0	2
South America	0	2	0	2
Africa	2	0	0	2
Australia/Oceania	0	1	0	1
Grand Total	34	48	6	88

The DCS Type II which includes neurological symptoms is the most common concern among the callers. The cutaneous DCS recently took over the pain-only DCS Type 1. In comparison to the average for the previous three years, in 2017 there were:

- 14% less type I decompression sickness cases (124 vs. 144)
- 8% less type II decompression sickness cases (254 vs. 275)
- 15% more cutaneous decompression cases (176 vs. 153)

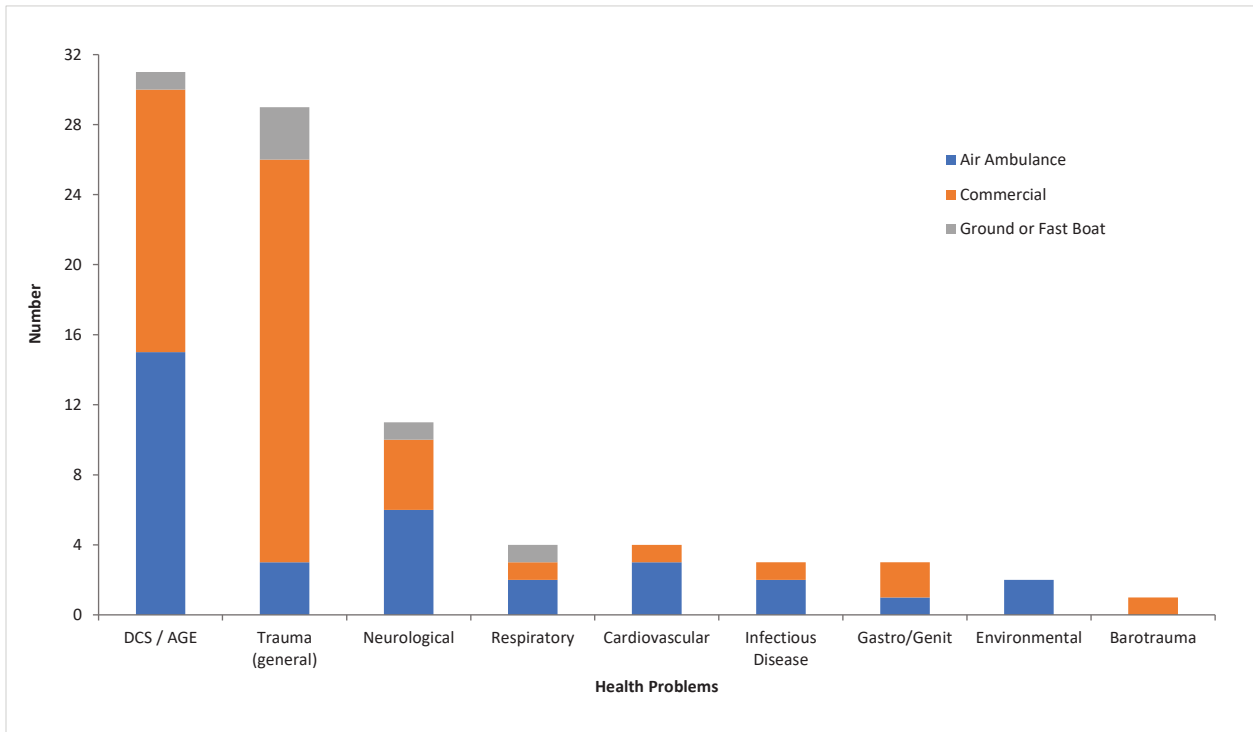


Figure 3-2. Distribution of evacuations by health problems

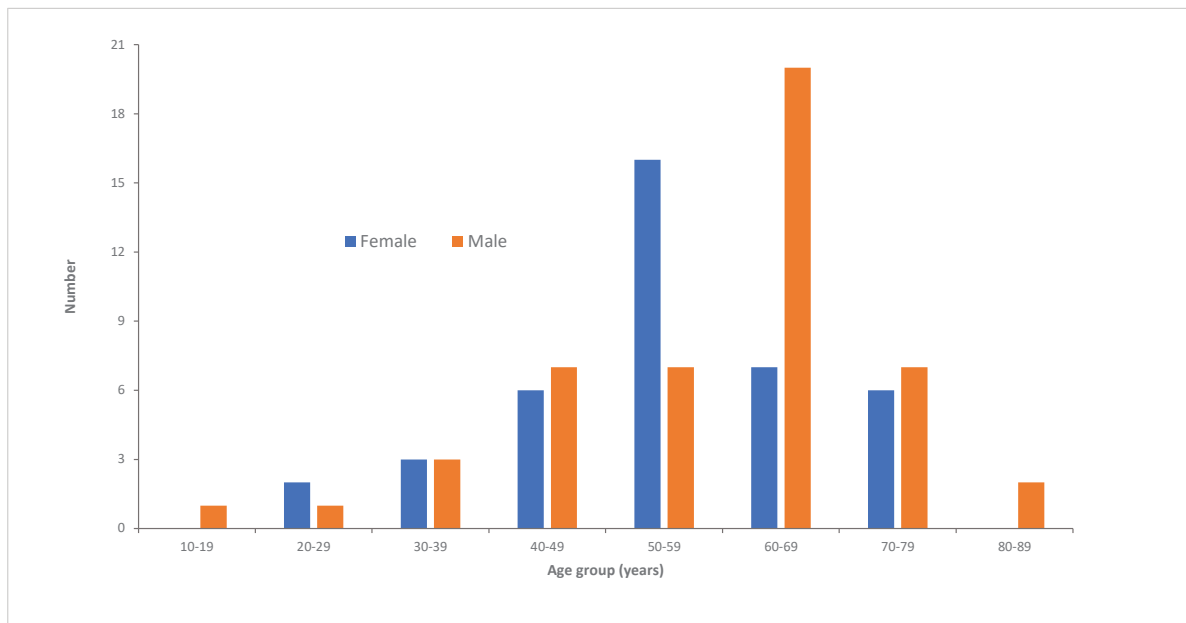


Figure 3-3. Average age of evacuee

EVACUATIONS

Some of the severe cases in remote locations required evacuations. The geographic area and the number of evacuations by means used is shown in Table 3-5.

The majority of cases were evacuated on regular commercial flights (48). The air ambulance was used in 34 cases and a fast boat in six cases. Most evacuations were assisted by Travel Guard (78.). In five cases the evacuation was organized directly by DAN and in five other cases, it was self-arranged by divers.

The distribution of evacuations by the health problem and means of evacuation is shown in Figure 3-2.

Most evacuations were due to DCI and trauma.

The age and sex of evacuee is shown in Figure 3-3.

Seventy-four percent of evacuees were 50 years or older. The difference between the number of evacuated men and women was not significant.

DIFFERENTIAL DIAGNOSIS OF DECOMPRESSION ILLNESS

DIFFERENTIAL DIAGNOSIS OF DCI - CHALLENGES INTERPRETING ACUTE POST-DIVE SYMPTOMS

DAN's Emergency Hotline staff receives around 3,500 calls per year, where about 1,500 of those calls pertain to a diver experiencing symptoms following a dive. These calls typically originate from lay people (the injured diver himself, a fellow diver or dive leader, or a family member), or from healthcare personnel seeking for expert dive medicine consultation when examining an injured diver (ER physicians, nurses, paramedics, or chamber staff).

LIMITATIONS AND CHALLENGES OF A TELECOMMUNICATION

Divers Alert Network is available for consultation regarding diving emergencies, fitness to dive, and diving physiology; assisting physicians all over the world to make the best decisions for candidates looking for medical clearance to dive, or when examining or treating an injured diver with a suspected case of decompression illness (DCI). Additionally, DAN medical staff helps coordinate emergency medical evacuations for DAN Members.

COMPRESSED GAS DIVING POSES INHERENT RISKS

A reputable and well-planned dive operation (chartered, or private) should have clear and well defined standard operating procedures (SOPs) to help mitigate these risks. When incidents or injuries happen, a thoughtful and properly established Emergency Action Plan (EAP) should help the dive operation manage the situation effectively and efficiently. DAN's 35+ years of experience have shown us that EAPs are often suboptimal. Through its different mission initiatives, DAN exists to assist injured divers, and their dive team members perform the best possible case management while in the field to ensure the best possible outcomes.

To provide the best possible recommendations for diving injuries, understanding the nature, possible extent and consequences of the injury becomes crucial. The best agents to triage these calls are medical professionals with training and experience in diving medicine. DAN's medical staff consists of medics, dive medical technicians (DMTs) nurses, and doctors, whose only clinical tool is what the diver verbally conveys to them.

It is impossible -and it would be utterly imprudent- to try to establish a physician-patient relationship between DAN's medical staff and a diver calling the hotline. Managing the diver's expectations as to what DAN can do over the phone can sometimes be a challenge, and this limitation often needs to be made explicit. An injured person becomes a patient when he/she is under the care of medical personnel. In the field, professional medical assistance starts with the local Emergency Medical Services (EMS). DAN does not admit patients to medical facilities, provide direct or indirect patient care, medical evaluation, diagnostic processes, or treatment decisions. There are no "DAN patients" because DAN has no patients.

When the caller is a layperson in the field, DAN's medical staff asks the caller basic questions to try to determine the problem (nature of symptoms, symptom onset, dive history, etc.) and then recommends what could be the best course of action by the dive team based on the information relayed by the caller. The information relayed by DAN medics takes into account other factors, such as the particular geographical location and local medical support available. One of DAN's initial goals is to provide the caller with first aid measures and assist in their actions to seek prompt, professional, medical evaluation at the closest medical facility. Once the injured diver becomes a patient at a local healthcare system (either when EMS arrives at the scene, or once the injured diver has been admitted to a medical facility), DAN's medical staff makes themselves available to assist medical professionals in making the best possible decisions for their patient.

While DAN strives to provide injured divers and those caring for them with the best possible assistance through its emergency line, telephonic communication imposes considerable limitation: the only contact DAN has with the caller (injured diver, dive team member, or examining healthcare professional) is verbal communication. DAN accepts all incoming calls from members and non-members from anywhere in the world; languages can sometimes be a challenge. Some of these calls originate in remote locations, and the technical quality of these telecommunications is often unpredictable, which contributes to the overall challenge of remotely assisting someone in need.

Skin DCS

A 52-year-old woman was diving with her husband in the ocean. They did seven dives over three days, with three dives on the last day of diving.

The maximum depth on the dive series was 33 msw (108 fsw) on day two, and the average depth for all dives was 22 msw (75 fsw). All dives were performed breathing air, within no-deco limits, and reported as uneventful. After the third dive on the last day of diving, the female diver noticed some blueish mottling and tenderness across her abdomen. This feeling was followed by vague constitutional symptoms, including generalized soreness and tiredness, dizziness, lightheadedness, and mild nausea.

The diver was evaluated at a local clinic by a knowledgeable dive medicine physician who recognized the skin mottling as a cutaneous DCS without neurological abnormalities. They prescribed a USN TT6 and intravenous hydration, which resulted in improvements. The next morning the diver reported feeling much better but was still experiencing some persisting deep tissue soreness on the abdomen and mild constitutional symptoms. She was treated with USN TT5, which resulted in a complete resolution. A 24-hour follow-up confirmed no relapse.

Comments:

This case illustrates a classic form of cutaneous decompression sickness. The abdominal skin mottling with a bluish marbled pattern on all four quadrants and associated deep tissue soreness on palpation, all in the context of three days of diving, is a common presentation of cutaneous DCS. The downloaded dive profiles did not seem to be aggressive dives, other than a few final rapid ascents from the safety stop to the surface. It is important to emphasize that it is not uncommon for divers to develop classic cases of decompression sickness without any apparent deviation from what is commonly considered to be a “safe and uneventful dive”. While the decompression stress is in general proportional to the severity of the dive profile, it is not always obvious what turns a moderate and uneventful dive series into one that triggered decompression sickness.

It is not uncommon to need several liters of fluid to rehydrate a diver after a case of DCS. Until rehydrated, have the diver rest and refrain from hot showers to avoid lightheadedness.

Inner ear decompression sickness (IEDCS) and residual dizziness

An emergency room physician called for consultation regarding a 50-year-old male diver who presented with vertigo, 2 1/2 hours after a single day of two successive deco dives as follows:

Dive #1: 42 msw (137 fsw)/:45min TDT (AIR)
10 min deco (EAN65) @ 10 msw
(33 fsw)
GF 95

SI: 2 hours

Dive #2: 26 msw (84 fsw)/:45min TDT (AIR)
11 min deco (EAN65) @ 10 msw
(33 fsw)
GF 95

Reportedly, the diver had no issues with the dives and felt “very well” on the 2.5-hour ride back to shore. He further said that upon reaching the dock, he bent over to collect his gear, and when he took the first step after that, he had a sudden onset of vertigo. He staggered to get to a bench, lay down,

and started vomiting. He denied having any problems with equalization during his dives. He had over 5,000 dives lifetime without incident or prior adverse events.

Upon examination, the ER physician reported a positive “impressive” bilateral nystagmus and vertigo. No other neurological deficits noted. His patient was reclining in bed, with eyes shut due to an unbearable spinning sensation. Per diver, “I feel like I am drunk.” The treating physician noted his oxygen saturation was 98% on room air, so he did not see a need for oxygen. DAN recommended normobaric oxygen at the highest inspired fraction possible since inner ear decompression sickness (IEDCS) could be a reasonable explanation for the patient’s condition, to which they hesitantly agreed.

The DAN Medic conferenced in the DAN doctor with the ER physician. Another differential diagnosis to consider was the inner ear barotrauma (IEBT). Consultation with an ENT specialist revealed a slightly reddened tympanic membrane, vertigo, nystagmus, no other neurological deficits, and no evidence of barotrauma to the inner ear. In the absence of signs of barotrauma, and regarding significant decompression stress, with symptom onset, 2.5 hours post-surfacing led to a diagnosis of IEDCS.

The patient was transferred to a hospital-based hyperbaric facility where he received five treatments in four days; as follows:

- Day 1 - USN TT6 (x1)
- Day 2 - 2.0 ATA for 2 hours (x2)
- Day 3 - 2.0 ATA for 2 hours (x1)
- Day 4 - 2.0 ATA for 2 hours (x1)

The patient experienced resolution except for some minor residual dizziness. He was advised this would likely resolve over time. The MRI before discharge found no abnormalities. Upon discharge, he was given a series of physical therapy exercises to do at home.

A DAN followup call a week later revealed the diver was still experiencing some mild dizziness, but that it was steadily improving. However, he reported he worried about his vision, having trouble focusing, and feeling dizzy after quickly turning his head right or left.

A second followup call, two weeks after being discharged, confirmed he had been evaluated in the meantime, and no issues were found. His sight and dizziness kept improving on a daily basis.

At the last followup call, 3 weeks after being discharged, the diver still had not recovered completely but was “95% normal”. The patient was lost to followup after that.

Comments:

Two things are remarkable on this case: It is not uncommon for DAN staff to have to persuade EMS personnel in the field or ER physicians to administer a high FiO_2 despite normal arterial oxygen saturation readings on room air. It is important to remind them that this is not intended to revert hypoxia but to wash-out residual inert gas.

IEDCS is a serious form of decompression illness that often requires multiple treatments. Convalescence might be protracted. The residual damage to the inner ear may persist even when all symptoms resolve. A diver should not return to diving before a complete functional evaluation of the inner ear.

After a prolonged series of hyperbaric oxygen treatments, it is not uncommon to suffer a temporary change in visual acuity. The patient is advised not to discard or change the prescriptive lens and allow time for the visual acuity to return to baseline.

SECTION 4. THE DIVING INCIDENT REPORTING SYSTEM (DIRS)

Peter Buzzacott, Caslyn Bennett, Petar Denoble, Jim Gunderson

Voluntary reporting of diving incidents may provide details missed in fatality data, including risk factors for incidents. We analysed the first 500 compressed gas incident reports collected September 2012 through February 2018 through the Diving Incident Reporting System (DIRS).

Reporters were prompted to describe divers' training and experience, equipment, environment, profile, unplanned incidents and outcomes. Divers may opt to leave contact information to allow for follow-up questions.

The types of incidents reported by divers often involved rapid ascents (15%), running out of gas (8%), loss of buoyancy control (5%), or starting the dive with the tank valve not fully open (2%). Seventy-five percent of reports involved an injury. In running out of gas incidents, proportionally more injuries were reported when consequential ascents were rapid than when ascents were controlled.

The majority of incidents were reported by the diver who experienced the incident, most commonly within one month of the incident occurring. Of the divers in this study, 68% were male, and mean age for all subjects was 45 years. Around half the incidents happened during the diver's first visit to the dive site, often on the first day of a dive series, most often within the first year or two since certification. Most divers were in a group or with a buddy, engaged in a diving activity they reported having prior experience in. More than half the dives occurred during the day, in the sea, in water that would be considered warm (>20°C/68°F), with moderate/excellent visibility. More than half also occurred while diving from boats.

New dive sites or the start of a dive series featured in reported diving incidents, the majority of which resulted in self-reported injuries. Pre-dive safety checks and paying close attention to remaining gas pressure throughout diving may prevent many incidents.

ANALYSIS OF 500 RECREATIONAL DIVING INCIDENT REPORTS

INTRODUCTION

Incident reports are widely used in various injury prevention settings including emergency radiology,¹ medication errors,² and surgical errors,³ to name a few. In scuba diving, incident reports are collected by various governmental bodies, (e.g. US Navy,⁴ National Oceanographic and Aerospace Administration,⁵ National Park Service⁶), training agencies,⁷ and online diving forums but, with the exception of diving fatality datasets, many collections are not systematically examined and results published. There may be many reasons for this, including the potential for litigation, or the potential for negative press in a commercial arena. Non-fatal and near miss incident reports have the potential to inform injury prevention strategies, the hypothesis being that by preventing near misses there will be fewer minor injuries, emergency department presentations, hospitalisations and fatalities.^{8,9}

In Australia in the late 1980's Dr Chris Acott started the Diving Incident Monitoring System (DIMS) and produced a steady stream of insights, as the DIMS collection grew to more than 1,000 reported incidents.¹⁰⁻¹⁵ While self-reported incidents say little about the prevalence of events in the wider recreational diving community, they do have the capacity to shape preventive interventions. For example, at an International Dive Symposium in Cairns in 1994 Dr Acott compared the outcomes from 168 incidents where the divers had reported running out of gas while underwater. Among the 89 out-of-gas incidents that were followed by a rapid ascent to the surface, 52 (58%) suffered some form of morbidity, whereas among the 79 out-of-gas incidents that were followed by a non-rapid ascent, for example while breathing from a dive buddy's alternate air source, only 5 (6%) reported any morbidity.¹⁶ This, and other evidence,¹⁷ underpins preventive messages the Divers Alert Network have developed with the aim of reducing the burden of injury associated with recreational scuba diving. It has, however, been more than a decade since voluntarily reported recreational diving incident research has been published and the sport has meanwhile continued to advance, with new technology,

new diving procedures, and new diver training programs introduced in recent years. This study aimed to determine if recreational divers are suffering the same mishaps and unplanned incidents, with the same consequences, as the divers of two decades ago.

METHODS

The Diving Incident Reporting System (DIRS) collected diving incident reports lodged through the DAN website. The DIRS project started in late 2012 and the 500th incident was reported in February 2018. After giving informed consent, divers are asked to describe the diving environment where the incident occurred, the diver's anthropometry, medical history and diving experience, and the circumstances surrounding the incident. In addition to the descriptive fields completed by the reporter (e.g., sex, age, depth of incident, etc), free format responses describing each incident were examined and binary classifications were noted for wreck dives, training, injury, hunting, rapid ascent, loss of buoyancy control, running out of breathing gas, failing to open the valve fully before diving, if gas contamination was declared and if an item of equipment reportedly failed. Where an injury or equipment failure was noted then the type of injury or equipment failure was also listed. Human research ethics approval was granted by the Institutional Review Board of the Divers Alert Network, approval number 011-018.

ANALYSIS

As each incident was reported online through the DAN website, the data were stored in a MS Access database. From there, a MS Excel spreadsheet of the 500 incidents was created. This spreadsheet of data was imported into SAS version 9.4 (SAS, Cary, NC) for analysis. Means with standard deviations (SD) are reported for approximately normally distributed variables, medians and interquartile ranges (IQR) for non-normal variables, and logistic regression was used to determine if the probability of injury after running out of gas was influenced by ascent rate.

RESULTS

There were a mean of 42 (SD 5.4) incidents reported during each calendar month, ranging from a low of 31 in November through 50 in June. Median delay between the incident occurring and being reported was one month (IQR 0-3 months). Inexperience featured in many reported incidents. Of the 301 reports that included the year of dive certification, 134 (45%) incidents reportedly occurred during the first year as a certified diver, and a further 52 (17%) by divers in their second year of certification.

There were 474 open circuit incidents (95%) and 26 rebreather incidents (5%). The majority of the reports ($n = 453$, 91%) were made in English, 45 (9%) were in Portuguese and one each were in French and German. The

five countries where the greatest number of incidents occurred were USA (194, 39%), Brazil (49, 10%), Mexico (41, 8%), Canada (23, 5%) and Indonesia (15, 3%). The victim of the incident being reported made the report firsthand in 320 cases (64%), and reports by third parties accounted for the remaining 180 cases (36%).

The sex of the diver involved in the incident being reported was given in 474 reports (95%), with 27 reports (5%) missing this information. Of those 474 reports where sex was known, 321 (68%) were male and 153 (32%) female. Age and Body Mass Index (BMI) characteristics of the divers involved in reported incidents are shown, by sex and overall, in Table 4-1. The majority of incidents happened on the first day of a diving series, as shown in Figure 4-1.

Table 4-1. Sex and Body Mass Index of divers involved in reported incidents ($n = 474$)

	Male (n=321)	Female (n=153)	Overall (n=474)
Age (years)	mean=46, range=16–83 (n=304)	mean=43, range=13–70 (n=144)	mean=45, SD 14.0 (n=448)
BMI* (kg.cm⁻²)	mean=28, range=18–47 (n=258)	mean=24, range=16–49 (n=113)	mean=27, SD 5.0 (n=375)

*Body Mass Index

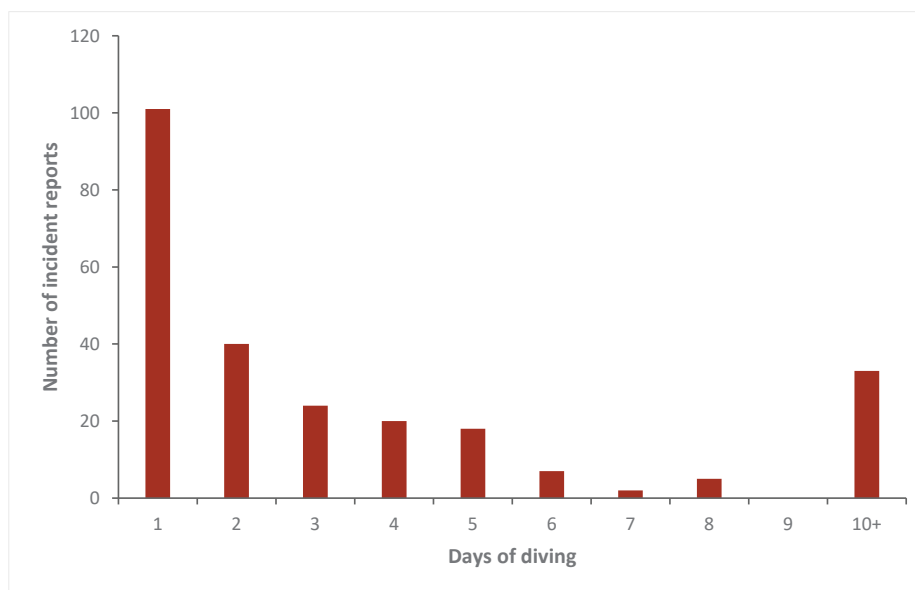


Figure 4-1. Day in the diving series when the incident occurred ($n = 250$)

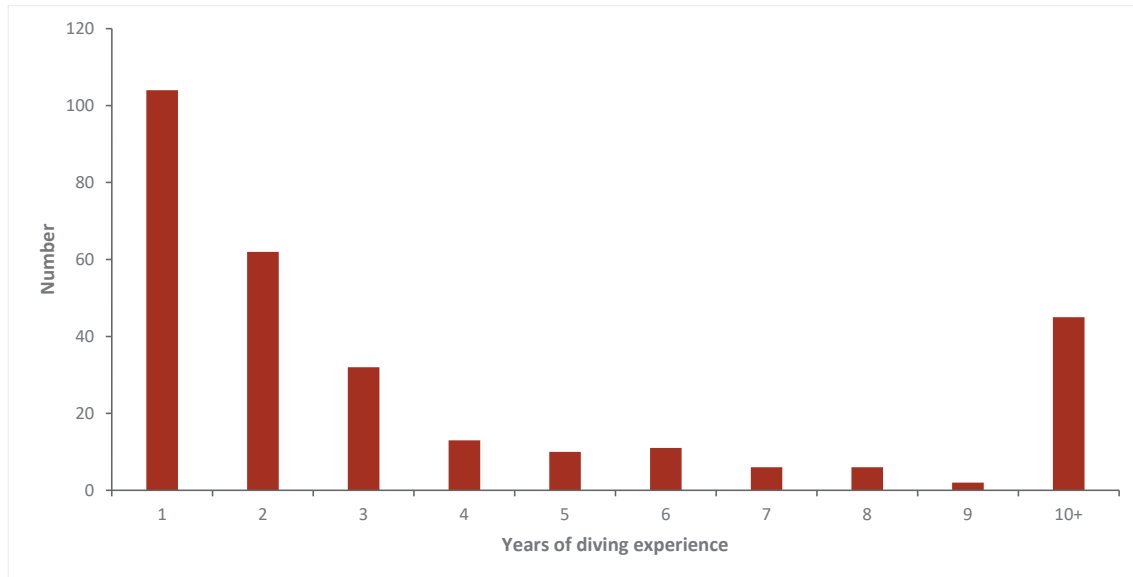


Figure 4-2. Years of diving experience since reported year of training when the incident occurred (n = 301)

Four hundred and seventeen reports (83%) noted the divers' degree of familiarity with the dive site where the incident occurred; 203 incidents (41%) occurred during the diver's first time at the site, while 214 (43%) occurred during a return visit to the site. The number of days of diving immediately before the reported incident were reported in 205 incidents and, of those, 101 (40%) occurred on the first day of diving, with a further 40 (16%) occurring on the second day. Eleven divers reported having made 3,000 or more lifetime dives. The median number of lifetime dives by the 360 other divers who reported their experience level was 67 dives, with an interquartile range from 8 to 225. Three hundred and ninety reports mentioned the number of dives made within the previous year; the median for these cases was 24 dives, with a range from 9 to 50. The delay in years between reported year of initial diver training and the year of the incident are shown in Figure 4-2.

Sixty-nine incidents (14%) occurred during training dives, 35 (7%) occurred while diving on a shipwreck, and 22 (4%) while hunting for game. The median depth of the 391 incident reports (78%) where incident depth noted was 21 msw (69 fsw) (IQR 15-29). The median maximum depth previously reached by the affected diver during the incident dives was 28 msw (92 fsw) (IQR 15-65 msw), with 276

reports (55%) mentioning this fact. The type of support each affected diver reportedly dived with during the incident dive is shown in Table 4-2, as are the dive platforms from which the incident dives occurred, equipment failures and injuries. The temperature of the water was reported in 424 incidents (85%), and tended towards the warmer end of the world's naturally occurring water temperature range, as shown in Table 4-3.

The time of day when reported incidents occurred was noted in 433 cases (87%); 388 (78%) were during the day, 12 (2%) were at night, 18 (4%) were at dawn, and 15 (3%) were at dusk. Three hundred and fifty one reported incident dives (70%) were in the ocean/sea, 54 (11%) in lakes, and 15 (3%) in springs or caves. Two incidents occurred in swimming pools and 78 reports (16%) did not mention the type of location. Visibility was reported for 429 incident dives (86%); it was poor (< 3 meters < 10 feet) in 56 cases (11%), moderate (3-15 meters 10-50 feet) in 174 cases (35%), and excellent (> 15 meters > 50 feet) in 199 cases (46%). The altitude of incident dive sites was reported in 418 cases (84%). It was between 0-305 meters (0 and 1,000 feet) in 400 cases (80%); between 305-1,000 meters (1,000 and 3,280 feet) in 11 cases (2%); and over 1000 meters (> 3,280 feet) in 7 cases (1%).

Table 4-2. Type of support, dive platform, equipment failures and injuries during reported diving incidents

		n (%)
Support type (n=500)	Group	141 (28)
	Dive partner (direct supervision throughout) dive	126 (25)
	Dive partner (limited supervision)	97 (19)
	None/solo diving	19 (4)
	Surface supplied scuba	7 (1)
	Other	23 (5)
	Not reported	87 (17)
Platform (n=500)	Day boat	255 (51)
	Beach/shore	95 (19)
	Live-aboard	44 (9)
	Pier	17 (3)
	Other	18 (3)
	Not declared	71 (14)
Equipment failure (n=77)	Regulator free flow	12 (16)
	BCD* inflator stuck	9 (12)
	Regulator stopped delivering gas	7 (9)
	Hose failure	5 (6)
	Second stage detached	5 (6)
	DIN valve dust cap exploded	3 (4)
	Tank explosion	3 (4)
	Second stage flooded	3 (4)
	Weight belt/pocket fell out/off	3 (4)
	Other	27 (27)
Injury (n=374)	Decompression sickness	75 (20)
	Fatality	47 (13)
	Loss of consciousness	27 (7)
	Barotrauma (ears)	23 (6)
	Immersion pulmonary edema	16 (4)
	Vomiting/nausea	15 (4)
	Hazardous marine life	12 (3)
	Dizziness	12 (3)
	Headache	9 (2)
	Difficulty breathing	7 (2)
	Paraesthesia	7 (2)
	Vertigo	6 (6)
	Water inhalation	6 (6)
	Sinus barotrauma	5 (5)
	Near drowning	5 (5)
Other	102 (27)	

Table 4-3. Water temperature during reported incidents (n = 500)

Temp °C	<4	4-9	10-15	16-20	21-26	≥27	Unknown
Temp °F	<39	39-48	50-59	60-68	69-79	≥80	Unknown
n (%)	9 (2%)	23 (5%)	62 (12%)	53 (11%)	113 (23%)	164 (33%)	76 (15%)

Table 4-4. Injury status among out-of-gas incidents by ascent rate (n = 38)

	No injury	Injury	Total n (%)
Non-rapid ascent n (%)	17 (71)	7 (29)	24 (63)
Rapid ascent n (%)	6 (43)	8 (57)	14 (37)
Total n (%)	23 (61)	15 (39)	38 (100)

The free-text incident summaries in the reports described incidents that involved rapid ascents ($n = 74$, 15%), loss of buoyancy control ($n = 24$, 5%) and/or a diver running out of gas ($n = 38$, 8%), with a further 12 incidents (2%) involved a diver starting the dive with a tank valve not fully open, an oversight that became noticeable only at depth, when the diver found it hard to breathe. Fifteen incidents (3%) were possibly associated with gas contamination, and 77 incidents (15%) were reportedly due to an equipment malfunction, as detailed in Table 2. Of these 77 equipment problems, 46 (60%) involved an air- supply problem and 23 (30%) a buoyancy-control problem.

The free-text incident summaries also offered insight into whether reported events had likely resulted in injury. These in-your-own-words incident descriptions resulted in 374 cases (75% of the 500) being classified as involving an injury. The most common 15 types of injuries identified in those 374 cases ($n = 272$, 73%) are shown in Table 4-2.

Finally, among the 38 incidents that involved running out of gas, the proportions that resulted in injury are shown in Table 4-4 by self-reported ascent rate, (rapid or not-rapid). Among the divers who did not make a rapid ascent, 29% suffered an injury yet among the divers who made a rapid ascent 57% were injured (OR 3.2, 95% CI 0.8, 12.8, $P = 0.09$).

DISCUSSION

Now that the DIRS is well established, it is collecting around 100 diving incidents per year, which is similar in scale to the DIMS of previous years. The majority were reported by the diver who experienced the incident, most commonly within one month of the incident occurring. In keeping with surveys of divers and analyses of diving fatalities, two thirds of the divers in this study were male, one third female, and overall mean age was 45 years old.¹⁸⁻²¹ Inexperience may have been a factor in many incidents. Where known, around half the incidents happened during the diver's first visit to the dive site, often on the first day of a dive series, most often within the first year or two since certification as a diver. Of course, this may be when divers are most likely to report unexpected incidents and no inferences can be drawn regarding the prevalence of unplanned incidents in the wider diving community. In addition, we do not know what is the attrition rate and how many divers continue to participate past their first year following diver certification.

Most divers were diving in a group or with a buddy. At 21 msw (69 fsw), median incident dive depth was deeper than basic open water divers are trained to dive to 18 msw (59 fsw), though it is not known how many of the incidents were reported by divers trained beyond basic open water diver. More than

half the dives occurred during the day, in the sea, in water that would be considered by the majority of divers as warm (> 20°C 68°F), with moderate to excellent visibility. More than half occurred while diving from boats.

The types of incidents reported by divers often involved rapid ascents, loss of buoyancy control, running out of gas or starting the dive with the tank valve not fully open. The first three of those four particular problems were also found among more than 50,000 recreational scuba dives.²² In this study the consequences of those mishaps included decompression sickness, loss of consciousness, barotrauma and fatalities. Lastly, in agreement with the findings of Acott,¹⁶ among divers in this study who reported running out of gas, the proportion of rapid ascents that resulted in injury was greater than the proportion of non-rapid ascents that resulted in injury, although the sample size was too small to reach significance. We recommend divers conduct pre-dive safety checks to prevent many types of incidents and pay close attention to their remaining gas pressure throughout diving.

Many divers provided their insights about the root causes within their textual descriptions of the incidents, identifying potential triggers or operational faults that preceded the incident. For example, *“The deck hand turned my air off instead of on and did so without my knowledge. Had I not had high quality equipment, well-tuned buoyancy, and good fitness I’m not sure I would have survived this simple mishap.”* Often these insights were accompanied with an expression of hope that, by sharing these incidents, other divers might avoid the same issues. To this aim more than 150 incidents have been anonymized and published in the DAN Annual Diving Report,²³ or on the DAN website, where they have been viewed up to 20,000 times per month. In addition, a number of divers considered if there may have been a more optimal way to respond to the incident, for example *“After the dive I discussed the incident with a dive master and realized that I should have left the primary regulator in my mouth and ascended slowly.”* These insights conform to the principles of reflective practice, a technique often used

in the disciplines of education and medicine by which participants improve performance through post-hoc introspective analysis of experiences.²⁴ It may, therefore, be that the divers who report incidents might be more reflective, or conscientious, than divers who prefer to simply move on after experiencing an incident.

The limitations of this study include the self-reported nature of the data, that there was rarely an opportunity to corroborate an incident report, and that the diagnoses of injury were not validated by a physical exam. Nonetheless, despite advances in equipment, procedures and training, it appears that twenty-first century recreational scuba divers are reporting the same types of unexpected problems as were reported, and observed, in the 1990’s. While this data is not suitable for statistical inference, and there may be a self-selecting bias in the data, between-groups comparisons can lead to valuable insights into potential risk factors for diving incidents, leading to further research.

CASE SUMMARIES FROM THE DIRS

This year, we selected a number of incidents that are actual reports from the DIRS for this section of the diving report. Other reports from the DIRS may have been covered in other sections. Each narrative has been edited for clarity, grammar, and spelling; inclusion of metric and imperial units; abbreviations, slang or less-known terminology has been clarified; and any names, dive boats or operations, dive businesses, and specific locations have been removed. Other than those edits, the original tone and scope of the report has been kept so the reader may gain a feel for the scenario as it was reported. Some of these reports are short while others are more detailed. The same follows for any commentary specific to that incident.

EQUIPMENT FAILURE INCIDENTS

Free flow of regulator first stage

Two Advanced Open Water divers with over 500 dives were diving at a well-known and oft-dived site. About 20 minutes into the dive at about 20 meters (65 feet), one of the diver's regulator's first stage "exploded", resulting in a free flow. The diver had taken a solo-diving course a few months prior, but since he was diving with a buddy, they immediately began breathing off the buddy's cylinder using the buddy's octopus rather than using the redundant air source he was carrying. After receiving his buddy's octopus, the buddy closed the tank valve and stopped the disorienting and loud stream of air bubbles. The diver credits his solo-diver training and presence of an experienced buddy for preventing any panic reaction. The regulator had recently been serviced and worked without issue during the prior day's dives.

Comment: Sometimes, a catastrophic O-ring or another component failure can happen, even on new or recently serviced regulators. While this is very rare, it does reinforce the practice of diving with a buddy, or with a completely redundant breathing gas supply and proper solo-diving training. Remaining calm, trusting your buddy, and good training is key in the safe resolution of these types of incidents.

Free flow, shared air

During a dive at approximately 24 msw (80 fsw), a diver and their buddy were in a "free fall" to 36 meters (120 feet), and the first diver felt as if they were breathing a lot. At 38 meters (124 feet), it was identified that even while the first diver was inhaling, there was a flow of bubbles, indicating a free flow. The diver switched to their octopus, and with the help of the buddy attempted to fix the free-flowing regulator at depth. After no more than one minute, they started ascending to the surface. At about 18 meters (60 feet), the diver ran out of the air and then began to share air with the buddy on the buddy's 2 meter (7 feet) hose. They took a one minute stop at 12 meters (40 feet), then proceeded to 3 meters (15 feet) for three minutes. The first diver ended with an empty cylinder while the buddy ended with 81 bar (80 psi) upon surfacing.

Comment: The divers performed the appropriate procedures in this situation and terminated the dive. The diver who was experiencing the free flow was able to breathe off their own cylinder until it was exhausted. This allowed more time to make a slower, safer ascent before switching to sharing air with their dive buddy. When two divers are breathing off one cylinder, monitoring the breathing gas supply is critical. Not only are two divers breathing off one cylinder, but it is also likely that both divers are breathing at a faster rate because of the circumstances of the dive, thus using more breathing gas quickly. Have the gear serviced by a qualified technician before using that equipment again.

The divers made the appropriate safety stops during their ascent. However, never run out of breathing gas to perform a safety stop. If you have to come up quickly or forego a safety stop for whatever reason, surface as safely as possible, stop diving for the rest of the day, watch for symptoms of DCI, get on 100% Oxygen if any DCI symptoms develop, and call DAN.

Regulator free flow while practicing regulator exchange with the buddy

While practicing regulator exchange and air sharing drills at 9 meters (30 feet), intermittent regulator free flows resulted in nearly exhausting one diver's air supply.

The second diver deployed his regulator to the first diver, and both made a smooth and controlled ascent including all safety stops.

Comment: Practicing emergency skills, such as air-sharing technique is a great habit. Practicing keeps those skills fresh and builds confidence in the event they are needed in a real emergency.

If you experience an intermittent regulator free flow, have the regulator tested and serviced. Intermittent free flows are usually caused by sand or other small debris that can cause the regulator seat to not properly close all the time. Be sure to rinse and soak your gear thoroughly with fresh water, especially when diving in sandy conditions.

Mouthpiece detached

During my descent at about 24 meters (80 feet), my regulator came apart from my mouthpiece, resulting in me inhaling water until I was able to reach my buddy's octopus and breathe again. After calming down and ascending to the surface safely and slowly, I began coughing and spitting up saltwater. Later that night I went to the emergency room for chest pain and to get a chest x-ray to ensure I did not have anything in my lungs.

Comment: Regular inspection of one's diving gear should be part of every divers' steps in assembling their gear. An often-overlooked piece is the 'zip tie' that holds the mouthpiece on the regulator. These can become worn, brittle, or crack with normal use. When assembling the regulator onto the cylinder, make a practice of inspecting the mouthpiece and zip tie to ensure they are in good condition. Similarly, some softer mouthpieces can develop a small tear where the end of the hard-plastic regulator joins the softer mouthpiece. This can lead to a 'wet breathing' regulator. So, it is important to pay a bit of extra attention to those two components when assembling your gear to ensure the zip tie is present and holes in the mouthpiece are not.

Regulator Failed to deliver gas when tank pressure dropped to 500 psi

An underwater photographer doing his first dive of the day in approximately 15 meters (50 feet) of water, began the dive with 200 bar (2900 psi). When the cylinder pressure dropped to 52 bar (750 psi), the diver started ascending to conduct a safety stop. A few moments later, the diver attempted to take a breath, but there was no air. The diver attempted to breathe from their alternate second stage as well, also to no avail.

The diver then approached his buddy and signaled that they were out of air. They executed the "shared air" skill, ascended to 3 meters (15 feet), and conducted a 3-minute safety stop and then surfaced without further incident. During the safety stop, the diver checked their gauges which read zero bar (0 psi). At the surface, the tank pressure read 34.5 bar (500 psi). At the surface, the regulator performed normally.

For the second dive, the diver used different cylinder and the same regulator. Everything was functional on the pre-dive check. When the cylinder again reached about 34.5 bar (500 psi), the same thing happened - no breathing gas available. The diver and their buddy did another shared-air safety stop. Again, during the safety stop gauges were checked and read 0 psi, and on the surface, the cylinder read 34.5 bar (500 psi). The diver assessed this to be a regulator issue and sent their regulator to be serviced.

Comment: There are several possible causes for this situation. The first that comes to mind involves the cylinder valve. Were the cylinders used equipped with "J" or "K" valves? While "J" valves are not common anymore, they are still in service from time to time. If a "J" valve was used and the "J" valve is not depth-compensating, or the reserve lever is in the incorrect position, this could manifest the situation reported. Similarly, if a valve was not opened all the way, this too can lead to similar issues to those mentioned in the report. By not opening the cylinder valve all the way, this can, but not always, give some constricted air-flow at lower cylinder pressures especially at depth.

The other issue focuses on the regulator. Were there issues with the internal workings of the regulator? When was it last serviced? Was there any physical damage to the regulator? It's always best practice to have your regulator serviced according to manufacturers specifications by a qualified technician.

Buoyant ascent - jammed BC inflator button

During the second dive, at 17 meters (56 feet), the diver pressed the BC inflating button, which jammed "on" and fully inflated the BC at the bottom resulting in an uncontrolled ascent. The diver did not pull the (dump) valve (on the BC). When he surfaced, the diver was free of symptoms but remained under observation for the next 24 hours.

Comment: Stuck or jammed inflator buttons are somewhat common. These usually happen because of some debris, like sand, becoming stuck in the inflator button, or corrosion build up because of insufficient rinsing or maintenance. This can cause the inflator to get stuck in the open position, which causes the gas to inflate the BC in an uncontrolled fashion - sometimes rapidly. The first step in dealing with this situation is to quickly disconnect the inflator hose from the BC, then vent the air from the BC and flare out your body to slow the ascent. Once the ascent is arrested, terminate the dive, make a slow, safe ascent to the surface, then orally inflate your BC, monitor for any signs/symptoms of DCI, and have your gear serviced. The diver was correct in staying out of the water for at least 24 hours.

REBREATHER

CCR (Closed Circuit Rebreather) diluent valve malfunctioned during cave dive

I was completing the final dive of my advanced cave diver and full cave courses. During a portion of the final dive, we had just completed an 'air sharing through a restriction' exercise during the return portion of the dive. While preparing to stow a long hose on my bailout cylinder, I noted the subtle sound of gas moving into space (like a gas injection), as opposed to a bubbling sound. I signaled to the instructor that something was wrong, and could he do a visual check for bubbles - a sign of a gas leak in rebreathers is not good. At this stage, I could feel the loop volume notably increasing. I decided something was more wrong than I was comfortable with, grabbed the line, and performed a boom drill/valve shutdown. I was able to diagnose that my oxygen system was fine, and my PO₂ hadn't really changed; so I reopened the oxygen regulator. On testing the diluent valve, I began to hear gas injection again, so I closed the valve and signaled that it was broken, and it was time to surface. I completed the remainder of the dive with the diluent valve shut. Approximately 20 meters (66 feet) from the exit, I began to notice bubbles coming from my mouthpiece/bailout valve (BOV), on exhale. I decided this was one problem too many and didn't want to have a caustic hit so close to the surface; so I bailed out to OC (open circuit). I surfaced without problems and felt fine afterward. On testing the unit on the surface, I was unable to replicate the issue. My final hypothesis is that somehow the button on the diluent manual add was wedged against a hose or the like, causing the gradual injection of diluent.

Comment: This is a prime example of relying on good training, careful (but expeditious) evaluation of the circumstances, communication problem solving, and coming up with the correct solution. It also perfectly illustrates the reason to have proper bailout equipment available.

TRAINING DIVES

Lost weights in kelp and buoyant ascent

Our class was doing our last dive for our open water certification course at a popular (cold water) dive site. We were at approximately 12 meters (40 feet) depth swimming through kelp when a strand of kelp wrapped around my quick release dive pouch on my BCD. As I tried to swim through the kelp, I felt resistance and noticed the entanglement. When I went to pull the kelp strand off, it pulled my weight pouch off. I tried to grab the weight pouch but was unsuccessful. I tried kicking towards it, but that too was unsuccessful. My buddy retrieved the weight pocket, but by that time, I was already floating up. I immediately dumped all the air from my BCD and tried to swim back down, but I continued to ascend slowly. I checked my computer to see if I was ascending too quickly, but I wasn't. I kept trying to kick downwards to slow my ascent. As I reached the surface, I inflated my BCD. Soon after, the instructor, who was leading the class, surfaced with one other diver and found me. A few moments after that, the rest of the class surfaced and gave me my weight pouch. Since this incident happened at such a shallow depth, I was lucky I did not suffer any consequences of rapid ascent.

Comment: Unintentional jettison of weight pouches or belts is one of the most dangerous incidents that can happen to a diver. Depending on the amount of weight lost, (especially heavier weights like in the example above), it can lead to a rapid and uncontrolled ascent to the surface. In these instances, the first step is to dump any gas in the BC and/or drysuit to reduce the rate of ascension. Swimming down is also an option, especially if the weight lost was not too great. If that is ineffective, flare out to slow the ascent while exhaling.

Proper weighting is also important. Too much weight can lead to several other issues. Any time there is a gear configuration change, (especially with exposure protection, different cylinder size or material, or different BC), or like in this instance a beginning class, a buoyancy check will help determine the proper amount of weight needed.

Environmental hazards, such as kelp, and what to do in the event of entanglement, should be covered during dive briefings.

Finally, DCI issues can manifest themselves in as little as 1 meter (3 feet) of depth change. In fact, in the first atmosphere (10 meters or 33 feet), divers experience the greatest percent of change in pressure compared to the surface. Changes of depth in shallow water can potentially become more problematic than in deeper water.

AIR SUPPLY

Cylinder valve closed

My wife and I learned the value of a pre-dive checklist. We were shore diving and entered the water. I was about 18 metres (59 feet) offshore waiting on her. She kept messing with her gear but not communicating to me there was a problem. The dive site is a lava shoreline and I noticed her getting closer and closer to the shore with the waves taking her in. I then realized there may be a real problem and swam to her as fast as I could. She was fighting to stay afloat and off the lava. Her air was not turned on. She didn't (fully) panic, but she panicked enough to not realize she could have manually inflated her vest. I turned her air on, she put air in her BCD, and all was well. Thankfully we were not hurt and settled down for a normal dive.

Mistakes: 1. Taking for granted air was on and not checking. 2. Not practicing for something that could go wrong. 3. Not having a strict checklist before entering the water. We have been diving for 30-40 years and had just become complacent. We know better now.

Comment: This scenario illustrates the necessity of running your pre-dive checklist every time you dive, regardless of how much experience you have. It's also a good habit to practice emergency situations, such as oral inflation of your BC, dropping weights, out of air (OOA) scenarios on a regular basis to keep those skills honed and in the forefront of your mind in case a real emergency was to occur.

WEIGHT AND BUOYANCY

Drysuit too large

I had just completed my drysuit certification. During my first drysuit certification dive, I had an “excess-gas-in-feet emergency ascent” incident, due to the huge boots in the dry suit and my smaller feet. On this dive, I was using a rental drysuit, quite a bit too large. This was my 20th dive, and because of the incident during my training dive, and because of the large drysuit, I was a bit over-weighted, including ankle weights, to prevent further issues. Our dive plan was to descend to about 27 meters (90 feet) and then swim out along the bottom and try to reach 40 meters (130 feet) depth. I was continually looking at my air gauge, but was apparently a little ‘narked’, as I failed to comprehend the reading. We had been going out for around 20 minutes, most of this over 30 meters (100 feet) deep and were almost to 40 meters (130 feet) depth when I realized my air gauge read 48 bar (700 psi) (I started at 193 bar (2800 psi). Still not thinking well, I indicated we should turn around and start heading back. We should have gone up, but we stayed at 38 meters (125 feet). The next time I looked at my gauge it was below 34.5 bar (500 psi), and then I realized we should head up. We went up to 4.5 meters (15 feet) and were about in the middle of the safety stop when I ran out of air. Instead of using my buddy’s secondary, I decided to just do a controlled emergency ascent to the surface, thinking I had hopefully been through enough of the safety stop. When I hit the surface, I had to manually inflate my BC. The two problems now were that I was over-weighted, and a storm had moved in causing fairly good-sized waves. It was quite a struggle to kick enough to stay up long enough to blow air into the BC, but eventually, I managed to get enough gulps of air between the crashing waves. It was a long, hard surface swim back to the dive boat in the wind and waves.

Comment: If there ever was a piece of equipment that must be properly fitted, it is your drysuit. A drysuit that is too big can lead to a myriad of problems, many of which can be life-threatening, including over-inflation, uncontrolled ascent, and unrecoverable inversion. The instructor should never have put

the student in the water with an improperly fitted drysuit during the drysuit course. When renting a drysuit, check the fitting, including the feet, before you leave the rental shop. When inverted, especially in drysuits where the boots or socks are too big, if there is too much air going into the boot or sock, the diver’s feet can come out of the feet of the suit quite easily. This can then lead to the loss of fins and thus propulsion and control in the water which becomes even more catastrophic. The use of additional weight and ankle weights to help mitigate the wrong size suit is not a proper solution to the problem. Use a properly fitted drysuit – and correct weighting! Diving to 40 meters (130 feet) affects a diver’s mental and physical capacities and having perfect equipment is even more important. Any intent to dive deep must include a calculation of gas consumption and adjust the plan accordingly.

If you become aware of narcosis, follow “the 3 Cs” – Confess, Communicate and Conform. Confess to yourself that you are ‘narked’. Communicate to your buddy your situation. Conform to your pre-established plan about dealing with narcosis. Being aware of yourself, and your buddy is important on every dive, but especially crucial on depths below 21 meters (70 feet), and more so the deeper you dive. You may not realize you are ‘narked’ but your buddy may notice some erratic behavior. Monitor each other’s breathing gas supply and follow the one-half or other pre-dive agreed upon rule to turn back.

OCEANOGRAPHIC INCIDENTS

Vertical down current

In the afternoon, about 50 divers in five separate dive boats were dropped into a popular dive site for the third dive of the day. We had just dived at this same site that morning which only had light to moderate currents. The site was a submerged reef with a steep wall that tapered off vertically into the deep blue, which plunges into 2,000 meters (6,562 feet) deep. As in the morning, the sea was choppy, with one to two-meter (3 to 7 feet) swells. Our dive group had ten people and one dive guide. We made a normal descent to 12 meters (40 feet) towards the edge of the reef wall and

followed our guide who was swimming against a strong current near the edge of the vertical reef wall. However, at around 14 meters (46 feet), just at the edge of the reef, an extremely fierce current suddenly sucked all the divers downwards into the deep. Within a matter of a few seconds, everything spiraled out of control, and nobody had any time to react or signal for help. We sunk very fast at a rate of about 10 meters (33 feet) per second, I had already been swept down about 30 meters (100 ft) or more into the deep. Some divers recounted that they were too far out to swim towards the reef and were sucked down to over 50 meters (165 feet).

We started to ascend. Back at 12 meters (40 feet), we were suddenly thrown into the surface currents which pushed us upwards. Most divers lost control and were swept up to the surface unable to make a safety stop. I hung completely inverted on the reef with my fins up and my BCD totally deflated while trying to hold onto a coral to stay down, before I was also swept up uncontrollably without being able to make a safety stop. Almost all the divers in our group aborted their safety stops and ascended immediately to the surface. The whole dive among all the divers lasted between 6 and 20 minutes.

Comment: Follow up discussion with the reporter discovered that this particular site is a popular one at this dive destination. All divers were at least advanced certified, diving air, and each group had a dive professional with them. According to the reporter, they were experienced (10+ years) dive operators, currents on this site are common, but not like the ones described in the narrative. The dive groups on the more central part of the reef experienced a more dramatic effect of the event than those groups who were father out on the sides of the reef.

This incident illustrates the importance of environmental awareness, especially when diving. There appears to be two separate, yet intertwined, oceanographic factors at play here - a "rogue wave" and a downwelling/upwelling event.

A "rogue wave" is a real phenomenon. They are formed by a process called "Constructive Interference". Waves travel across a body of water at different speeds, directions and wavelengths.

As these waves pass through one another, their crests and troughs sometimes get 'in sync' with each other and reinforce themselves. This process can sometimes form unusually strong swells, and sometimes large waves that quickly appear (and disappear) - which makes them very hard to study. This process is unpredictable and potentially very dangerous. Some rogue waves have been estimated at 18 meters (60 feet) in height. Rogue waves are not to be confused with a tsunami, which is an entirely different phenomenon.

The opposite is also true. Waves sometimes 'collide' with each other and cancel each other out making the water less wavy. In other words, the crest of one wave intersects with the trough of another wave. This process is called "Destructive Interference".

Regarding the vertical currents the author described is sometimes referred to as a vertical down current and up current, or more accurately, a "downwelling" and "upwelling" in the water column.

Downwelling occurs when a current (usually wind-driven), comes into contact with another physical structure. That structure can be a submerged reef wall, (as described in the narrative), an island or atoll, a larger landmass, or it can be another current itself. The water collides with the object and is forced down - hence 'downwelling'.

Upwelling typically occurs when wind-driven currents push water away from a given area. Other water then rises up from below the surface to replace the water that was pushed away. Upwelling usually occurs along coastlines but occasionally in the open ocean. Upwelling areas are usually nutrient-rich as they pull nutrients from deeper water up towards the surface. This means that the waters higher up in the water column in an area with upwelling often has much higher biological productivity. Thus, good fishing areas are commonly found in areas where upwelling occurs.

Upwelling and downwelling currents can range from very mild to quite extreme, depending on a number of factors about the current and the other structures involved.

Given the description of the events described by the author and some follow-up questions, it is surmised that a rogue wave impacted the reef wall, creating a sudden, extraordinary and probably unprecedented downwelling event in that area. Divers were inadvertently caught in the event, then pushed by the downwelling. Because of the transitory nature of the rogue wave/downwelling event, this was a short-lived incident. Then, as water wants to be in a state of homeostasis (a state of relative equilibrium), water rushed back in at depth, again hitting the reef wall and creating the subsequent upwelling event.

There are a variety of potential injuries in an event like this. They can range from minor cuts, scrapes and bruises from colliding into the reef or other divers, to nitrogen narcosis – which may contribute to other problems, barotrauma including DCS and AGE, oxygen toxicity, and even death.

In this particular incident, all parties involved were very fortunate. Some divers reported some equalization issues due to the rapid descent, one diver reported a nose bleed (possibly caused by barotrauma), and a variety of cuts and scrapes were reported. Luckily, there were no reports of DCS or AGE.

*What do to in these types of events:
If diving in a known area where upwelling and/or downwelling occurs, or you experience an unpredictable event like this one, the first thing to do is attempt to arrest your descent or ascent as quickly as possible. While it is never ideal to touch the reef, in an instance like this, it would be acceptable. Grab some solid substrate as quickly and safely as possible – while trying to avoid any harmful marine life such as fire coral.*

Try to protect your regulator and mask from being ripped away from you. If your regulator and/or mask is ripped away, remain calm, retrieve your regulator, and continue to breathe. If you can recover your mask safely, do so. If not, a mask is easily replaced.

If you are descending, be sure to be constantly equalizing your ears. If ascending, continuously exhale, inhaling only when needed, then continue to exhale again.

If you are unable to physically arrest your ascent or descent quickly, get vertically streamlined in the water. By making yourself vertically streamlined, this allows the water to pass by you with less drag on your body. This may slow down your ascent or descent to a degree and make it more possible to maneuver to a position to be able to grab onto something solid.

Once your ascent/descent is under control, begin to make an ascent at a safe rate, monitoring your breathing gas supply as you will likely be breathing much faster than on a relaxed dive. This is especially critical if you were caught in a downwelling and taken deep. If you can locate your buddy, do so, and make the ascent together, helping each other keep the ascent under control and monitoring each other's gas supply. Make a precautionary (safety) stop only if it is safe to do so.

If you are unable to make a safety stop safely, or like the divers in this incident, were swept directly to the surface, do not go back down to do a safety stop. Terminate the dive, get to safety (on shore or onto the boat), cease any diving activity for at least 24 hours, monitor for signs of Decompression Illness (DCI), i.e. DCS and AGE, treat any symptoms that may arise as appropriate and call DAN.

Injury due to boat hitting a wave wall

Ten other divers, the boat crew, and I were headed out for our last day of diving. Winds were mild to moderate on that day but had exceeded 30 knots all week prior. The winds, however, had changed direction.

On our way through the reef, we hit two small waves, and as I looked out in front of the boat, I saw a wave that was at least as high as the boat just ahead. The wave crashed through the front windows of the boat, threw me against the rails, and caused some injury. Various pieces of equipment were being tossed about the boat into me and overboard. I suffered

various injuries, including a scalp laceration, concussion, vision issues, and torn ligaments which required surgery.

Comment: This probably, is another 'rogue wave' incident. (See the "Vertical down current" incident on the previous page for details). Always be sure to properly store dive gear, accessories and other equipment to reduce the opportunity for flying objects to cause (more) injury to those on board. Keep in mind that sometimes, events like this can dislodge even the most securely fastened gear.

SKILLS IN ACTION

Successful drowning rescue

The dive buddy called for help when a female diver surfaced unconscious. The divemaster jumped in the water, performed rescue breaths as she was towed to the back deck of the boat. Her equipment was removed and the victim was pulled on the back deck of the dive boat. The captain radioed for help and initiated a diver recall. The divemaster checked the victim's vitals, gave rescue breaths and turned her on her side to help the fluids out of her lungs. The victim started to breathe on her own again and was given oxygen, and symptoms started rapidly improving. Local lifeguard assistance arrived on the scene, and transferred the victim to their vessel, she was escorted to the dock, where she was met by paramedics and transferred to the local hospital.

Comment: This is a great example of the proper execution of an Emergency Action Plan for an unresponsive diver and further illustrates the importance of proper and up-to-date first aid training.

Fatal outcome

On the first dive of the day, conditions were overcast, there were one meter (three feet) swells and less than a meter (1-2 feet) surface chop. The diver (who was large in stature) was first in the water. He entered the water with a giant stride from the boat with no apparent difficulty. He swam over to the anchor line to descend. He was wearing a drysuit and apparently (according to the captain who knows him well), usually does a headfirst dive to get to the bottom. As he was

starting this maneuver, he lost his left fin. He was noted to begin swimming arm over arm on the surface after the fin which was moving with the current. A (rescue) diver was deployed to assist.

However, while the (rescue) diver was swimming towards him, the victim started thrashing his arms, feet in the air, head down. When the first rescue diver reached him, he still seemed to be moving purposely, but his regulator was out of his mouth, and his BC and tank were below him, and connected only to his dry suit via the drysuit inflator hose. His head was beneath the water, his BC was not inflated, his drysuit was inflated. Within a very short time, he became flaccid and apparently unconscious. The rescue diver disconnected his dry suit inflator hose and flipped him on his back. He yelled to the captain to call 911, which she did by radio and notified the coast guard. By then, several other divers were in the water and towed him back to the boat on his back. He was brought onto the deck, which was difficult as he was obese. His drysuit was cut off immediately upon getting up to the deck while two-rescuer CPR was administered. Several minutes into the CPR effort, an AED was brought from another nearby boat. The AED repeatedly indicated that no shock was advised. CPR was continued until the boat got back to the dock where rescue personnel took over. It was reported the the victim did not survive the incident, and it was determined he had a medical event on the surface.

Comment: Events like this can happen to anyone, at any time. It is likely the increased strenuous activity of swimming after his lost fin precipitated the event, but without knowledge of the formal findings, this is conjecture. But it does underscore the need to be fit to dive, regardless of your age, training, or experience. Why the diver's BC was not inflated on the surface, and how the diver's gear became detached from the diver, save the drysuit hose, is unknown. It seems that the rescuers followed their training and did what they could. This also illustrates that not all rescues are successful.

DECOMPRESSION ILLNESS

Mild DCS

A diver developed muscular pain over the left shoulder after a dive. That evening, he called DAN who excluded joint decompression sicknesses (DCS), but referred the patient to the local hospital. The on-call hyperbaric physician was alerted. Physical and neurological examination were unremarkable, with only a slight pain over the left shoulder which diminished by morning. The patient was sent for an ambulatory visit to a hyperbaric facility the morning after. There were no clear signs of DCS, but there was still minor pain in the shoulder. The patient was treated at 2.4 ATA in an ambulatory session with other (non DCS) ambulatory patients. No more pain after the treatment. Another treatment was given after eight hours. At the follow-up, the patient was symptom-free.

Comment: The dive profiles that led to this event is unknown. The report is missing details of the conversation with DAN that was a base for DAN advice. In this case, the diagnosis of DCS was not very likely to the examining physician and he invited the patient for another follow-up visit the next day. The opportunistic HBO treatment and a complete resolution of an already diminishing shoulder pain do not prove DCS. Other conditions like strains may benefit from HBO, too.

DCS within no-decompression limits

I'm a rescue diver with 48 logged dives. Symptoms: pain in my shoulder muscles/joints and chest initially followed by tingling in my fingers and back of hands. It was just a lingering pain that would hurt no matter how I held my arms or body.

I had three dives on 21% oxygen:

1. Depth - 17.9 meters (59 feet), bottom time - 54 minutes, 3 minutes safety stop at 5 meters (16 feet), average depth - 12.2 meters (40 feet), Surface time - 1 hour 17 minutes before second dive
2. Depth - 13.5 meters (44 feet), bottom time - 51 minutes, 3 minutes safety stop at 5 meters (16 feet), average depth - 9.1 meters (30 feet), surface time - 54 minutes before third dive

3. Depth - 10.9 meters (36 feet), bottom time - 67 minutes, 3 minutes safety stop at 5 meters (16 feet), average depth - 7.3 meters (24 feet).

After dinner I became very tired, I excused myself and went to my cabin at 11 PM. I did not sleep due to the pain. It was not until 12:30 AM that I experienced the tingling in my fingers and hands. The next morning at 6:30 AM I still had the same pain. I told the dive instructor about what symptoms I was facing. He agreed with me that it seemed impossible to have any form of DCI due to our dives. He suggested I take oxygen to see if I felt better. I took oxygen free flow for 10 minutes. Off oxygen for 45 minutes. Then free flow again for 20 minutes. About two hours after the oxygen, I felt completely normal. Probably better than normal. I felt that the oxygen helped. I skipped the first two dives that (second) day but did go on the third dive. The dive was on 21% O₂ air - max depth 17.8 meters (58 feet), 50 minutes bottom time, 5 minutes safety stop at 5 meters (16 feet), average depth - 11.9 meters (39 feet). The surface time before this final dive was 16 hours and 33 minutes. I felt fine after the final dive.

Comments: It was not reported if the diver was using tables or a computer. These dive profiles were run on four different tables. Three of the four tables produced a profile that was outside the no-decompression limits. If a computer was used, the model and algorithm are not known, so it is impossible to verify if the computer registered the diver in or out of no-decompression limits.

Regardless of the use of dive tables or a dive computer, it is possible to experience DCI even with strict compliance to dive tables and/or dive computer profiles. Some call these "undeserved deco hits". The term 'undeserved' is a misnomer. DCI can happen even under ideal conditions and even within table limits. DCS is not just a factor of depth and time (although those are key components), but other factors come into play as well, such as exertion, temperature, breathing gas, hydration, fatigue, and genetics. Ideally, the oxygen would have been administered at the onset of symptoms.

The administration of oxygen at the surface does not require any air breaks for emergency situations. If symptoms develop, cease all diving activity, administer 100% oxygen, call DAN, and seek medical attention. Do not dive until you are cleared to do so by a qualified physician.

MISCELLANEOUS REPORTS

SMB line tangled around gear and pulled diver up

I was deploying my sausage (Surface Marker Buoy or SMB) and my rope reel got tangled. Then the sausage pulled me up, and I got tugged to about 5 meters (16 feet) before I reached my knife and cut the rope.

Comment: Deploying an SMB at depth can be a tricky operation and takes a lot of practice to become proficient. Entanglement and rapid ascent are the two biggest risks. When deploying an SMB at depth, be sure to work with everything in front of you to minimize those risks. To arrest the ascent as quickly as possible, be prepared to either let go of the SMB or cut the line if you begin to ascend uncontrollably. If ascending uncontrollably, always be exhaling, make your body as big as possible by flaring your arms and legs out and try to slow the ascent as quickly as possible.

Food poisoning

I was diving nitrox 36%. It was our second dive. I had gone to 27 meters (90 feet). Near the end of the dive, at 21 meters (70 feet), my camera slipped off my wrist. I noticed it gone right away and looked up. I could see it heading to the surface. I went after it. I made a slow ascent but maybe not slow enough. I was still in the no deco zone on my computer. I slowed down and stopped briefly at 4.5 meters (15 feet). I grabbed the camera at the surface and headed back down. I spent the rest of the dive doing a very slow ascent. I drank a lot of water and didn't have any alcohol. I was tired after the dive but not unusually so. Also, my neck felt strained but also not unusual. I rested for a few hours. I had no symptoms and went to dinner. I ate lionfish ceviche from fish caught by my fellow divers. About four hours later, I was voiding from both ends. I felt really bad in the morning, but I had a rough night that seemed

more due to food poisoning. I dragged myself out of bed and started to pack to go home just 24 hours after this incident. I'm scared to get on the plane. But I don't think I have any DCS symptoms.

Comment: Given that this happened a few hours after a dive with an unplanned and possible unsafe ascent, it would be best to contact DAN and be referred for evaluation by a physician for DCS, especially if your travel plans include flying. While it is possible it was food poisoning, it's best to consult with a physician for proper diagnosis and treatment.

CONCLUSION

Every year, we receive hundreds of reports via the DIRS, all of which are lessons learned. Some of those lessons are repeats, some are new, all are valuable. Regardless of the outcome of the incident – no injury, minor injuries, major problems, or even fatalities, they are told by survivors (or witnesses) in details that no investigation could reveal. Such reports help make diving a little safer. Few incidents are totally out of the divers' control (the "rogue wave" incident, for example). Most incidents can be mitigated by following proper training and safe diving practices and maintaining & servicing your gear according to manufacturers' specifications.

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

Divers or other first-hand witnesses are encouraged to report any diving-related incidents to the Diving Incident Reporting System (DIRS) on the DAN website. If you experience or witness a diving incident, please report those incidents, with as much detail as possible, to the DIRS system <https://www.diversalertnetwork.org/diving-incidents/>.

When in doubt, call DAN.

REFERENCES

1. Mansouri M, Shaqdan KW, Aran S, Raja AS, Lev MH, Abujudeh HH. Safety incident reporting in emergency radiology: analysis of 1717 safety incident reports. *Emerg Radiol.* 2015;22:623-30. doi: 10.1007/s10140-015-1336-3. PubMed PMID: 26246282.
2. Westbrook JI, Li L, Lehnbohm EC, Baysari MT, Braithwaite J, Burke R, et al. What are incident reports telling us? A comparative study at two Australian hospitals of medication errors identified at audit, detected by staff and reported to an incident system. *Int J Qual Health Care.* 2015;27(1):1-9. doi: 10.1093/intqhc/mzu098. PubMed PMID: 25583702. PubMed Central PMCID: PMC4340271.
3. Williams TL, Tung DK, Steelman VM, Chang PK, Szekendi MK. Retained surgical sponges: findings from incident reports and a cost-benefit analysis of radiofrequency technology. *J Am Coll Surg.* 2014;219:354-64. doi 10.1016/j.jamcollsurg.2014.03.052. PubMed PMID: 25081938.
4. O'Connor P, O'Dea A, Melton J. A methodology for identifying human error in US Navy diving accidents. *Hum Factors.* 2007;49:214-26. doi 10.1518/001872007X312450. PubMed PMID: 17447664.
5. NOAA. NOAA Diving Manual. Diving for science and technology. 4th ed: US Department of Commerce. National Oceanic and Atmospheric Administration.
6. National Park Service. Diving Safety and Operations Manual. Reference Manual - 4.: US Department of the Interior; 2014.
7. Cumming B, Peddie C. NDC Diving incidents report 2015. South Wirral, Cheshire: British Sub-Aqua Club; 2015.
8. Polinder S, Haagsma JA, Toet H, van Beeck EF. Epidemiological burden of minor, major and fatal trauma in a national injury pyramid. *Br J Surg.* 2012;99(Suppl1):114-21. doi 10.1002/bjs.7708. PubMed PMID: 22441864.
9. Lee LK, Fleegler EW, Forbes PW, Olson KL, Mooney DP. The modern paediatric injury pyramid: injuries in Massachusetts children and adolescents. *Inj Prev.* 2010;16(2):123-6. doi 10.1136/ip.2009.022723. PubMed PMID: 20363820.
10. Acott C. Scuba diving incident reporting: the first 125 incident reports. *SPUMS Journal.* 1992;22:214-21.
11. Acott C. The diving incident monitoring study dive tables and dive computers. *SPUMS Journal.* 1994;24:214-5.
12. Acott C. 457 equipment incident reports. *SPUMS Journal.* 2001;31:182-95.
13. Acott CJ. An evaluation of buoyancy jacket safety in 1,000 diving incidents. *SPUMS Journal.* 1995;26:89-94.
14. Acott CJ. Recreational scuba diving equipment problems, morbidity and mortality: an overview of the diving incident monitoring study and project stickybeak. *SPUMS Journal.* 2003;33:26-30.
15. Acott CJ. Human error and violations in 1,000 diving incidents: A review of data from the Diving Incident Monitoring Study (DIMS). *SPUMS Journal.* 2005;35:11-7.

16. Acott C, editor. Diving incidents - errors divers make. Safe Limits: an international dive symposium; 1994; Cairns: Division of Workplace Health and Safety. Available from: <http://archive.rubicon-foundation.org/xmlui/handle/123456789/6424>. [cited 2018 May 7].
17. Rowley B, Buzzacott P, Denoble P. Ten years of recreational diving fatalities in the United States and Canada: harvesters vs non-harvesters. *J Travel Med*. 2016;24:1-3. doi 10.1093/jtm/taw068. PubMed PMID: 27738111.
18. Buzzacott P, Rosenberg M, Pikora T. Western Australian recreational scuba diving fatalities, 1992 to 2005. *Aust NZ J Public Health*. 2009;33(3):212-4. doi 10.1111/j.1753-6405.2009.00377.x. PubMed PMID: 19630838.
19. Buzzacott P, Schiller D, Crain J, Denoble PJ. Epidemiology of morbidity and mortality in US and Canadian recreational scuba diving. *Public Health*. 2018;155:62-8. doi 10.1016/j.puhe.2017.11.011. PubMed PMID: 29306625.
20. 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. *Brain injury*. 2017; 31:366-9. doi 10.1080/02699052.2016.1255781. PubMed PMID: 28128653.
21. Buzzacott P, Pollock NW, Rosenberg M. Exercise intensity inferred from air consumption during recreational scuba diving. *Diving Hyperb Med*. 2014;44:74-8. PubMed PMID: 24986724.
22. Buzzacott P, Denoble P, Dunford R, Vann R. Dive problems and risk factors for diving morbidity. *Diving Hyperb Med*. 2009;39:205-9. PubMed PMID: 22752740.
23. Divers Alert Network Annual Diving Reports. In: Buzzacott P, editor. DAN Annual Diving Report 2017 Edition: A Report on 2015 Diving Fatalities, Injuries, and Incidents. Durham (NC): Divers Alert Network 2017 Divers Alert Network.; 2017. PubMed PMID: 29553634.
24. Tsingos C, Bosnic-Anticevich S, Smith L. Reflective practice and its implications for pharmacy education. *Am J Pharm Educ*. 2014;78(1):18. doi 10.5688/ajpe78118. PubMed PMID: 24558286. PubMed Central PMCID: PMC3930242.

SECTION 5. BREATH-HOLD DIVING

Hannah DeWitt, Asienne Moore, Frauke Tillmans

Breath-hold diving is defined as holding one's breath while submerged in water. This covers everything from children playing in the pool, excursions to a shallow depth in recreational snorkeling, collecting or harvesting game, all the way to competitive freediving, which pushes the limits of human physiology one record at a time. The incidents connected to breath-hold are as diverse as the tasks the individuals are fulfilling, and new trends in water sports keep emerging. Because of this, monitoring incidents and accidents is of vital importance to keep the sport safe and raise awareness of the common errors that lead to incidents.

Decades of research on breath-hold divers revealed genetic adaptations in freediving populations, like the Ama divers of Japan, spleen and lung volume adaptations in Bajau divers of Indonesia, and record-seeking freedivers, and modulation of a variety of biomarkers after just one breath-hold dive.^{1,2}

It is most important to understand that the response of the human body to breath-hold and submersion is highly individual. The preparedness and training level of an individual will, therefore, directly influence performance and safety.

Untrained divers will find it difficult to extend their breath-hold time beyond one minute. The maximum depths they could attain is most likely influenced by pain in their ears caused by the differential pressure between the middle ear and the external environment. Learning how to equalize this pressure can contribute to a diver's ability to push past their previous limits to reach depths of 30 meters (99 feet) where the lungs of an average person are squeezed to their residual volume. At these depths, additional risks are introduced, but the urge to breathe often prompts a diver to rush to the surface before trouble can occur. This is not true for all divers and especially not for those attempting to accomplish a task underwater, such as fishing or harvesting. The pressure to complete the task before returning to the surface may push the diver past his or her limits where they can experience a blackout due to hypoxia.

For the trained breath-hold diver engaged in freediving activities, the limit on how deep they can go is influenced by special training and a desire to continuously improve. Special considerations are needed for the extreme of this sport: freediving competitions. Table 5-1 lists the records currently being held in the freediving disciplines recognized by the International Association for the Development of Apnea (AIDA).

Table 5.1. AIDA-recognized competitive freediving disciplines and record performances (current December 2019)

Discipline	Description	Record Performance			
		Women		Men	
Static Apnea	<i>Resting, immersed breath-hold in controlled water (usually a shallow swimming pool)</i>	09:02 min	21-Jun-2013	11:35 min	8-Jun-2009
Constant Weight	<i>Vertical self-propelled swimming to a maximum depth and back to the surface; no line assistance allowed</i>	107 m	26-Jul-2018	130 m	18-Jul-2018
Free Immersion	<i>Vertical excursion propelled by pulling on a rope during descent and ascent; no fins</i>	97 m	26-Jul-2018	125 m	24-Jul-2018
No Limit	<i>Vertical descent to a maximum depth on a weighted sled; ascent with a lift bag deployed by the diver</i>	160 m	17-Aug-2002	214 m	14-Jun-2007
Dynamic without Fins	<i>Horizontal swim in controlled water</i>	191 m	1-Jul-2017	244 m	1-Jul-2016
Constant Weight without Fins	<i>Vertical self-propelled swimming to a maximum depth and back to the surface; no line assistance allowed</i>	73 m	22-Jul-2018	102 m	21-Jul-2016
Variable Weight	<i>Vertical descent to a maximum depth on a weighted sled; ascent by pulling up a line and/or kicking</i>	130 m	18-Oct-2015	146 m	1-Nov-2015
Dynamic with Fins	<i>Horizontal swim in controlled water</i>	253 m	21-Jun-2019	300 m	2-Jul-2016

OVERVIEW OF CASES 2017

Since 2004, DAN has collected and analyzed breath-hold incidents. The sources of information are public media, calls to the DAN emergency or help line regarding voluntary reports from witnesses or divers experiencing problems, and DAN's online Diving Incident Report System (DIRS). The amount of data captured is only a fraction of all incidents that occur each year. There is no regulation of common breath-hold activities such as snorkeling, spontaneous breath-hold diving, and recreational spearfishing, nor is there a formal reporting system for related incidents and injuries. Even so, the amount of data collected by DAN continues to increase each year. Figure 5-1 shows data captured annually since 2004.

In 2017, DAN captured information on 140 cases, of which 52 were fatalities, and 88 refer to incidents or injuries. It is important to note that while there has been a disproportionate trend between the number of recorded fatalities and the number of injuries, this trend does not reflect the high mortality of breath-hold incidents. Instead, this reflects the availability of data. We can see that in 2017 the number of reported incidents increased, following the trend set by the previous year, which may be due to the differences in the data collection effort. Improving the data collection process and the reporting system that DAN maintains is necessary to increase data capture, learn more about incidents, and introduce additional interventions as needed. Incidents can be reported to the online Diving Incident Reporting System (DIRS) at <http://DAN.org/incidentreport>.

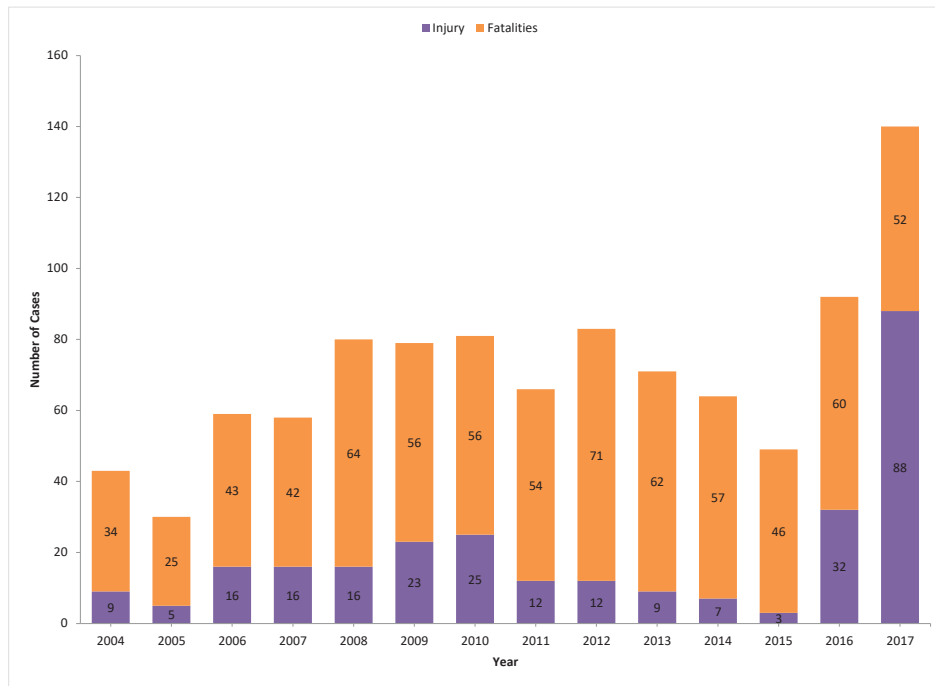


Figure 5-1. Breath-hold incidents between 2004 and 2017 (n=995, 73% fatal)

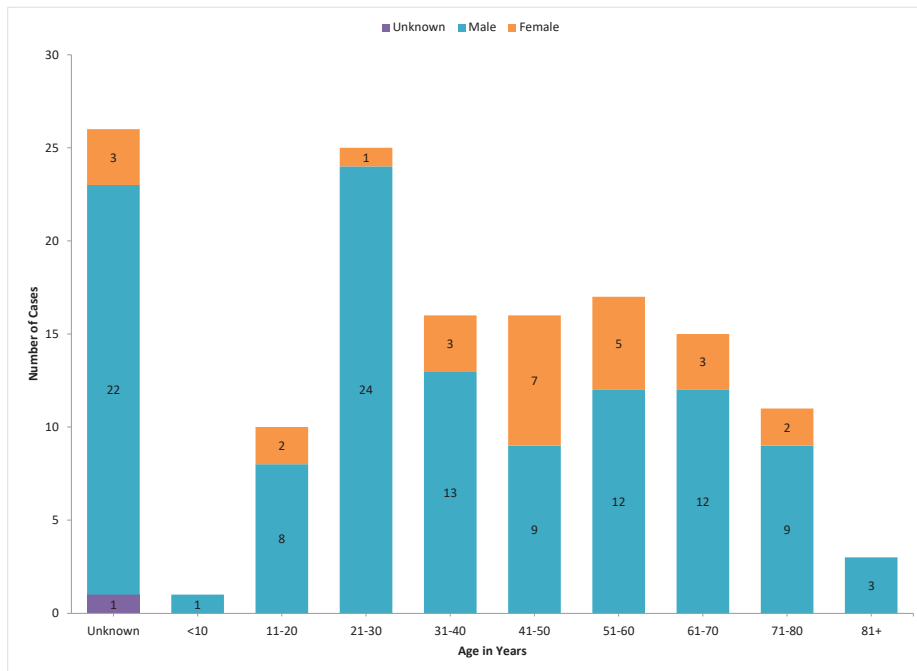


Figure 5-2. Age and gender distribution for breath-hold incident victims in 2017 (n=140, gender unknown 0.7%, men 80.7%, women 18.6%)

The age and sex distribution for breath-hold incidents and fatalities victims are shown in Figure 5-2. In most age groups male divers dominate (>80%) and the highest number of incidents was reported for the 21-30-year old male group. With 26 cases of unknown age (almost 19%), this graph also emphasizes the need for an improved reporting system. Figure 5-3 breaks the 140 reported incidents down into breath-hold fatalities and non-fatal incidents by age group. Breath-hold fatalities occurred in all age groups in 2017, with 21 (40%) occurring in divers forty years old or younger and 31 (60%) in divers more than 40 years old.

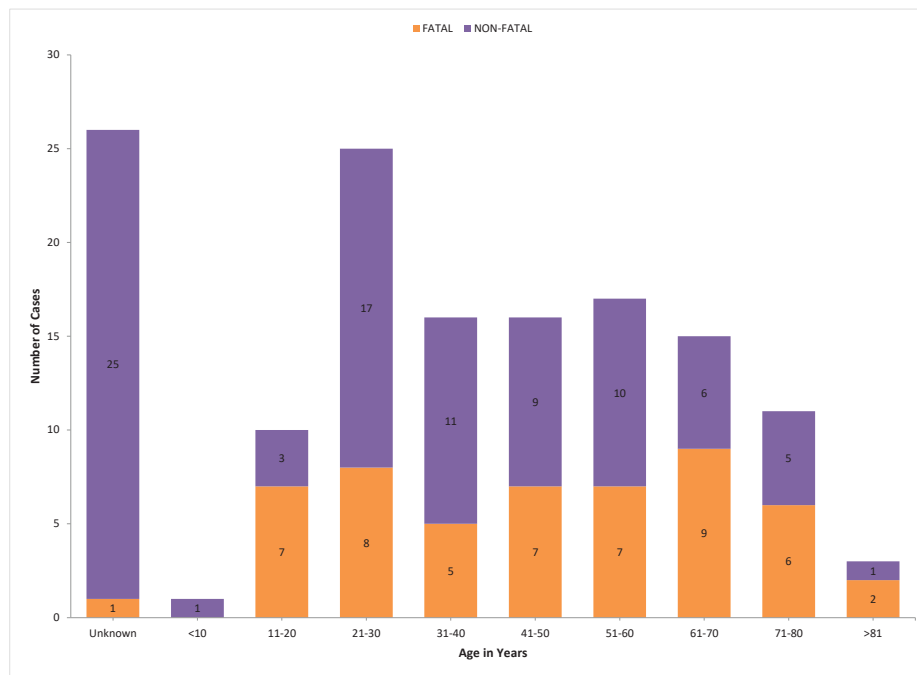


Figure 5-3. Age of victims and severity of breath-hold incidents in 2017 (n=140)

ACTIVITIES WHILE BREATH-HOLD DIVING

The activities in which divers were engaged when the incident or injury happened are shown in Figure 5-4. Activities were categorized into three categories: freediving, snorkeling, and tasks. The main difference between the categories is the motivation of the individuals pursuing the sport. While recreational snorkeling does not necessarily require specific training or prior knowledge, individuals classified as freedivers are more likely to have taken training from available agencies to improve their performance. The tasks include breath-hold activities such as spearfishing, harvesting, clearing anchors, retrieving objects, photography, etc.

Most reported breath-hold fatalities were engaged in snorkeling, which is expected regarding the massive and unrestricted participation. Freediving has the smallest portion of fatalities recorded, which could be due to the organizational structure and rules typically associated with this activity as well as the selection and specialized training. Freediving associations have strict guidelines and safety protocols that must be followed, and any deviation can result in disqualification.

This provides for relatively low rates of incidents despite pushing the boundaries of physiological limitations.

Freediving while participating in additional activities or tasks such as spearfishing, photography, game collection, etc. adds additional risks that can lead to injury or death. These tasks can lead to divers descending deeper than planned or delaying ascent too long as they wait for that perfect shot.

The mean age of the victims involved in different activities is shown in Figure 5-5. As previously reported, the victims in snorkelers are on average older, despite the activity being practiced by all ages. The older age of victims indicates that health-related factors may play a role in snorkeling injuries and fatalities. Unlike freediving, snorkeling is an activity that occurs with no medical clearance required and little or no training before participation.

It needs to be stressed once more that these statistics are likely an underrepresentation of the total incidents that occur but reflects what is reported to DAN and collected.

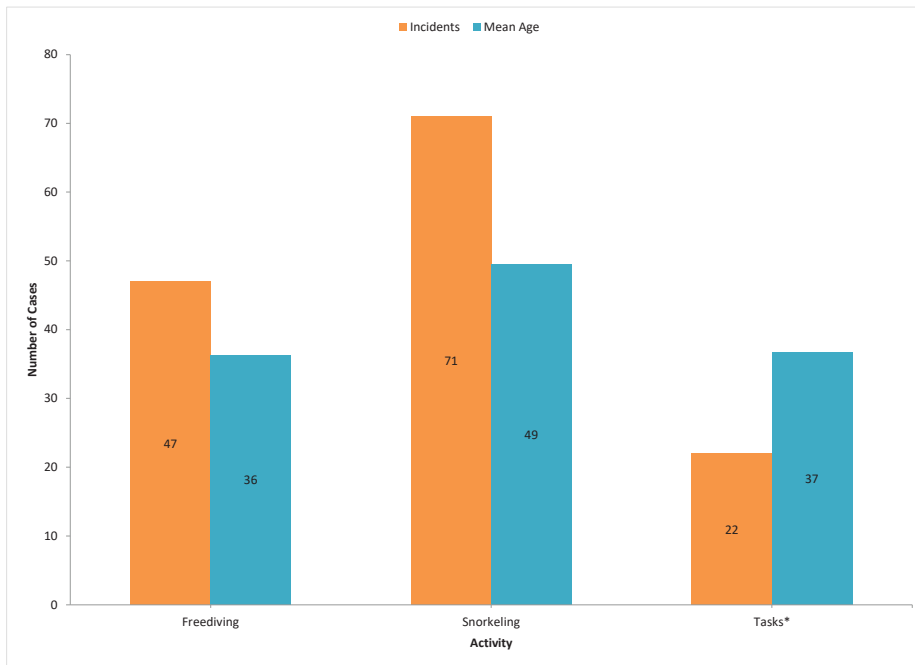


Figure 5-4. Distribution of breath-hold incidents by activity category

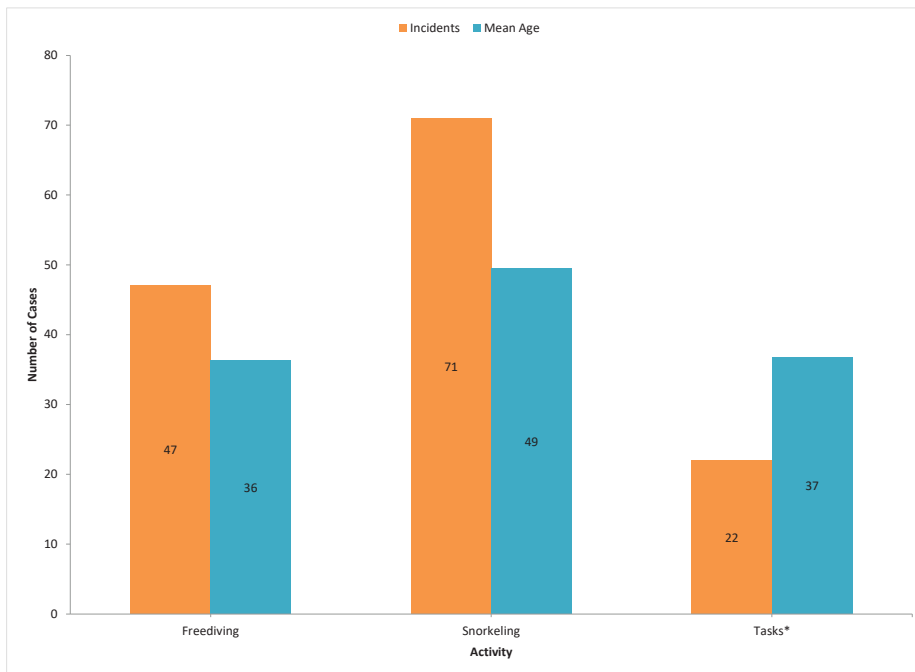


Figure 5-5. Mean age of victims by activity preceding the incident in 2017

SELECTED CASES

Immersion Pulmonary Edema while snorkeling

A male snorkeler with over 20 years of experience, self-reported surviving a cardiac arrest which he suspects was caused by immersion pulmonary edema (IPE). The day before the incident, the victim was snorkeling alone while his wife was diving from a boat. He decided to exit the water after an hour, feeling a tightness in his chest. He did not return to the water that day and instead returned to their hotel room. The next day, he went snorkeling with his wife. They walked with their gear up the beach for roughly a mile. Once suited up, they entered the water and snorkeled for 45 minutes before the victim decided to head back to shore after having some issues with his snorkel (water that entered the snorkel was blown out and not aspirated). Within minutes, he experienced shortness of breath and extreme difficulty breathing. He held on to a nearby float-line until his wife reached him and towed him to shore. Incidentally, there were two doctors at the beach who evaluated him and noted that his pulse was thready and lips blue. Emergency services were called and arrived shortly. After they provided oxygen, they transported the victim to the ER. During the transport, the victim began spitting out frothy pink sputum. Upon arrival to the hospital, he lost consciousness and was intubated. Soon, he went into cardiac arrest and had to be resuscitated. Once stable, he was moved to a different hospital that was equipped to provide intensive care. His electro physiologist attributed the near-drowning to a probable cardiac event as the victim had a history of premature ventricular contractions (PVCs). Cardiac catheterization showed no blockage of the arteries, and a CT scan showed no damage to the brain. Further research on the part of the victim led him to believe that his symptoms were SIPE but there is no indication that this diagnosis was confirmed or even considered in the hospital.

Comment: This incident is a good example of why a functioning buddy system is crucial. The victim's wife was trained and able to assist in this critical situation in the water, which can make all the difference between a fatal outcome and survival. Regarding his future participation, the diver should consult a sports medicine or diving medicine specialist. He should discuss his risks of malignant arrhythmias and SIPE with immersion and exertion before making an informed decision.

Survived samba

This is a self-reported incident that occurred during constant weight freediving training. The diver recollects diving down to 32 meters (106 feet) and remembers feeling very well at depth, before starting a slow ascent back to the surface. When checking his computer on the way up, he realized that he had taken more time in this dive than usual. Close to reaching the surface, he started feeling dizzy and lost consciousness. The next thing he remembered was his instructor shouting at him 'breathe, breathe!'. His instructor later told him that he had been watching him before reaching the surface and that his movements were those of a samba, a blackout and muscle contraction that freedivers can experience when ascending due to low levels of oxygen.

Comment: Samba, a form of shallow water blackout, is not uncommon in competitive freediving. In this case, the experience and adequate reaction of the instructor who recognized his condition prevented a possibly fatal outcome. This case highlights how important constant monitoring of a freediver is both during training sessions and in competitions.

Two freediving teenagers

A caller from a diving school in the Caribbean, reached out to seek advice for two male students (16 and 17-years-old) who had been freediving to a maximum depth of 10 meters (33 feet) that day. Both students complained of a headache and had difficulty with equalization. The 16-year-old experienced a bloody nose after surfacing from the dive while the 17-year-old had blood in his sputum and discomfort with inspiration. It was reported that a noise could be heard with inspiration. The caller was not able to describe the noise in more detail.

Comment: Given that the two teenagers experienced difficulties after a relatively shallow dive we can only speculate that they were not experienced in freediving. Reported symptoms were likely caused by ear, sinus or even lung barotrauma in one case, and required medical evaluation. As DAN does not diagnose over the phone, the caller was urged to seek medical evaluation at the local medical facility. Equalization issues like these and ear barotrauma are repeatedly reported to DAN with a variety of reasons from being exposed to high swell (sudden pressure changes), wrong or missing advice or explanations from peers or parents, or simply due to inexperience and lack of proper training. In a case of discomfort with breathing, divers should always be evaluated for pulmonary barotrauma.

The Buddy System is important - Snorkel Fatality

A 52-year-old woman vacationing in Hawaii was snorkeling with her buddy. Her buddy became tired and they both decided to return to the beach. The events of the following minutes are unclear, but when the buddy turned back to check on her, she was floating face down on the surface, her mask and snorkel removed from her face. Brought to the beach, CPR was initiated, but unsuccessful. The medical examination revealed drowning with water found in nasal passage and lungs.

Comment: Many snorkeling fatality reports have incomplete narratives, often due to a lack of a buddy or other supervision of the diver. Snorkeling is as risky as any other water sport, whether breath-hold diving is involved or not. When an unattended swimmer loses consciousness, the most likely outcome is drowning. The most common causes of a sudden loss of consciousness in older swimmers are of cardiovascular origin, which out of the water is not necessarily fatal. Thus, the buddy system is as important in snorkeling as it is in any other form of diving, but unfortunately, most snorkelers lack skills to practice it efficiently.

FATAL BOATING INJURIES

Case 1

A 50-year-old woman vacationing in Southeast Asia, was snorkeling with a buddy when she was struck by a boat who had not seen her in the water. She suffered a broken neck and was transferred to an intensive care unit where she died the same night.

Case 2

A man snorkeling in Southeast Asia decided to return to the boat alone while his friends stayed in the water. He was later discovered on the floor of the boat with a head wound. He was not breathing. It is suspected that he fainted due to the heat and, upon collapsing, suffered a head wound when he hit the floor.

Comment: Despite being unrelated, both these incidents outline the importance of a buddy system and the necessity of being aware of your surroundings. Safety on and around boats is not only the responsibility of the boat captain, but it also should be a vital part of each individual's emergency action plan.

Medical History

A 44-year-old female snorkeler (BMI: 40.7) was snorkeling alone roughly 18 meters (59 feet) off the beach while her husband remained on the shore reading a book. Water temperature was 25.5° C (78° F). According to witnesses, the victim was seen drifting slowly to shore without signs of distress. Approximately 45 minutes after she entered the water, bystanders discovered her unresponsive, floating near the shoreline. They pulled her ashore and called paramedics and started CPR. Responding paramedics found the victim to have no pulse and despite further attempts at resuscitation, she was pronounced dead at the scene roughly thirteen minutes after she was first discovered by bystanders. The medical examiner ruled her death an accidental drowning with epilepsy, hypertensive heart disease, and obesity as contributing factors.

Comment: This is a tragic incident, where once again, several accumulating factors led to the irrevocable outcome. The final cause remains unclear, but it is worth noting that several medical conditions are considered a contraindication for diving and snorkeling, epilepsy being one of them. Whether supervision by a buddy would have prevented the incident remains speculation, but it could possibly have engaged emergency services at an earlier stage.

Game Collection

A 45-year-old freediver was collecting shark teeth in 4 meters (13 feet) deep water, a couple of hundred yards away from the coast. His friend remained on a boat in the vicinity. At some point, the woman on the boat heard a thump against the side of the boat and discovered her friend unresponsive and face-down in the water. She managed to get the diver onto a raft but could not get him back into the boat. Emergency services were informed, and the diver was transported back to shore. CPR attempts by paramedics were unsuccessful, and the diver was pronounced dead on the scene. It was later reported that the diver had a habit of continuing his breath-hold until he started to see black underwater before returning to the surface.

Comment: Valuable lessons can be learned from this incident. This case is one of many reports where several accumulating risk factors presumably contributed to an undesirable outcome. The diver was diving by himself and was not supervised underwater. He was known for his risky behavior while diving. He also did not have an emergency action plan in place; the friend in the boat had no means of getting the unconscious diver back on the boat by herself. She managed to get him on a raft towed by a boat, but it is reasonable to assume that there was a significant delay until the arrival of the EMS and initiation of the CPR.

REFERENCES:

1. Schagatay E, Richardson MX, Lodin-Sundström A. Size Matters: Spleen and Lung Volumes Predict Performance in Human Apneic Divers. *Front Physiol* [Internet]. 2012 Jun 18 [cited 2018 Jun 7];3. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3376424/>
2. Schagatay E, Lodin-Sundström A, Abrahamsson E. Underwater working times in two groups of traditional apnea divers in Asia: the Ama and the Bajau. *Diving Hyperb Med*. 2011 Mar;41(1):27-30.

SECTION 6. TRAINING AND EDUCATION

Patty Seery

The early years of Divers Alert Network (DAN) spawned the evolution of the three prongs of DAN's Mission: Medical Services, Diving Medicine Research and Training and Education. It was through the early calls about diving injuries that the lack of surface first aid oxygen became evident. To address the need, the *Oxygen First Aid for Scuba Diving Injuries* course was developed. The value and quality of the program spread quickly.

Over the decades DAN First Aid Training has expanded the scope of courses, numbers of individuals trained, and the geographical reach of diving first aid training. DAN now offers seven first aid courses, a provider recognition program and an oxygen grant program. These elements were blended together to fulfill a more informal mission of having oxygen and individuals trained to use it at every dive site.

Prevention programs and materials are also part of DAN's diving safety education. Online seminars, videos on DAN TV (hosted on YouTube), elearning safety programs plus downloadable infographics, health and diving materials, and a wealth of online resources are all part of DAN's service to divers globally.

DAN has embraced educating physicians and health care providers of the impacts of the diving environment on body systems and how they may result in compromised health and safety as well as how to respond and treat when accidents do happen.

With programming that reaches from the newly certified diver to the range of professionals who train and care for them, DAN supports the entire diving community.

SCUBA DIVING INJURY FIRST AID AND SAFETY EDUCATION

While Divers Alert Network was founded in 1980, the training arm of the organization as it exists today was first conceived in 1989. The use of oxygen in first aid for scuba diving injuries was slow to emerge. It was first proposed as part of hyperbaric medicine in the 1930s. It was a couple of decades before the use of oxygen first aid found its way into recreational diving and its use for scuba diving first aid did not come into mainstream use until the 1980s.

At DAN's inception, research into diving injuries found roughly one-third of injured divers were receiving surface oxygen first aid. As a result, the majority of injuries were going untreated until reaching a medical facility. And even medical facilities presented hurdles in receiving appropriate care. The challenge became not just on-site care but appropriate follow-up care.

THE BEGINNING

The DAN Oxygen First Aid course was designed for recreational divers and developed as a four-hour modular program. It was introduced at DEMA in January 1991. By August that same year, a thousand providers had been trained in oxygen first aid for scuba diving injuries.

With a growing demand that could not be accommodated by DAN staff, an instructor trainer workshop was developed and implemented. The first workshop was held in September, 1992. By the end of 1993, 1000 instructors had been trained through this new group of DAN Instructor Trainers. In just one year that number doubled, then reached 5000 by May 1996! By 1997 there were 7000 instructors.

Figure 6-1 shows the growth over five year periods.

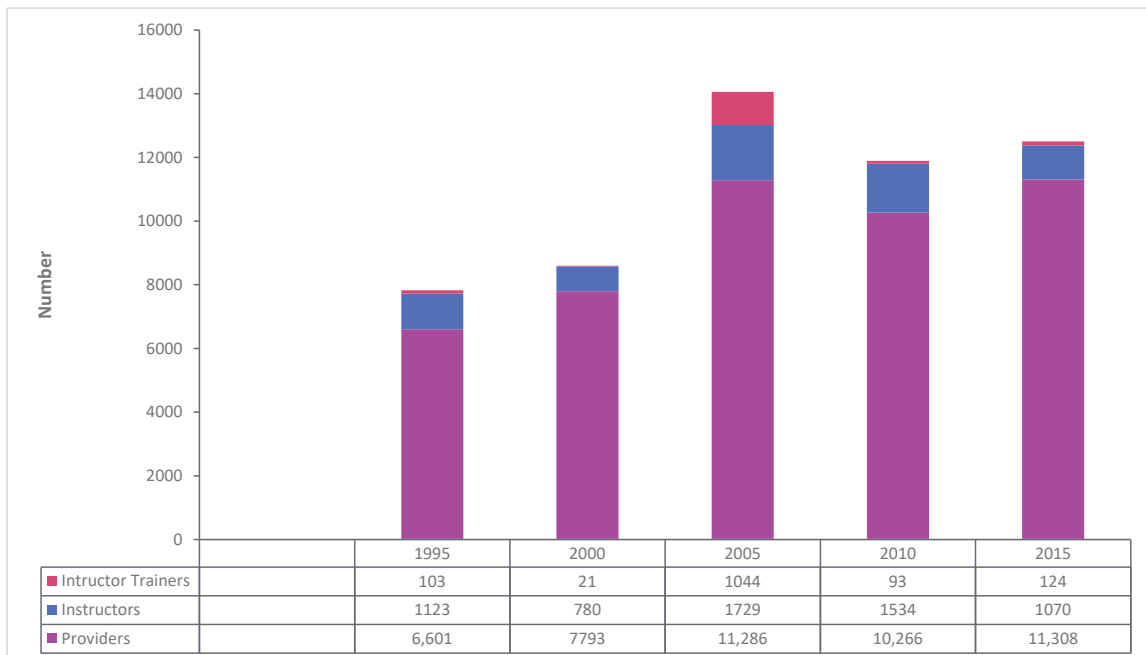


Figure 6-1. Training growth with traditional course delivery



Figure 6-2. DAN First-Aid Courses

FIRST AID COURSES FOR SCUBA DIVERS

The oxygen first aid course was the beginning of specialized training to handle diving injuries. The original oxygen course expanded to include adjunct equipment to provide oxygen to nonbreathing or inadequately breathing divers. Even a configuration to provide extended oxygen delivery with limited supplies was developed. Unfortunately, a long-term, committed manufacturer could not be retained and that specific program was discontinued due to a lack of an ongoing appropriate equipment supply.

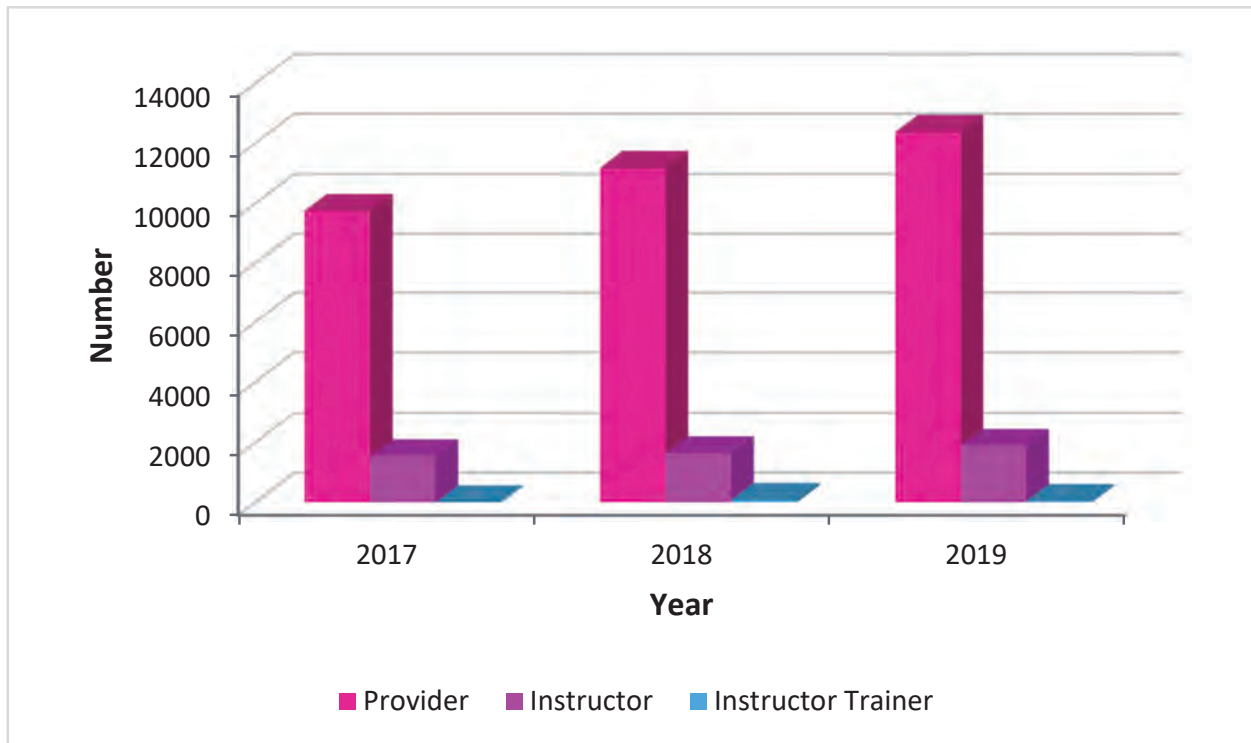
Oxygen first aid was not the end of DAN first aid training with divers in mind. Given divers' exposure to marine life in the diving environment, a specialized first aid course

that addressed accidental injuries inflicted by marine life, *First Aid for Hazardous Marine Life Injuries*, was introduced in 2000.

DAN ventured into first aid course translations to provide expanded support for the Latin American community of divers in 2002.

The year 2003 saw a number of training advances with the introduction of *Diving Emergency Management Provider (DEMP)* course, implementation of early online learning, and participation as a delivery site for an accredited Diver Medical Technician program.

DAN now has a Neurological Assessment first aid course that focuses on field assessment of



6-3. Training growth with elearning

an injured diver for some of the more subtle manifestations of decompression illness. Additionally, DAN offers two CPR courses focused at different levels of training: a basic cardiopulmonary resuscitation course (*Basic Life Support: CPR and First Aid*) as well as team focused CPR that also covers care for children and infants (*CPR: Health Care Provider*).

One of the most successful first aid courses came at the request of aquarium dive program administrators and their need for consolidated training. *Diving First Aid for Professional Divers (DFA Pro)* was developed in response to that request and, in the current version, goes beyond the basics of other DAN first aid courses and delves into the greater obligation of care that accompanies supervising divers, whether aquarium, recreational, commercial, research/scientific or public safety divers. All of these

markets utilize this comprehensive program to satisfy accreditation as well as training needs.

Tangible success of our first aid courses is seen in the approval of *DFA Pro* as well as *Basic Life Support: CPR & First Aid (BLS:CPR&FA)* by the U.S. Coast Guard as meeting the first aid and CPR training requirements. *DFA Pro* satisfies the requirements for Captain and Mate licenses while *BLS: CPR & FA* meets the requirements for seafaring individuals.

In addition, the American Camp Association (ACA) also recognizes *DFA Pro*, *BLS:CPR&FA*, *CPR: HCP*, and for their water-based camps, *DEMP*.

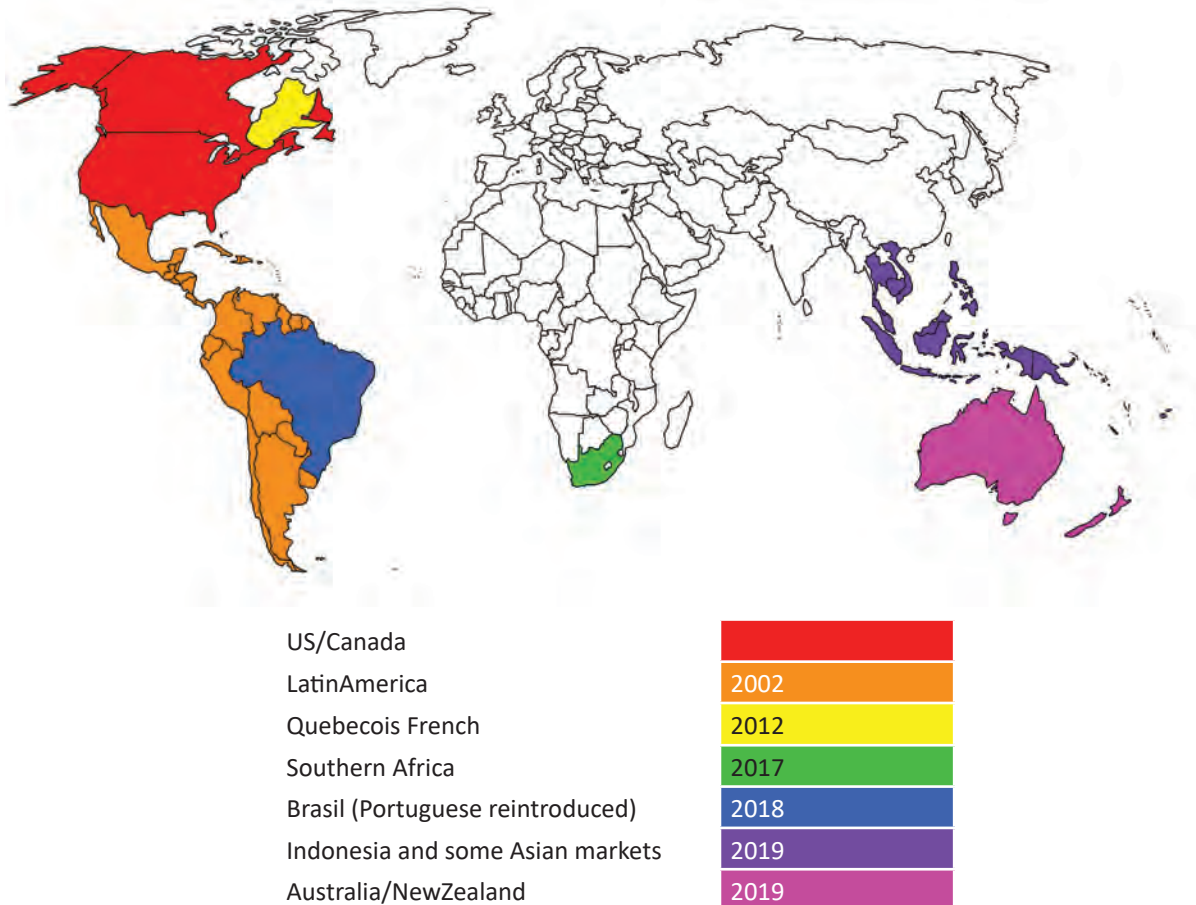


Figure 6-4. World Map showing areas of adoption and years

EXPANSION OF DAN'S DIVING FIRST AID COURSES

It is not just the breadth of training, but the utilization of the DAN First Aid courses that has also had its impact. From the first 1000 providers who completed the oxygen first aid training course, the numbers have grown to more than 300,000 provider and 37,000 instructor credentials issued.

The DAN first aid courses spread into Latin America with translations into Spanish and Portuguese as well as Quebecois French used by our northern neighbors.

The DAN first aid courses experienced a major transition and impact when the elearning platform was introduced in December 2016. With students being able to complete their knowledgebase online and thereby streamline the classroom time, skill development and scenario training became the in-class focus and interest picked up.

Another positive result of this format was eliminating the need to stockpile hard copy books. This made the international market especially open to program adoption. With the elimination of shipping, import and custom fees, interest reached some of the far corners of the globe.

The DAN first aid courses were implemented by DAN Southern Africa in 2017. Brazilian Portuguese returned to the first aid courses in 2018, and DAN Asia Pacific came on board in 2019. The growing market in the Indo-Asia region of the Pacific is taking steps to implement these programs as well. In addition, some international scuba training agencies have adopted the DAN first aid courses as their preferred curriculum. This utilization has resulted in essentially global delivery.

GRANT PROGRAMS

As part of the informal mission to have oxygen equipment at every dive site and people trained to use it, the oxygen grant program was implemented in 2002. DAN has now granted over 300 oxygen kits under the full and matching grant programs. More information on how to apply for an oxygen grant is available at <https://www.diversalertnetwork.org/training/grants/oxygen>

RECOGNITION PROGRAMS

The Dive Emergency Specialist (DES) program was implemented in 2004 to recognize individuals who had completed the *DEMP* training and held a rescue diver certification from their training agency.

The DAN Provider Award is given to individuals who have utilized DAN training to provide care for an injured or ill person. This award has recognized responders at motor vehicle accidents, workplace and community based cardiac arrest, or even long-term care for an ailing family member. These stories are often featured in *Alert Diver's Skills in Action* column.

ONLINE TRAINING SEMINARS AND DAN TV

In addition to the first aid courses, there is a series of multimedia seminars available free to members on the DAN website or on DAN's elearning platform. For those wanting to know and understand more about the effects of diving and the pressures of diving, these seminars provide scientific explanations delivered by experts in the field of diving medicine.

The following are video lectures available on the DAN website.

- Remote Management of DCS
- Does CPR Really Work?
- Children and Diving
- Aging and Diving
- Medical Evaluation to Dive
- Mechanisms and Management of Dive Accidents
- Situational Awareness: Metacognitive Approach to Person and Team Safety

- “The Bends”: Diagnosis and Treatment
- Defining Dive Safety for Public Safety Divers
- Challenges in Diagnosing DCI
- How Good is Your Emergency Plan?
- Dive Accident Management
- Diver Fatalities
- Medications and Diving

Additional topics are available at <https://dan.diverlearning.com/>

- The Optimal Path
- Breathing Underwater is an Unnatural Act
- Diabetes and Recreational Diving
- Inert Gas Exchange, Bubbles, and Decompressions Theory
- Pathophysiology of Decompression Illness
- Ears and Diving

DAN also hosts a YouTube Channel with video messages and recorded live presentations. <https://www.youtube.com/user/DiversAlertNetworkTV/>

CONTINUING MEDICAL EDUCATION

In the early years of DAN, the lack of training for physicians and other health care providers to handle diving emergencies was apparent. To address this void in medical education, the first Dive Accident and Hyperbaric Treatment course was held in partnership with Duke University in 1983. The need for physician education has only continued and DAN has steadily offered ongoing programs for physicians under Accreditation Council on Continuing Medical Education (ACCME) approved continuing medical education.

Over the years, these programs have been delivered under joint providership with Duke University, the Wilderness Medical Society and the Undersea and Hyperbaric Medical Society

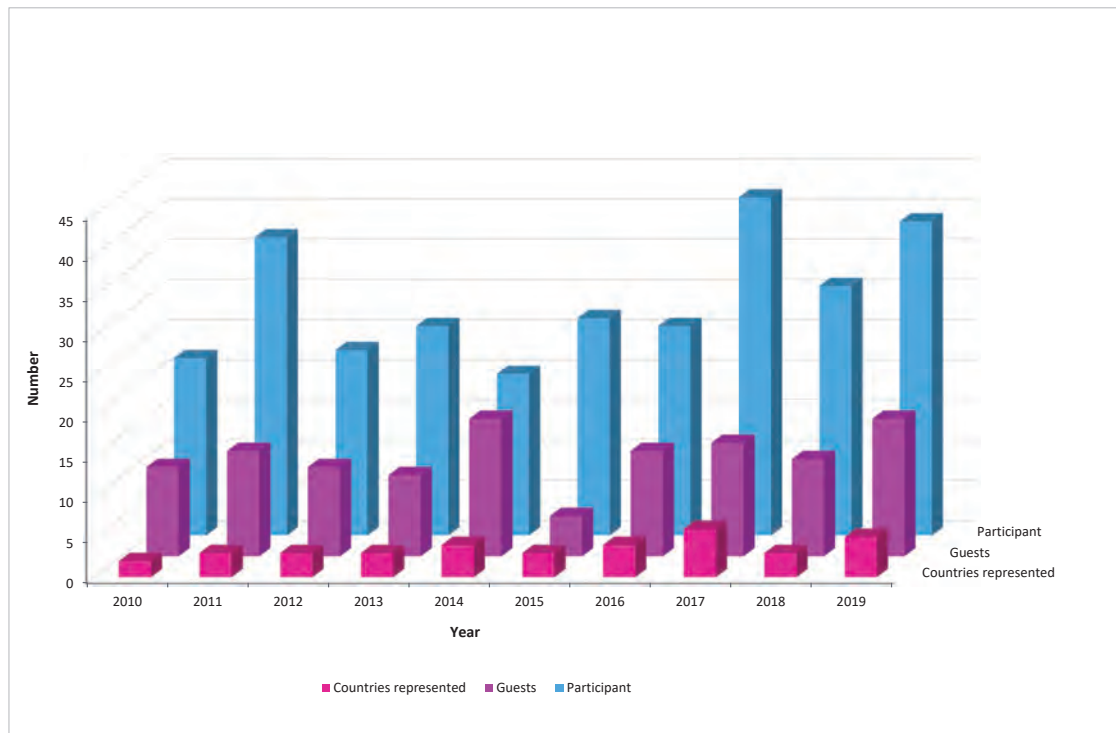


Figure 6-5. CME participation growth from 2010 to 2019
Years with only one course offering: 2014, 2015, 2018

RESEARCH WORKSHOPS

Tangent to the CME offerings by DAN, the Research department has hosted regular workshops to address the specific needs for understanding and research advancement. Many of these workshops have offered CME credit for physician attendees but more importantly these workshops have expanded the knowledge base of physicians, other health care providers, and even dive professionals. These workshops have reviewed the scientific literature, provided a venue for open discussion and consensus, and have helped pave the way to safer diving through shared knowledge.

- Nitrox Workshop (2000)
- Flying After Diving (2002)
- Management of Mild or Marginal Decompression Illness in Remote Locations Workshop (2004)
- Diving and Diabetes (2005)
- Breathhold Diving (2006)
- Technical Diving Conference (2008)
- Recreational Diving Fatalities (2010)
- Rebreather Forum 3 (2012)
- Medical Examination of Diving Fatalities (2014)
- Patent Foramen Ovale and Fitness to Dive (2015)
- Differential Diagnosis of Decompression Illness (2018)

Download proceedings from any of these workshops at <https://www.diversalertnetwork.org/research/workshops/>

INTERNSHIPS

Growth of any field is at least in part dependent on fostering future generations. To this end, DAN has hosted the DAN Research Internship program since 1999. Each year college students with an interest in diving research have participated in this program. Projects have varied with specific current research activity and to some extent the personal interests of the interns themselves.

In 2018 the Dive Safety Education Internship was added under the joint sponsorship of DAN and the Our World-Underwater Scholarship Society. This internship was established to support the need for professional educators in the diving industry. Specific goals of the internship are to:

- Introduce scuba diving as a unique professional opportunity in the field of education
- Link academics of education theory and design in context of a recreational activity
- Educate the diving public about DAN and its programs.

The education internship provides direct experience with development of safety, prevention and first aid programs.

As of 2018, DAN has hosted over 100 interns during the course of this program. More information about this program is on the DAN website at <https://www.diversalertnetwork.org/research/intern/>.

HEALTH AND DIVING SERIES

To provide additional resources to the DAN membership and in part to divers at large, a library of downloadable resources is available on the DAN website at <https://www.diversalertnetwork.org/health/>.

The range of materials available include the Health Information Library (*Ears and Diving*, *Hazardous Marine Life*, *Decompression Illness*, and *The Heart and Diving*), Smart Guides for Diving Safety, and Dive and Safety Quizzes plus Public Service Campaigns. Infographics on dive critical topics (diabetes, flying after diving, PFOs, and diving fatalities) are available at <https://www.diversalertnetwork.org/research/infographics/index.asp>

The DAN website contains an abundance of articles, guides, and quick reference materials.

SUMMARY

Training and Education are a significant part of prevention. Dive accidents do not have a single cause. Knowledge to prevent problems, mitigate impact of problems and provide timely first aid care to minimize effects of any injury is part of the DAN Mission to make every dive injury-free.

SECTION 7. THE DAN HIRA INITIATIVE

A retrospective review of the common safety concerns when applying the Risk Assessment Guide for Dive Operators and Dive Professionals over eight years

Francois Burman

INTRODUCTION

The 2018 edition of the Annual Diving Report described DAN's operational safety programs for dive operations, detailing how the Hazard Identification and Risk Assessment (HIRA) initiative has been developed and tested over the past eight years with systematic application in the field.

Thirty prospective diving safety officers (DSOs) have taken a series of extensive training courses. The part-theory and part-field-practical modules covered all the primary elements of a dive business as well as fundamental principles of dive equipment, diving injuries, emergency action plans, risks to the dive environment, monitoring of safety plans and the methodology in performing safety assessments.

An online assessment survey launched in August 2018 is available in eight languages and has been completed by 829 dive operators and dive professionals as of the end of September 2019.

The lessons learned, most common findings, and areas for greatest improvement discovered through the work of the DSOs and the survey responses have been used to complete and publish the Risk Assessment Guide for Dive

Operators and Dive Professionals; the first edition was released in November 2018.

This article presents the collated and analyzed common safety concerns identified during assessments at approximately 89 dive businesses in 15 countries.

METHODOLOGY & TOOLS USED

A risk may be quantified using a definition applied to a multitude of industries with their significant requirements for safety analysis to prevent accidents and injuries: The *probability* that the *exposure* to a hazard will lead to negative *consequences*.

Each of these three conditions needs to be present and evaluated before a real risk can be identified and quantified. A hazard is a potentially dangerous condition; it does not necessarily imply that there is a risk.

One method to assign a relative value to risk is by multiplying values assigned to probability, exposure and consequence.

While a degree of weighting between risks might affect the outcomes, probability and exposure are consistent despite relative importance, and consequence requires no weighting.

Using the Likert scale below is intuitive and does not appear to have a significant effect on the final scores.

Probability:

- ① unlikely ② unusual ③ possible ④ expected ⑤ definite

Frequency of exposure:

- ① rare <1/yr ② unusual -1/mo ③ occasional -1/wk ④ frequent -1/d ⑤ continuous

Consequence:

- ① noticeable ② significant ③ serious ④ severe ⑤ catastrophic

A qualitatively determined score for any risks thus falls within the range of 1 to 125.

The following table describes suggested risk levels (RLs) that are based on experience and actual events and considering each of the three factors listed above.

Table 7-1. Qualitative Scoring of Operational Risks in the Scuba Diving Industry

Score	RL	Rating	Description
≥100	5	Very high	Attention and risk mitigation are critical and must have the highest priority. A potentially dangerous situation may exist, with the possibility of very serious/ catastrophic consequences in the event of an incident. The activity should stop immediately and should not recommence until effective mitigation is in place.
60 - 99	4	High	Attention and risk mitigation are urgently required and must have high priority. A serious situation may exist that could endanger people or equipment or could seriously disrupt or jeopardize the business. The discretion of the person responsible is required for the activity to continue under carefully-monitored conditions. A permanent solution is required as soon as practically possible.
20 - 59	3	Medium	Attention is required. Eventual exposure to this risk could likely result in an incident. Outcomes may include business disruption, financial or liability consequences, injuries or equipment damage. Mitigation of the risk should happen within practical time and cost considerations.
10 - 19	2	Low	Give attention to the risk for the safe functioning of the dive operation. Record the risk mitigation steps already in place.
≤ 9	1	Very Low	The risk is acceptable. Take note of the risk, but either it has already been suitably mitigated or has a low impact.

The guide contains the risks applicable to the scuba diving industry, which are identified and quantified using the rating system above.

During site visits to each of the 89 facilities, DSOs interviewed the staff on a variety of selected safety-related topics. Only a few facilities had a full risk assessment due to time constraints. The primary purposes of the site visits were to focus on key areas of concern and to introduce the guide as an information resource and a means of conducting self-assessments.

The selection of which key safety elements to assess was made on-site by the primary safety assessor (a trained DSO) based on their training, knowledge, experience and competence in the field of operational and occupational safety.

The focus of the visits was on awareness, education and facilitating ongoing risk self-assessments, rather than to determine compliance with any regulation, standard or accepted industry practice.

It was made clear to all operators that the safety assessment was neither an inspection nor an audit. The outcomes were solely for their use.

Every visit concluded with a full debriefing and any findings were discussed on-site with the operator. In select cases, operators received follow-up reports or letters containing recommendations. The follow-up and additional questions continued after the visits.

The online survey was intended to enable self-assessment, focusing on a limited range of basic operational areas that would be expected to be in place for any mature and safe diving operation. The intended outcome was to determine the degree of compliance with essential safety standards and requirements.

The goal of this retrospective review was to identify common areas of concern, not to be a complete assessment of safety findings within the scuba diving industry. The information is indicative only, providing qualitative assessment results.

The overall intended purpose of this exercise was to determine the applicability of this form of risk assessment and to determine suitable education initiatives to make diving operations safer.

SCOPE OF APPLICATION

Each of the 13 categorized areas of potential risk, as described in the guide, were evaluated at the diving operations based on their actual scope of activities.

These areas of risk included the following:

- Staff health and safety
- Customer health and safety
- Staff training and certification
- In-water training conditions
- Classroom conditions
- Dive shop operations
- Non-boat dive operations
- Diving boat operations
- Compressor and cylinder-filling operations
- Rental equipment storage area
- Equipment repair workshop
- Vehicle safety
- Travel and health advice for customers

Assessments took place at facilities in geographical regions where a higher concentration of scuba divers either reside or are physically active. Dive operations may be found everywhere, including in areas with no local diving locations.

The regions included southern Africa and islands off Africa's east coast, Europe and the Mediterranean Sea, the Middle East, the U.S., the Caribbean and northern parts of Latin America, and the Maldivian and Philippine archipelagos.

Trained DSOs active in these regions conducted the assessments with additional training and support provided by DAN.

RESULTS

The information gathered from the risk assessments is presented in tabular form. Table 7-2 indicates the country, the number of assessments and the time period of assessment. Tables 7-3 through 7-9 describe the activities extracted from reports, follow-up emails and letters, and observations made by the DSOs and recorded by the DAN Risk Mitigation department as having the most common issues. These are listed in order of

categorized area of risk as described in the guide and not in order of magnitude of the risk score.

The number of assessments in each country does not reflect the amount of diving activity. The locations and lack of assessments in some countries is partly a result of the geographical concentration of DSOs and partly due to commitment to and changes in the various regional DAN organizations.

Table 7-2. Assessments Conducted: 2012-2019

No.	Country	Assessments	Time period
1	South Africa	7	2012-2017
2	Madagascar	3	2014
3	Maldives	7	2014
4	Mauritius	1	2013
5	Mozambique	4	2013-2014
6	Seychelles	3	2015
7	Belgium	6	2018-2019
8	Cyprus	2	2013-2019
9	Italy	8	2012-2015
10	Malta	1	2017
11	Spain	2	2019
12	Dubai	2	2013
13	Honduras (Utila, Roatan)	15	2018
14	USA (Continental)	24	2012-2018
	Puerto Rico	2	2019
15	Philippines	2	2014
Total assessments		89	

Table 7-3. Staff Health and Safety

Applicable to:	All workers on site
Hazard:	Workplace injuries & illnesses
Likelihood:	Possible: ③
Exposure:	Continuous: ⑤
Consequence:	Legal sanction, future compensatory claims: ②
Assessment:	Risk score: 3 x 5 x 2 = 30; Risk Level 3
Attention:	Attention required
Mitigation steps:	<ul style="list-style-type: none"> - Appropriate screening & surveillance - Personal protective equipment - Education & training

The results of the online surveys indicated the degree of interest in the DAN HIRA initiative. The two levels available on the website, levels one and two, focus on achieving the minimum requirements for dive safety and generating awareness for addressing and building on these within the confines of the current status.

The longer-term goal is providing the necessary education and preparedness to have dive operators and dive professionals perform self-assessments using the online version of the guide.

Table 7-10 shows the geographical spread of survey results from the launch in November 2018 through the end of September 2019.

Table 7-4. Staff Health and Safety

Applicable to:	All employed staff
Hazard:	Legal compliance & violations
Likelihood:	Possible: ③
Exposure:	Continuous: ⑤
Consequence:	Legal sanction, future compensatory claims: ②
Assessment:	Risk score: $3 \times 5 \times 2 = 30$; Risk Level 3
Attention:	Attention required
Mitigation steps:	- Posted signs and placards - Education and basic legal knowledge

Table 7-5. General Safety Management

Applicable to:	Establishment, implementation and drilling of emergency action plans (EAPs)
Hazard:	Inability to deal with emergencies
Likelihood:	Possible: ③
Exposure:	Continuous: ⑤
Consequence:	Serious injury/loss; liability exposure: ③
Assessment:	Risk score: $3 \times 5 \times 3 = 45$; Risk Level 3
Attention:	Attention required
Mitigation steps:	- Establish effective EAP's - Continuously update emergency contact details - Perform regular drills and take them seriously

Table 7-6. Equipment Workshop

Applicable to:	Servicing oxygen equipment
Hazard:	Failure in service leading to oxygen fires
Likelihood:	Possible: ③
Exposure:	Continuous: ⑤
Consequence:	Serious injury, loss or fatality: ⑤
Assessment:	Risk score: $3 \times 5 \times 5 = 75$; Risk Level 4
Attention:	Urgent attention required
Mitigation steps:	- Education and training in oxygen cleaning - Suitable servicing equipment and clean areas - Use of safe cleaning chemicals

Table 7-7. Compressors and Cylinder Filling Stations

Applicable to:	Location and risks surrounding compressor intake
Hazard:	Carbon monoxide poisoning
Likelihood:	Possible: ③
Exposure:	Continuous: ⑤
Consequence:	Serious injury or fatality: ⑤
Assessment:	Risk score: $3 \times 5 \times 5 = 75$; Risk Level 4
Attention:	Urgent attention required
Mitigation steps:	<ul style="list-style-type: none"> - risk assessment of intakes - protection and signage - operator education

Table 7-8. Diving First Aid Equipment

Applicable to:	Equipment located at pool, dive site or on boat
Hazard:	Equipment not accessible or non-functional
Likelihood:	Expected at some stage: ④
Exposure:	Exposure to injury-causing hazards: ④
Consequence:	Severe: ④
Assessment:	Risk score: $4 \times 4 \times 4 = 64$; Risk Level 4
Attention:	Urgent attention required
Mitigation steps:	<ul style="list-style-type: none"> - Regular monitoring for condition - Regular inspection and function testing - Planned maintenance schedule

Table 7-9. Effective Client Safety Management

Applicable to:	Non-qualified, unfit, non-compliant clients
Hazard:	Client induced accidents or injuries
Likelihood:	Expected at some stage: ④
Exposure:	Continuous: ⑤
Consequence:	Severe/fatal, significant liability exposure: ⑤
Assessment:	Risk score: $4 \times 5 \times 5 = 100$; Risk Level 5
Attention:	Critical attention and risk mitigation needed
Mitigation steps:	<ul style="list-style-type: none"> - Educate, screen and manage clients - Policies for denial and cancellation - Consistent and non-discriminatory application

Table 7-10. HIRA surveys taken to end September 2019

Region	Member type	HIRA 1	HIRA 2	Totals
DAN America & World	Professionals	174	74	248
	Businesses	29	9	38
Dan Europe	Club	499	70	569
Totals		702	154	855

DISCUSSION

The on-site surveys revealed a significant lack of understanding of the preparation for and prevention of accidents and injuries throughout the dive operations. There were very few dive-related findings.

Occupational health and safety (OHS) requirements of all people engaged by a dive operator to perform the relevant activities appear to be disregarded by most of these businesses.

Operators were largely unaware of three specific risk areas; other commonly-identified areas were more familiar to dive operators, and the presence of risk and the need for mitigation were more easily accepted.

1. The first issue is the denial that non-permanent staff are not subject to OHS requirements. The dive business manager is responsible for anyone who works on the site of an operator, including where diving activities take place or on the road transporting any goods or passengers both on- and off-site.

The guide provides an explanation of and mitigation steps for many of these requirements.

2. A second and safety-critical shortcoming is the lack of realistic emergency action plans for activities that fall outside of the basic, dive-site related operations, combined with an almost complete lack and recording of any properly-simulated drills.

The guide provides examples of many potential emergencies for each of the 13 areas of risk.

3. The third important finding is the apprehension and confusion regarding the right to deny a customer to dive. There were many reasons given as to why this is either very difficult to do or in some cases impossible. Based on the safety of the customer, staff, other passengers, the general public and the business operation itself, there are indeed cases where denial is an essential step in the safety chain.

Concerns included loss of potential income, bad publicity, the inability to assess fitness, the right to medical privacy, the diver's choice to disregard the advice of physicians without dive medicine training, safety at the dive site or onboard vessels, and customers with behavioral or disability-related concerns.

Mitigating this situation is never a black and white issue. The responsibility for safety rests with the dive operator and dive professional. Education and training, appropriate policies, legal advice and common sense are all required to manage the right of denial. The concerns of potential liability exposure for denying a customer versus the liability exposure of harm in the event of an accident, regardless of any signed waivers, must be considered and used as a determining factor on a case-by-case basis.

The outcomes of the assessments also provided an opportunity to refine the guide through better quantifying risks and considering additional mitigation strategies. This was made possible through exposure to a wide range of different operations, including aspects such as the size and scope of operations.

Education of the broader diving community, which includes divers themselves, is the key to improving safety and reducing incidents. The delivery of education, however, remains the challenge.

One avenue currently under development is breaking down the many aspects described in the guide into stand-alone online learning modules. Time will tell what effect this will have.

Finally, while an ambitious goal, correlating DAN's safety education, training and efforts to enhance awareness with actual incidents would provide the ultimate validation of this strategy to make diving safer.

CONCLUSIONS

The challenge of making every dive and incident- and accident-free can be approached or perhaps only better understood through physical, face-to-face engagement by properly trained DSOs.

The results of these efforts over the past eight years have provided significant insights into the broad range of activities that present exposure to risks leading to reported incidents and accidents.

The development and eventual publication of the guide in November 2018 represents the distillation and compilation of risks in the diving industry. This work will hopefully become the industry standard in terms of operational safety, leading to greater awareness, preparedness and prevention.

REFERENCES

1. Burman F, Risk Assessment Guide for Dive Operators and Dive Professionals, 2nd edition, Divers Alert Network, Durham, NC, USA, November 2019. ISBN 978-1-941027-78-3

SECTION 8. INTERNATIONAL DATA

John Lippmann, Yasushi Kojima, Akiko Kojima, Dinesh Ariyadewa

As much as we would like to compile a worldwide recreational diving fatality and injury data, it remains an elusive goal. The main reason is the lack of organized data collection efforts or differences in data collection methods. For this report, we received contributions from DAN Europe, DAN Japan, and DAN Asia-Pacific. We also referred to the British Sub-Aqua Club (BSAC) data in their report for 2017.¹ Here are some summary characteristics of data from each source.

DAN Europe collects data only on its members. In 2019, they had 86,473 members. The number of fatalities is shown in Table 8-1.

Table 8-1. DAN Europe fatalities

Year	Men	Women	Total
2015	21	1	22
2016	26	1	27
2017	25	3	28
2018	18	4	22
Total	90	9	99

The fatality rates among DAN Europe members appear to be about 20 per 100,000 members, which is significantly higher than in other

membership organizations of recreational divers. It is important to notice that the composition of DAN Europe membership does not reflect the general population of recreational divers in Europe. Among its members, there are proportionally more dive professionals than recreational divers. The small percentage of women among the fatalities (9%) does not necessarily reflect women's participation in scuba diving. It is rather a reflection of the underrepresentation of women in the membership.

The BSAC report for 2017 records two fatalities among BSAC members and nine fatalities among other divers in the United Kingdom. The BSAC membership and fatality data for three recent years are shown in Table 8-2.

Table 8-2. BSAC membership and fatality data

Year	Membership	Number of fatalities
2015	27803	3
2016	27346	5
2017	26774	2
Total	81923	10

Based on this data, the fatality rate for BSAC members is 12 per 100,000 member-years.

The fatality rate for British divers who are not BSAC members could not be calculated due to the unknown number, and on the other hand, the BSAC members' fatality rate could not be generalized to the entire population of recreational divers. The fatality rates for BSAC members and DAN Europe members probably reflect the differences in the makeup of the two memberships.

DAN Japan reported a total of 16 fatalities among Japanese recreational divers, not distinguishing members from non-members. For more details, see DAN Japan fatality report on page 97. That is more fatalities than what we captured for Japan (see Table 1-2, Fatality chapter).

John Lippmann reported the incidents and fatality data for Australia (Diving accidents in Australia). Lippmann obtained the fatality data through The Australian National Coronial Information System, which receives all fatality data in the country. In 2017, there were only four reported scuba fatalities, which is significantly less than in previous years. The main reason is that it takes several years for coroners to

finalize and release the case, and this is only a fraction of all fatalities that have occurred in 2017. The data we collected, as shown in the Fatality chapter, Table 1-2, indicate that in 2017 there were 14 fatalities in Australia.

From Sri Lanka, we received a series of DCI case summaries. We included it here to provide some insight into how the diving injuries are managed in this country with beautiful dive sites not yet discovered by tourists.

Much more could be done on data collection worldwide. The BSAC reports is an example of a well-organized data collection effort and thorough reporting. The effort in Australia is another complementary model which with access to the coronial system, provides excellent data for analysis of fatality causes.

The discrepancies between what we show in Table 1-2 of the Fatality chapter and what is reported by our international contributors, are another confirmation that regional efforts have better chance to collect comprehensive data, but a coordination of efforts is necessary to collect high quality data that may be compiled into one global report.

DIVING ACCIDENTS IN AUSTRALIA

THE DIVING EMERGENCY SERVICE

The Australian Diver Emergency Service (DES) has operated since 1983, initially from the School of Underwater Medicine in Sydney. From 1986 it has been based at the Hyperbaric Unit at the Royal Adelaide Hospital in South Australia. DAN Asia-Pacific has proudly sponsored the hotline since 1995. Until early 2019, calls to the DES hotline were answered by a paramedic from the South Australian Ambulance and then transferred to an on-call hyperbaric doctor. The doctors, who have

always worked on a voluntary basis, advise the caller on what action should be taken and, in the event that the injured diver is a DAN member, they will contact DAN to oversee the case. The DES receives approximately 320 calls per year.

Table 8-1 shows the origin of the majority of the 316 calls in 2017. The remainder of the calls came from a variety of countries both within and beyond the Asia-Pacific. Thanks to Steve Goble from Royal Adelaide Hospital for the collection of these data.

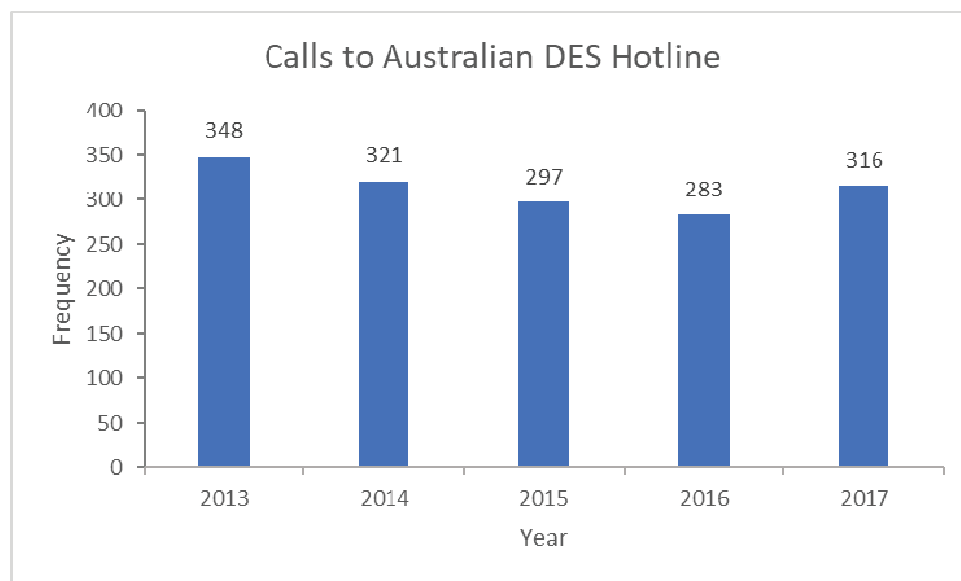


Figure 8-1. Calls to Australian DES / DAN hotline, 2013-17

Table 8-3. Origin of emergency calls to the Australian DES / DAN hotline

Country	Frequency
Australia	118
Indonesia	77
Philippines	26
Fiji	21
Singapore	11
Thailand	10
PNG	10
Malaysia	9
Solomon Is	5
Vanuatu	5

The annual number of calls from 2013 to 2017, inclusive are shown in Figure 8-1.

DIVING FATALITY REPORTING IN AUSTRALIA.

In Australia, the publication of diving fatality reports formally began with Dr. Geoff Bayliss, who reported civilian diving fatalities between 1957 to 1967. It was continued by Dr. Douglas Walker, 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. From 2003, Dr. John Lippmann, on behalf of DAN Asia-Pacific (DAN AP) and, recently, the Australasian Diving Safety Foundation (ADSF), assumed responsibility for Australian dive mortality surveillance. The subsequent fatality reports have continued to be published in *Diving and Hyperbaric Medicine*.

Initial accident data are collected by authorized on-scene investigators. 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 includes:

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

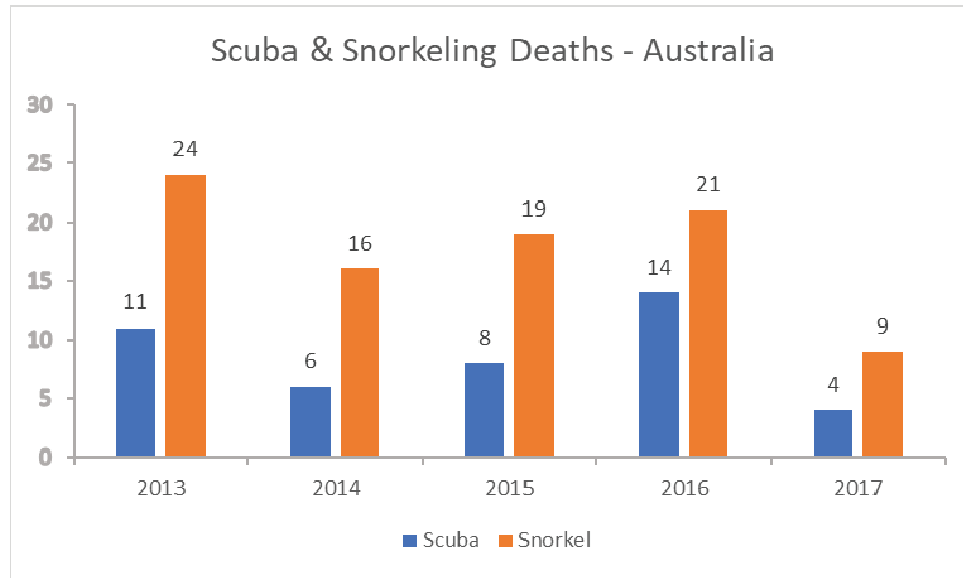


Figure 8-2. Scuba and snorkeling deaths in Australia, 2013-2017 (Provisional)

The Australian National Coronial Information System (NCIS) was launched in 2000 and is supposed to include all deaths reported to a State or Territory coroner since that time. The information available for each case includes the coroner's report, a summary of the police report and, sometimes, the autopsy report. To obtain more complete data, Lippmann liaises with the Australian State and Territory Coroners who often provide (under relevant ethics approvals) complete case files. Key information from these is recorded in the mortality database.

A recent study by this author revealed that between 2001 and 2013 inclusive, 301 divers died in Australian waters. These included 128 scuba divers and 175 snorkelers (including surface snorkelers and breath-hold divers). The mean (Standard Deviation) age of the scuba victims was 44 (13) years and 49 (18) years for the snorkelers. Somewhat unsurprising in these older cohorts, cardiac-related disabling injuries contributed in 25% of the scuba divers and 35% of the snorkelers.^{1,2}

Figure 8-2 indicates the provisional annual fatalities from 2013 to 2017, respectively. We currently have confirmed 43 scuba and 89 snorkeling deaths during that period. Although the numbers for 2013 and 2014 are likely accurate, those numbers for the more

recent years are significant underestimates (possibly by as much as 50%) as data is only available on cases that have been finalized by the coroners. This process often takes several years and is the reason why there is a substantial lag in the publication of Australian diving fatality data.

Three of the scuba divers were using rebreathers. Snorkelling deaths include surface snorkelers and breath-hold divers.

Sixty-nine percent of the scuba divers and 89% of the snorkelers were males. The mean age of both the scuba divers and snorkelers was 48 years, although there was greater variation in the snorkelers. The relative ages of the victims are shown in Table 8-2.

Table 8-4. Mean (SD) ages of scuba and snorkelling victims by gender (in years)

Age, mean (SD), yrs	Scuba	Snorkel
Males	47 (9)	46 (18)
Females	49 (13)	55 (18)
Combined	48 (10)	49 (19)

Range (scuba) = 23 to 64 years.

Range (snorkelers) = 17 to 78 years.

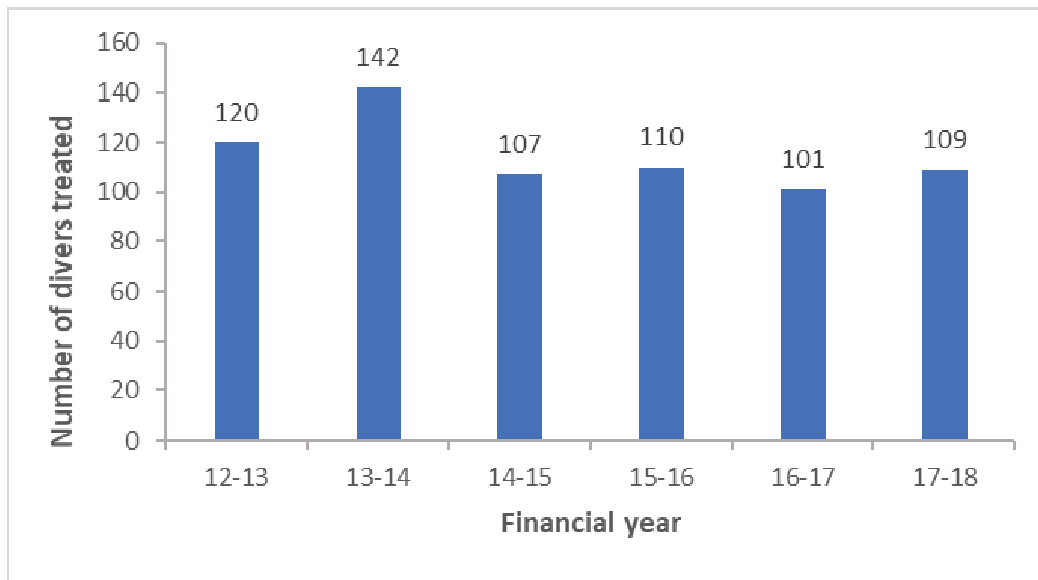


Figure 8-3. Divers treated for DCI in Australia, 2013 – 2018

DECOMPRESSION ILLNESS TREATMENTS IN AUSTRALIA

Currently, in Australia, there are nine hospital-based hyperbaric units that routinely treat divers. Each state and the Northern Territory have at least one public facility that treats divers, although most of their caseloads involve the treatment of non-diving illnesses and injuries such as diabetic ulcers, gas gangrene, and burns, among other indications. There are also several additional recompression facilities that generally do not treat divers.

The numbers of divers treated each financial year from 2013 to 2018 are shown in Figure 8-3.

The Mean and Standard Deviation of divers treated annually over this period is 115 (15). Of interest, these measures for a decade earlier were 180 (47). In the 1990s, it was usual for around 350 divers to be treated each year. Arguably, this decrease is likely due to a combination of reduced diving activity over time, as well as the introduction of safer diving practices such as slower ascent rates and the routine use of safety stops, among other factors.

REFERENCES

1. Lippmann J. Analysis of scuba diving-related fatalities in Australia. doctoral thesis. Deakin University; 2018.
2. Lippmann J. Snorkelling and breath-hold diving fatalities in Australia, 2001 to 2013. Demographics, characteristics and chain of events. *Diving Hyperb Med* (in press)

SCUBA DIVING FATALITIES IN JAPAN, 2017

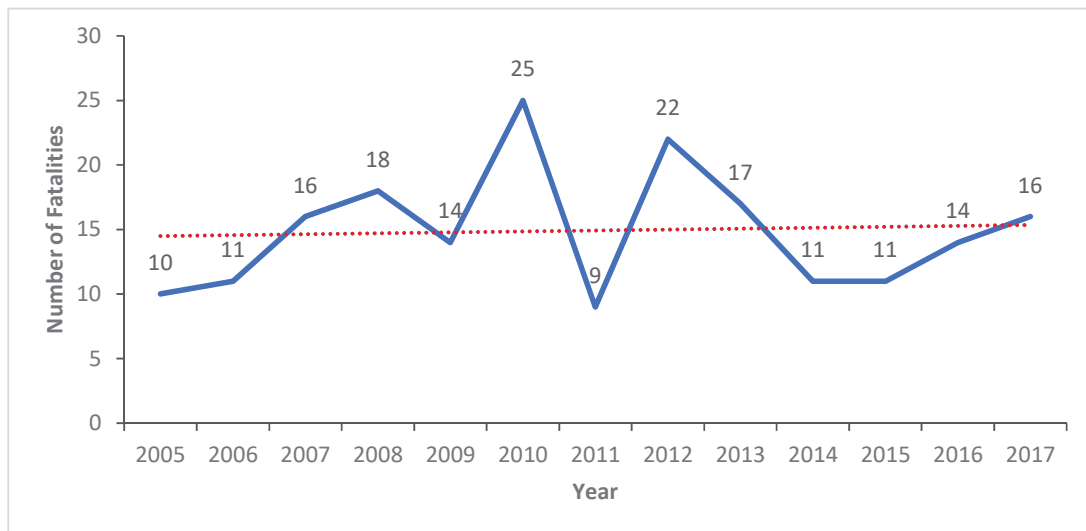


Figure 8-4. Number of reported recreational diving fatalities by year in Japan, 2005–2017

For this report, we compiled data about fatal accidents in recreational scuba diving in Japan provided by the Japan Coast Guard (JCG), Divers Alert Network Japan (DAN JAPAN), and online media. In 2017, there were a total of 16 fatalities which is close to the average number (15) reported per year between 2005 and 2016 (Figure 8-4).

Of the 16 fatalities that occurred in 2017, nine victims were male (56%) and seven were female (44%). The mean age is unknown because six of the 16 cases were recorded in 10-year age-groups. One fatality occurred among divers in the 10-19 age group, four among those in their 30s, two among those in their 40s, five among those in their 50s, two among those in their 60s, and two among those who were over 70. Of the 16 fatalities, 9 (56%) involved divers 50 years old or older (see Figure 8-5).

Seventy-five percent of fatal accidents occurred during the summer months (July to September) (Figure 8-6). This is not surprising as more divers dive in the summertime.

The distribution of fatalities by prefecture is shown in Figure 8-7a and 8-7b (map). Of Japan's 47 prefectures, diving fatalities occurred in 7 of them.

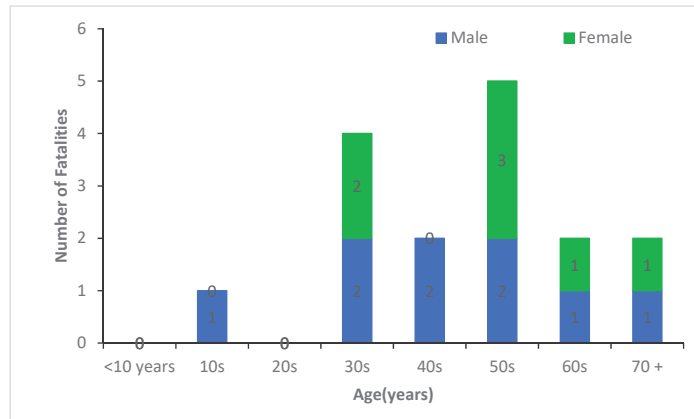


Figure 8-5. Age and sex distribution of diving fatalities in Japan, 2017

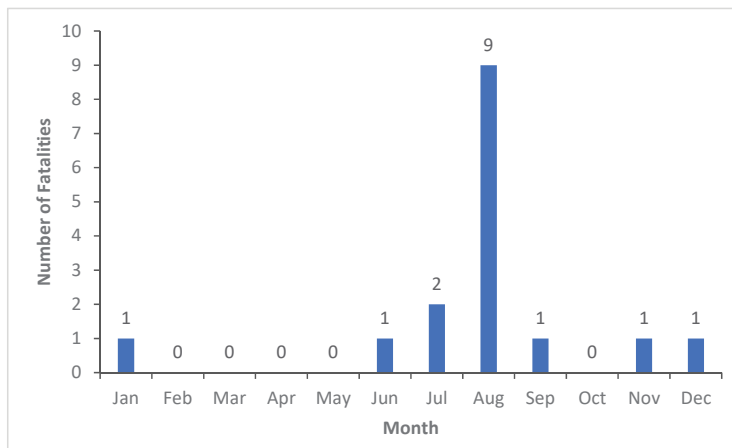


Figure 8-6. Distribution of diving fatalities in Japan by month, 2017

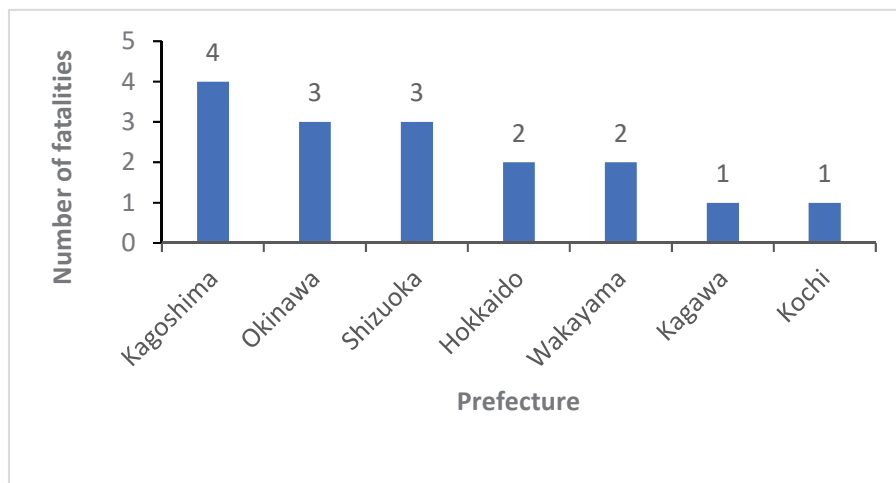


Figure 8-7a. The geographic distribution of fatalities by prefecture

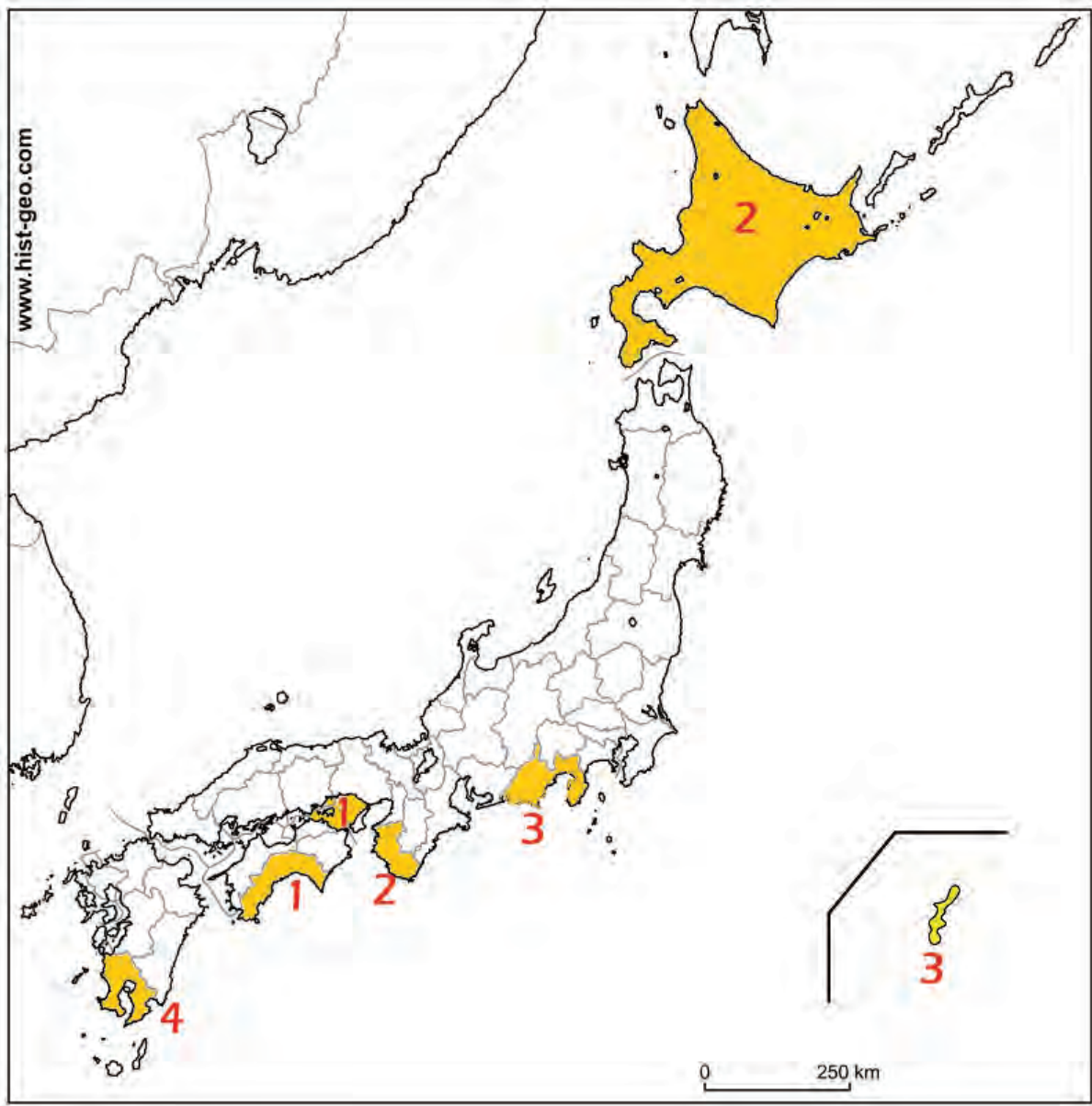


Figure 8-7b. The geographic distribution of fatalities by prefecture

Figures 8-8 and 8-9 show the dive platforms and dive activity of 2017 fatality cases respectively. Similar to 2016, there were no fatalities among divers diving off of live-aboard dive boats in 2017. The largest number of fatalities, 7 (44%) occurred during guided recreational diving.

Figure 8-10 shows the experience level of victims by the number of lifetime dives. In three cases, the victims did not have previous diving experience.

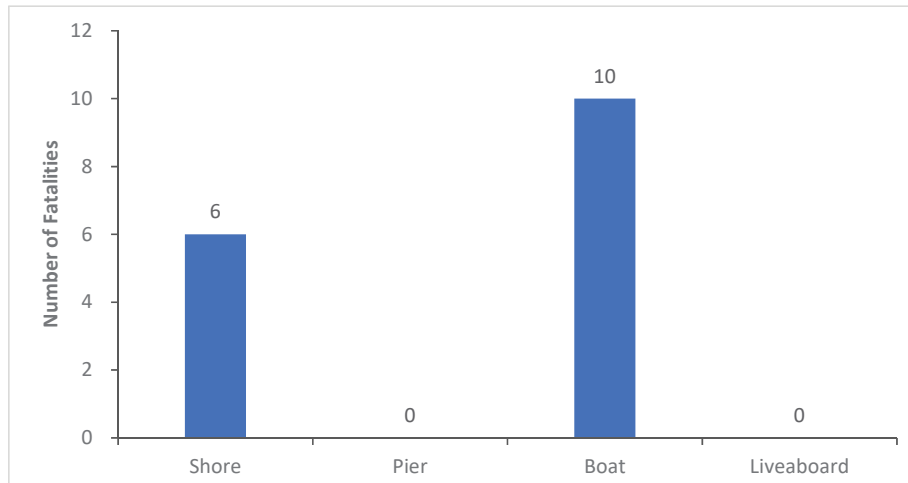


Figure 8-8. Dive platforms associated with diving fatalities in Japan, 2017

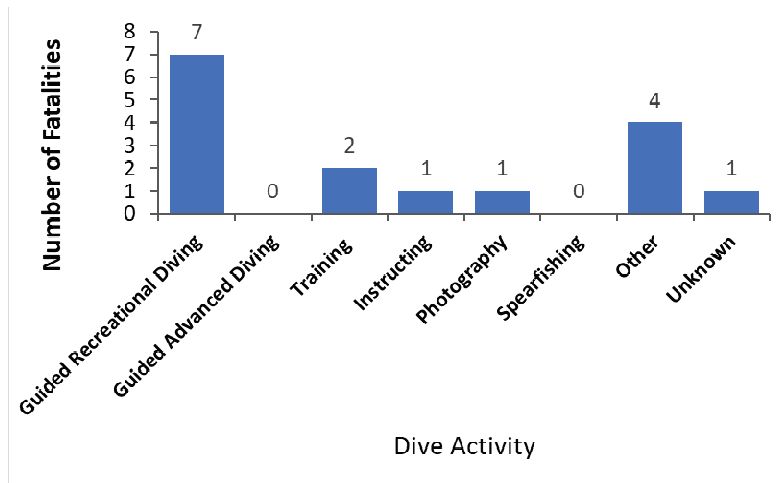


Figure 8-9. Dive activities associated with diving fatalities in Japan, 2017

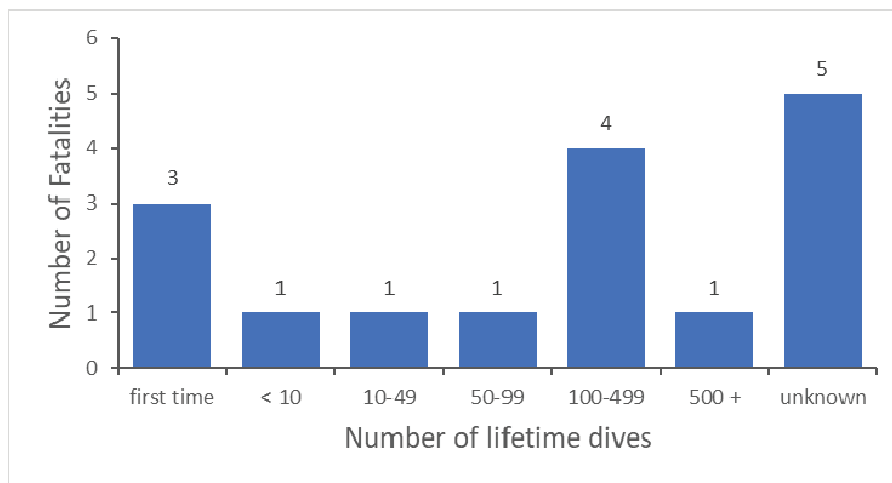


Figure 8-10. Number of lifetime dives associated with diving fatalities in Japan, 2017

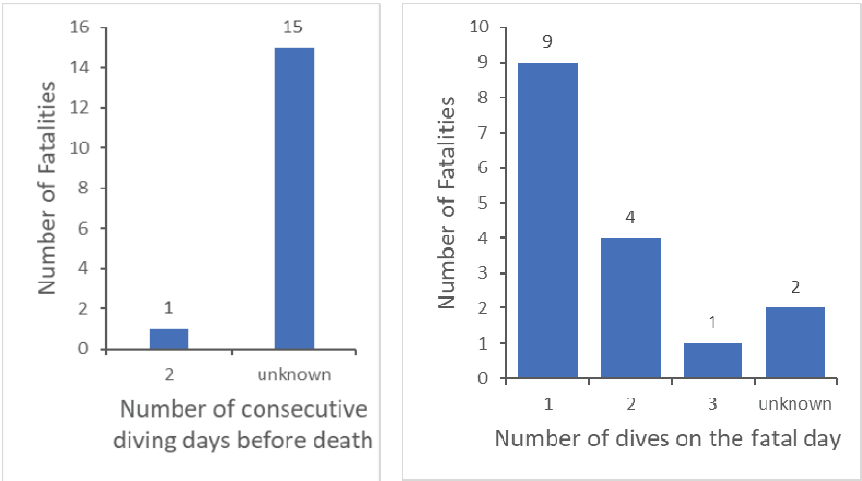


Figure 8-11. Number of consecutive diving days before death and dives on a fatal day

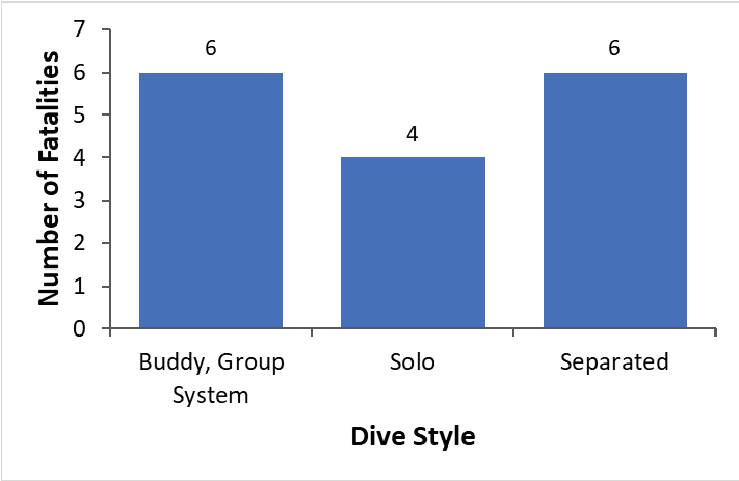


Figure 8-12. Buddy status during diving fatalities in Japan, 2017

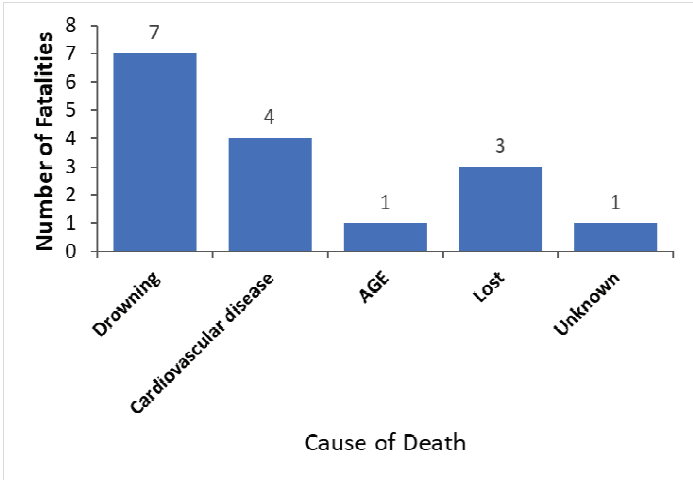


Figure 8-13. Cause of death in diving fatalities in Japan, 2017

In 9 cases (56%) the fatality occurred on the first dive of the day. (Figure 8-11)

Figure 8-12 shows the buddy status of the divers at the time the fatality occurred. Ten fatalities (63%) occurred while diving solo or separated from the buddy. However, fatalities occurred even when a buddy or group system was maintained.

Trigger events were identified in only four fatalities (25%); those four cases involved cardiovascular disease.

The cause of death was reviewed and identified by diving medicine experts. In seven fatalities (75%) the cause of death was due to drowning, four to cardiovascular disease, and one to arterial gas embolism (AGE). As in previous

years, drowning was the most common cause of death. Cardiovascular disease accounted for 1/3 of the total identifiable causes of fatality. (Figure 8-13)

Panic was associated with two cases (13%) and resulted in a rapid ascent. The triggers of panic could not be identified.

REFERENCES

1. Buzzacott P, ed. 2018. DAN Annual Diving Report, 2018 Edition. Durham, NC: Divers Alert Network.
2. Buzzacott P, ed. 2017. DAN Annual Diving Report, 2017 Edition. Durham, NC: Divers Alert Network.

SRI LANKA CASE STUDIES

Case 1

This 30-yr-old male recreational diver came as a tourist to Sri Lanka for diving at the Great Basses Reef Lighthouse area located 15 miles of the southern end of the island.

He had no known comorbidities except for a bicuspid aortic valve but he was not on any medication.

He was a novice diver and went with his instructor for a morning dive. He had performed two dives over the last three hours using compressed air. The instructor used a dive computer to keep track of time, depths and decompression stops. The last dives recorded on the dive computer are as follows:

- a. 18 msw (60 fsw) depth for 39 minutes total diving time
- b. 45 minutes rest at the surface
- c. 19 msw (63 fsw) depth for 46 minutes of total diving time.

The divers followed proper decompression stops during the ascent. About three hours after the second dive, the diver developed pain in his right knee. The pain was aching in nature and of moderate to severe intensity (6/10). The pain relieved with flexion of the knee. No bodily rashes, other joint pain, numbness or weakness of limbs were noted. Normal bowel and bladder functions were preserved.

The diving medical officer was called and he advised having plenty of fluids orally while traveling to the diving and hyperbaric medical center, Naval Hospital Trincomalee.

The patient arrived at the hospital in the morning the following day. The travel distance is shown on the Figure 8-14. His neurological examination was normal, and all the vital parameters were stable. The clinical diagnosis was Type 1 decompression sickness with right knee joint involvement.

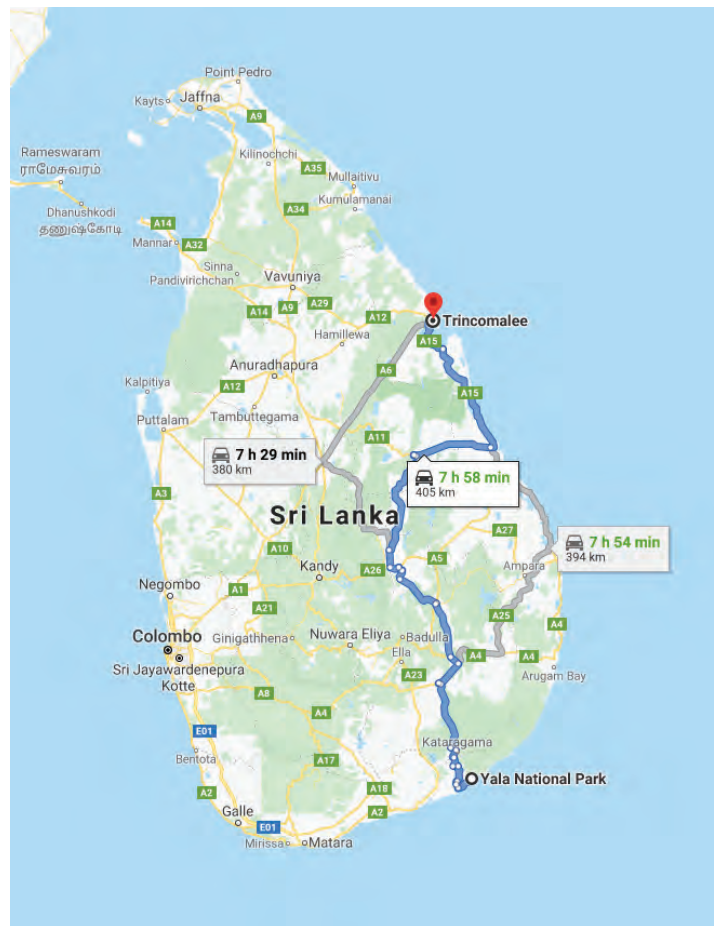


Figure 8-14. Map of Case 1

The patient was recompressed on the same day following the USN TT5. During the first 20 minutes of recompression, he had significant relief of pain. He recovered fully by the end of the first cycle of the treatment table and was discharged.

Case 2

This 51-yr-old commercial diver regularly dives for ornament fish (color fishing) around the Kalpitiya area. He had no known chronic illnesses or previous diving accidents.

On the day of the accident, he dived with his buddy diver for color fishing.

He performed three dives to a depth of about 30 msw (100 fsw) with a cumulative bottom time for three dives of 180 minutes. His ascent was with proper decompression stops.

About three hours after his last dive, he developed vertigo, giddiness, and subsequent numbness and weakness of both legs. He was unable to stand up and walk, and his symptoms were worsening. He contacted the Navy Hospital Trincomalee and was advised to have plenty of water, breathe 100% oxygen, and come to the treatment center.

On arrival, he was conscious, rational and all the vital parameters were stable. He had motor weakness of both legs, diminished reflexes of all the segments and decreased anal sphincter tone. The clinical diagnosis was Type 2 decompression sickness with spinal cord involvement.

He was recompressed in USN TT6A. During the recompression, he had significant relief of motor weakness after the first 20 minutes of oxygen breathing at the depth of 18 msw (60 fsw).

The motor weakness of legs resolved nearly completely after the first session. Though he was advised to undergo the second recompression session, he refused it because of the cost involved and requested discharge.

The diver walked without support with mild weakness of both hip joints at the time of discharge. He was instructed to come for a review after two weeks and not to dive until then.

Case 3

This 52-yr-old male, commercial diver was a fisherman who dives for ornament fish around the Galle area. He had no known comorbidities and was not on any medication. No past history of diving accidents.

He was diving with his buddy for color fishing. He had performed two dives to depth about 28 msw (93 fsw) and the total bottom time was 90 minutes. His ascent was uneventful with decompression stops completed.

About 30 minutes after the ascent from the second dive, he developed chest pain, vertigo, and vomiting, and was admitted to the Teaching Hospital Karapitiya.

Subsequently, he developed numbness and weakness of both lower limbs and was unable to stand up and walk. His symptoms were progressive in intensity. He was transferred to the Diving and Hyperbaric Medical Center, Naval Hospital Trincomalee, the following day. The travel distance is shown on Figure 8-15.

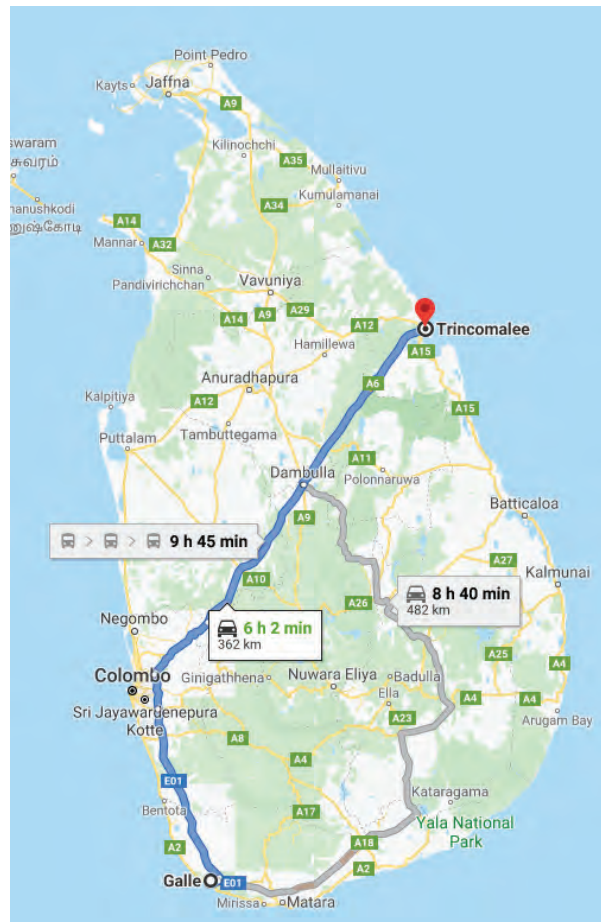


Figure 8-15. Map of Case 3

On admission, he was conscious, rational and all the vital parameters were stable. He had motor weakness of both legs, diminished reflexes of all the segments and anal sphincter tone was also reduced. The clinical diagnosis was Type 2 Decompression Sickness with spinal cord involvement.

The patient was recompressed on USN TT6. He had significant relief of motor weakness after the of first 20 minutes of oxygen breathing at the depth of 18 msw (60 fsw) hence the same table was continued. He recovered the motor weakness of quadriceps and calf muscles after the first session and subjected to second recompression sessions under USN TT6 the following day. He recovered fully of his motor weakness and no further recompression was considered. The diver did walk without support, and was neurologically normal at the time of discharge.

Case 4

This 55-year-old tourist came to Sri Lanka for recreational diving at the Beruwala area. He had no known comorbidities and had no history of diving accidents.

His diving experience was about 10 years. On the day of the incident he had done two dives with maximum depth of about 18 msw (60 fsw) and total bottom time about 60 minutes.

On ascent, he did decompression stops according to his usual practice.

He developed vertigo and giddiness about two hours after surfacing. He was unable to stand up and walk. His symptoms were progressive in intensity. He contacted the Navy Hospital and he was instructed to have plenty of fluids orally, breath 100% oxygen via mask and keep his foot end elevated and come to the Diving and Hyperbaric Medical Center, Naval Hospital Trincomalee as soon as possible.

He reached the center approximately 12 hours after onset of symptoms. On examination, he was conscious, rational and all the vital parameters were stable. He had sensory ataxia with positive Romberg sign and heel-shin slide test. Finger-to-nose test was also positive. No motor or sensory deficit was observed in the

upper or lower limbs. Clinical diagnosis was Type 2 Decompression Sickness. With the USN TT6, he had significant relief of vertigo after the first 20 minutes of oxygen breathing at the depth of 18 msw (60 fsw). He was subjected to second recompression session under USN TT6 which he showed progressive improvement of symptoms. No further neurological improvement was observed at the end of the third recompression session. The diver walked with support but he had mild sensory ataxia for which neurology referral was done.

He was referred to his diving physician in Europe and advised to fly under a fixed cabin pressure aircraft.

Comments:

This diver suffered from CNS DCS which had responded partially after management with USN TT6. The 12-hour delay might have caused limited permanent damage to the CNS.

Case 5

This 40-yr-old commercial diver was a male fisherman who dives for ornament fish around the Trincomalee sea area. He had no known comorbidities and was not on any medication. No past history of diving accidents.

He is an experienced diver with five years of diving practice. On the day of the accident, he was diving with his buddy for ornamental fish.

He had performed one dive to 27 msw (90 fsw) and spent 50 minutes at the bottom. On ascent, he was running out of gas and ascended rapidly without decompression stops. About 20 minutes upon surfacing, he developed numbness and weakness of both legs. He was unable to stand up and walk due to weakness and could not void. He attempted an in-water recompression by descending to 9 msw (30 fsw) with air for 30 minutes but the attempt failed. His symptoms were progressively worsening. He contacted the diving medical officer at the Navy Hospital Trincomalee was instructed to have plenty of fluids orally, breathe 100% oxygen via face mask, keep his foot end elevated and be transported to the Diving and Hyperbaric Medical Center as soon as possible.

He reported to our center on the same day after four hours of the onset of the symptoms. He was conscious, rational and all the vital parameters were stable. He had motor weakness of both lower limbs and the anal sphincter tone was reduced. His bladder was full and relieved by catheterization. The clinical diagnosis was Type 2 Decompression Sickness with spinal cord involvement.

He was recompressed according to USN TT6A. The motor weakness significantly improved after the first 20 minutes of oxygen breathing at the depth of 18 msw (60 fsw) but at the end of the session was still present. He was subjected to six more USN TT6. At the end of the seventh recompression session, no further improvement was observed. The diver could walk without support and his urinary catheter was removed. He had a residual motor deficit of his right hip joint for which physiotherapy was recommended.

Comments:

This diver suffered from Type 2 DCS which he had unsuccessfully tried to manage with an improvised in-water recompression breathing air. The recompression with USN TT6A and USN TT6 recovered the diver from major permanent neurological damage.

Case 6

This 38-yr-old male recreational diver came from abroad to Sri Lanka for diving activities around the Trincomalee area. He had no known comorbidities and was not on any medications.

He is an experienced diver. On the day of the incident, he had gone diving with a buddy. He dived to 18 msw (60 fsw) depth and stayed for about one hour breathing air. His dive was uneventful and he followed proper decompression stops. About one hour after his dive, he developed pain in both knee joints, both ankle joints, and right arm. The pain was aching in nature and moderate to severe in intensity. Pain relieved with flexion of joints. He described the pain as 5/10 on the visual analog scale (VAS). No numbness or muscular weakness presented. Normal bowel and bladder habits were observed.

He contacted the diving medical officer over the phone and was instructed to have plenty of fluids orally and come to Naval hospital Trincomalee as soon as possible.

He came to our center on the same day. His neurological examination was normal and all the vital parameters were stable. The clinical diagnosis was Type I Decompression Sickness.

He was offered recompression treatment according to the USN TT5. During the recompression he had significant relief of pain in the first 20 minutes of oxygen breathing at the depth of 18 msw (60 fsw) hence the same table was continued. He recovered fully at the end of the table, therefore no further recompression was considered.

APPENDIX A. PUBLICATIONS

Jeanette Moore

2018

REFEREED ARTICLES (PRIMARY LITERATURE)

Buzzacott P, Mease A. Pediatric and adolescent injury in aquatic adventure sports. *Res Sports Med.* 2018;26(sup1):20-37.

Buzzacott P, Edelson C, Bennett CM, Denoble PJ. Risk factors for cardiovascular disease among active adult US scuba divers. *Eur J Prev Cardiol.* 2018 Sep;25(13):1406-1408.

Buzzacott P, Schiller D, Crain J, Denoble PJ. Epidemiology of morbidity and mortality in US and Canadian recreational scuba diving. *Public Health.* 2018;155:62-68.

Lucrezi S, Egi SM, Pieri M, Burman F, Ozyigit T, Cialoni D, Thomas G, Marroni A, Saayman M. Safety Priorities and Underestimations in Recreational Scuba Diving Operations: A European Study Supporting the Implementation of New Risk Management Programmes. *Front Psychol.* 2018 Mar 23;9:383. doi: 10.3389/fpsyg.2018.00383. eCollection 2018.

Shreeves K, Buzzacott P, Hornsby A, Caney M. Violations of safe diving practices among 122 diver fatalities. *Int J Environ Res Public Health.* 2018;16(2):94-98.

Ranapurwala SI, Kucera KL, Denoble PJ. The healthy diver: A cross-sectional survey to evaluate the health status of recreational scuba diver members of Divers Alert Network (DAN). *PLoS ONE.* 2018;13(3): e0194380.

NON-REFEREED ARTICLES

Bennett C. A different kind of dive club: the volunteer program at the Oregon Coast Aquarium exemplifies a culture of safety. *Alert Diver.* 2018;34(1):18-21.

- Burman F. Emergency planning: why do we need it? Alert Diver. 2018;34(1):66.
- Burman F. Emergency planning: what makes a good plan? Alert Diver. 2018;34(2):74.
- Burman F. Emergency planning: practicing the plan. Alert Diver. 2018;34(3):68.
- Burman F. Fire safety in the dive industry – prevention is paramount. Alert Diver. 2018;34(4):68.
- Burman F. Safety Improvement : Planning to Do better. UHMS Pressure magazine. 2018;1st Quarter:15.
- Burman F. Safety report Carbon monoxide, the silent killer, can be an unexpected presence in your facility. UHMS Pressure magazine. 2018;2nd Quarter:15.
- Buzzacott P. Catastrophic regulator failure. Alert Diver. 2018;34(1):64-65.
- Buzzacott P. The Future of Dive Medicine. Alert Diver. 2018;34(2):52-57.
- Buzzacott P. Nitrox Diving Safety. Alert Diver. 2018;34(2):70-71.
- Buzzacott P. Scuba diving and life expectancy. Alert Diver. 2018;34(3):58-61.
- Chimiak J. Up to the challenge – cave diver Ben Reymenants discusses the challenges of rescuing young soccer players from a cave in Thailand. Alert Diver. 2018;34(4):60-63.
- McCafferty M. Explore all possibilities. Alert Diver. 2018;34(4):66-67.
- Seery P. Keep your head – situational awareness and safety fundamentals can save the day. Alert Diver. 2018;34(3):64-65.

NON-REFEREED LETTERS

- McCafferty M. Varicose veins and diving. Alert Diver. 2018;34(1):57.
- McCafferty M. Can I dive with hearing loss and tinnitus? Alert Diver. 2018;34(1):57-58.
- McCafferty M. Can I dive while using eye drops for conjunctivitis? Alert Diver. 2018;34(3): 54-55.
- McCafferty M. Propensity for decompression sickness. Alert Diver. 2018;34(3):56.
- McCafferty M. Diving after a tattoo. Alert Diver. 2018;34(4):54-55.
- McCafferty M. Is there an increase risk of injury if you dive without a spleen? Alert Diver. 2018;34(4):57.
- Smith F. Who to call first in an emergency. Alert Diver. 2018;34(1):56.
- Smith F. Spontaneous pneumothorax history and diving. Alert Diver. 2018;34(1):58-59.
- Smith F. Will Nitrox prevent recurrence of skin bends? Alert Diver. 2018;34(2):62-63.

Smith F. Can I safely dive after being diagnosed with a pulmonary bleb? Alert Diver. 2018;34(2):63-65.

Smith F. Return to diving after breast cancer diagnosis. Alert Diver. 2018;34(2):66-67.

Sorrell L. Use of menstrual cup while diving. Alert Diver. 2018;34(1):56-57.

Sorrell L. Is it safe to dive while taking anxiety medication? Alert Diver. 2018;34(4):55-56.

Ward T. Skin bends or suit squeeze? Alert Diver. 2018;34(3):55-56.

Ward T. Marine life sting during a dive. Alert Diver. 2018;34(4):56-57.

APPENDIX B. PRESENTATIONS

Jeannette P. Moore

Burman F. International ATMO safety director, acrylics and hyperbaric facility maintenance courses. San Antonio, TX. January 15–20, 2018.

Burman F. DAN Diving safety officer course. DAN Headquarters, Durham, NC. January 25–30, 2018.

Nochetto M. Our World Underwater Dive & Travel Show. Chicago, IL. February 17–18, 2018.
The perils of artisanal divers in the Americas
Remote operations injury management

Chimiak J. SAR presentation. Charleston, SC. March 2, 2018.

Seery PL. Examiner workshop. DAN Headquarters, Durham, NC. January 26–28, 2018.

Buzzacott P. DAN Research into diving incidents and the safety of nitrox. North Shore Frogmen, Boston, MA. March 8, 2018.

Buzzacott P. The frontier of decompression research. Boston Sea Rovers, Boston, MA. March 11, 2018.

Chimiak J. Safety at sea. USNA, Annapolis, MD. March 24, 2018.

Buzzacott P. Beneath the Sea, Secaucus, NJ. March 24, 2018.
Frontier of decompression research
The DAN annual diving report
Lessons from 500 diving incident reports

- Nochetto M. Beneath the Sea, Secaucus, NJ. March 24, 2019.
Delta P and barotrauma: what pressure can do to gas filled spaced
Cases from the DAN emergency hotline
Recompression therapy: one does not just squeeze bubbles
- Buzzacott P. Evidence-based diving safety. Duke University, Durham, NC. April 4, 2018.
- Buzzacott P. Using the BRFSS to characterize adult US Scuba divers. CDC BRFFS Training Workshop. Atlanta, GA. April 9-13, 2018.
- Seery PL. Instructor trainer update into eLearning and new course methodology (DAN and NAUI Trainers). Sao Paulo, Brasil. April 8-15, 2018.
- Sorrell L. Stuff happens...now what? The Blue Wild, Ft. Lauderdale, FL. April 14-15, 2018.
- Buzzacott P. TechDive USA. Orlando, FL. April 27-29, 2018.
Cave diving fatalities monitoring and prevention
Tech diving near misses, injuries and fatalities in the DAN database
- Sorrell L. Defining dive safety. Villages Scuba Club, The Villages, FL. May 02, 2018. (webinar)
- Sorrell L. Medications & diving. Blue Dolphins Skin Diving Club, Erie, PA. May 3, 2018. (webinar)
- Seery PL. Internal DAN staff - Instructor Trainer Workshop. DAN headquarters, Durham, NC. May 16-18, 2018.
- Buzzacott P. First 500 incident reports. Rum Runner Dive Club meeting. May 21, 2018.
- Burman F. DAN Diving safety officer course. DAN, Durham, NC. May 21-25, 2018.
- Burman F. The Dive safety officer course. Braine-l'Alleud, Belgium. May 27-June 01, 2018.
- Buzzacott P. International Extreme Sports Medicine Congress, Boulder, CO. June 1-2, 2018.
Pediatric and adolescent injury in aquatic adventure sports
Medical aspects of world record scuba dives - deep water and high altitude
Free diving - injuries and fatalities in the quietest of extreme sports
- Denoble PJ. Decompression stress. DAN Interns Training, Durham, NC. June 1, 2018.
- Buzzacott P. Frontiers of decompression research. DAN Public Lecture, Durham, NC. June 6, 2018.
- Burman F. Diving and hyperbaric safety course. Simon Frazer University, Vancouver, Canada. Jun. 8-9, 2018.
- Burman F. International ATMO Safety Director, Acrylics and Hyperbaric Facility Maintenance courses. San Antonio, TX: June 14-19, 2018.
- Buzzacott P. Scuba Show, Long Beach, CA. June 22-23, 2018.
High altitude "fizziology"
30 Years of the DAN annual diving report

Burman F. Scuba Show. Long Beach, CA. June 22-23, 2018.

Customizing your emergency action plan

DAN HIRA: The risk assessment and mitigation program

Nochetto M. Scuba Show. Long Beach, CA. June 22-23, 2018.

Delta P and barotrauma: what pressure can do to gas filled spaces

Recompression therapy: one does not just squeeze bubbles

Buzzacott P. UHMS Annual Scientific Meeting. Orlando, FL. June 28-30, 2018.

Estimated workload intensity during volunteer aquarium dives

Self-reported recreational scuba diving incidents – analysis of 500 cases

Sorrell L. Women and diving. Charleston Scuba Women's Divers Day, Charleston, SC. July 21, 2018. (webinar)

Burman F. Hyperbaric safety lectures. 3rd Academy of Dive Medicine. Rio de Janeiro, Brazil. August 10-11, 2018.

Nochetto M. DAN/UHMS Diving and Hyperbaric Medicine. Anse Chastanet, St. Lucia. September 8-15, 2018.

Gas toxicities

Remote operations injury management

Case studies

Parasitic infections in dive travel

Burman F. International ATMO Safety Director, Acrylics and Hyperbaric Facility Maintenance courses. San Antonio, TX: September 17-21, 2018.

Denoble PJ. Intra-individual variability of post-dive venous gas bubbles occurrence: an invitation for multi-centric collaborative study. TRICON2018. Durban, South Africa. September 23-29, 2018.

Tillmans F. Effect of the antioxidant quercetin on ROS-induced DNA fragmentation in human lymphocytes. TRICON2018 (EUBS, SPUMS, SAUHMA), Durban, South Africa, September 23-29, 2018.

Sorrell L. An exercise in critical thinking...a look at case studies and emergency preparedness through the eyes of dive professionals. Cozumel Seminars, Cozumel, MX. October 09, 2018.

Burman F. A risk-based approach to recompression chamber safety. DAN Divers Day. Galatasaray University. Istanbul, Turkey. October 14, 2018.

Burman F. Safety concerns in the diving industry: a culture of safety. DAN Divers Day. Istanbul, Turkey. October 14, 2018.

Burman F. Hyperbaric safety management course. Istanbul Public Hospital. Turkey. October 16, 2018.

Burman F. Hyperbaric risk management program. Istanbul Florence Nightingale Hospital. Turkey. October 16, 2018.

Burman F. Safety concerns in the diving industry: a culture of safety. DAN Divers Day. Banja Luka, Bosnia. October 18, 2018.

Burman F. Hyperbaric facility safety management. Baromedicine Conference. Banja Luka, Bosnia and Herzegovina. October 19, 2018.

Tillmans F. Top 3 most annoying medical problems for diving professionals. 25th Anniversary of the Hyperbaric Chamber in Sharm El Sheikh. Egypt. November 3, 2018.

Tillmans F. The bumpy road to personalized decompression. 25th Anniversary of the Hyperbaric Chamber in Sharm El Sheikh. Egypt. November 6, 2018.

Buzzacott P. 30 Years of the DAN Annual Diving Report. 2018 British Hyperbaric Association Annual Scientific Meeting. London, UK. November 8-9, 2018.

Buzzacott P. Frontiers of decompression research. 2018 British Hyperbaric Association Annual Scientific Meeting. London, UK. November 8-9, 2018.

Burman, F. The Diving Equipment and Marketing Association (DEMA) Show 2018 – Las Vegas, NV. November 10-14, 2018.

- Common safety concerns in dive businesses: are you really prepared?
- Risk mitigation for the safety-conscious dive operation: a systematic approach
- Will my emergency plan work when I need it?

Denoble PJ. The Diving Equipment and Marketing Association (DEMA) Show 2018. Las Vegas, NV. November 10-14, 2018.

- Conditions that physicians and divers may confuse for diving injury
- Research advances in breath-hold diving

Nochetto M. The Diving Equipment and Marketing Association (DEMA) Show 2018. Las Vegas, NV. November 10-14, 2018.

- Challenges in interpreting acute post-dive conditions
- DAN Case series: test your 'diagnostic' skills
- Do child divers get injured?
- Injury management in remote locations

Seery PL. The Diving Equipment and Marketing Association (DEMA) Show 2018. Las Vegas, NV. November 10-14, 2018.

- Delivering education with today's technology.
- Instructor Trainer Workshop.

Tillmans, F. The Diving Equipment and Marketing Association (DEMA) Show 2018. Las Vegas, NV. November 14-17, 2018.

- The top three annoying medical problems for dive professionals
- Cold-water diving – challenges and rewards for suffering the cold
- The bumpy road to personalized decompression: Where are we headed?
- Women and diving – equal opportunity vs. physiology

Burman F. Hyperbaric safety training course. Bahrain. December 8-11, 2018.