ANNUAL DIVING REPORT

30th ANNIVERSARY

PUBLISHED SINCE 1988

2017 Edition | Diving Fatalities, Injuries and Incidents From 2015

DAN

DAN ANNUAL DIVING REPORT

2017 EDITION

A REPORT ON 2015 DIVING FATALITIES, INJURIES, AND INCIDENTS

PETER BUZZACOTT, MPH, PHD
EDITOR

DIVERS ALERT NETWORK
DURHAM, NC


ANNUAL DIVING REPORT
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INTERNATIONAL DAN

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

DAN

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

DAN BRAZIL

Region of coverage is Brazil.

Diving Emergencies:	+1-919-684-9111 (accepts collect calls)
	0800-684-9111 (local number - Portuguese only)

DAN WORLD

Regions of coverage include the Caribbean, Polynesia, Micronesia (except Fiji), Puerto Rico, Guam, the Bahamas, the British and U.S. Virgin Islands, Central and South America, and any other area not designated here.
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Korean Hotline:	010-4500-9113 (Korean and English)

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

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

FOREWORD

In 2017, we are celebrating 30 years of the DAN Annual Diving Report. The first issue, published in 1988, was titled the DAN Report on 1987 Diving Accidents. A formal data-collection process had started a few years earlier. The purpose of collecting data was to estimate the burden of injuries within the dive community, to learn more about the causes of injuries and to inform the development of preventive interventions.

At the outset of those efforts, data about exposure to risk were limited to subjective reports. The use of dive computers was not yet widespread, and even for the small number of divers who used computers, a download feature was not yet available. The severity of dive exposures was judged mainly in reference to U.S. Navy decompression tables. The most common findings were highlighted in a "Summary Remarks" section of the early reports. Delays in seeking treatment and incomplete resolution of injuries were at that time the factors of major concern. The authors of early reports emphasized the importance of reducing the number of injuries, as well as their severity, and the importance of improving response times when injuries did occur. Specifically, they pointed out the need for better recognition of diving injuries, for increased use of first-aid surface oxygen, and for improved field management of diving injuries by divers and emergency medical services.

Thirty years later, despite significant advances in diving technologies, we still see some of the same issues. Thanks to the ongoing educational efforts of training agencies, DAN, and other entities, established divers know more about diving injuries and are better prepared to respond. However, educational efforts must be sustained to make sure that new divers attain necessary knowledge and skills before they take to the water. Immediate recompression in cases of decompression illness remains out of reach for most divers, due to the spread of diving activities to ever more remote areas and due as well to the declining number of hyperbaric chambers willing to treat injured divers.

The prevention of diving incidents and injuries remains high on DAN's agenda. The DAN Annual Diving Reports will continue to bring to the attention of the organization's members, as well as the dive community in general, how and why injuries happen. We hope that the lessons thus learned will help us all – both as individual divers and as dive communities – to sustain our commitment to safe diving.

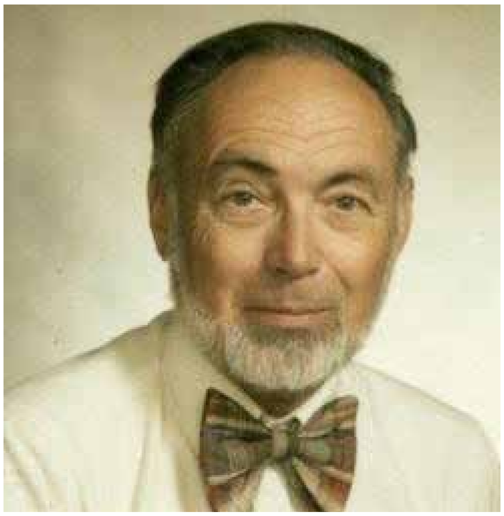
Petar J. Denoble, MD, DSc
Vice President, Mission
Divers Alert Network

DEDICATED TO THE MEMORY OF

DR. GILES YANCEY MEBANE

1928-2017

DIVERS ALERT NETWORK ASSOCIATE MEDICAL DIRECTOR 1987-1998



Giles Yancey Mebane, MD, died at the age of 89 on July 9, 2017. He was associate medical director for DAN from the day the organization was founded, in 1987, until 1998. It is thus with gratitude and appreciation that we dedicate this report to his memory.

Here is how Joel Dovenbarger, former director of medical services at DAN, remembers Dr. Mebane:

When I first came to DAN in 1985, Dr. Mebane was already involved in the newly formed international diver safety service. He was semiretired, as I recall, from a family practice he owned in Mebane, N.C. He was a traditional "country doctor" and a pretty good one, too. He was not only involved with DAN, but was also the medical director of the local EMS in Alamance County, which in those days was not as well served as areas with larger populations and more medical facilities.
At DAN, Dr. Mebane was able to indulge his love of the outdoors, which included not only scuba diving but snow skiing as well. He was very good at both sports. There is no question in my mind that outside of the love he had for his family, he loved practicing medicine and educating his patients and those he worked with as much as anything else. You could not work with Yancey and not come away a wiser and more effective caregiver. He was not only a wonderful physician, he was a great teacher. His early influence on how DAN operated, answered calls, and provided emergency assistance and direction laid the groundwork for the modern-day Divers Alert Network.

His experience and expertise in medicine and directing patient outcomes made Dr. Mebane someone you could rely on, someone who would pitch in when a diver or a friend was going through a rough patch. He advised DAN on every part of its operations, and his input was always sound and trustworthy.

He was missed when he finally retired in 1998, took his Airstream and spent his final years out in Idaho. Anybody who ever worked with Dr. Mebane or was advised by him benefited in some way. He was dedicated to his occupation and to bettering the health of the people he served.
After Dr. Mebane left the Divers Alert Network, we looked forward to getting the occasional postcard from out west to let us know what he was up to. He had worked hard, and he deserved an enjoyable retirement.

Now that he is gone, I think I can best sum up Dr. Mebane by saying his life was well spent. As a traditional "country doctor and caregiver," a teacher, and an outdoor enthusiast, his influence continues on in the lives and careers of others.

Joel Dovenbarger

And here is more about Dr. Mebane's life and career, including his work for DAN:

Dr. Giles Yancey Mebane was born on January 10, 1928, in Beaufort, North Carolina. He was predeceased by his mother, Ruth Amelia Robinson Mebane, and his father, William Giles Mebane. He served in the U.S. Navy from 1945 to 1947, then graduated from Duke University in 1950 and from Duke University Medical School in 1954. He completed his residency at the Medical College of Virginia (MCV) in 1956. While at MCV, he met Charlene Robbins, who became his wife on March 12, 1955. In 1956, he and Dr. William Glenn Aycock opened a medical practice at Mebane Medical Arts in Mebane, N.C.

He was board certified by the American Board of Family Practice. He served as medical examiner for Alamance County, medical director of the Alamance County Rescue Service, and with the Alamance County EMS, where he was instrumental in developing programs for Advanced Life Support, EMT-I, and EMT-P. He also started the Alamance County Rescue diving team and was a member of the Wilderness Medical Society and the Professional Association of Diving Instructors.

In addition, Dr. Mebane was on the founding board of directors of the Divers Alert Network. He brought to DAN wide experience in emergency medicine and a love for diving and diving education. He helped to shape the DAN Emergency Line and served as the organization's senior physician. At DAN, Dr. Mebane developed educational materials for divers and contributed to the Annual Injury and Fatality Reports from the first issue, in 1988, until he retired from DAN, in 1998. He was also a member of the Institute of Nautical Archaeology (INA) and of the National Geographic Society. He served as the expedition medical officer on several underwater archeological expeditions to Turkey with INA, Texas A&M University, and the National Geographic Society, and he appeared in the December 1987 issue of National Geographic magazine.

Dr. Mebane was also passionate about model railroading. He earned several blue ribbons for scratch-building models and enjoyed riding on steam engine fan trips. His other interests included photography, cross-country skiing, horseback riding, camping, cycling and traveling.

Dr. Mebane is survived by his wife, Charlene Robbins Mebane; a daughter, Ann Yancey Mebane; three sons — William Giles Mebane and wife Kelly Gauldin, Michael Scott Mebane and wife Teresa, and John Anthony "Tony" Mebane and wife Karen; grandsons John Yancey Crandell, Daniel Giles Mebane and wife Hannah, Jordan Yancey Mebane, Justin Michael Mebane, Matthew William Mebane, Logan Alexander Mebane, and William Alexander Mebane; granddaughters Casey Mebane Buie and husband Sam and Emily Marie Mebane; a great-granddaughter, Louisa Mae Mebane; and his dog, Penny.

SECTION 1. DIVING FATALITIES

PETER BUZZACOTT, JEANETTE P. MOORE, CASLYN M. BENNETT,
JAMES L. CARUSO, CRAIG NELSON, PETAR J. DENOBLE.

1.1. INTRODUCTION

DAN prepares this Annual Diving Report to raise awareness of the factors that come into play in recreational diving fatalities, in the hope that such information may better inform the diving community. But injury and fatality surveillance is worthless unless it translates into actions calculated to prevent future injuries. We thus encourage every diver to read this section and to think carefully about the data presented here. Look at the factors that affected some divers' abilities to overcome difficulties. What could have made the difference in those situations? Often, the diver's own actions could have led to a more positive outcome. Sometimes those actions — such as careful equipment checks — should take place before a diver even enters the water. And once a diver is in the water, there are many actions — such as staying within sight of one's buddy and remaining within the limits of one's training and experience — that are key to enjoying a safe dive.

THE DATA COLLECTION PROCESS

The data collection process at DAN starts with identification of diving- and scuba-related deaths through internet alerts; media reports; dive forums; reports from relevant officials, such as county coroners, public safety divers, and county medical examiners; and reports from members of the public. All recreational diving fatalities that occur in the U.S. or Canada are tagged for follow-up, and any deaths of U.S. or Canadian divers that occur in foreign countries are also marked for follow-up. Fatalities outside the U.S. or Canada involving foreign nationals are tagged as no–follow-up.

News reports, mostly online, are monitored constantly for keywords involving diving and scuba deaths. Other sources for notifications regarding fatalities include reports from families of DAN members, as well as from friends and acquaintances of decedents who are aware of DAN's data-collection efforts. The DAN Medical Services Call Center (MSCC) is also a valuable resource for data on fatalities, as the DAN Medical Services Department assists with the management of any diving event that is called in, whether the victim is a DAN member or not. (Note that the information collected by DAN on nonfatal injuries associated with scuba diving is covered in Section 2 of this report, while information on injuries and fatalities associated with breath-hold diving is covered in Section 4.)

INVESTIGATOR AND MEDICAL EXAMINER REPORTS

Most diving-related deaths in the U.S. are investigated by local law enforcement agencies or the U.S. Coast Guard (USCG), and many are subject to autopsies. These investigative reports and autopsies are integral to DAN's research into the causes of scuba-related fatalities. Without access to these reports, it would be virtually impossible to compile enough data for analysis.

Each state in the U.S. has its own set of regulations regarding the release of personal health information, on top of the federally mandated HIPAA (Health Insurance Portability and Accountability Act of 1996) Privacy Rule. Some states consider investigative and medical examiner reports to be public information and release such documents readily, while others have more stringent privacy laws. In addition, within a given state, the regulations (and, hence, the ease of procuring reports) can sometimes vary from county to county. As shown in Table 1.2-2, the majority of diving deaths in the U.S. occur in Florida and California. Fortunately, these two states have straightforward protocols for requesting and obtaining copies of reports.

Local investigative agencies (sheriff's and police departments) follow privacy laws similar to those of medical examiners. However, since their reports typically do not contain private medical information, those entities are often able to release reports upon requests under the Freedom of Information Act (FOIA).

Reports for cases investigated by the USCG can now be requested from one central location in Washington, D.C. However, it may take up to two years after an incident before a case is closed and the report is released. The USCG follows FOIA protocols and will not release personal information contained in their reports. A redacted copy, with all personal and identifying information removed, is usually requested. When they're available, downloaded dive-computer profiles are included in USCG case files.

REPORTS FROM WITNESSES AND NEXT OF KIN

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

DATA ENTRY AND ANALYSIS

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

1.2. GEOGRAPHIC AND SEASONAL DISTRIBUTION OF FATALITIES

Despite the extent and rigor of the data-collection process described in Section 1.1, it is impossible to gather information on all diving fatalities worldwide. Reporting of fatalities is not mandatory, and DAN often does not have access to relevant sources of information outside of the United States and Canada.

Worldwide, DAN received notification of 127 deaths involving recreational scuba diving during 2015. This is shown in Table 1.2-1. Only the deaths of 67 US and Canadian recreational diving fatalities were actively investigated by DAN. Reports of 60 dive-related deaths from other regions were recorded but, due to geographical limitations, were not investigated. There were also 13 deaths that were not recreational divers and breath-hold fatalities are covered in Section 4.

Region	Country	Count
Asia	Philippines	6
	Maldives	4
	Thailand	5
Asia total		12
Caribbean	Bahamas	1
	Cayman Islands	6
	Cuba	1
	French West Indies	1
	Netherlands Antilles	1
	St Kitts and Nevis	1
	Turks and Caicos	1
	Virgin Islands	3
Caribbean total		15
Central America	Belize	4
	Costa Rica	1
Central America total		5
Europe	United Kingdom	7
	Italy	5
	Malta	5
	Spain	2
	Switzerland	1
	Norway	1
	Luxembourg	1
Europe total		22
Northern Africa	Egypt	4
Northern Africa total		4
North America	Bermuda	1
	Canada	4
	Mexico	2
	United States	39
North America total		46
Middle East	Israel	1
	Turkey	1
	United Arab Emirates	2
Middle East total		4
Oceania	Australia	8
	Fiji	1
	French Polynesia	1

Table 1.2-1. Distribution by region and country of scuba fatalities reported to DAN, 2015 (n=127)

Region	Country	Count
	Guam	1
	Marshall Islands	1
	Micronesia	2
	New Zealand	4
Oceania total		18
South America	Brazil	1
South America total		1
Overall total		**127**

Table 1.2-1. (continued) Distribution by region and country of scuba fatalities reported to DAN, 2015 (n=127)

Table 1.2-2 shows the geographic distribution of the 43 2015 fatalities that occurred in the U.S. or Canada or their territories. Another 24 fatalities involved U.S. or Canadian citizens who died while scuba diving overseas. As in previous years, Florida again had the largest number of fatalities, followed by California, then Washington.

State/Province	Count
Florida	14
California	6
Washington	4
Rhode Island	3
Wisconsin	3
Massachusetts	2
Ontario	2
Pennsylvania	2
British Columbia	2
Guam	1
New York	1
North Carolina	1
Oklahoma	1
Ohio	1
Total	**43**

Table 1.2-2. Distribution by state or province of scuba fatalities in the U.S. and Canada, 2015 (n=43)

1.3. AVAILABILITY OF DETAILED INFORMATION

Autopsies — the most thorough source of information on causes of death — were available for 16 of the 67 U.S. and Canadian fatalities (24%). Table 1.3-1 shows the information available in all 67 cases; the body of the decedent was not recovered in 2 cases (3%).

Availability of autopsy information	Count
Autopsy available	16
Unknown if autopsy was conducted	34
Autopsy was conducted but not supplied to DAN	12
No body	2
Coroner's summary or death certificate available	2
No autopsy was conducted	1
Total	**67**

Table 1.3-1. Medical examination data for U.S. and Canadian scuba fatalities, 2015 (n=67)

1.4. AGE AND HEALTH OF DECEDENTS

The victims in the 67 U.S. and Canadian fatalities were male in 79% of cases (n=53) and female in 21% of cases (n=14). The vast majority of the victims — 91% of males and 93% of females — were 40 years of age or older, and a significant majority — 75% of males and 71% of females — were 50 years of age or older. Figure 1.4-1 shows the age distribution for these 67 fatalities.

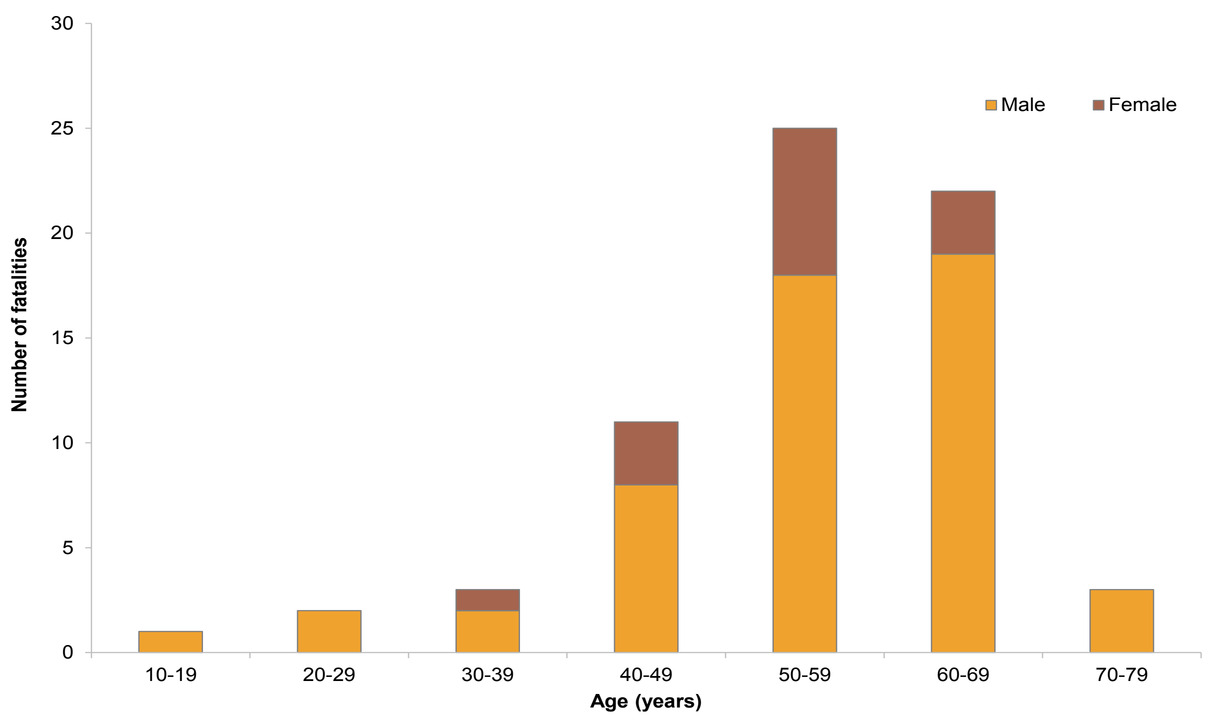


Figure 1.4-1. Distribution by age and sex for U.S. and Canadian scuba fatalities, 2015 (n=67)

The medical history of the decedents was, in most cases, incomplete or unknown. Any known pre-existing medical conditions that were reported to DAN are listed in Table 1.4-1; in one case it was explicitly reported that the victim had no known medical conditions.

Condition	Count
Hypertension	2
Diabetes	2
Cardiovascular disease	2
Depression	2
None	1

Table 1.4-1. Known medical history of victims of U.S. and Canadian diving fatalities, 2015

The true prevalence of hypertension and cardiovascular disease among victims is not known. The numbers presented in Table 1.4-1 represent only the cases reported to DAN. In addition to the fact that a medical history was not available for many victims, some of those who were reportedly healthy may have had undiagnosed hypertension, heart disease or diabetes, as is often the case in the general population.

CASE 1-34: A PROBLEM AT DEPTH PROVED FATAL

A 65-year-old male, an experienced diver, was described as being in good health despite reportedly having undergone triple bypass surgery the previous year. The diver descended with his dive group but signaled a problem at 50 fsw (15 msw) depth and ascended. At the surface, the diver began vomiting and lost consciousness. CPR was initiated, along with mouth-to-mask supplemental oxygen. Then the victim was helicoptered to shore, where he was declared dead.

CASE 1-30: EFFORTS FAILED TO REVIVE A 70-YEAR-OLD DIVER

A 70-year-old male diver's certification and experience level were unknown. He made a one-hour dive from a commercial dive boat, had about a one-hour surface interval, then made a second dive. He was brought to the surface in distress 20 minutes into the second dive. Others on the boat began CPR, lifeguards were notified, and the victim was unconscious when lifeguards arrived. The victim was pronounced dead on the shore.

The body mass index (BMI) of victims was available in 19 cases (28%) — 15 males and 4 females. According to the BMI classifications of the U.S. Centers for Disease Control and Prevention (CDC 2016), 26% of the victims whose BMI was known were classified as normal weight (BMI of 18.5 to ≤25), 37% as overweight (BMI of 25.0 to ≤30) and 37% as obese (BMI of 30.0 or higher). One diver was classed as severely obese (BMI of ≥40.0). This pattern of obesity among victims of scuba fatalities is similar to that found in the U.S. population at large — about 36.5% (CDC 2017). Data for the general scuba population is not available, however, so it is impossible to know if obesity is more or less common in divers than in the wider population and/or if obesity is linked to an increased risk of dying while scuba diving.

CASE 1-77: A DIVER DROPPED HIS WEIGHTS AND SURFACED BUT REDESCENDED

A 52-year-old male was certified and experienced but had a history of hypertensive cardiovascular disease, diabetes and obesity (his BMI was 33). He was with a group of divers but was making his third dive of the day without an assigned buddy. The group descended down an anchor line, then the victim surfaced behind the boat, yelled for help and sank. A crew member entered the water to locate the victim but was unsuccessful. The victim surfaced a second time but then disappeared again. His body was located two days later, after extensive searches by multiple agencies. The victim's integrated weight pockets had been removed, suggesting an attempt to establish positive buoyancy. The victim's dive tank still contained 3,400 psi (234 bar) of air, but it is not known whether the valve was open or closed because the recovery diver manipulated the on/off knob before recording its position.

CASE 1-48: A DIVER HAD DIFFICULTY CLIMBING A LADDER IN ROUGH SEAS

A 41-year-old female had a BMI of 43. A week before this trip, she had participated in two training dives in a lake. This was the victim's first ocean dive and was intended to count toward her certification. The dive group boarded the boat and set out for a reef about five miles offshore. Witnesses described the sea conditions as "rough." The diver entered the water, and witnesses said she appeared distressed almost immediately. Efforts to assist her out of the water via the boat's ladder were initially unsuccessful. After several attempts, the dive guide removed her scuba equipment and pushed her up the ladder from below while the boat captain pulled from above. By the time they got the diver onto the boat, she was unconscious. She had no pulse and had stopped breathing, so the boat crew started CPR. The other divers were by that time diving; they were recalled to the boat so it could leave for shore. The diver's equipment had sunk but was recovered. The tank contained 2,800 psi (193 bar) of air, and the valve was open. The U.S. Coast Guard arrived and gave assistance and EMS met the boat onshore. The diver was pronounced dead at the hospital.

1.5. DIVING CERTIFICATION AND EXPERIENCE

Information about decedents' dive certification was available in 26 of the 67 cases (39%), as shown in Figure 1.5-1.

The number of years of experience that divers had logged since achieving their initial certification was known in only 14 cases. That information is shown in Figure 1.5-2.

Here are some of the fatalities reported to DAN where inexperience, often in combination with medical issues, likely played a role:

CASE 1-88: CARDIOVASCULAR DISEASE CAUSED A LOSS OF CONSCIOUSNESS AT THE SURFACE

A 58-year-old inexperienced and uncertified male had enrolled in a guided scuba experience. The diver had a BMI of 39 and a history of medical problems, including diabetes, but had supplied a diving medical form signed by a physician. Preliminary instruction took place in the morning, then in the afternoon the diver and his instructor dived to 38 fsw (12 msw) for 29 minutes. They then surfaced and swam to

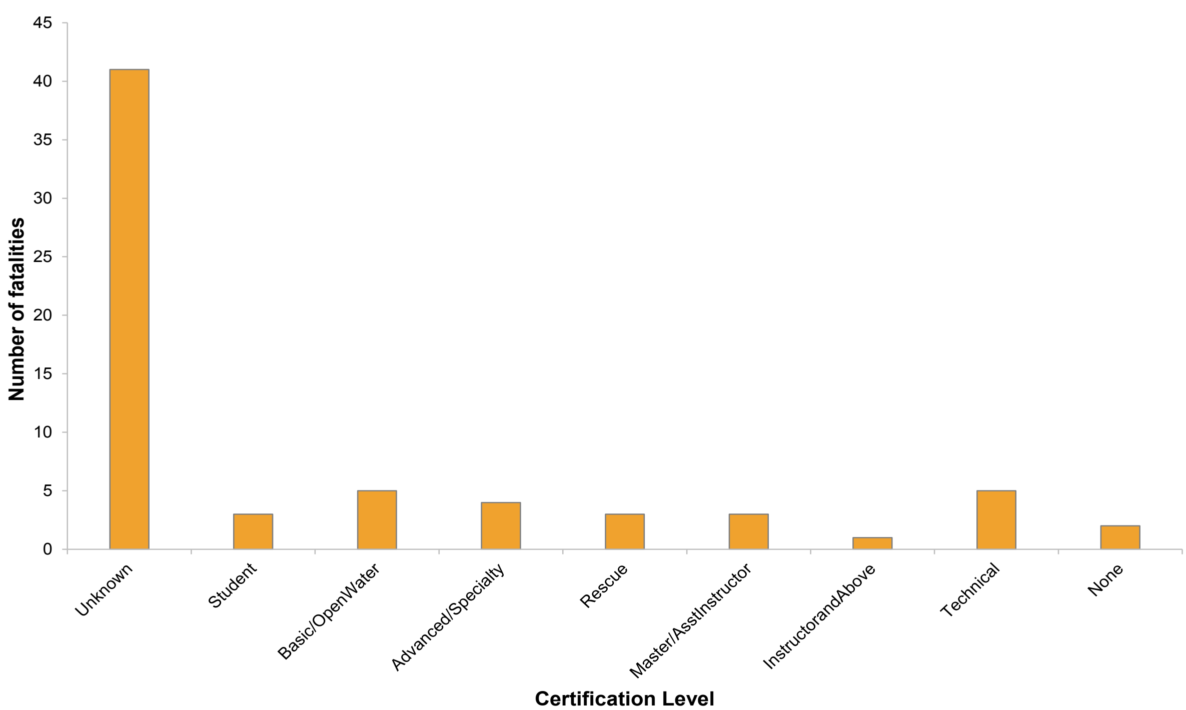


Figure 1.5-1. Distribution by dive certification level for U.S. and Canadian scuba fatalities, 2015 (n=67)

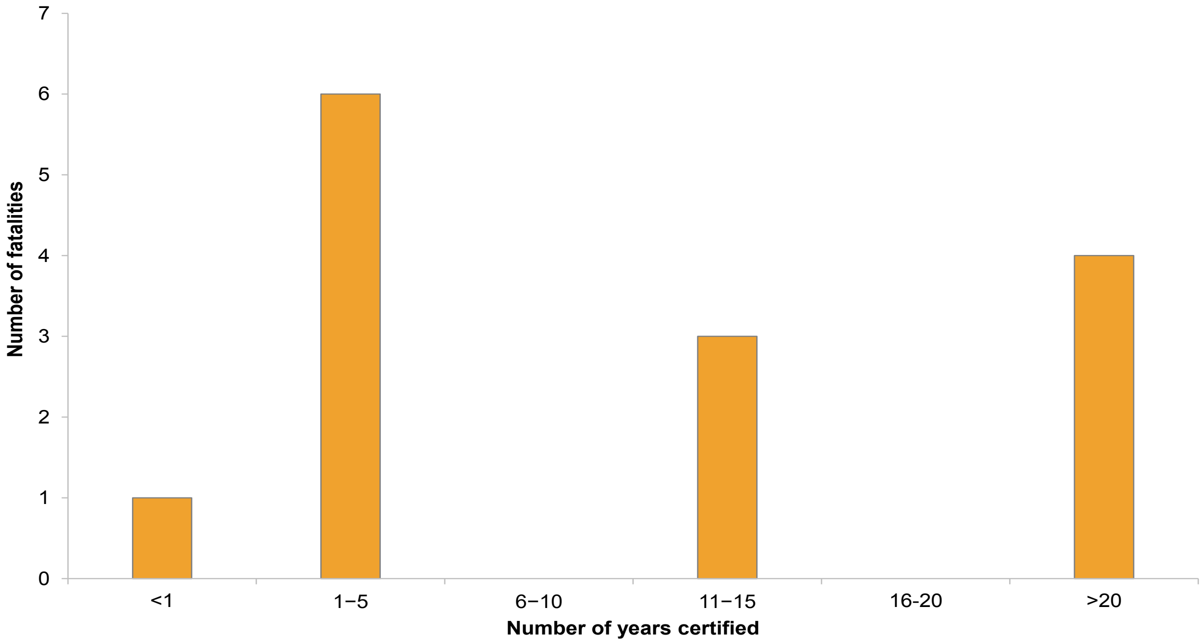


Figure 1.5-2. Years since initial certification for U.S. and Canadian scuba fatalities, 2015 (n=14)

the boat. At the ladder, the victim lost consciousness and was lifted onto the boat, where CPR was started. The victim was pronounced dead at the hospital. An autopsy revealed extensive narrowing of his coronary arteries, and the cause of death was determined to be atherosclerotic and hypertensive cardiovascular disease.

CASE 1-81: RAPID GAS DEPLETION FOLLOWED BY A RAPID ASCENT PROVED FATAL

A 51-year-old male, uncertified and inexperienced, was participating in a check-out dive for an open water training course. The previous day, the victim had aborted his second dive after practicing an ascent and reporting "asthma issues." On the day of the fatal dive, the victim was diving with an instructor, one-on-one, and reportedly started his final dive with 2,400 psi (165 bar) in his scuba tank. After 15 minutes underwater, having reached a maximum depth of 62 fsw (19 msw), the victim signaled that his tank was down to 500 psi (34 bar). The instructor reported that the victim grabbed him tightly, and they commenced a rapid ascent. At the surface, the instructor released both of their weight belts and started towing the victim toward the dock, while calling for help. A bystander called 911 immediately, and CPR was commenced, but it was unsuccessful.

CASE 1-27: A NOVICE DIVER SUFFERED A CATASTROPHIC LOSS OF BUOYANCY

A 50-year-old female was an inexperienced novice diver, wearing a rented BCD and newly purchased scuba gear, including a 7mm wetsuit, a total of 30 pounds (14 kilograms) of lead weights, and a steel scuba tank. The diver was making her first open water dive since certification two weeks earlier. She was in a group consisting of eight divers plus a divemaster, intent on visiting an artificial reef starting from the shore.

The group descended at about 1:00 p.m. Soon after, a witness on shore called 911 to report a diver in distress at the surface, shouting for help. The other divers in the group surfaced later and noticed the victim was missing. Her body was found by a solo recreational diver four days later, in 35 fsw (11 msw), with both of her integrated weights still in place. The local police department dive team's recovery diver noted that the victim's weight belt was rotated such that the quick-release buckle was behind her. The diver had removed one glove and was still holding it in her gloved hand. Her tank had also slipped loose from her BCD, and her power inflator had come away from the corrugated hose. The corrugated hose had an unusual design, in that it was divided into two halves connected by a quick-release mechanism. Three retaining clips for the low-pressure inflator hose were located on either side of the quick release, to further support that connection, but in this case the low-pressure hose was not clipped into place. The victim's dive computer had recorded an uneventful dive profile until around 18 minutes, when a rapid ascent from 41 fsw (12 msw) to the surface occurred, followed by an immediate redescent to 41 fsw. The equipment inspection report concluded that a catastrophic loss of buoyancy was a significant factor in the fatality.

CASE 1-93: TWO NEW OPEN WATER DIVERS FOUGHT OVER ONE WORKING REGULATOR

A 15-year-old male had been certified as a junior open water diver but did not dive again for more than two years. He then made 20 lake dives one month before making his first ocean dives from a liveaboard boat anchored near an island. The victim made six dives on the first day, including a night dive. The first dive of the second day was for about 20 minutes, to a depth of 45 to 50 fsw (14 to 15 msw). Conditions at the reef were described as "ideal," with visibility of over 40 feet (12 meters). For his second dive that day, the victim took a spear gun with him. When the victim's buddy, who was making his first-ever dive without an instructor, had 1,000 psi (69 bar) remaining in his tank, he started ascending. He looked back down and saw the victim signaling that he needed to share air, so he returned to depth and donated his back-up regulator. The pair started ascending together, but at 70 fsw (21 msw) the victim removed the back-up regulator and pulled his buddy's primary regulator from his mouth. After watching the victim take two full breaths, the buddy concluded the victim was not going to return his regulator, so he pulled the low-pressure hose to forcibly reclaim his regulator from the victim's mouth.

The buddy saw the victim fall away rapidly without moving his arms; then he also ran out of gas, surfaced rapidly, and suffered a seizure, requiring first-aid oxygen and subsequent hyperbaric oxygen therapy at the nearest chamber. Meanwhile, the victim had aspirated water and landed on the bottom, unconscious. Two divers happened upon the victim after spotting his speargun lying on the sand at 94 fsw (27 msw) and ascended with him. CPR com-

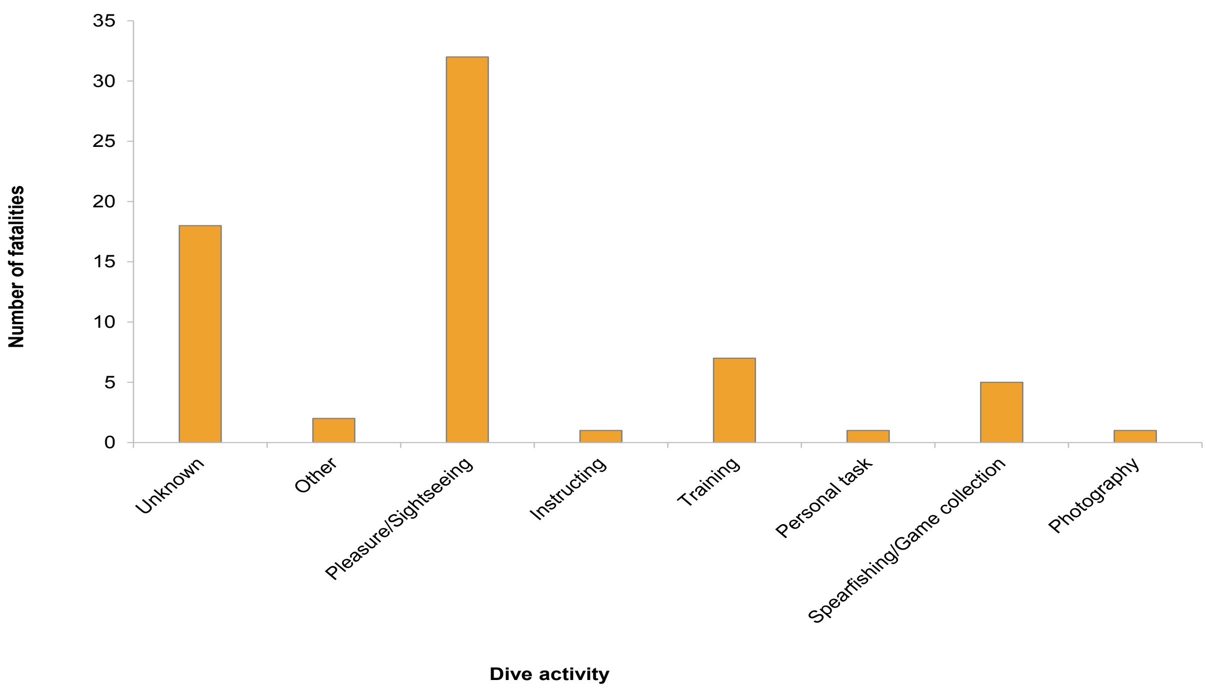


Figure 1.6-1. Primary dive activity during U.S. and Canadian scuba fatalities, 2015 (n=67)

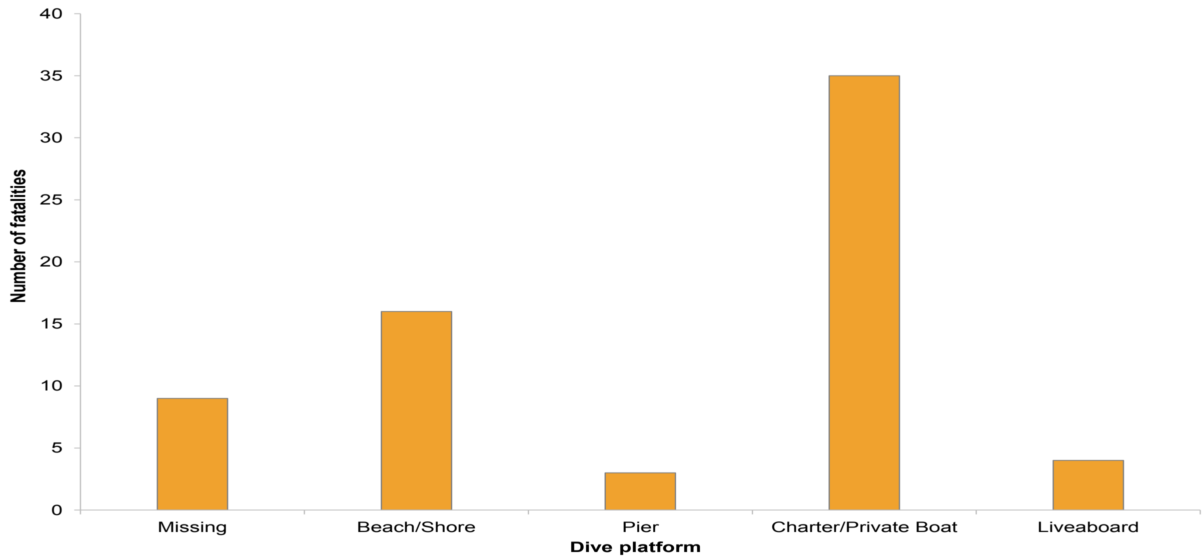


Figure 1.6-2. Dive platform for U.S. and Canadian scuba fatalities, 2015 (n=67)

menced as soon as the victim was back aboard the boat. The U.S. Coast Guard and the local sheriff's dive team arrived within minutes; the victim was transported to a nearby medical facility, where he was pronounced dead.

1.6. CHARACTERISTICS OF FATAL DIVES

PRIMARY ACTIVITY:

The primary activity was reported for 49 of the 67 fatal dives (73%) during 2015. For almost half of them (32, 48%) it was pleasure or sightseeing; 7 (10%) were training dives (not necessarily involving a student, however), and 5 (7%) involved spearfishing, hunting or collecting game. Figure 1.6-1 shows the distribution of primary activities during fatal dives in 2015.

DIVE PLATFORM:

In most cases, fatal dives began from a charter boat or private vessel (n=35, 52%). Dives began from a beach or pier in 19 cases (28%). Figure 1.6-2 shows the platform from which fatal 2015 dives began.

Here are a couple of the fatalities reported to DAN where the dive platform may have been a factor:

CASE 1-74: A DIVER MADE A GIANT-STRIDE ENTRY WHILE THE BOAT THROTTLE WAS ON

A 61-year-old male, a certified and experienced diver, was on a dive vacation with nine other divers. Conditions were described as "choppy," so the divers made a giant-stride entry. The dive guide entered the water at the same time as the victim. When the dive guide looked up, he saw the victim underneath the platform at the rear of the boat and blood in the water. The victim was brought back on board; he appeared to have been struck in the head, by either the propeller or the platform. The victim was unconscious and had aspirated water. He was taken to the local hospital, where he underwent surgery and fluid was drained from his lungs. He was then repatriated to a hospital in the U.S. but died within days.

CASE 1-90: A LEFT-BEHIND DIVER'S NAME WAS MISSING FROM THE ROLL

A 45-year-old female was a well-known regular aboard a certain dive boat. The divers entered the water and descended to hunt for lobster. The victim was last seen descending from the boat, at a depth of 15 fsw (5 msw). When the divers returned to the boat, a roll was called — but four divers' names were missing from the roll, including that of the victim, so those names were not called out. The boat left for another dive site, and the victim was not seen again.

ENVIRONMENTAL FACTORS:

There are several environmental factors that may play a role in fatalities, as follows:

Type of water: Most fatal dives in 2015 occurred in an ocean/sea environment (n=45, 67%), though a significant minority occurred in stationary fresh water (n=9, 13%) or in rivers or springs (n=6, 9%). Seven cases (10%) did not include a description of the dive environment.

Visibility: This factor was reported in only 13 of the 67 cases (19%). It was excellent (>50 feet [15 meters]) in 4 cases (6%), moderate (10–50 feet [3–15 meters]) in 7 cases (10%), and poor (<10 feet [<3 meters]) in 2 cases (3%). Visibility in the remaining 54 cases (81%) was unknown.

Sea conditions: This factor was reported in 16 of the 67 cases (24%). Calm seas were noted in 5 cases (7%), moderate seas in 4 cases (6%) and rough seas in 7 cases (10%).

Current: The presence (or lack) of a current was noted in 10 of the 67 cases (15%). The reported currents were strong in 5 cases (7%), slight in 3 cases (4%) and none in 2 cases (3%).

Time of day: This factor was reported in 48 of the 67 cases (72%). All of those occurred during daylight hours.

This is an example of a fatality where environmental factors were clearly an issue:

CASE 1-27: CONDITIONS OVERWHELMED A VISITING DIVER

A 27-year-old male diver had been certified for eight years and held advanced open water and nitrox certifications, though his log book indicated that he had made only 14 dives, the most recent of them one month earlier. While visiting from overseas, he rented dive equipment and was diving from a boat with a guide and four other divers in an area known for strong currents. The water was just 45°F (7°C), though the victim was wearing a drysuit. The victim and the guide dived to 40 fsw (12 msw) for approximately 17 minutes, before the victim signaled that he was down to 1,000 psi (69 bar) of air. The pair commenced their ascent, but the guide later reported that they had difficulty resisting a downward current (also known as a back eddy), and they had to kick hard to ascend. At 20 fsw (6 msw), the victim was down to 500 psi (34 bar), and the guide was holding on to the victim as they continued to ascend. At around 9 fsw (3 msw), they encountered some kelp, and the guide signaled for the victim to hold onto him while he untangled the kelp from his regulator. The victim let go of the guide and was last seen being carried away by a strong undertow. His body was recovered seven weeks later, after being spotted on the surface not far from the dive site.

EQUIPMENT AND GEAR:

There are many sorts of equipment and gear considerations — especially proper maintenance — that can play a role in fatalities. It is often difficult to gather such information after the fact, however. Information about protective suits worn by divers involved in fatalities was available in 24 of the 67 cases (36%). Of those, 15 victims (22%) wore wetsuits, 3 (4%) wore swimsuits or dive skins, and 6 (9%) wore drysuits.

Here is an example of a fatality in which the diver's equipment appeared to have been a central factor:

CASE 1-99: A DIVER WENT DEEP WITH NEW EQUIPMENT AND RAN OUT OF GAS

A 59-year-old male had a number of dive certifications, but this was his first dive since the previous year. He was testing out a new drysuit and a new dive computer. He had planned to dive solo, but he found another diver who needed a buddy. They were ascending from a 130-ffw (40-mfw) bounce dive when, shortly after a brief stop at 65 ffw (20 mfw), the buddy noticed the victim struggling with his equipment. He nonetheless indicated that all was okay. At approximately 20 ffw (6 mfw), the victim was again seen struggling with his equipment, this time with his mask. The buddy assumed the victim was not getting enough air, so he gave him his primary air source and switched to his secondary. The victim lost consciousness before they reached the surface.

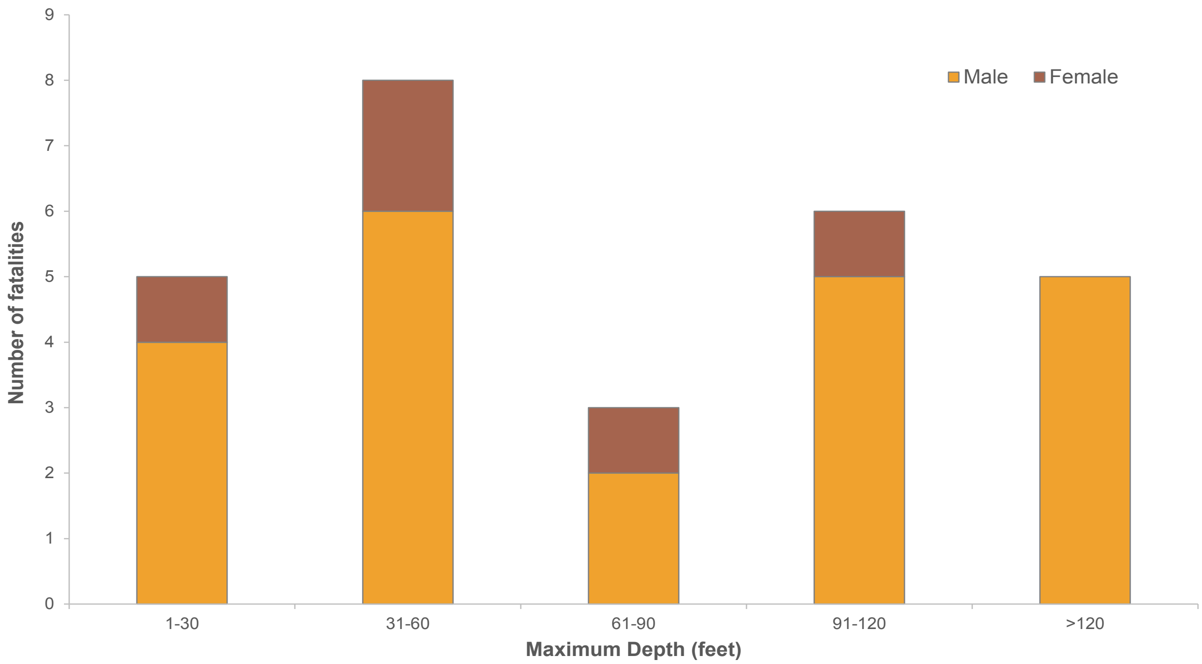


Figure 1.6-3. Maximum depth by sex for U.S. and Canadian scuba fatalities, 2015 (n=26)

The buddy brought him up and started emergency rescue procedures. EMS arrived when the victim was out of the water; by that time, he had no pulse and was not breathing. He was pronounced dead at the local hospital. Inspection of his equipment showed that it was poorly maintained, that the primary tank was empty and that the pony tank was mounted in such a way that the second stage could not reach the diver's mouth.

MAXIMUM DEPTH:

The maximum depth of a dive is another factor that can be involved in fatalities. In 27 of the 67 investigated cases (40%), the maximum depth of the fatal dive was reported; 5 of those cases (7%) occurred in water up to 30 feet (9 meters) deep, 8 cases (12%) in water 31–60 feet (9–18 meters) deep, 3 cases (4%) in water 61–90 feet (19–27 meters) deep, 6 cases (9%) in water 91–120 feet (28–37 meters) deep, and 5 cases (7%) in water deeper than 120 feet (37 meters). Depth data were not available for 40 cases (60%). Figure 1.6-3 shows the depth distribution of fatal dives in 2015.

Here is an example of a fatality in which the depth of the dive was clearly a factor and perhaps the primary cause.

CASE 1-68: A WORLD-RECORD DEPTH ATTEMPT ENDED IN DEATH

A 56-year-old male, an experienced diver, was attempting a world-record open-circuit dive to 1,200 fsw (366 msw). He had previously dived to a depth of 815 fsw (248 msw). According to news reports, he expected to descend rapidly down a 1,300-foot (396-meter) descent line weighted by a 250-pound (113-kilogram) anchor, clip a marker onto the line at the 1,200-foot (366-meter) mark, then start his ascent immediately. The plan was that he would meet with support divers at 350 fsw (107 msw) on his return from depth, an estimated 38 minutes after his initial descent. The intent was that the line would then be retrieved, and the position of the marker would confirm the depth he had reached. The diver was reportedly wearing seven scuba tanks of various sizes, with another 28 tanks on site. The dive plan, including decompression, was for the diver to be underwater a total of 10.5 hours. After his descent, the support divers moved into their agreed-upon positions along the ascent line, starting at 350 fsw (107 msw) depth. However, the victim failed to arrive at the appointed time. The support team waited but eventually had to surface. The diver's body was recovered a few days later, when a vessel capable of raising the rope and anchor arrived on site.

GAS TYPE AND BREATHING EQUIPMENT:

In only 20 of the 67 cases (30%) was it known what type of breathing gas the victim was using. In 15 of those cases (22%), the victim was using air. The type of breathing gas involved in 2015 fatalities is shown in Figure 1.6-4.

Open-circuit scuba equipment was used in 50 of the 67 cases (75%), rebreathers in 4 cases (6%) and surface supply in 1 case (1%). The breathing unit involved in the remaining 12 cases was unknown. Figure 1.6-5 shows the type of breathing equipment used.

The following case illustrates the role breathing equipment can play in fatalities:

CASE 1-56: A HOOKAH STOPPED AND DIVERS MADE RAPID ASCENTS

A 37-year-old male, who reportedly lacked formal certification but did have diving experience, was diving with a buddy to spearfish. They were using a surface-supplied hookah diving system but were not carrying redundant air sources. It was their second dive of the day, to 80 fsw (24 msw). The hookah diving system had not been refueled between the two dives; it ran out of fuel during the second dive and stopped supplying air to the divers. The victim, along with another diver, made a rapid ascent to the surface. The victim became unresponsive upon surfacing. He was recovered by the nondiving occupants of the boat, and CPR was administered, but he was pronounced dead on shore. The medical examiner's report indicated that the victim had suffered significant injuries consistent with lung overexpansion.

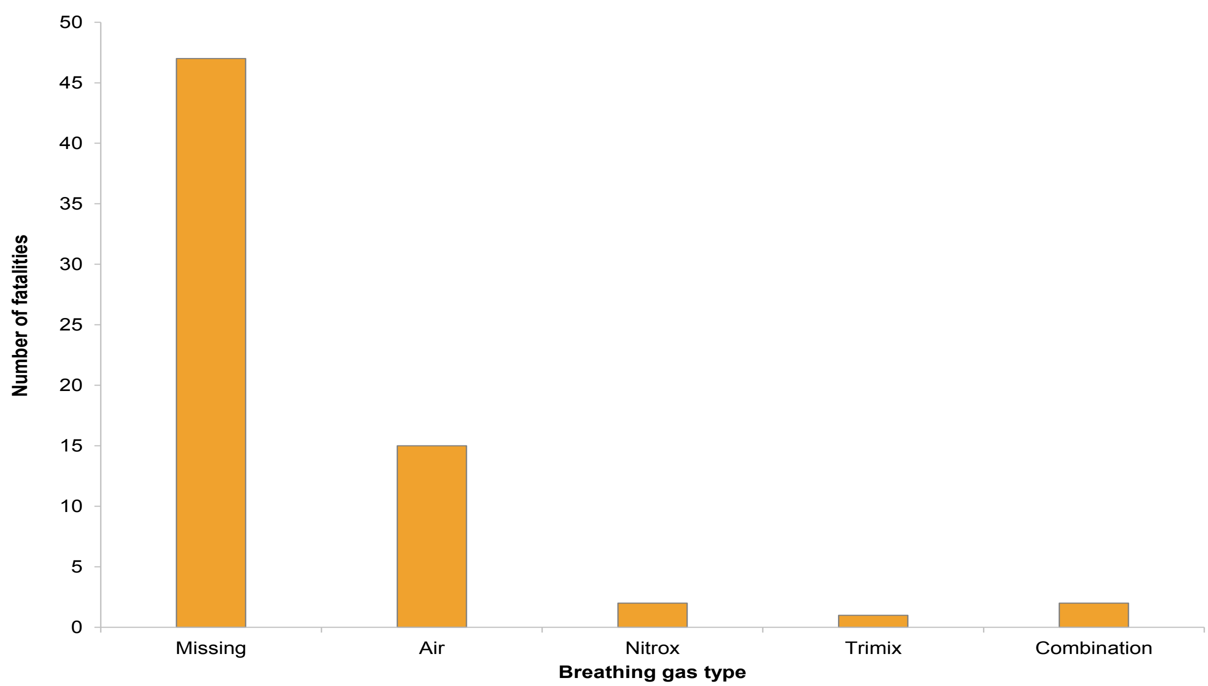


Figure 1.6-4. Type of gas used in U.S. and Canadian scuba fatalities, 2015 (n=67)

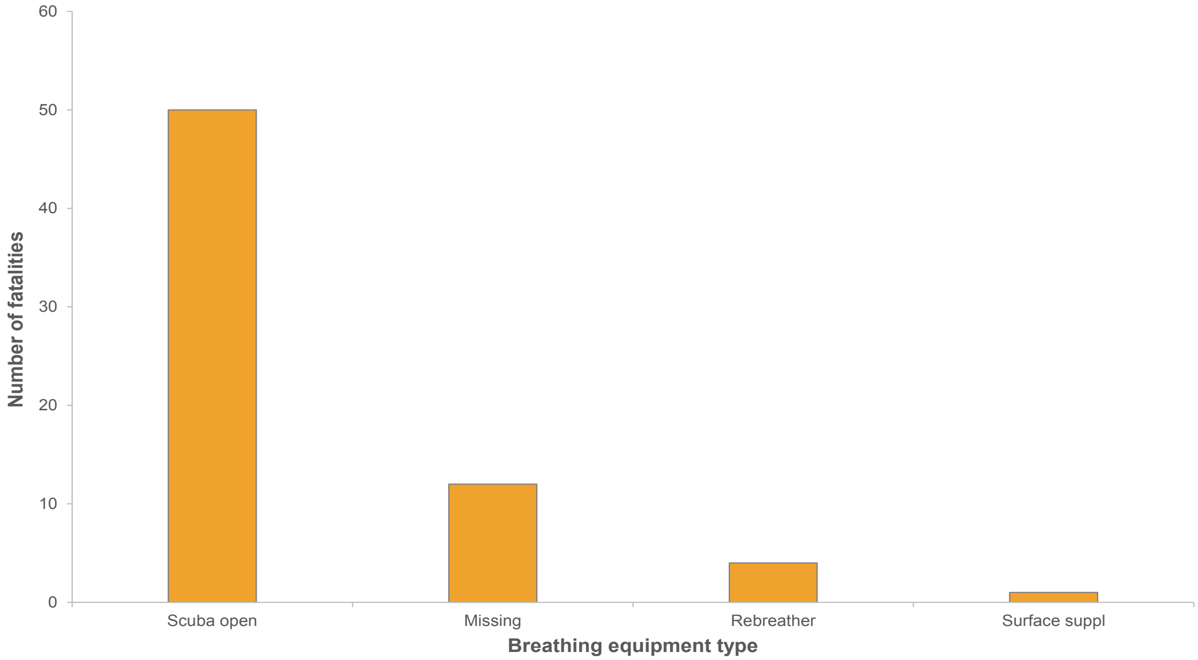


Figure 1.6-5. Type of breathing equipment used in U.S. and Canadian scuba fatalities, 2015 (n=67)

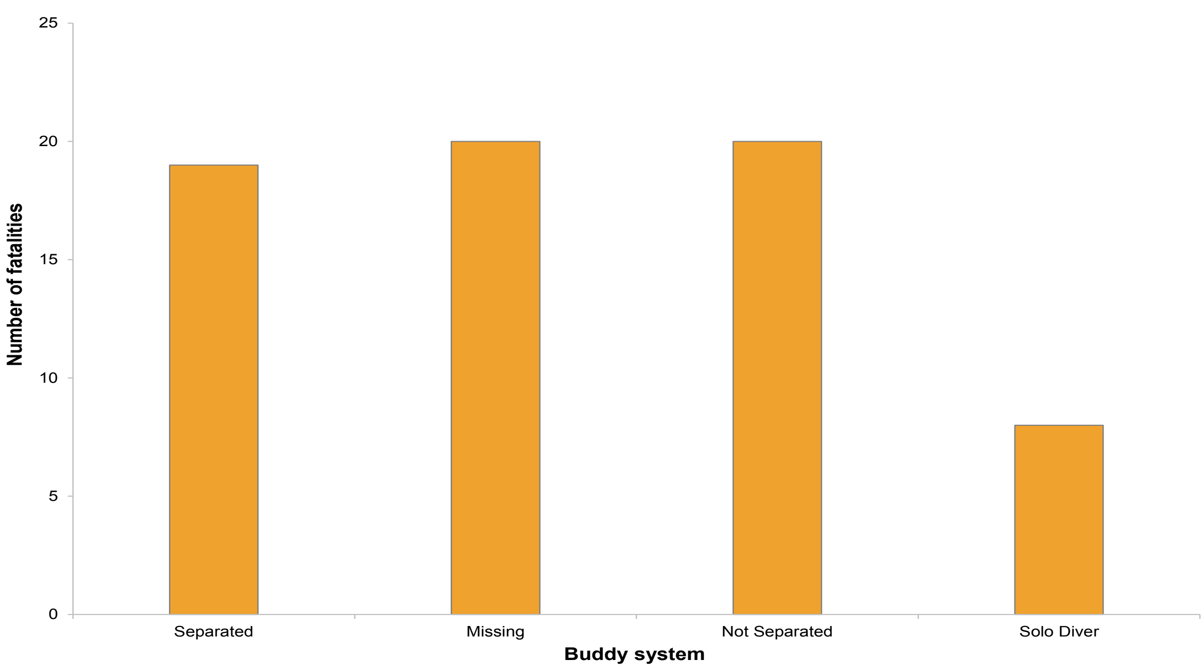


Figure 1.6-6. Buddy status during U.S. and Canadian scuba fatalities, 2015 (n=67)

DIVE BUDDY STATUS:

While at least 8 (12%) of the 67 fatal dives were intended as solo dives, most of the 2015 fatalities began as buddy dives. Adherence to buddy-system best practices is difficult to establish retrospectively. When survivors notice that their buddy is missing, it does not necessarily mean that the buddy became intentionally separated; rather, it may mean that nobody noticed the diver was having the problems that eventually led to the fatality. Yet either circumstance indicates a failure of the buddy system. Figure 1.6-6 shows the distribution of fatal dives according to buddy status.

Here is an example of a fatality in which buddy status played a role:

CASE 1-65: SILT CAUSED AN UNPLANNED SEPARATION AND A FATAL DELAY IN EXITING A CAVE

A 68-year-old male, an experienced and certified cave diver, had completed several dives in the same cave system prior to the fatal dive. The diver and his buddy entered the cave system with two primary tanks each, one diver propulsion vehicle (DPV) each, and a decompression tank each, which they staged near the exit. The divers scootered to around 3,000 feet (900 meters) penetration and then left the main line to explore a side passage. The victim was wearing his primary tanks on his back, while his buddy was wearing hers on either side. The pair entered a low section of cave, where the floor was covered in mounds of dark silt. Visibility was suddenly compromised, and the divers lost contact with each other. The buddy found her way back to the main line and reported waiting for three to four minutes before leaving for the cave exit. By the time the victim returned to the main line, leaving his DPV in the side passage behind him, his buddy was gone and the victim started the long swim out. At the time, they were the only dive team in the cave. Meanwhile, the buddy surfaced and notified officials. A team from International Underwater Cave Rescue and Recovery arrived on site, entered the cave, noted the decompression tank just inside the entrance, and found the victim about 300 feet (90 meters) from the exit, his tanks empty.

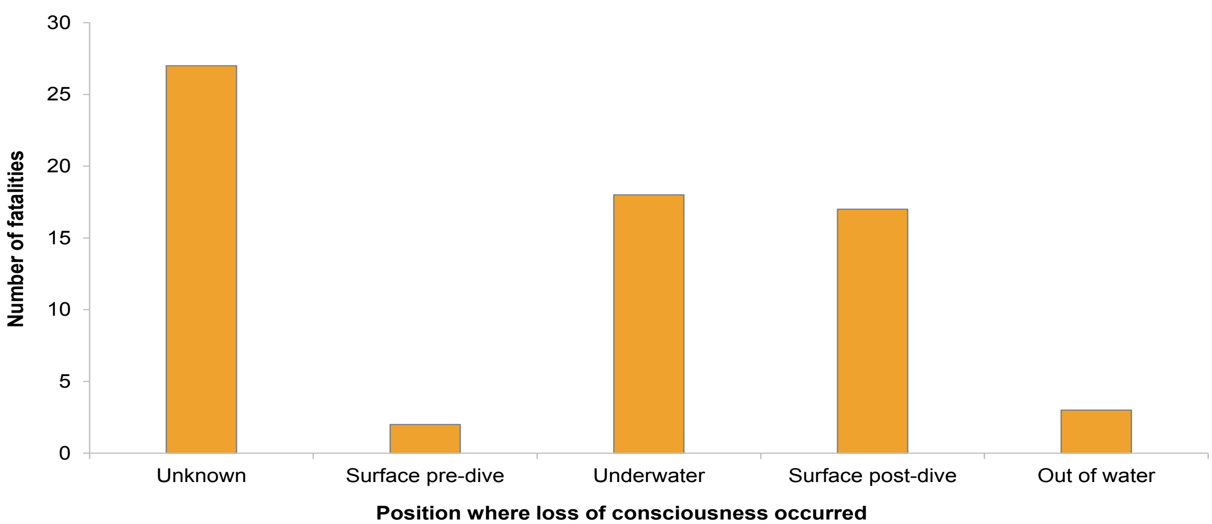


Figure 1.7-1. Dive phase when the victim lost consciousness in U.S. and Canadian scuba fatalities, 2015 (n=67)

1.7. ANALYSIS OF SITUATIONS AND HAZARDS

We classified each fatality that we investigated according to the phase of the dive during which the incident occurred and also recorded the chronological chain of events that ended in death.

FATALITIES BY DIVE PHASE

The dive-phase categories are as follows: 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 40 of the 67 cases (60%). Figure 1.7-1 shows the phase of the dive when the victim lost consciousness. As can be seen, in the majority of fatalities this occurred either underwater (n=18, 27%) or on the surface following the dive (n=17, 25%).

This case is an example of a fatality that occurred on the surface after completion of a dive:

CASE 1-39: BOAT COULDN'T REACH A LONE, STRUGGLING DIVER

A 65-year-old male was on a guided dive to 40 fsw (12 msw). He reportedly separated from the dive group to surface alone. At the surface, he was seen struggling to get to the tag line. He sank before anyone on the boat could reach him to offer assistance. His body was recovered three hours later.

CAUSES OF INJURY AND DEATH

DAN's determination of the causes of these reported fatalities was based on the following sources of information: a) the autopsy findings and/or the underlying cause of death as reported by a medical examiner; b) the victim's dive profile; c) the sequence of events as reported by witnesses; d) the findings from analyzing the victim's equipment and gas supply; and e) the expert opinions of DAN reviewers. This process is described in further detail in a published paper (Denoble et al. 2008).

The 2015 fatalities' root causes (also known as triggers, mechanisms, disabling injury, and causes of death), could not be established in 33 of the 67 cases (49%), mostly because of missing information and inconclusive investigative results. Among the 34 cases (51%) for which such information was available, the most common triggers were an underlying health problem (15%) and running low on or being out of air (6%). Table 1.7-1 lists all triggers that could be identified.

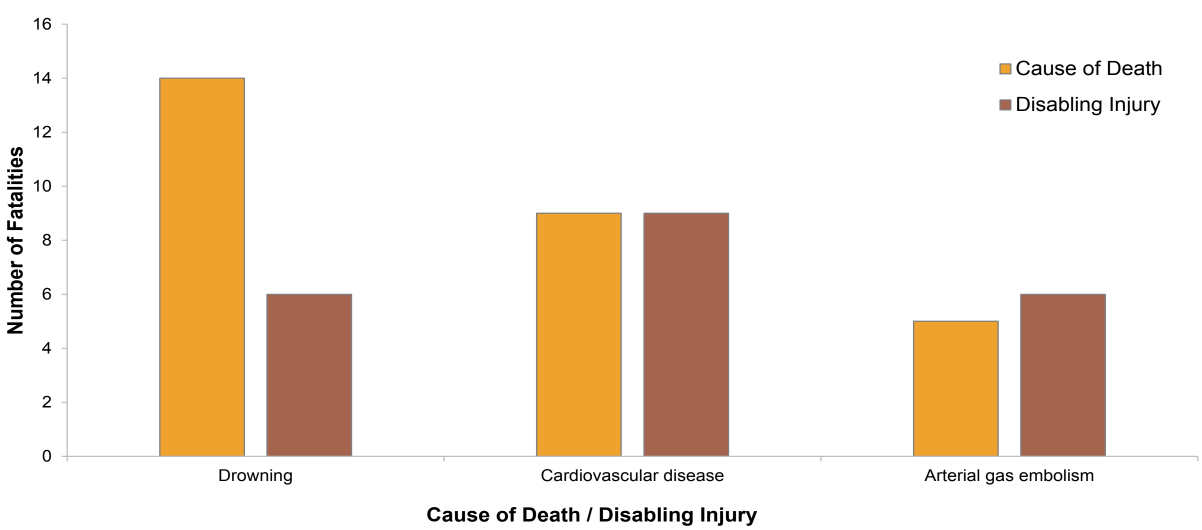


Figure 1.7-2. Most common causes of death (n=28) and disabling injuries (n=21) in U.S. and Canadian scuba fatalities, 2015

Trigger	Count
Alcohol intoxication	1
Difficulty breathing	1
Equipment malfunction	1
Health problem	10
Low on or out of air	4
Not applicable	7
Overweighting	1
Panic	2
Rough seas	1
Unknown	6
Total	**34**

Table 1.7-1. Triggers for U.S. and Canadian scuba fatalities, 2015 (n=34)

The most commonly identified harmful events, or actual mechanisms of injury, were underlying health problems (12%) and insufficient breathing gas (9%). Table 1.7-2 lists all the known mechanisms.

Mechanism	Total
Ethanol intoxication	1
Health problem	8
Insufficient breathing gas	6
Not applicable	7
Other	1
Panic	1
Rapid ascent	5
Unknown	5
Total	**34**

Table 1.7-2. Mechanisms of injury for U.S. and Canadian scuba fatalities, 2015 (n=34)

In most of these 34 fatalities, the cause of death as established by medical examiners was drowning. However, according to DAN's expert reviewers, the data indicated that a leading cause of disabling injuries was an acute cardiac event. Tables 1.7-3 and 1.7-4 list these 34 fatalities' disabling injuries and causes of death, respectively, while Figure 1.7-2 compares disabling injuries and causes of death side by side. These presentations of the data show clearly that in 2015, the leading cause of death was drowning and the leading disabling injury that led to death was heart problems.

Disabling Injury	Total
Arterial gas embolism	6
Drowning	6
Heart problem	9
Intoxication	1
Loss of consciousness	1
Not applicable	7
Unknown	4
Total	**34**

Table 1.7-3. Disabling injuries in U.S. and Canadian scuba fatalities, 2015 (n=34)

Cause of death	Total
Acute myocardial infarction	2
Arterial gas embolism	5
Atherosclerotic cardiovascular disease	4
Dilated cardiomyopathy	1
Drowning	14
Hypertensive and atherosclerotic cardiovascular disease	2
Hypertensive cardiovascular disease	1
Hypertrophic cardiomyopathy	1
Unknown	4
Total	**34**

Table 1.7-4. Causes of death in U.S. and Canadian scuba fatalities, 2015 (n=34)

These two cases illustrate the complex interplay between the disabling injury and the cause of death in incidents that result in a fatality:

CASE 1-07: A LONE DIVER SUFFERED HEART PROBLEMS

A 66-year-old male with unknown certification and experience had an arrangement with a local landowner to park his truck near a beach from which he frequently dived alone. He was last seen alive two hours before his body was found floating on the surface by kayakers. Investigators were called to the scene. According to a news report, heart problems were a factor in the death, which was ruled an accident by the coroner's office.

CASE 1-33: ANTIDEPRESSANTS WERE RULED A CONTRIBUTING FACTOR

A 41-year-old female had been diving for 23 years and had made more than 400 dives. She had experience in a variety of diving conditions and was certified as both a divemaster and a nitrox diver. Her most recent dive medical examination had been performed three years earlier. She was being prescribed fluoxetine (also known by the brand name Prozac), a drug commonly prescribed for treating depression. This dive was in a popular flooded quarry, and the plan was for a group of four divers to navigate underwater between manmade objects. About 40 minutes into the dive, the victim calmly pointed to her pressure gauge, pointed to her chest, and gave a thumbs-up signal, then pointed at the other divers and made a "shooing away" motion. The diver then waved goodbye and moved away toward the exit point. The other members of the group surfaced approximately 20 minutes later. They could not see the victim and noticed her gear was not at their vehicle, so they alerted the facility staff and called EMS personnel. Two members of the group re-entered the water and found the victim in 50 ffw (15 mfw) after about 11 minutes of searching. The victim was returned to the surface an hour and 20 minutes after last being seen alive. Her pressure gauge indicated her tank was empty. The autopsy found markedly high levels of fluoxetine, and the cause of death was ruled to be drowning, with fluoxetine toxicity a contributing factor.

Fluoxetine is sold under a number of brand names, including Prozac and Sarafem. In 2010, more than 24 million prescriptions for generic fluoxetine were filled in the U.S. The U.S. Food and Drug Administration recommends a starting dose of 20 mg/day and a maximum dose of 80 mg/day, but the pathology report in this case indicated the diver had taken far in excess of the recommended maximum safe dose. It was reasonable, therefore, for the medical examiner to conclude that the diver was likely impaired and that this was a contributing factor in the drowning.

DAN receives many inquiries concerning antidepressants, and this case serves to highlight the fact that divers may not fully understand what is happening inside their dive buddies, even when a dive seems uneventful. DAN recommends that whenever a diver signals that they intend to exit, a buddy or team member should escort the diver to the exit point and see them safely out of the water.

1.8. REBREATHER FATALITIES

DAN is aware of four recreational diving rebreather fatalities in 2015 that occurred in the U.S. or involved a U.S. citizen whose body was repatriated to the U.S. Three of those cases are described below.

CASE 1-25: THE CURRENT WAS TOO STRONG FOR A REBREATHER DIVER

A 53-year-old male, a certified and experienced technical diver, was participating in an annual technical diving event. An hour into the dive, the victim reportedly experienced difficulties with a strong current and was assisted to the surface by his buddy. The victim was unconscious by the time they reached the surface. The buddy signaled for assistance, the pair were collected by a dive boat, and CPR was performed while the boat headed for shore. An ambulance took the victim to the hospital, where he was pronounced dead.

CASE 1-91: A REBREATHER DIVER LIKELY FORGOT TO TURN HIS VALVE ON

A 57-year-old male had been trained on a rebreather (though to what level is unclear) and had made a total of about 2,000 open water dives. He had not consistently dived with his rebreather since achieving certification two years earlier, however. He was an active open water dive instructor and had booked dives on a dive charter boat to explore a shipwreck in 150 fsw (46 msw). He was without a buddy and was believed to be using a brand new DPV that he had used only once before, in a pool. He was also using a drysuit for the first dive in some time, because he had recently been training students while wearing a wetsuit. Another diver on the boat was using the same model of rebreather and the same type of DPV, so these two divers buddied up.

The victim delayed getting into the water, taking about 15 minutes to don his equipment, and entered the water with a partial pressure of oxygen (ppO_2) of 0.22 bar. The set point on his electronic handset was 0.19 bar. The victim then surprised his buddy by engaging his DPV for the descent, rather than using the descent line. The victim descended without conducting buddy or bubble checks.

The pair lost sight of each other for the first 10 minutes of the dive, then the buddy spotted the victim near the wreck. When the buddy saw the victim, he appeared to be having trouble and was using his bailout open circuit regulator instead of his rebreather. By the time the buddy reached the victim, there were no bubbles coming from his regulator and the victim appeared to be unconscious. The buddy pressed the victim's purge button but no gas came out, and the victim's submersible pressure gauge indicated that his bailout tank was empty. During the rescue, attempts to inflate the victim's buoyancy compensator device (BCD) were unsuccessful, and it was discovered that the victim's diluent valve was closed. The buddy opened the valve to inflate the victim's BCD.

The victim was sent ahead to the surface, feet first, while the rescuers and the buddy completed their decompression stops. The victim was recovered at the surface and swiftly taken to the nearest hyperbaric chamber but was pronounced dead shortly after his arrival there. The ppO_2 displayed on his dive computer reached 2.50 bar before falling during the dive, indicating that his oxygen valve was turned off at depth (it is of note that 2.50 bar is the maximum possible value displayed by his model of dive computer, even if ppO_2 levels are higher). Estimates, based on the recorded millivolt output from the oxygen sensors in his dive computer, suggest that the ppO_2 in his breathing loop when he reached 151 fsw (46 msw) was likely around 4.8 bar. None of the warnings displayed by his dive computer, from one minute into the dive onward, were acknowledged by the victim pressing a button on his handset.

It is thought that the victim descended with his diluent valve closed. During testing of his equipment, it was discovered that his diluent valve could not be turned on while someone was wearing the unit, because the drysuit inflator valve obstructed access to the diluent value. The victim had apparently arrived at depth, bailed out to a 40-cubic-foot tank, was unable to inflate his BCD, ran out of gas, and drowned while wearing a fully functioning rebreather with one of its valves turned off. The dive computer worn by the victim logged a total dive time from surface to depth to resurfacing of 21 minutes.

CASE 1-95: A DIVER FELT UNWELL BEFORE LOSING CONSCIOUSNESS AT THE SURFACE

A 54-year-old male was diving with a rebreather in a flooded quarry. The diver's certification and experience level were unknown. The victim complained of feeling unwell before the dive but decided to dive anyway, putting his stomach's uneasiness down to his previous night's meal. According to investigative reports, the victim initially went into the water with a friend, then signaled that he planned to surface a short time later. At the surface, he indicated that he still felt unwell, then descended without his rebreather loop in his mouth. The buddy grasped the victim, towed him to shore and then called emergency services. The main findings at autopsy included an enlarged heart, heart disease and plaque-

obstructed arteries. There were no findings suggestive of drowning or gas emboli. Toxicology tests found no signs of recreational drugs or alcohol. The victim's equipment was checked by an expert who found a small gas leak; however, the tank still had residual gas, which was tested and shown to be a normal mixture.
The symptoms this diver experienced before the dive were probably related to acute coronary syndrome, but the diver may not have recognized them.

All divers should remember that it is important not to dive if they feel unwell, regardless of the possible or assumed cause. And divers over 45 should be familiar with the symptoms of acute heart problems and should seek evaluation if they ever experience such symptoms.

1.9. DISCUSSION

This year's "Fatalities" section highlights data in support of the messages that DAN consistently communicates to the diving community. Divers, like the population in general, are getting older and heavier. And, being human, divers sometimes make mistakes. While many of the cases in this year's "Fatalities" section appear (with hindsight) to have been preventable, some cases involving older victims had no obvious provocative or contributive factor.

No one wants to police recreational divers, but a quiet word when someone is about to make a poor decision should be tolerated by most divers. It is high time for the diving community to fully embrace a culture of safety, a culture where predive checks become as routine and expected as safety stops have become. Checklists have gained popularity among rebreather divers, and, just as the octopus regulator was pioneered in cave diving but has moved into mainstream diving, DAN sincerely hopes checklists will move beyond technical diving and into mainstream diving.

Shortcomings in personal fitness, stamina and general health again seem to have played a role in some of this year's fatalities. The sea is an unforgiving playground. While obese divers may be able to manage recreational diving when conditions are benign, if the current picks up or surface conditions deteriorate, then, all else being equal, a fitter diver will be better able to cope. If we love diving as a lifestyle, if we look at dive magazines and imagine ourselves drifting over pristine coral reefs, if we proudly tell our friends that we're going scuba diving on vacation, then we owe it to ourselves, our family and those we care for to stay in shape for diving. Start today. Let being fit to dive be your motivation to succeed. You will likely see your air consumption improve, too.

In addition, given that cardiovascular problems remain a significant contributory factor in many diving fatalities, DAN encourages every diver to know the signs and symptoms of acute heart problems. Procedures for the medical evaluation of fitness to dive may be due for updating to account for the aging diver population and thus the increased prevalence among divers of medical conditions associated with aging.

This Annual Diving Report contains the lowest number of American and Canadian recreational scuba fatalities in more than 20 years, but that does not necessarily mean diving is getting safer. The British Sub-Aqua Club also reported a 20-year record low number of deaths for 2015 among its membership. Perhaps we, as a community, are getting better at diving safety? However, as in the U.S., it is thought that British divers are getting older (Cumming and Peddie 2015). So perhaps it is more likely that, as a community, we are not making as many dives each year. It must also be noted that, while every effort is made to compile the most accurate data available, we nonetheless do sometimes hear about a small number of diving fatalities years after they happened. The numbers presented in the DAN Annual Diving Report do not change much after the reports are published, but they never decrease — they can only increase.

Rebreathers continue to gain popularity, and this year's report again highlights the fact that common triggers for rebreather deaths include both pre-existing medical conditions and simple human error — such as in Case 1-91 (see page 25), where a diver likely forgot to open his diluent valve. Other contributing factors in that case may have included new equipment, a configuration that prevented opening the valve during the dive, a failure to complete a predive checklist, a failure to make buddy and bubble checks, the use of a DPV instead of a descent line to descend — the list of possible factors goes on. Rarely does a single mistake kill a diver; most fatalities culminate from incremental increases in risk and/or incremental reductions in a diver's likelihood of surviving, until the tipping point is reached and the diver is unable to recover. This is where a culture of dive safety that engages everyone in our community, at all levels, increases safety — through many incremental reductions in risk.

Buddy checks, checklists, clear dive plans, gas planning, maintenance of dive skills, properly equipping yourself for every dive, staying fit to dive: all these steps reduce risk, so we can keep diving safely, year after year.

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SECTION 2. DIVING INJURIES

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

This section's two main sources of information about scuba diving injuries are the DAN Medical Services Call Center (MSCC) and data regarding treatment of injured divers in the Annual Survey of Hyperbaric Chambers. (Note that information collected by DAN on fatalities associated with scuba diving is covered in Section 1 of this report and on injuries and fatalities associated with breath-hold diving in Section 4.)

Table 2.1-1 shows the volume of calls to DAN's medical department. In 2015, there were 11,558 calls or emails requesting assistance, information or consultation. The medical staff answered 3,589 calls requiring assistance, 5,954 calls requesting medical information, and 2,015 email inquiries. In addition, there were 43 calls about fatalities.

Year-to-year comparison						
Activity	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Emergency Line Calls	2,518	3,493	4,382	5,047	5,041	3,589
Information Line Calls	5,727	6,266	5,923	5,556	5,506	5,954
Email Inquiries	3,470	3,444	2,758	3,161	2,642	2,015
Totals	**11,715**	**13,203**	**13,063**	**13,764**	**13,189**	**11,558**

Table 2.1-1. Volume of MSCC contacts, 2010 – 2015

In 2015, 3,589 callers asked DAN for assistance with acute health issues — 2,124 concerning dive-related issues and 1,474 concerning health issues not related to a dive. The classification of cases in the MSCC is usually done early in the case management process, when not all pertinent details are available. The follow-up process focuses on decompression illness (DCI), immersion pulmonary edema (IPE), unconsciousness and severe nondive-related issues like chest pain. The tallies in Table 2.1-2 reflect cases reviewed through the follow-up process and retrospectively for this report.

Case classification	Initial	Reviewed
Decompression sickness (DCS)	**599**	**250**
DCS Type 2 (all)	279	106
DCS Type 1 (pain only)	138	62
Cutaneous DCS	173	76
Inner ear DCS	31	34
Pulmonary problems/chokes	9	2
Barotrauma	**1,211**	**733**
Ear and sinus barotrauma	871	631
Unspecified ear barotrauma (EBT)	*	19
External EBT	*	4
Middle EBT	*	445
Inner EBT	38	13
Alternobaric vertigo	5	3
Facial baroparesis	*	2
Sinus problems	118	113
Arterial gas embolism (AGE)	41	12
Pulmonary problems	143	64
Mask squeeze	20	14
Gastrointestinal problems	6	1
Dental problems	6	2
Suit squeeze	1	0
Other	**407**	**194**
Marine envenomation	250	124
Immersion pulmonary edema (IPE)	36	19
Nonfatal drowning	34	12
Fatality	28	22
Gas contamination	22	4
Finfoot	20	7
Loss of consciousness	8	6
Cardiac arrhythmia	9	2

*Not available as an initial classification

Table 2.1-2. Number of cases reviewed by initial classification, 2015

Ear and sinus barotrauma was the most common health issue reported. It is likely that many more divers experience some degree of ear or sinus barotrauma but don't report it, because they either handle it on their own or seek help from local medical facilities without calling the DAN MSCC.

Decompression sickness was the second most common dive-related reason for calls to the MSCC. The reported cases of DCS Type 2 included 34 cases of suspected inner ear decompression sickness (IEDCS). Cutaneous DCS was also quite common. It appears that cutaneous DCS has been reported more often in recent years, but some divers still fail to recognize it. Thus this report describes several cases and includes photos of the skin rash to help divers better recognize the condition.

2.2. CUTANEOUS DCS (SKIN BENDS)

Skin changes that occur after diving are the source of many calls to the MSCC, in part because such symptoms are so visible they are easily appreciated by anyone. The fact is, such changes are often rapid and dramatic and are sometimes associated with other signs and symptoms. Unfortunately, the etiology for many rashes, skin eruptions and pruritus is never definitely found and only a list of suspected causes can be identified.

Cutaneous DCS, also referred to as "skin bends," is one condition that is often readily identified. Acute onset of mottling after diving is the most common cutaneous manifestation of DCS. It is nearly exclusive to diving. The importance of skin mottling is that it is obvious and may draw attention to other less obvious signs or symptoms of DCS.

A troubling number of cases begin with cutaneous DCS that resolves spontaneously or with the administration of surface oxygen. But all too often, the diver disregards these symptoms and continues to dive, either that day or the next day, only to be stricken with a serious case of neurological DCS. So divers who suffer any form of cutaneous DCS are advised to engage in no further diving until they're seen and cleared by a physician who specializes in dive medicine.

Several cases histories of cutaneous DCS, with photographs, are presented here for review. These cases demonstrate some of the important aspect of cutaneous DCS. For example, divers will often ignore symptoms of serious DCS, such as weakness or loss of sensation. This may be intentional, may be due to the dramatic skin presentation, or may be simply because such symptoms aren't noticed until they're detected during a neurological examination. Many cases of cutaneous DCS occur alone, but serious cases of DCS can also include skin manifestations. Also of note is the fact that patent foramen ovale (PFO) cardiac defects have been associated with cutaneous DCS.

CASE 2-01: CLASSIC CASE OF SKIN ITCHING AND MOTTLING

The caller was the wife of a diver who, after a single day of diving, developed itching and marbling across his abdomen. The symptoms occurred approximately 60 minutes after his last dive. She said, "It looks just like the pictures of skin bends I see on the internet."

His dive profiles, on air, were as follows:
#1: 65 fsw (20 msw) for 80 minutes; surface interval (SI) of 1:05
#2: 64 fsw (20 msw) for 71 minutes

We recommended prompt evaluation at the closest emergency department, since the nearest hyperbaric chamber was on another island. Upon our request, the diver took pictures of his abdomen and emailed them to us.

Figure 2.2-1. Skin mottling on abdomen

The pictures showed typical skin mottling of the abdomen. The diver was seen in a local emergency department; although no neurological or other DCS symptoms were found, the diver was treated with surface oxygen for two hours. His symptoms improved and had resolved by the next morning. The treating physician advised the diver not to dive for six days and to dive more conservatively when he resumed diving. During a follow-up call 10 days later, the diver reported that he was back to diving but was diving conservatively and using enriched air nitrox. He has not had any problems since.

CASE 2-02: CUTANEOUS DCS WITH ABDOMINAL BLOATING

The caller was a divemaster with 23 years of diving experience who complained of a swollen abdomen and skin color changes. While on vacation, he did two days of diving, two dives per day. His first day of diving was to a maximum depth of 82 fsw (25 msw) for 45 minutes, with a one-minute stop at 45 fsw (14 msw) and a five-minute safety stop. His second dive was to a maximum depth of 75 fsw (23 msw), with a 40-minute total run time, a one-minute stop at 45 fsw (14 msw), and a five-minute safety stop. He used 32% nitrox for all his dives. About five hours after his last dive of the day, he noticed that his abdominal region felt abnormally swollen and tender.

The next day he did another two dives, the first to a maximum depth of 90 fsw (27 msw), with the same stops as the previous day, and the second to 75 fsw (23 msw), with the same stops and same gas mix. Following the second dive, he noticed marbling on his stomach, which was very tender. When asked if during these dives he had noticed the abdominal bloating he had mentioned from the day prior, he said he felt good at depth and did not notice any bloating.

He did not know what was going on and thought maybe he had a hernia or had pulled a muscle. He went to a local physician, who did an ultrasound of his abdominal muscles and found no hernia but thought maybe he had a torn muscle that was bleeding. That evening, the patient still felt unwell and was up all night.

The following day, after doing some searching on the internet and finding some pictures of lymphatic DCS and abdominal swelling that looked like his, he went to a different physician. This physician administered surface oxygen (which he had not been given the day before). The patient was then treated in a hyperbaric chamber with U.S. Navy Treatment Table 6 (TT6). His skin symptoms had resolved the previous night, prior to his coming to the chamber. He said that his abdominal bloating and discomfort resolved after he had been at depth for approximately five or so minutes. He felt fine after treatment in the chamber and did not need any further treatments. It was recommended that he not fly for 72 hours; his recollection was that he flew 74 hours later.

He had recently been diagnosed with celiac disease and asked whether celiac-related inflammation sites could possibly promote bubble formation. The resolution of his abdominal bloating just five minutes after recompression may indicate that he experienced an accumulation of gas rather than of fluid.

CASE 2-03: A SCRATCH IS CONFUSED WITH SKIN BENDS

A call came in on the emergency line from Asia. The caller complained of skin mottling, which she had noticed about one hour after her last dive. She described it as a six-inch-by-one-inch stripe across her stomach, similar to a birthmark. She thought it looked like a sunburn and said it was slightly itchy. She had done one dive per day on two consecutive days, the first in 30 fsw (9 msw) for 42 minutes and the second in 50 fsw (15 msw) for 45 minutes. The rash had not changed for four days by the time she called DAN. She sent the photo below.

Figure 2.2-2. Rash not typical of cutaneous DCS

The skin change was not typical of cutaneous DCS, which has two common appearances: a red skin rash or skin mottling. This was neither of those. Also, mottling related to DCS usually fades out within a few days. When treated with surface oxygen or hyperbaric oxygen

(HBO), the bluish tones fade out first and the red gradually fades over the next few days. This was most likely a scratch acquired from a rough object rather than cutaneous DCS.

CASE 2-04: ITCHING AND MOTTLING OF SHOULDER AND BACK

The caller was a woman in her late 40s who complained of an odd, itchy feeling in one shoulder, beginning 30 minutes after her last dive. She also noticed mottling on her shoulder and the top of her arm an hour later, as well as a tender spot at the back of her neck.

Her dive profiles, on air, were recorded by a dive computer as follows:
#1: 75 fsw (23 msw) for 42 mins; SI of 1:00
#2: 79 fsw (24 msw) for 33 mins

Figure 2.2-3. Mottling on shoulder and back

She was advised to seek evaluation, but she never called back. This remains a likely but unconfirmed case of skin bends.

CASE 2-05: ABDOMINAL RASH AFTER A NO DECOMPRESSION LIMIT (NDL) VIOLATION

A caller to the emergency line had performed two dives that morning. On his second dive, the computer displayed an NDL violation, and he cleared deco prior to surfacing.

Following his second dive, the caller noticed a rash or bruise on his back and abdomen and a sensation of pain.

His dive profiles were as follows:
#1: 85 fsw (26 msw) for 49 mins on air;
SI of 1:00
#2: 75 fsw (23 msw) for 49 mins

Figure 2.2-4. Abdominal rash that disappeared within 12 hours

The rash disappeared within 12 hours, before the diver could see a physician. The changes were quite mild and not very typical of DCS. A red milliary rash, associated with inflammation, could disappear in a few hours. Mottling, however, takes a few days to resolve.

CASE 2-06: ABDOMINAL ITCHING AND MOTTLING ASSOCIATED WITH NEUROLOGICAL SYMPTOMS

This diver exceeded the NDL on her first dive (to 90 fsw [27 msw] on air) and did the required decompression stops. Dives two and three were consecutively shallower (60 fsw [18 msw] and 50 fsw [15 msw]) and on nitrox.

She began to feel itching one hour after her last dive, during the boat ride to shore. She noticed major rash-like mottling after using a hot tub. On her flight home, the next day, she felt superficial abdominal pain. After two days, her symptoms were still evident, and she was admitted for evaluation and treatment. Lab tests and a chest X-ray were normal, but a neurological examination showed poor mentation, confusion, confabulating answers, poor performance on the Romberg test and a minor abdominal rash.

After an HBO treatment, her mentation was greatly improved and her Romberg results were normal. The rash and itching resolved. Her only remaining symptom was superficial abdominal pain/tenderness on touch. At a follow-up appointment seven days later, she reported she was back to normal.

Figure 2.2-5. Abdominal mottling with neurological symptoms requiring HBO treatment

CASE 2-07: ABDOMINAL RASH AND HAND NUMBNESS

A moderately experienced diver with 55 lifetime dives called the emergency line and reported that about three hours after getting out of the water, following two deep dives, she began to feel "off." She felt pressure in her eyes and was seeing "white spots"; she had a pink, blotchy rash over her stomach and upper legs; and she'd had two episodes of left-hand numbness, with her thumb and index finger feeling like they were asleep. She believed she was never closer than 14 minutes from deco.

Her dive profiles, on 29% enriched air nitrox (EAN), were as follows:
#1: 103 fsw (31 msw) for 30 minutes; SI of 0:55
#2: 103 fsw (31 msw) for 32 minutes

Figure 2.2-6. Abdominal rash

She was admitted to a local HBO facility and was evaluated and then given surface oxygen for four hours. On follow-up two days later, she said that after breathing the surface oxygen, the numbness in her hand was gone and her vision had returned, although the outer part of her left arm and her left calf still did not feel normal. She complained of reduced sensation and soreness in her quads, hamstrings and gluteus muscles, noting that the effects had resolved while she was breathing surface oxygen but had returned the following day. She was referred to a local HBO facility, where an HBO treatment was scheduled. At this point, further contact with her was lost.

CASE 2-08: CONTACT DERMATITIS, NOT DCS

This caller asked only for the location of the hyperbaric chamber closest to his location.

It turns out that the day after he did three dives (18 hours after his last dive), he flew without incident in an unpressurized plane, at an estimated altitude of 16,000 feet, and went home to bed.

The following day, about 32 hours after his last dive and 14 hours after his last flight, he awoke with a blotchy rash on his side, bilateral elbow pain, and numbness in his left palm and in the fingers of his right hand (thumb, index and middle finger). After a Google search for symptoms of DCS and skin bends, he was concerned that his rash signaled skin bends. He was not worried about the elbow pain.

Figure 2.2-7. Contact dermatitis

All his dives were estimated, as he was with a group of divers. This diver did not have a computer, nor did he track his personal dive profiles. The skin changes in the photo he sent did not fit the usual appearance of skin bends, though other symptoms he had could be considered typical of DCS. He was advised to seek evaluation but was told that his skin manifestations were likely contact dermatitis rather than DCS.

CASE 2-09: SKIN MOTTLING WITH CEREBRAL NEUROLOGICAL SYMPTOMS

The caller had noticed itching across her abdomen, a mottled rash and deep muscle pain several hours following the last of six dives over two days. The itching began approximately three hours after the end of her last dive. Her symptoms had gotten progressively worse in the previous two hours, and she was seeking suggestions. She admitted to having had some trouble equalizing during her descents and ascents, but otherwise had had no issues during her dives. She did not have her computer with her (it was in her dive locker), so she reported her dive profiles as she remembered them.

Her estimated dive profiles, all on 30% EAN, were as follows:
Day 1
#1: 70 fsw (21 msw) for 60 mins; SI of 2:00
#2: 50 fsw (15 msw) for 50 mins
Day 2
#1: 90 fsw (27 msw) for 55 mins; SI of 1:00
#2: 60 fsw (18 msw) for 50 mins; SI of 2:00
#3: 70 fsw (21 msw) for 50 mins; unknown SI
#4: 40 fsw (12 msw) for 55 mins

Figure 2.2-8. Skin mottling

She had then been admitted to a local hospital with a hyperbaric facility. The physician detected some left-hand grip weakness and balance instability and an inability to walk heel-to-toe; results of a Romberg test were also positive. She was treated in the recompression chamber with one round of USN TT6 and two of USN TT5, for a total of three HBO treatments, before complete resolution of all her balance and strength issues was achieved.

She called seeking referrals for follow-up. The treating physician had recommended that she wait six months before returning to diving. She was a volunteer diver at a local aquarium, where she typically did dives in 15 to 20 fsw (5 to 6 msw). She asked if she might be able to get back in the water at the aquarium sooner than six months. She had been diving for eight years and had done about 250 dives, excluding aquarium dives. She had never had problems previously. She was advised to discuss her health and her diving practices with an experienced dive physician before she returned to diving.

2.3. DCS TYPE 2

A possible DCS 2 classification was initially assigned in 279 cases reported during 2015. A follow-up was attempted in all but 22 cases, where contact information was not available. In 128 cases, the follow-up was not completed due to inability to connect or lack of cooperation from the patient. In 129 cases, the follow-up was completed, and 13 cases were marked for long-term follow-up. Type 2 DCS may manifest itself with neurological and cardiorespiratory symptoms. The most common are symptoms and signs of spinal cord or brain and inner ear injuries. In severe cases, divers may feel excessive fatigue. Among MSCC cases of suspected DCS, those involving neurological symptoms (DCS 2) are more common than those involving only joint and muscle pain or a skin rash (DCS 1). This is because divers and medical professionals are more likely to call DAN for assistance and consultation for severe cases than for cases of DCS 1, which is perceived as being milder. Following are some interesting cases of DCS 2, which may help readers appreciate the variety of DCS manifestations.

CASE 2-10: SPINAL INJURY WITH RESIDUAL BLADDER DYSFUNCTION CAUSED BY RAPID ASCENT

A hyperbaric medical physician called for a consult regarding a 45-year-old novice diver who had suffered spinal cord DCS and after five days of treatment could still not pass urine. The physician asked for advice as to the best course of action.

The patient had done a rapid ascent from a depth of about 30 fsw (9 msw) and within 10 minutes of surfacing had experienced numbness in his toes; the sensation rapidly progressed up his legs as far as his thighs. This was followed by numbness in his fingers that progressed up his arms as far as his shoulders. He was found to have a staggering gait and could not pass urine. Neurological testing confirmed that he had general peripheral loss of sensation and motor weakness.

The diver had done two dives on the day in question. The maximum depth of his first dive was 70 fsw (21 msw) and of his second 57 fsw (17 msw). His bottom times and surface interval are not known. During his ascent, about 38 minutes into the dive, the diver erroneously inflated his buoyancy control device instead of deflating it and was launched to the surface from a depth of 30 fsw (9 msw). Symptom onset came within 10 minutes, and his symptoms progressed from numbness to motor weakness affecting both legs and arms. The patient reached the hyperbaric facility within four hours of surfacing. He was evaluated promptly, and HBO treatment with USN TT6 was started within six hours of surfacing. Following his initial recompression treatment, his arms improved but his legs were worse. The following day, he underwent a second round of USN TT6, which resulted in significant improvement.

He received a total of five USN TT6, one per day, and experienced a full return of motor strength in both his arms and his legs, but he still could not pass urine. His urinary catheter was removed on days two and five to check his urinary function, and when he was unable to urinate the catheter was replaced. The patient continued to feel a pressure sensation around his waistband region and showed a reduced response to a pin prick from his waist to his thighs. He did not feel any sensation of needing to move his bowels but had no apparent difficulty with bowel function, as verified by an abdominal X-ray, which revealed stool in his colon but an empty rectum. His bladder function remained the main issue. At the time of the call, the patient was in the chamber receiving a USN TT6, and the treating physician asked whether they should continue with USN TT6 or drop back to USN TT5 or USN TT9.

In the opinion of the DAN expert, this was an obvious case of spinal cord DCS, with findings initially consistent with involvement as high as the cervical level. Even though recompression in the hyperbaric chamber was started within six hours of symptom onset (which is much sooner than in most cases of DCS during recreational diving), some of the patient's symptoms continued to get worse during the first USN TT6 session. It is not clear how much of his gradual improvement was due to treatment and how much would have occurred spontaneously.

The advice the DAN expert gave was to consider one or two additional sessions of hyperbaric oxygen (and to consider USN TT9), stopping if no additional objective neurological improvement was noticed after treatment. The expert also advised that the patient's bladder function might improve with time. An early urology consult was suggested to discuss ongoing rehabilitation, as well as ongoing catheterization and bladder training.

CASE 2-11: POSSIBLE ANXIETY OR INCOMPLETE CASE INFORMATION

A caller on the emergency line stated that his girlfriend had had a dive accident after completing two dives. Both dives were to a maximum depth of 59 fsw (18 msw), the first for 28 minutes and the second for 42 minutes, with an 84-minute surface interval. Both dives were on air, with a slow ascent and full safety stop. Their last dive ended in the late afternoon. That evening, three hours later, she developed tingling in both hands. They went to the dive shop, where she was given fluids to drink, and her tingling disappeared. The same symptoms reappeared 20 minutes later, and she went to a local clinic, where she was placed on surface oxygen for suspected DCS.

That same night, a hazardous night-time boat transfer was arranged, and she was transferred by speedboat from the clinic to a hospital on a larger island. The hospital placed her back on oxygen and did a chest X-ray, which came back normal. By the time she reached a chamber, she had also developed tingling in her feet. A USN TT6 was started early that same morning. Her symptoms resolved while she was at depth, but as she was surfacing in the chamber her symptoms returned. After the treatment, she was kept in the hospital on surface oxygen for observation. As the day progressed, she developed pain in her chest and back, as well as difficulty breathing that came and went. She was moved to a different part of hospital, still on oxygen, and was put back in the chamber for one hour the next morning. At that point, all her symptoms disappeared except for some lightheadedness. She spent another day in the hospital, during which the tingling returned in her hands and feet. The RN advised that she might need additional treatment, probably a USN TT5, the next day.

The caller wanted to know if the treatment she was receiving was appropriate and what to expect during her recovery. He noted that she had no previous history of dive-related medical problems, trauma or diabetes. He mentioned that her breathing difficulties and shortness of breath had resolved.

The DAN expert observed that the patient's reported dives were not aggressive and that the presentation and evolution of her symptoms were atypical for DCS. DCS typically does not occur first in the hands then in the feet. Isolated, intermittent tingling in both the hands and the feet that reappears after two rounds of HBO treatment (HBOT), two days after a dive, is unusual and suggests that a diagnosis of DCS is unlikely. And even if they were caused by DCS, her symptoms were mild, and two days after their onset there is no risk of deterioration. In all circumstances, such a situation would not call for additional HBOT.

In retrospect, if we had had a chance to talk to the treating physician and learn more about his findings, we could have provided more detailed advice. It possible in this case that we may be missing part of the story, and we did not explicitly advise against another treatment. However, continued unnecessary HBOT, if given in a prolonged fashion in an ambiguous case, can lead to mild pulmonary oxygen toxicity that could further increase anxiety in such a patient and actually precipitate rather than alleviate some of these symptoms.

CASE 2-12: MULTISYSTEM PRESENTATION POSSIBLY ASSOCIATED WITH PFO

A caller reported that she had been diving in the Caribbean when she experienced DCS Type 2 symptoms (vision changes and pain in her left shoulder and left hip). She was treated at a local HBO facility with one TT6 and experienced complete relief. She was cleared to fly by the treating physician. Her call came in after the first leg of her flight; she reported that prior to the flight she had experienced a return of some pain on her left side and in her left arm and a recurrence of the vision changes. She still had two legs to go on her flight and was concerned about the possibility of a recurrence of DCS.

In her opinion, this was an "undeserved" DCS hit. She had been doing technical dive training at a maximum depth of 173 fsw (53 msw), with 20 minutes of bottom time and a total run time of 61 minutes. She had completed all deco stops and safety stops per her dive plan and dive computer. Her bottom gas was air, her first deco gas was 38% nitrox, and her second deco gas was 60% nitrox. The red in the graph below shows the ceilings that she had not exceeded, but this was definitely a dive with mandatory decompression stops and probably a high load of venous gas bubbles.

On follow-up, the patient responded with the following email:

"Thanks for following up. I am feeling well now but for three weeks after the hit I had a lot of fatigue and slept a lot (some days close to 15 hours). I was also told that I have been repeating myself a bit, which I hardly ever did, so was noticeable. The past two weeks, I felt that I got most of my energy back.

"I followed up with a dive specialist. I had return of visual disturbances within 12 hours of returning back home which is at 5,600 feet elevation. The hyperbaric doctor thought the symptoms were related to the DCS, specifically due to inflammation at that point. I did

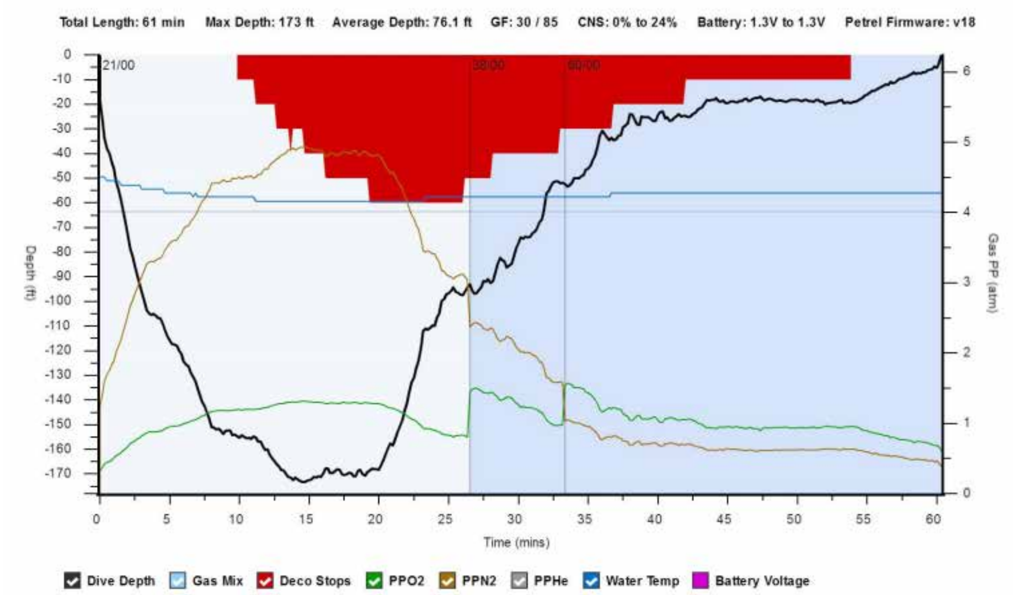

Figure 2.3-1. Dive profiles for the diver with possible PFO

go in the chamber again to see if I would feel differently there, and did not. The doctor's official diagnosis of my DCS event was of having a paradoxical cerebral arterial gas embolism. He thought I had a PFO/ASD [patent foramen ovale/atrial septal defect] due to my DCS symptoms: cutis marmorata, neurological symptoms, and a history of migraines with aura. It also turns out that what I thought were just severe dizzy/weakness spells that I've had since childhood were likely transient ischemia attacks! He recommended that I get an echocardiogram with bubble contrast done. The test was performed a couple weeks later and I do have a significant communication between the right and left sides of my heart. Based on the stroke risk alone, I have been recommended by four different doctors to get the closure procedure. I met with a cardiologist who does many such closures, and have the procedure scheduled. It's a bit scary and so I've done a ton of reading up on it. It does seem like the best idea for me in the long run since my risk of stroke is much higher than the risk of complications from the procedure and I don't want to be on antiplatelets for the rest of my life. Do you have any thoughts on that?

"You asked about the initial onset of symptoms. I'm not sure exactly of the time (the times in the dive profile are guesses), but somewhere around an hour after surfacing is when I really started noticing the skin rash on my shoulder. It was already pretty strong at that point, so it likely started earlier and I think I had been scratching at it for a time (I have urticaria and am itchy a lot normally, so it didn't seem odd)."

When this diver first called, she had told us about her pain and visual disturbances. We did not inquire further at that time because she had already been evaluated and treated, and her symptoms had resolved, so we answered only the questions she asked. On follow-up, we learned more details. Besides the pain and visual disturbances, she had also had neurological symptoms (mental issues with short term memory), skin mottling and prolonged fatigue. Taking into consideration the severity of her exposure (a deep dive with mandatory decompression), the proximity of her symptoms' onset time to her decompression period, and the resolution of her symptoms under HBOT, a diagnosis of DCS with neurological, cutaneous and osteomuscular manifestations becomes more likely. Association with PFO in such cases is very common, and in this case the PFO test did come back positive. When there are high venous gas bubble loads in patients who have right-to-left intracardiac communication, a symptomatic paradoxical embolus is likely. Many of this patient's symptoms are, in fact, typical of an arterial gas embolism.

CASE 2-13: LOSS OF VISION, NOT DCS

A call came in from a university dive safety officer (DSO) concerned about a diver who was complaining of blurry vision, feeling "weird," headache, nausea but no vomiting, and dry heaves. The diver had completed a single dive to 130 fsw (40 msw) for 25 minutes, on air, with a five- to six-minute safety stop at 15 fsw (5 msw). It was a scientific dive, to check an instrument. There was no exertion involved. Upon surfacing, she took off her mask and possibly scratched her contact lens. She also had a history of migraines. The dive had taken place on an island, and the nearest hospital was on the mainland. The caller had also spoken with a nurse at an HBO chamber who had advised the diver to take over-the-counter migraine medication, suggesting that if it helped, the vision problems could be due to a scratched cornea. The diver had said that it normally took about an hour for migraine medication to provide her with relief. By the time of the DSO's call, the diver had been breathing oxygen for 15 minutes and was feeling worse. She had also drunk half a liter of water in the previous 30 minutes, about an hour and a quarter after surfacing.

At that point, it was not possible to either confirm or rule out DCS, though the patient's dive had been provocative and her symptoms were consistent with DCS. Her symptoms continued to worsen while she was on oxygen, and she felt too nauseated to eat anything. The DAN expert recommended that the patient seek care at the closest emergency department, explaining that they would likely place her on high-flow oxygen, begin intravenous (IV) rehydration therapy and do a complete physical and neurological evaluation. The results of the evaluation would determine if she needed to be transferred to an HBO facility.

We did not hear back from the DSO or the patient until a few days later. The patient called the DAN emergency line and said she had been treated several days before for total vision loss following a dive. We confirmed with her that she had in fact lost all vision, and she said yes. She said she had been fine since receiving treatment but that the day of her call she had started to once again experience vision issues. She said she'd contacted the HBO facility where she was treated but that they'd told her they didn't think she was experiencing a dive-related problem, since it would be highly atypical to have a return of symptoms like hers. We agreed with that assessment and urged her to follow up with her own physician. Our expert also said that the way she described her symptoms sounded like she might have floaters in her eye and advised her to seek evaluation from an ophthalmologist.

In this case, the presence of a possible scratched eye confounded the diagnosis. However, neither the DSO nor the DAN specialist was deceived. When the symptoms fit DCS, there was sufficient exposure, the onset of symptoms was proximate to decompression, and the symptoms progress despite treatment, it is always advisable to consider DCS. In this case, the patient's visual disturbances progressed to a complete loss of vision, which responded well to HBOT. Given the circumstances and geography, the care given the patient was proper at each step, the assessment was adjusted according to her symptoms' evolution, and treatment was escalated as needed.

The reappearance of visual symptoms (floaters) a few days later called for additional evaluation, but they were probably not related to DCS. These symptoms may have been due to a pre-existing condition that contributed to the patient's postdive symptoms; it was suggested that her workup include an echocardiogram to rule out the presence of a PFO. She was also advised to do no further diving until the etiology for her total vision loss and recurring visual symptoms is identified.

CASE 2-14: SHOULD I WAIT UNTIL TOMORROW OR BE SEEN NOW?

The caller, a 51-year-old male diver, said his legs felt weak and possibly numb or tingly. He said he had done a series of three dives that day (see Figure 2.3-2). After the last of the three dives, he became aware that his legs felt

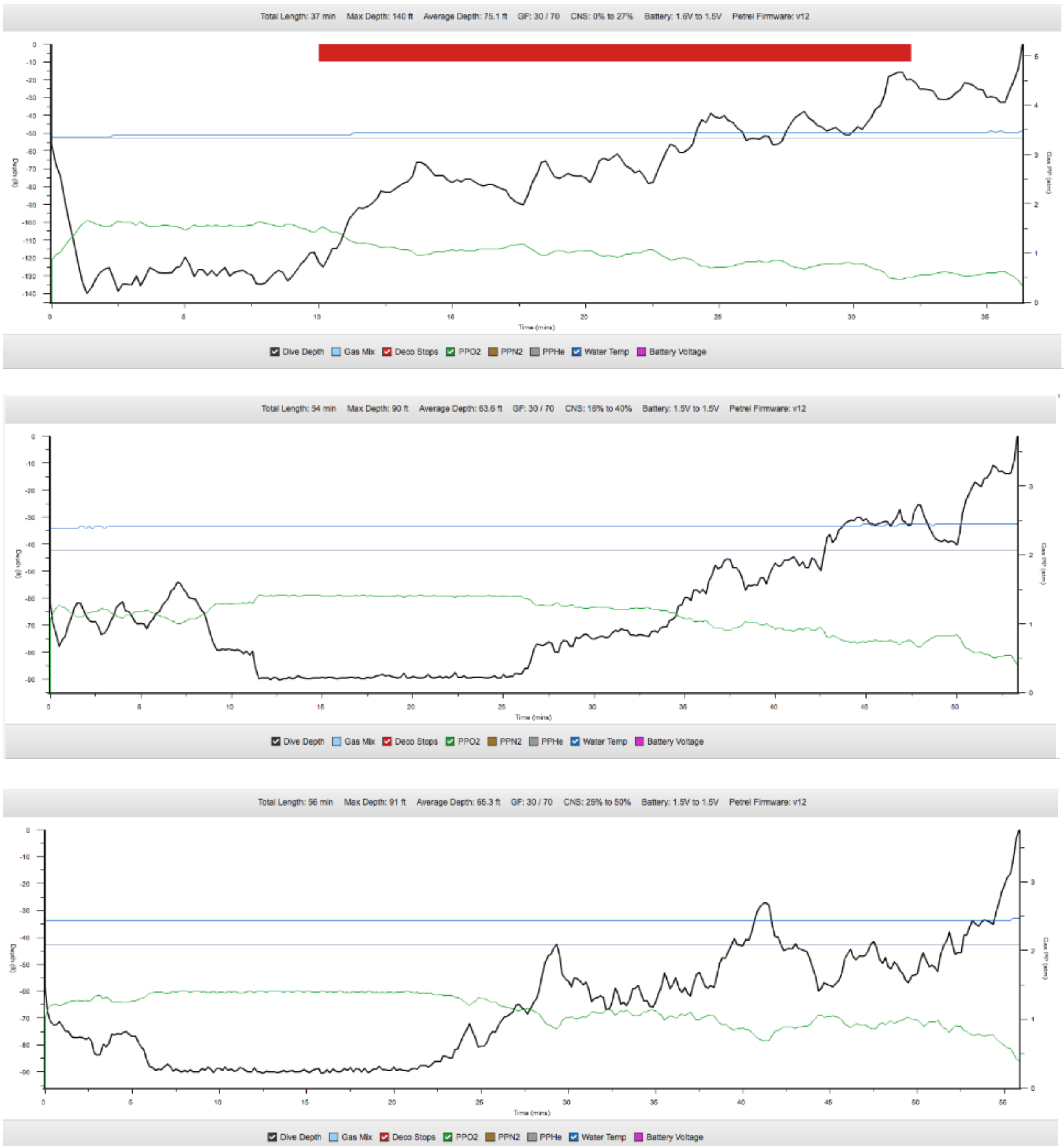

Figure 2.3-2. Dive profiles for the 51-year-old male diver

"odd." He asked whether he should wait to see if he improved or should seek care that night. DAN advised that with the symptoms he described, it would be in his best interests to be seen that night, and he was referred to a local hospital.

Later that night the DAN expert called to follow up, but the call was not returned until the following morning. The diver reported that he had been admitted the previous night and treated with a USN TT6 with two extensions. He had also received a TT5 as a tailing treatment that morning. He said that he had seen some improvement in his symptoms but that the change wasn't dramatic. He added that another treatment was planned for the following morning. The caller also offered to send his dive profiles after he was discharged.

Twenty days later, the patient called again. He said he was still having residual symptoms, noting that he felt as if he had "soaked my lower limbs in cold water," but added that his symptoms were improving with time. He stated that he kept looking at his dive profiles and still could not pinpoint "what I did wrong."

He explained that he had noticed after his last dive that his legs felt "weird." On the car ride home, he had noticed that he could not get comfortable. At home, a few hours later, the sensation had progressed to the point that it felt as if his legs were falling asleep. He went to the hospital and was treated around midnight with a USN TT6. His symptoms persisted after the HBOT, so the doctor was skeptical that he had DCS and did a number of tests (stroke workup, cardiac panels, etc.). All the tests were negative, though, so the doctor's working assumption was that he did have DCS. The patient received a week's worth of HBO treatments (he thinks they were three-hour treatments and that he had eight in all). He asked about the likelihood of residual symptoms; we discussed that possibility with him, as well as his return to diving — advising him to discuss that decision with his physician. He said that he would follow up with his primary-care physician that week and might ask for a referral to a neurologist.

Leg weakness, numbness and tingling soon after a dive are serious symptoms; they are very likely caused by diving and may worsen over time. Divers with such symptoms should seek evaluation at the nearest medical facility. And anyone with such symptoms should not dive. Partial improvement, as in this case, does not exclude DCS. The dive profiles this patient provided appear multilevel and typically would not cause symptoms, but they are not innocuous and risk-free. DCS is a probabilistic event that can occur even in divers who precisely follow the directions derived from mathematical equations.

CASE 2-15: LATE RECOGNITION OF SPINAL CORD DCS

The caller was a 51-old-year-old male diver. Earlier that afternoon, he had surfaced from a dive with a headache. Within about 30 minutes of leaving the water, he noticed a "wobbly" feeling and reduced sensation in his legs ("not working real well," he said); friends had to help him walk. His also said his arms were "feeling funny," but not as bad as his legs. He stated that he was on his way to a regional hospital (he was being driven by a friend) and was calling just to alert DAN.

This was not his first DCS event. Indeed, the caller sounded as if such events were routine. He said that he had done two dives to a maximum depth of 95 fsw (29 msw), for approximately 30 minutes each, with an SI of 1:00, on air. He said he uses tables rather than a dive computer. He said he had breathed "some oxygen" but did not know the quantity or duration. DAN advised the diver to breathe oxygen all the way to the hospital and notified the hospital of a likely incoming injured diver. By the time the diver was admitted, he could not walk due to leg paralysis.

By the time of a follow-up call, after a second TT6 treatment, he was still wobbly but able to walk with assistance. On further follow-up, several days and weeks later, we learned that the diver ultimately received a total of 12 HBO treatments and was improving slowly. One month later, he was able to walk, but still with difficulty, and his hands were very tingly.

Muscular weakness in the legs indicates a spinal form of DCS — a very serious condition. This diver's symptoms developed gradually, and it was some time before he realized that he needed help. He knew where he should be taken and had friends who took him there. Despite being on the mainland and relatively close to a good HBO facility, more than six hours had passed by the time the patient was in recompression, mainly due to his late recognition of his symptoms. In view of the fact that he admitted to having a history of previous DCS, one would have expected a more prompt recognition of the relevant symptoms and a more immediate departure for the hospital.

The incomplete resolution of the symptoms in this case is fodder for ongoing discussion as to how delays in receiving treatment may affect the long-term outcome for DCS patients. Still, while it is highly recommended that affected individuals seek help immediately, there is no guarantee that early treatment (unless it is within a very short postdive window of opportunity) will provide a complete cure in cases of neurological DCS. But divers should do everything they can to avoid delays in seeking care. We don't know what kind of review this diver underwent following his previous episodes of DCS, but we strongly advise consulting a dive medicine specialist for an extensive review of one's fitness to dive and diving practices after any episode of DCS.

It is because of the importance of receiving care in a timely fashion that DAN notified the hospital of this diver's arrival ahead of time, to help get him processed and, if necessary, into the chamber, faster. However, divers sometimes don't follow DAN's advice about seeking care and don't call us back to let us know they have decided not to go to the hospital we've referred them to. But it is frustrating for an on-call hyperbaric team to get summoned to the facility and then have the patient fail to show up. This has contributed to a steady decline in the number of medical professionals and facilities willing to continue offering this essential service on a 24/7 basis. Divers are thus strongly encouraged not to contribute further to this decline — and instead to call back if they are unable to make it to the hospital or if they change their mind or their plan for seeking care.

2.4. VERTIGO

Vertigo can have various causes. However, when it occurs during or soon after a dive, a dive injury is the primary suspected cause. Vertigo may be a symptom of an injury to the inner ear or the brain caused by barotrauma, an arterial gas embolism or DCS. Distinguishing the location and causes of such injuries is often not possible without extensive clinical testing, and especially not when giving advice over the phone to somebody who has little or no medical expertise.

Oftentimes, DAN is asked to provide assistance in behalf of patients who are unable to talk on the phone themselves, and thus information about many cases is likely to be secondhand, limited, incomplete or inaccurate. DAN is also often called by medical professionals who need assistance deciding about the disposition of a patient in their care. They typically request a consultation for two reasons — first, to establish if their patient's injuries are dive-related and second, to determine if recompression is needed or contraindicated.

Vertigo is a dive-related symptom that may but may not require recompression; recompression may not be in the patient's best interests if the vertigo is caused by barotrauma only. Here is a list of relevant questions when someone complains of vertigo. Any callers who are acting in behalf of an injured diver should try to collect this information before calling:

Patient's current status

1. What are the specific symptoms?
   - Does the patient feel a whirling sensation (like they're spinning or the room is spinning around them) or do they have a sensation of fainting or giddiness?
   - Is the patient able to stand and walk?
   - Is the patient nauseated and vomiting?
   - How long did the vertigo last or is it still present?

   When did the symptoms occur?
   - During the dive (at depth or during the depth change, and did they have any difficulty equalizing)?
   - After the dive (and how long afterward)?
   - At rest or after a specific movement?
2. Is there any new hearing loss present?
3. Is the injured diver experiencing tinnitus (ringing in the ears)?
4. Are there any signs or symptoms of ear barotrauma present (feeling of fullness or pain in the ear, discharge from the ear canal or blood in the sputum)?
5. Are there any signs or symptoms associated with DCS (skin changes, neurological changes)?

6. What is the otoscopic appearance of each of the injured diver's tympanic membranes (if anyone present is qualified to perform such an assessment)?

Patient's previous medical history
1. Age of diver
2. Previous episodes of vertigo/dizziness
    - Associated with diving
    - Associated with nondive-related neurological disorders (such as transient ischemic attack, stroke, multiple sclerosis, migraine headaches, etc.)
3. Previous episodes of DCS
4. History of ear pain, infection or surgery
5. Recent illness
6. Chronic conditions
7. All current medications
8. Recreational drug/alcohol consumption

If calls regarding possible vertigo come from an emergency department, we will also ask for these findings, if they're available:
1. Hearing (with tuning forks)
2. Otoscopic examination
3. Ophthalmic examination (including extraocular movements, nystagmus assessment and retinoscopy)
4. Cranial nerve examination, with particular attention to nerves 3, 4, 5 (especially the corneal branch), 6, 7, 9, and I0
5. Neck examination (for evidence of carotid artery disease and range of motion)
6. Blood pressure (to consider hypertensive and orthostatic processes)
7. Pulse, including strength, rate and irregularities (to diagnose arrhythmias)
8. Neurological examination (to exclude neurological disease, especially multiple sclerosis or a cerebrovascular accident)

IS IT VERTIGO, DIZZINESS OR SOMETHING ELSE?

When a diver complains about "vertigo," the first objective is to clarify the nature of the symptoms the diver is experiencing. Callers often do not distinguish between dizziness and vertigo or use these terms interchangeably, but the causes of the two conditions can be quite different.

Dizziness is a general term indicating a sense of disequilibrium; it can have a variety of symptoms and causes. A sense of disequilibrium is common in the general population, and episodes of brief or prolonged duration affect approximately 20% to 30% of people. It can manifest as vertigo, impending loss of consciousness (presyncope), disequilibrium without a whirling sensation, or just a vague sense of lightheadedness (Mukherjee 2003). Other types of dizziness may be associated with various organic or psychophysiologic causes, like a sudden drop of blood pressure due to either a cardiac arrhythmia or orthostatic hypotension, hypoglycemia, anxiety, depression, or panic disorder. The presence of such conditions in divers may be provoked by diving or may be unrelated to diving. And of course seasickness, which can be accompanied by dizziness, also affects many divers.

Vertigo is an illusion of rotational, spinning or whirling movement. Divers who experience vertigo usually feel nauseated, often vomit, and may be unable to walk and/or may feel the need to lie down. Vertigo is caused by asymmetric involvement of the inner ear (the cochlear-vestibular system) or by lesions affecting the brain (the pons, medulla or cerebellum). When divers suffer vertigo upon completion of a dive, barotrauma or DCS should be suspected.

Distinguishing whether vertigo is caused by an inner ear injury or by a brain injury is not simple. Sudden severe vertigo with nausea, vomiting, tinnitus and hearing loss is usually an indication of a cochlear-vestibular injury; in such cases, the patient is not able to stand or walk. A cerebellar injury usually causes less severe vertigo, variable nausea, ataxia and no hearing loss.

Both inner ear barotrauma (IEBT) and inner ear decompression sickness (IEDCS) may manifest themselves with a triad of symptoms — vertigo, tinnitus and hearing loss — but not all three symptoms need always be present. Vertigo alone more often indicates a vestibular lesion caused by DCS, while sensorineural hearing loss more often indicates a barotraumatic injury of the cochlea, often a rupture of the oval window with a fistula (Klingmann 2007, Elliott 2014). IEDCS is often an isolated cochlear-vestibular syndrome, with no signs of involvement of other organ systems, though skin mottling or neurological symptoms of DCS may be evident. The inner ear can also be vulnerable to a paradoxical embolism, due to venous gas bubbles passing through a right-to-left shunt. In various studies, PFO was detected in 56% to 77% of patients with IEDCS (Guenzani 2016, Gempp 2013). DCS affects parts of the labyrinth more often than the cochlea. This may be due to differences in the compartments' size and blood supply. The vestibular apparatus has a 30% larger fluid space than the cochlea but only a quarter of its blood supply, which contributes to slower off-gassing and a greater chance that a bubble embolus will expand due to the influx of gas from its supersaturated surroundings (Klingmann 2012).

In 2015, there were 58 MSCC calls about vertigo. Of those 58 calls, 35 were initially classified as suspected barotrauma and 22 as suspected DCS of the inner ear.

Seven of the 35 barotrauma cases appeared to be alternobaric vertigo. In three of those cases, the diver felt a spinning sensation while still at depth — in one case on ascent from 90 fsw (27 msw) to 75 fsw (23 msw), in another case while ascending from 94 fsw (29 msw) to 74 fsw (22 msw), and in the third while ascending from 75 fsw (23 msw). In one case, the diver felt a spinning sensation upon descent to 90 fsw (27 msw), after struggling for 10 minutes to equalize and get to depth. The onset of alternobaric vertigo at depth is not pleasant and may trigger a panic reaction. In one case, vertigo occurred after yo-yo diving during training in a shallow pool. The diagnosis of alternobaric vertigo is usually based on the time of symptom onset (during ascent or descent), some difficulty equalizing, and short duration. However, there are some cases where divers report no equalization problems and some cases where the sensation lasts a bit longer.

A few cases were classified as "Other." One was a case of short-lasting vertigo that occurred five minutes after a dive and was provoked by leaning down to pick up something from the floor. Another case classified as "Other" occurred 48 to 72 hours after a dive. Unusual presentations like these may well have nondive-related etiologies.

CASE 2-16: IS IT POSSIBLE TO DENY OR IGNORE VERTIGO?

A caller on the emergency line reported having had vertigo and balance problems that started 45 to 60 minutes after her dive ended and that lasted for three hours. She said her right ear was painful and her hearing was distorted until she felt her ear "pop," and at that point her vertigo and balance issues resolved. When she had attempted a Valsalva maneuver, she said, the pain in her ear got worse with some movements of her head. She denied having tinnitus. She said she had a history of vertigo occurring when she has had a cold, but she had never seen a physician. At the time of her call, it seemed that she was asymptomatic and that her troubles were caused by her inability to equalize — but that once she succeeded, everything was back to normal.

Nevertheless, she was advised to see a physician and was provided with a referral to the local hospital. She was admitted the same evening and was diagnosed with IEBT, with a documented hearing loss and negative pressure in her right middle ear. She was given medicine for the pain, which helped, and medicine to treat the vertigo, which was not very helpful (the vertigo apparently was either not resolved or had reappeared in the meantime). She was advised not to go out on a boat, to dive or to fly the next day. She was given assistance with canceling her flight home.

She was seen by the physician again the next day, and he cleared her to fly at that point, but she did not feel well enough to do so because of the effects of the opioid painkillers. She flew two days later. Her ears were slow to equalize on descent from the first leg of her flight, and some symptoms, including vertigo, returned. She was advised to take a decongestant before the next leg of her flight, as she intended to continue on home. Despite the medications, she experienced ear pressure and pain on the second leg, but she eventually arrived home.

She was advised that she might have suffered an oval or round window rupture and need evaluation by an ENT. She drove to work that day but continued to have difficulty walking, describing the room as spinning and saying she was unable to focus on her computer monitor, as it appeared to be moving. She said she felt continuously dizzy and was unable to walk without holding on to a wall; every time she stood up, she said she felt like she was going to fall over. She was advised to see an ENT, and she acknowledged the advice but did not call back for follow-up.

CASE 2-17: IS VERTIGO AN EMERGENCY?

A caller on the emergency line complained of vertigo, pain in his left ear and blood in his mucus. He was calling to ask if he should go to the emergency department that evening or wait to see his primary-care physician the next morning. He had been diving all week, completing open water and advanced open water classes. He admitted to having had trouble equalizing all week. The day before his call, he had completed two dives — the first one to 30 ffw (9 mfw) for 22 minutes and the second one to 50 ffw (15 mfw) for 25 minutes, with a one-hour surface interval; both dives were on air. He had aborted the last dive due to his ear problems. The day after the dive, he still had slight pain in his left ear and vertigo.

He was referred to a local hospital, where he was diagnosed with barotrauma and referred to an ENT specialist. He was lost to further contact. Vertigo is an emergency and should be evaluated as soon as possible, especially if it is possibly caused by DCS and would benefit from early treatment.

CASE 2-18: ARE 10,000 LIFETIME DIVES A GUARANTEE AGAINST DCS?

The patient was a 62-year-old male diver with reportedly 10,000 dives to his credit. The day before the call, he had developed vertigo and vomiting about 30 minutes after surfacing. He did not monitor the depth and time of his dives accurately, saying he typically used the depth meter from the boat instead. He had been diving for lobsters in the same spot for 30 years. His estimate of his dive profiles is as follows: first to 90 fsw (27 msw) for 30 minutes, then a two-hour surface interval, then another dive to 100 fsw (30 msw) for 30 minutes; he was breathing 36% EAN. He recalled having minor difficulty equalizing. He had to have a friend operate the boat to shore because he could not stand on his feet. He was breathing oxygen for about 30 to 40 minutes while en route to the hospital.

In the hospital, after he was evaluated (including a CT scan and other tests), the physician said he had likely ruptured his oval window and administered medication to alleviate his symptoms. After treatment, he was able to function but still felt dizzy. He was also given a referral to an ENT. He had called us seeking a referral to a dive medicine-ENT specialist in his area, for a second opinion. About a month before, he had recovered from shingles on his head and face. The ENT physician who ultimately evaluated him suggested that he had suffered IEBT but also administered corticosteroids to treat possible inflammation caused by the shingles.

CASE 2-19: INNER EAR BAROTRAUMA

A call came from a diver's spouse, who advised DAN that her 62-year-old husband was being evaluated for DCS at a hospital in the Caribbean. She said he had done a single dive that morning — to 69 fsw (21 msw) for 39 minutes on 34% EAN — and had surfaced in very rough seas. He'd had a difficult time accessing the boat due to a surge and had bounced up and down multiple times. When he finally climbed the ladder, he almost immediately developed vertigo, accompanied by vomiting. He had a history of myocardial infarction and had had a triple coronary artery bypass.

At the hospital, the diver underwent evaluation of his cardiovascular status and had a CT scan to look for evidence of cerebral apoplexy. Both exams were negative. His symptoms persisted for about one hour and resolved spontaneously. The ENT specialist who'd examined him established a diagnosis of IEBT. The diver was kept overnight at the hospital and released the next day, without additional therapy prescribed.

CASE 2-20: VERTIGO IN A REBREATHER DIVER

A call came from a concerned dive companion of a 50-year-old male recreational tech diver. They were calling from the location where he had completed a series of two dives earlier that day, with a closed-circuit rebreather, both to 100 ffw (30 mfw) with mandatory decompression stops. The patient denied having had any unusual problems or complications with his dives and denied any difficulty equalizing. Approximately 40 minutes after his final dive, he experienced the onset of vertigo ("spins"), nausea and visual disturbances.

The caller stated that she had placed him on oxygen via a nonrebreathing mask. She was contacting DAN for a recommendation as to the best course of action in a dive emergency in their location. She was advised to safely transport the diver to the nearest emergency department for evaluation and stabilization. The locations of the nearest recompression facilities that accepted divers were also provided, in case recompression was indicated.

CASE 2-21: VERTIGO SIX DAYS AFTER A DIVE

A caller complaining of vertigo said he was calling from his home. He had awoken that morning feeling like the room was spinning, as if he were on a violently rocking ship. Six days previously, he had returned home from a week of diving in the Galapagos. He had spent several days in transit to arrive home. For the last week, he had felt tired but not unusually so and had otherwise been fine until that morning. He attributed the fatigue to jet lag and travel. He had felt fine the previous night, drank a little wine and smoked some cannabis, and had gone to bed feeling normal.

He had had vertigo for two hours by the time he called. He said it quieted when he lay down but returned whenever he attempted to sit up. The DAN medical expert advised that it was not likely to be related to diving. DCS does not hit six days after a dive. He was strongly advised to go to an urgent care center or an emergency department. A few hours later, he answered a follow-up call and said that his symptoms has resolved spontaneously and he felt no further vertigo. He had not sought medical care, opting instead to relax and wait it out.

2.5. IN-WATER RECOMPRESSION (IWR)

CASE 2-22: AN INCOMPLETE IWR FOR SPINAL MANIFESTATIONS OF DCS

A 35-year-old diver called the emergency line from home after experiencing DCS earlier that day and conducting in-water recompression. At the time of the call, he indicated that he felt discomfort in his left shoulder and felt like he had overly exerted himself. He was wondering if he should go to the emergency department for evaluation.

He had done two decompression dives on air, one to 153 fsw (47 msw) and one to 123 fsw (37 msw). He had completed all decompression obligations at 25 fsw (8 msw), switching to nitrox with 60% oxygen. About 10 to 15 minutes postdive, he had felt a dull ache in his shoulder blades, neck and upper back. This sensation progressed to numbness in his legs from the knees down. He then had trouble walking — due, he said, not so much to weakness as to numbness. He says he'd had people help place him in the water for IWR, which was done at 25 fsw (8 msw) for 30 minutes on 60%. He said all his symptoms started to clear within a few minutes. Nevertheless, DAN advised the diver to seek evaluation at the nearest emergency department, but we did not hear from him again until a week later.

The caller stated that he had had 12 HBO treatments and still had residual though intermittent sensory symptoms in his feet. He said he had a history of an L3 bulge and stenosis of his vertebral canal. He also noted that the dive in question had been deeper than he had initially reported and that his IWR had been on 100% oxygen. He said this was done after he collapsed and could not feel his feet. The treating physician had informed him that no additional tests were necessary unless the problems continued, in which case the patient should contact him. The patient had not done so because he wanted a second opinion from DAN. The patient also had questions about returning to diving. The treating physician had advised that he not dive again for at least three months. The patient also asked whether he might still have residual nitrogen in his tissues, since the chamber treatment was only to 60 fsw (18 msw) and his dives were much deeper.

In this case, the diagnosis was very likely DCS. Sudden onset of leg weakness and numbness, preceded by neck and back pain, 15 minutes after two successive deep air dives is highly indicative of DCS. This patient's history of intervertebral discus herniation confounds the diagnosis but should not postpone action to treat for DCS. IWR on breathing oxygen had been attempted. This was a technical diving group, and it is likely that the group was prepared for IWR. The risk of progression of DCS was present.

It is of note that there was no record of surface level oxygen (SLO_2) first aid. Surface oxygen may suffice to stop symptom development and in some cases may achieve symptom resolution before the patient reaches the hospital. When symptoms improve on SLO_2, the risks of IWR can be avoided. It is not clear why this IWR team did not follow this protocol. A longer treatment might have achieved a more complete recovery. Even in the case of IWR success, SLO_2 should be continued after IWR and until admission. It took 12 in-chamber recompression treatments for this patient to achieve near-complete resolution of his symptoms. This means the diver had a lot of symptoms remaining after IWR. There is a possibility that his symptoms were caused by his underlying chronic spine condition, but the clinical impression of the treating physician and the evolution of the patient's symptoms during treatment leaned more toward DCS.

When it comes to a return to diving, this diver should be more concerned about his spinal cord injury than about any remaining nitrogen in his body. Most likely, all the nitrogen was washed out during his first chamber treatment. However, his spinal cord injury may take up to six months to stabilize, and such divers are usually advised not to dive for at least six months. His return to diving depends on a thorough medical evaluation, including a discussion of his spine pathology, which in some cases of DCS is a suspected contributing factor. Underlying medical conditions often lead divers to deny that they've suffered DCS and may result in unnecessary delay in seeking recompression treatment.

CASE 2-23: DANGEROUS IWR PRACTICE IN A CASE OF MISDIAGNOSED DCS

A diver called because of persistent paresthesia in his hand. He described it as feeling like he'd slept on his arm in a funny way. The diver did not seem to be concerned about the possibility of DCS because, he said, he is "always very conservative with his dives." He wondered whether his symptoms might be due to carpal tunnel syndrome.

The caller said he had been doing rebreather cave diving for the previous 11 days. Two days before his call, he had done a dive to 300 ffw (91 mfw) and had developed shoulder pain. The next day, he attempted IWR to 160 ffw (49 mfw) and what he called a "simulated TT6." The day after that, he had done another 300 ffw (91 mfw) dive, and on the day of his call to DAN he did a 100 ffw (30 mfw) dive with a total dive time of 240 minutes. He said on every dive he'd completed all required decompression stops, plus extra on the day of his call.

He said he had been drinking a lot of water and had taken ibuprofen, saying both are good for abating symptoms of DCS. He said that he felt better following his last dive — that his shoulder was better and that some associated swelling had resolved. But he continued to have what he described as a mild pins-and-needles sensation in his right hand, a feeling that had not changed during any subsequent dives.

DAN advised him to go to the nearest emergency department for evaluation. He decided instead to drive home, a few hundred miles away. MSCC records indicated that two years previously, this diver had been treated for DCS after complaining of left shoulder pain, but he had seen little change upon treatment and was discharged with a recommendation to see an orthopedist.

Later, he had an appointment with a neurologist to evaluate his persistent shoulder and wrist symptoms. The shoulder had improved by 50% after he started taking prescription pain medication, but he still had numbness in his fingers. He had an MRI that reportedly demonstrated impingement of the nerve at the cervical level and cartilage damage to his shoulder joint, as well as areas of arthritis and carpal tunnel syndrome.

This diver made several mistakes. First, he attempted IWR without proper indications and without attempting to use SLO_2 first. Second, the way he did the IWR was dangerous, because he went too deep and because he didn't have anybody else in attendance. Third, he continued diving the next day despite the persistence of his symptoms. Fourth, he did not disclose when he first called for advice that he had a previous history of shoulder and hand pain that was not diagnosed as DCS. Shoulder pain after a dive is a common manifestation of DCS unless there is another obvious reason for it. Hand swelling and pain are not typical manifestations of DCS, but DCS could not be ruled out in the absence of other possible causes. In this case, the diver's previous history of carpal tunnel syndrome made it unlikely that his symptoms were due to DCS.

To be prepared for an emergency, all divers should have with them, on every dive trip, a written medical history that can be quickly relayed when calling for advice or receiving medical evaluation.

2.6. CASE MANAGEMENT IN REMOTE LOCATIONS

CASE 2-24: TYPE II DCS IN THE PHILIPPINES

A call came in from the office of a liveaboard that was located on a reef in the Philippines, about 100 miles from shore. Apparently, earlier in the day, an older woman had surfaced from a dive (her dive profile was unknown at the time of the call) and passed out. When she came around, she complained of itching and shoulder pain, and she had a blotchy rash. She felt weak, was unable to stand and was vomiting. One of the passengers on the liveaboard who was a physician (of an unknown specialty) did the initial evaluation, consulted via telephone with an HBO physician on shore and diagnosed DCS. The patient was placed on oxygen while they called for the local version of the Coast Guard. It took about 10 hours for the CG boat to reach the liveaboard and another 10 hours for it to get back to port. The caller informed DAN that there were hospitals in the town but no hyperbaric facility. DAN arranged for an ambulance to wait for the patient at the pier and transfer her directly to the airport. The boat transporting the patient reached port in the early evening, 24 hours after her dive. The local airport had 24-hour capability, with landing lights, so the patient was evacuated that night by helicopter to a hyperbaric facility one hour away.

This diver was fortunate that a CG boat was available and the weather was fine for an evacuation. Everything else lined up fairly well, except for a short delay with the helicopter transfer. She reached the hyperbaric facility, got HBO treatment within 28 hours, and recovered with only minor residual symptoms that did not affect her physical fitness. Nine days after the incident, she was back home and during a 40-mile bike ride felt as well as she did before her injury. The mean delay to HBOT in diving injuries is about 24 hours, and most cases are resolved despite that delay. We did not get all the details in this case. When diving in remote locations, divers should adopt a more conservative approach so as to limit their exposure to injury. Evacuations are extremely difficult, and often very limited resources are available to assist a stricken diver.

CASE 2-25: A CASE OF SEVERE VERTIGO WHILE DIVING ON A REMOTE PACIFIC ISLAND

A call came in from a dive medical technician (DMT) at a coastal HBO facility who'd received a call from a liveaboard near the island. They required assistance for a 54-year-old male diver who was unable to walk or stand due to vertigo, nausea and vomiting after a dive. He had been seen at a military base on the island. They had diagnosed the diver with IEDCS, but the hyperbaric chamber was not available. The next nearest chamber was 210 miles across the ocean, and the island's landing strip was closed at night. DAN was called about four hours before dark. An air ambulance was arranged, and the patient was picked up and transferred to the mainland the next day. He still had the same symptoms but their severity had lessened. The diagnosis of IEDCS was confirmed, and the patient was treated with two USN TT6 and one USN TT5. The doctors reported continuous progress and discharged the patient home.

On follow-up three weeks later, he provided additional information. The incident had occurred on his first full day of diving from the liveaboard. Four dives had been scheduled that day, in the 80 fsw (24 msw) to 95 fsw (29 msw) range. He had felt nauseated prior to the first dive. On the final dive he had felt fine. He had used 32% nitrox. When he surfaced from the last dive, he experienced vertigo within 15 minutes. On the boat, he started to vomit and was unable to use oxygen. He was taken to the military base hospital and by that point was unable to walk. By the next day, he was able to walk but had to "hold on to things." Another day passed, and he could walk without holding on.

After he received the HBO treatment, he was flown out and said by that point he was much better. He felt that he was improving daily but that the chamber had not made a significant difference. He remained dizzy. He said he felt able to go to the gym and drive, but when he turned his head it was bothersome. He was an instructor with 2,000 dives to his credit. On follow-up two months later, he said he had completely recovered and had not seen a neurologist or an ENT yet but planned to do so because he wanted to get back in the water soon.

In this case, without appropriate clinical testing, it is impossible to tell with confidence whether this diver had DCS or barotrauma of the inner ear. Diving in remote locations always carries a risk of significant delays in receiving treatment. Thus it is wise to dive conservatively, do fewer dives a day and increase the margin of decompression safety. If symptoms persist, as they did in this case, a diver should not hesitate to seek a complete ENT evaluation. The fact that there was no significant hearing loss in this case would point toward a perilymph fistula. But most IEDCS results in residual damage, even in divers who get asymptomatic over time. In addition, a complete ENT evaluation is necessary to establish fitness to dive again.

CASE 2-26: OMISSION OF DECOMPRESSION IN AN ASYMPTOMATIC DIVER

The caller identified herself as being with a dive fleet in a remote island. She had received a call from one of the fleet's boats regarding a young female staff member. She had made an abbreviated deco stop, and as a precaution they had placed her on oxygen. After the oxygen was stopped, she continued to feel a tingling in her chest. The neurological examination showed no other symptoms. The caller and the crew were wondering if she needed to be evaluated as soon as possible. The call was short and did not provide many details.

Omitted decompression is always considered a risk for DCS. There are specific procedures for reimmersion and completion of decompression with some added stops and time, as described in U.S. Navy Diving Manual. However, the sea state in the Galapagos may not always be favorable for reimmersion, in which case surface oxygen may be provided instead. If symptoms do not occur during the initial postdive hours, the diver should be observed for 24 hours. Evacuation is not indicated for an asymptomatic diver.

2.7. MISCELLANEOUS SITUATIONS

CASE 2-27: AN UNDERWATER ATTACK OF ATRIAL FIBRILLATION

A call came from the U.S. Coast Guard regarding a 42-year-old male diver who had done a rebreather dive to 105 fsw (32 msw) for a total dive time of 115 minutes, at unknown settings. It was a square profile, his single dive of the day. When the diver surfaced, he exhibited labored breathing and was vomiting. He was alert and oriented, however, was ambulatory, and had no reported neurological deficits but did say that he had a "pounding pulse." The boat was en route to shore, and the diver was on 100% oxygen.

Later, the diver himself contacted DAN to report more details. He stated that he had a previous history of atrial fibrillation (A-fib). He suspected that he had been experiencing another episode. The trip back to the dock took three hours. He was met there by EMS personnel, who established that he was in A-fib and administered diltiazem, oxygen and an IV of normal saline during transport to the hospital. The emergency department there monitored his rhythm and after about 60 minutes performed cardioversion, with positive results. He was discharged approximately 60 minutes later. He stated that he usually takes an ASA (acetylsalicylic acid, or aspirin) prior to diving, and on this day he had used Afrin nasal spray. DAN recommended that he discuss the use of Afrin with his cardiologist.

This case illustrates the need for a thorough evaluation of fitness to dive when a diver has a known medical condition, and for such an evaluation to include possible effects of over-the-counter drugs. This is even more important for divers who use closed circuit rebreathers (CCRs) as well as any technical divers, since direct ascent to the surface is often problematic in these types of diving if a medical problem or medication reaction occurs at depth.

CASE 27: A-FIB AND DIVING

A caller reported new onset of A-fib, with a rate of 150 to 170 beats per minute, but said he was asymptomatic. He said he self-converted to sinus rhythm after about 90 minutes in the emergency department. He had had his first appointment with a cardiologist and had an additional workup scheduled after the DEMA (Diving Equipment & Marketing Association) Show. The caller was planning to do some diving after the show while he was still in Florida. He said he was a technical and rebreather diver. He was seeking information.

CASE 28: IMMERSION PULMONARY EDEMA (IPE)

A caller said that he'd had an issue after a dive three weeks before and that he suspected IPE. He had recently started using a rebreather, and over 12 to 15 hours on the unit he had twice developed a nasty, raspy cough that got progressively worse and resulted in production of phlegm. He said he had a history of high blood pressure controlled by medication. He was seeking additional information, as he had been reading about IPE online and noted, "It's almost like I wrote it myself." He said that he had been symptomatic immediately after diving and had relaxed on the boat and that it took several hours before he began to feel better. The description this diver provided fit the picture of IPE. He was advised to discuss his options with an experienced dive physician before returning to diving, since IPE may repeat and the next time might be more severe.

CASE 29: SHOULDER PAIN THAT STARTED DURING ASCENT

A call came in from a 42-year-old male recreational tech diver who stated that two days before, he had completed a single trimix rebreather dive to 220 fsw (67 msw), with 15 minutes of bottom time and 90 minutes of total run time. He said that toward the end of the dive, at a depth of approximately 30 fsw (9 msw), he began experiencing pain in his left shoulder and that it seemed more pronounced after he'd surfaced. He was examined by a traveling companion who is a emergency physician, who seemed uncertain about the diagnosis and suggested treatment with NSAIDs (aspirin) and a re-evaluation the following day. The NSAIDs relieved the diver's pain temporarily; he returned to diving the following day and completed a dive to 60 fsw (18 msw), for 90 minutes with an oxygen partial pressure (ppO_2) of 1.5. The next morning he awoke at 3:00 a.m. and felt a dull ache (1 on a scale of

1 to 10) in his left shoulder and at that point became concerned about the possibility of DCS. DAN advised that pain that starts during a shallow deco stop after a deep dive is cause for suspicion of DCS. He was informed that both NSAIDs and a dive to 60 fsw (18 msw) while breathing oxygen at a high partial pressure could provide temporary relief but that he should seek further evaluation and definitive treatment.

CASE 30: ELBOW PAIN DURING A DECO STOP

A caller on the emergency line had just finished a technical dive and had developed pain in the left elbow during a 10 fsw (3 msw) deco stop, about one hour before. The diver had done a single dive that day, on a rebreather, to 202 fsw (62 msw) for 103 minutes, using a 10/50 mix, completing five stops. At 10 fsw (3 msw), the diver felt pain in his left elbow (5 to 6 on a scale of 1 to 10) so went back down to 30 fsw (9 msw), where the pain completely resolved. The diver then went back up to 20 fsw (6 msw) for seven to eight minutes; the pain came back, but only at a level of 1 to 2 out of 10. The diver said there had been no computer violations and it had been a nonworking technical/recreational dive with no spear fishing. He said he works for a dive shop, that he tied the boat on the mooring line and his dive buddy did most of the work — that he was just helping; he explained it as a “cupcake dive.” At the time of the call, the diver was on SLO_2. The diver was advised that pain under pressure is a serious symptom and requires prompt attention. Attempts to trivialize a dive to 202 fsw (62 msw) for 103 minutes is counterproductive when significant complaints occur that need attention.

CASE 2-31: REFUSAL OF RECOMMENDED TREATMENT DUE TO COST

A caller on the emergency line had run out of air the previous day and been forced to make a rapid ascent. He had developed tingling from his lower abdomen down and a blotchy rash. The symptoms cleared quickly. The hospital did labs and recommended HBOT, but the patient refused not knowing if his insurance would cover it. He was seeking advice as he was driving home. His only remaining symptom was fatigue. He had also had a headache the previous day that had resolved.

This diver’s decision could have resulted in permanent injury to his spinal cord, leading to paralysis and loss of bladder, bowel and sexual function. Developing contingencies for possible emergencies is part of any good dive plan. Knowing how to deal with a dive emergency should be part of any such plan.

CASE 2-32: A POSSIBLE POSTDIVE STROKE

A caller on the emergency line stated that her 56-year-old husband had been diving earlier that day and, within about 10 minutes of the dive, had said he was not feeling well. An EMT advised the wife that he suspected a ministroke. The diver was placed on oxygen until they reached the shore and was then taken to the local hospital. At that time, the diver had memory loss and was not able to remember even his or his wife’s name. He had no other apparent signs or symptoms. His wife said the hospital had done a Doppler ultrasound and detected air bubbles. She reported that her husband had done only one dive that day, to 65 fsw (20 msw), for 35 to 40 minutes. His previous medical history included high blood pressure that was controlled with medication.

The diver was treated in a hyperbaric chamber several times locally, but he deteriorated despite the treatment. Finally he was transferred to a major hospital on the mainland, where more diagnostic tests were conducted and one more HBO treatment was administered. Unfortunately, the patient went in respiratory failure. A tracheotomy was performed, and the patient was put on a ventilator. He also received an IVC filter to prevent a pulmonary embolism.

In the hospital, more details about his dive and his previous medical history were obtained. It turned out he had done nine dives within a period of four days. The maximum depth of his last dive had actually been 90 fsw (27 msw) and its duration 36 minutes. And his past medical history also included transitory ischemic attack (TIA), high blood pressure, resolved metabolic syndrome and obesity (a BMI of 39).

An MRI of his brain revealed multiple diffuse scattered ischemic infarcts throughout the brain. Among the many other tests performed was a contrast echocardiogram, which was positive for a PFO.

Despite extensive diagnostic testing and additional imaging, the diagnostic dilemma persisted in this case. The patient's signs and symptoms could have been the result of a dive injury, due to bubbles from either decompression or barotrauma, or the result of an acute cerebrovascular insult due to "natural causes." Whether his dive exposure had been sufficient to cause DCS could not be verified because of the incomplete and conflicting information. A square dive profile of 65 fsw (20 msw) for 35 minutes could certainly produce sufficient bubbles to cause injury, especially if the ascent was too fast. However, a multilevel dive within the same depth-time frame could be innocuous.

This diver did have risk factors associated with stroke — obesity, hypertension and a history of TIA — but that doesn't prove that he actually suffered one. Furthermore, the short amount of time between his ascent and the onset of his symptoms (10 to 20 minutes at most) make a dive-related cause more likely. The incident took place not far from the shore of an island with good treatment options. The patient reached the chamber within a short time, and the HBOT was administered early, but even so his outcome was not favorable. Indeed, the patient's condition further deteriorated. A lack of improvement on recompression does not disprove DCS but does suggest that alternate diagnoses remain plausible. The outcome in this case could have been the result of DCS complicated by the patient's pre-existing conditions. A history of TIA and excessive obesity should be considered seriously when deciding whether to participate in scuba diving. The decision in such cases should be made only after a frank and open discussion with a physician knowledgeable about dive medicine.

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SECTION 3. DIVING INCIDENT REPORTING SYSTEM (DIRS)

PETER BUZZACOTT

The Diving Incident Reporting System (DIRS) collects diving incident reports lodged through the DAN website. Divers are encouraged to report unplanned incidents that occur during recreational compressed-gas diving. Reports of fatalities are forwarded to the diving fatality investigation team. The DIRS project started in late 2012. In 2015, the 107 reported incidents were divided among open circuit incidents (n=98, 92%), rebreather incidents (n=5, 5%) and breath-hold incidents (n=4, 4%). The four breath-hold incidents are discussed in Section 4 of this report. The remainder of this chapter concerns the other 103 incidents; of those, 65 (63%) involved males, 34 (33%) involved females, and 4 (4%) involved an individual of undeclared sex.

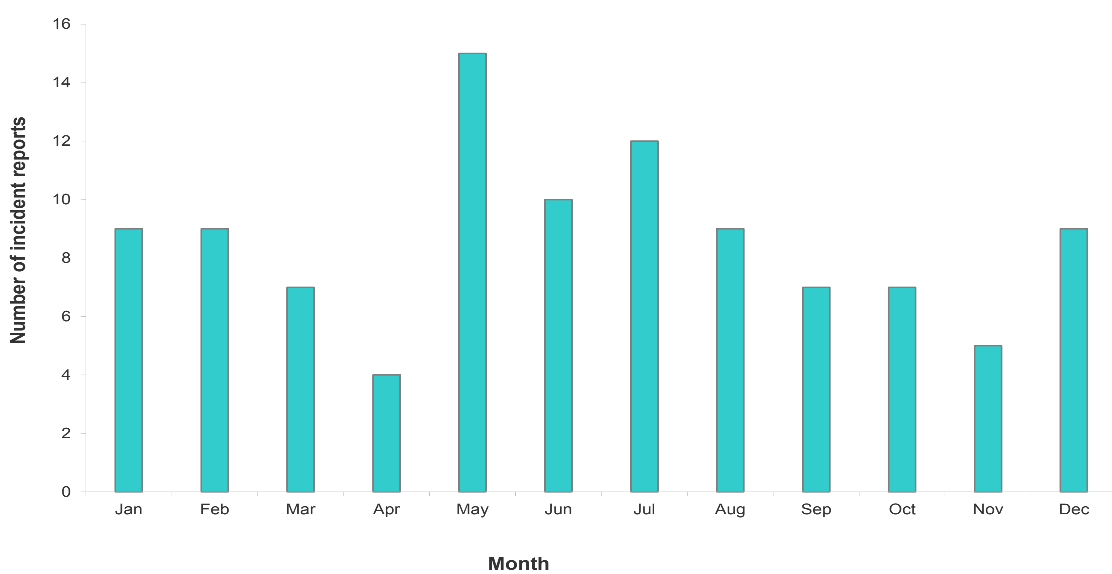

Figure 3-1. Monthly distribution of compressed-gas diving incident reports in 2015 (n=103)

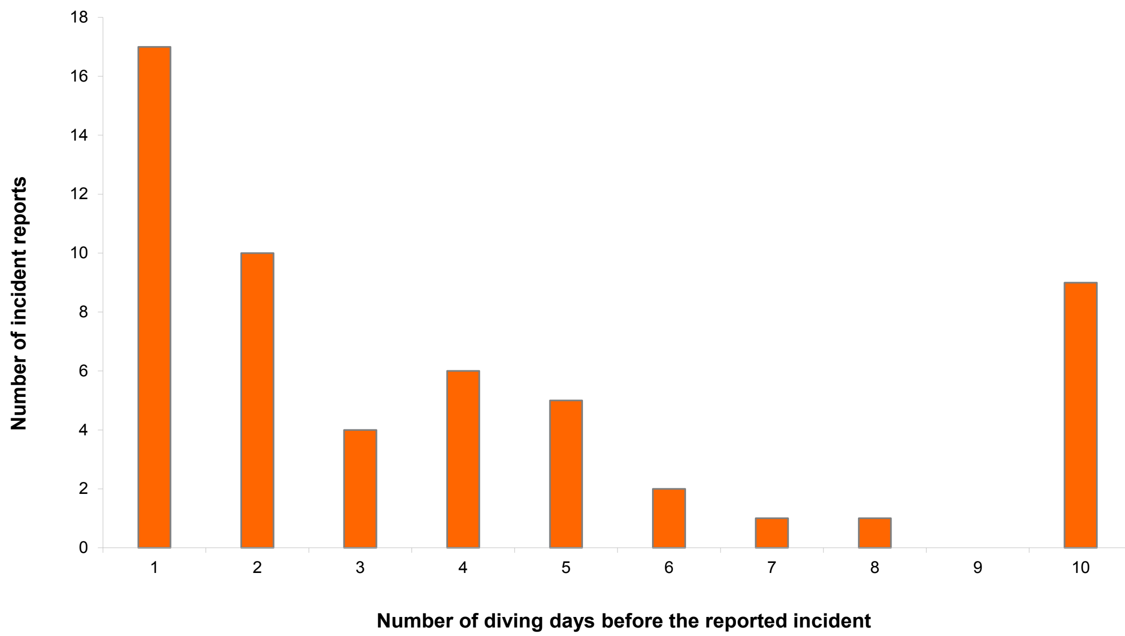

Figure 3-2. Number of days in the diving series before the incident occurred, 2015 (n=55)

The majority of the reports (n=89, 86%) were made in English, 13 (13%) were in Portuguese and one (1%) was in French. The victim of the incident being reported made the report first-hand in 64 cases (62%), and reports involving third parties accounted for the remaining 39 cases (38%). The monthly distribution of reports for 2015 is shown in Figure 3-1.

Of the 103 reports made in 2015, 85 (83%) occurred during 2015, 10 (10%) occurred during 2014, 7 (7%) occurred in 2013 or before, and 1 (1%) did not state the year in which the incident occurred. The majority of incidents happened on the first day of a diving series, as shown in Figure 3-2.

Eighty-five reports (83%) specified the diver's degree of familiarity with the dive site where the incident occurred; 37 of those incidents (44%) occurred during the diver's first time at the site, while 48 (56%) occurred during a return visit to the site. Almost half of the incidents (48%) took place during the first dive of the day, 33% during the second dive of the day and 18% during a third or later dive of the day. Inexperience featured prominently in reported incidents, with 54% of reports involving divers with less than two years of diving experience since they were first certified. Indeed, of the 95 divers who reported their training status, 8 (8%) reported having received no formal training. Self-reported experience level in the activity the diver was engaged in at the time the incident occurred is shown in Figure 3-3.

Three divers reported having made 3,000 or more lifetime dives. The mean number of lifetime dives by the 77 other divers who reported their experience level was 152 dives, with a range from 1 to 1,164. Eighty reports mentioned the number of dives made within the previous year; the mean for these cases was 49 dives, with a range from 1 to 350. Sixty-seven reports mentioned the year in which the diver was first trained; this information is shown in Figure 3-4. Characteristics of the divers involved in reported incidents are given in Table 3-1.

Key

Level	Number of dives
None	None
Novice	1–5
Intermediate	6–20
Advanced	21–60
Expert	>60

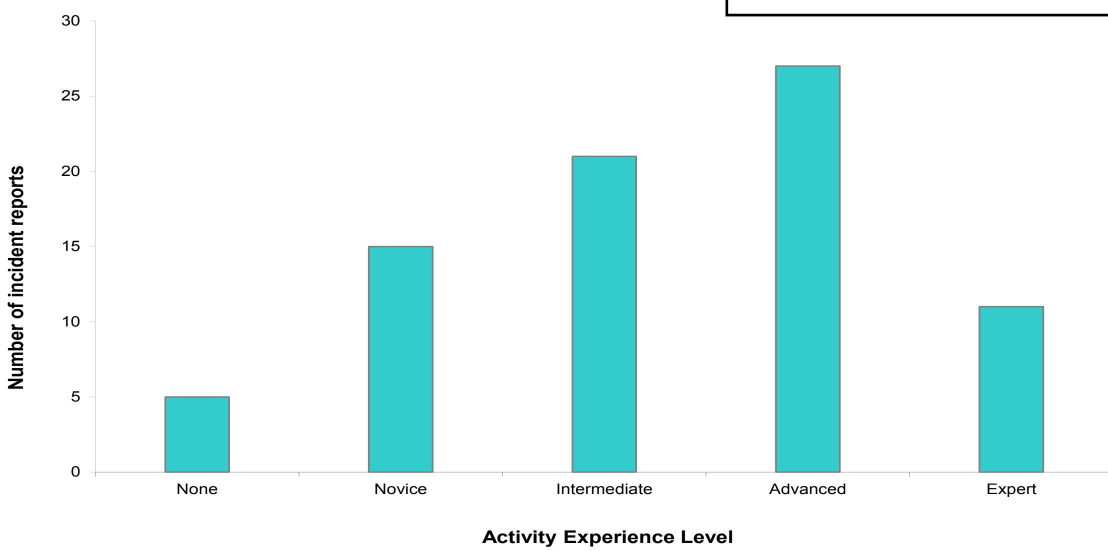

Figure 3-3. Self-reported experience level in the activity during which incidents occurred, 2015 (n=79)

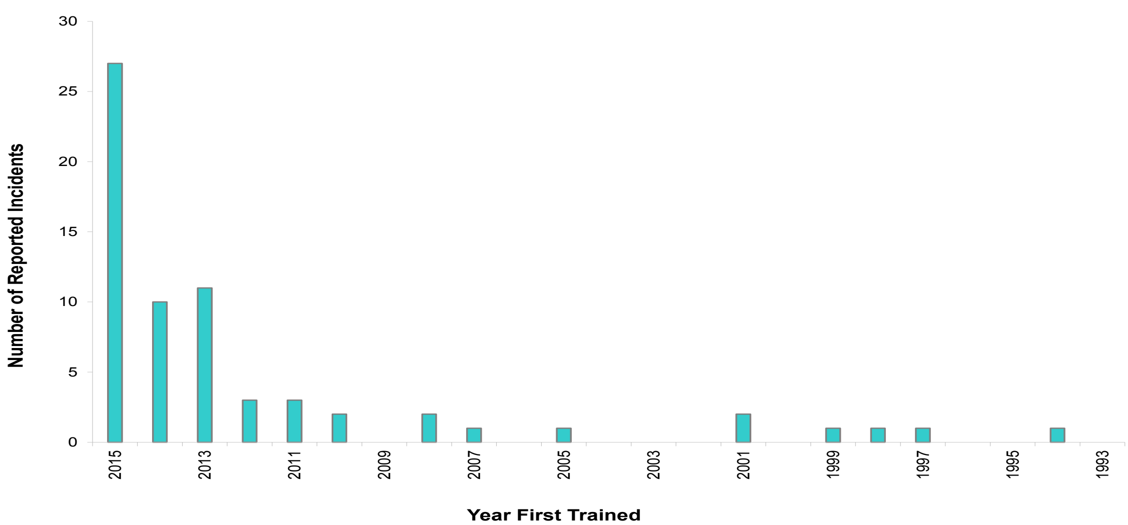

Figure 3-4. Year of first dive training by divers who reported incidents in 2015 (n=67)
Demographic characteristics of the divers involved in reported incidents are shown in Table 3-1.

	Male (n=65)	Female (n=34)	Overall (n=103)
Age	mean=44, range=16–73	mean=43, range=23–67	mean=44, range=16–73
Body mass index (BMI)	mean=27, range=18–44 (n=69)	mean=23, range=16–36 (n=27)	mean=26, range=16–44 (n=75)

Table 3-1. Sex and anthropometry of divers involved in reported incidents in 2015

Depth was not reported in 36 incidents (35%); the mean depth of the other 77 reports (65%) was 70 fsw (21 msw). The mean maximum depth previously reached by the affected diver was 69 fsw (21 msw), with 63 reports (61%) mentioning this fact.

The type of support each affected diver reportedly received is shown in Table 3-2.

Surface support type	n (%)
Dive partner (direct supervision throughout dive)	36 (35)
Group	27 (26)
Dive partner (limited supervision)	15 (15)
Other	3 (3)
None/solo diving	2 (2)
Surface supplied scuba	1 (1)
Underwater	1 (1)
Not reported	18 (18)

Table 3-2. Type of support during reported incidents in 2015 (n=103)

Temp °C	<4	4-9	10-15	16-20	21-26	27-32	Unknown
Temp °F	<39	39-48	50-59	60-68	69-79	80-90	Unknown
n (%)	**1 (1%)**	**2 (2%)**	**10 (10%)**	**7 (7%)**	**31 (30%)**	**33 (32%)**	**3 (3%)**

Table 3-3. Water temperature during reported incidents in 2015 (n=87)

The time of day when reported incidents occurred was noted in 89 cases; of these, 78 (76%) were during the day, 1 (1%) was at night, 6 (6%) were at dawn, and 4 (4%) were at dusk. Seventy-three reported dives (71%) were in the ocean/sea, 7 (7%) in open freshwater, and 10 (10%) in springs or caves; 13 reports (13%) did not mention the type of location. The water temperature during reported incidents tended to be warmer, as shown in Table 3-3.

Visibility was reported for 88 incident dives; it was poor (<10 feet <3 meters) in 7 cases (6%), moderate (10–50 feet 3-15 meters) in 32 cases (31%), and excellent (>50 feet >15 meters) in 49 cases (48%).

The altitude of incident dive sites was reported in 86 cases (83%). It was between 0 and 1,000 feet (0–305 meters) in 83 cases (81%); between 1,000 and 3,280 feet (305–1,000 meters) in 2 cases (2%); and over 3,280 feet (>1000 meters) in 1 case (1%).

The dive platforms from which the incident dives occurred are shown in Table 3-4.

Platform	n (%)
Day boat	52 (50)
Beach/shore	17 (17)
Liveaboard	8 (8)
Pier	6 (6)
Other	3 (3)
Not declared	17 (17)

Table 3-4. Dive platform for incident dives in 2015 (n=103)

The severity of the outcome was declared in 101 (98%) of the 103 DIRS reports logged in 2015; given a multiple-choice option of "death," "injury" or "no injury," 7 incident reporters (7%) checked death, 57 (56%) checked injury, and 37 (37%) checked no injury (while the remaining two incident reporters did not check any of those options).

The free-text incident summaries in the 2015 DIRS reports described incidentsthat occurred involving diving around wrecks (n=4, 4%), underwater hunting (n=6, 6%), training dives (n=11, 11%), rapid ascents (n=14, 14%), and/or loss of buoyancy control (n=12, 12%). Four incidents (4%) involved a diver running out of gas, and 2 more (2%) involved a diver starting a dive with a tank valve not fully open, an oversight that became noticeable only at depth, when the diver found it harder to breathe. Three incidents (3%) were possibly associated with gas contamination, and a fourth incident involved breathing gas contaminated with carbon dioxide following a "breakthrough" of gas in a closed-circuit rebreather. Eleven incidents (11%) were due to an equipment malfunction, as detailed in Table 3-5.

Of these 11 incidents involving a reported equipment failure, 7 (64%) involved an air-supply problem, 3 (27%) a buoyancy-control problem and 1 (9%) a mask issue.

Equipment failure (n=11)
Almost empty tank not refilled between dives
Half-full tank used for second dive without refilling
BCD inflator stuck open
Tank valve not fully open, hard to breathe at depth
Weight belt buckle opened and weight belt fell off
Regulator free flowed
Submersible pressure gauge read 700 psi (48 bar) with an empty tank
BCD unexpectedly self-inflated
O-ring in a second-stage swivel extruded, causing a free-flow
Second-stage regulator detached from the low-pressure hose
Mask strap detached from mask during loosening

Table 3-5. Types of equipment malfunction (one of each type) reported in 2015

The free-text incident summaries also offered more nuanced insight than the multiple-choice injury-severity question into whether reported events had resulted in injury. These in-your-own-words incident descriptions resulted in 73 cases (71% of the 103) being classified by a DAN expert as involving a nonfatal injury (compared to only 57 classified that way by the incident reporters in response to the multiple-choice injury-severity question). Table 3-6 shows the distribution of injuries identified by the DAN expert in those 73 cases.

While statistics can certainly help identify possible targets for preventive interventions, case vignettes are richer in detail and can also often provide useful learning points. Following is a selection of edited case reports. These are actual reports from divers, received through the DAN Diving Incident Reporting System. Units of measurement are given in both imperial and metric formats; abbreviations and slang have been clarified; and the names of people, dive boats, dive businesses and specific locations have been removed. Other than those few changes, the original tone of each report has been retained in the hope that readers will get an authentic feel for the experiences being reported. DAN thanks everyone who supplied incident reports in 2015.

Injury	Cases	%
Decompression sickness	26[a]	25
Immersion pulmonary edema	5	5
Dizziness	5	5
Headache	4	4
Ruptured tympanic membrane (ear drum)	4	4
Ear barotrauma	3	3
Near drowning	3	3
Nausea/vomiting	3	3
Loss of consciousness	2	2
Pain	2	2
Blunt-force trauma	2[b]	2[b]
Possible carbon-dioxide breakthrough in CCR	1	1
Fire coral sting	1	1
Contaminant in eye	1	1
Subconjunctival hemorrhage (mask squeeze)	1	1
Sea-jelly sting	1	1
Leg cramps	1	1
Lion fish sting	1	1
Stroke	1	1
Coughing up blood	1	1
Decompression illness (unspecified)	1	1
Inhaled water	1	1
Pneumothorax (collapsed lung)	1	1
Finger torn off	1	1
Paralysis	1	1

[a]Includes 8 skin bends and 1 lymphatic decompression sickness

[b]Includes 1 buddy rolling backwards onto victim's head (with 15 stitches resulting) and 1 boat flipping over (with multiple injured divers)

Table 3-6. Nonfatal injuries according to analysis of incident summaries in 2015 (n=76 cases)

BOATING INJURIES

CASE 678: WHEN A DIVE BOAT HIT A WAVE, A DIVER WAS THROWN INTO THE AIR

While traveling from one dive site to another, the water was rough. I was sitting at the front of the boat and was thrown into the air and landed on my back. The wind was knocked out of me and the pain was excruciating. At first I couldn't breathe and I couldn't move. The next dive was canceled and the boat made its way back to the dive shop. A serious back injury was suspected, and I was transferred out of the boat on a surfboard. Luckily there was a doctor who specialized in spinal injuries at the dive shop who instructed the staff how to get me off the boat. I was transported by ambulance to the local hospital. X-rays and a CAT scan were performed, and I was diagnosed with no spinal injury but a partially collapsed left lung.

CASE 679: A DIVER LOST HIS BALANCE AND HIS FINGER

I was wearing my dive equipment on the platform at the back of the boat, and my buddy was already in the water waiting for me. A speedboat passed by and a wave rocked the boat, then I got unbalanced and fell into the water. In the fall, my left hand was caught on the edge of the boat by the cleat. My finger was severed, torn off my hand by the ring I was wearing.

DECOMPRESSION SICKNESS (DCS)

CASE 700: SKIN BENDS CUT A DIVE HOLIDAY SHORT

An American male diver (age 46) went on a dive holiday. He made four dives in two days, on air, with maximum depths ranging from to 51 feet (16 meters) down to 89 feet (27 meters); all total dive times were just over one hour long, including 3-minute safety stops at the end of each dive. He felt no symptoms after the first day and went to eat dinner. Later that night he got up to pee at 11:30 p.m. and felt soreness in his ribs but he put it down to probably sleeping oddly on his pillow. He went back to bed and felt fine in the morning, so he made two more dives. The pain came back noticeably about an hour after surfacing from the last dive, but this time it burned/itched just a little, and he noticed a blotchy rash on his torso. The diver had read a case study about skin bends in Alert Diver magazine and remembered the blotchy rash. He went to the dive shop, they supplied him with oxygen, then after a few minutes the rash almost went away and the pain was reduced.

By now convinced this appeared to be a case of skin bends, the diver went to the hospital and was assessed by a DAN-affiliated medical doctor who confirmed the diagnosis. The doctor conducted a neurological exam to rule out more serious signs of DCS, then advised the diver to not dive again before flying home. Some time later the rash and soreness returned, so the diver once again saw the DAN doctor and this time was given more oxygen, plus he was hydrated with an IV. The rash dissipated, the soreness resolved, and the diver flew back to America, where he is now recovering (some residual soreness remains).

He writes: “I will be apprehensive the next time I dive — but I am planning to use only nitrox and stay away from the limits of my computer. After 25 years of diving, I guess I am finally getting old!”

Editor’s comment: There are many divers who feel in the same boat (“After 25 years of diving . . .”). This case also reminds us that DCS does not always have a clear cause. In this particular case, the diver seems to have made all the right decisions. First, he was a member of DAN and recognized his injury from reading Alert Diver. Next, he accepted oxygen at the dive shop, then sought out medical advice from a doctor familiar with dive medicine. Then he took it easy and didn’t dive again, even though he wanted to. Finally, he returned home and reported the incident to DAN so others might learn from it.

While many divers trust their dive computers implicitly, the fact is that no dive computer takes into account the physiology of the diver who is wearing it, and the underlying algorithm used by a dive computer may have been tested on people who were physically different from the diver now wearing the computer. Although probably none of us like to admit it, no diver is as young as we all once were, and this diver’s plan to dive more conservatively sounds like a prudent approach for avoiding another uncomfortable and inconvenient case of skin bends.

CASE 734: A DIVER WITH POSSIBLE DCS WAS WORRIED ABOUT THE COST OF TREATMENT

I’m age 72. Diving began on Thursday, and most of the dives were relatively deep, in the range of 90–120 feet (27–37 meters). The first day I made three day dives and one night dive. I was wearing a 5-4-3 wetsuit on all of the dives. All surface intervals were two hours or more. For all dives, everybody on board was using EAN 32%.

On Saturday, I noticed that I was feeling itchy on my torso after the second dive. I felt like scratching myself but decided not to. After the third dive, which was a bit shallower, I noticed that I was no longer itchy. This phenomenon repeated itself over the next five days. After two dives on Monday, I felt itchy again. On this particular day we were given the option to visit an island or do a third dive. I opted to visit the island. After walking on the island for about an hour, the itchiness seemed to disappear.

At first I thought it could have something to do with the saltiness of the water and completely ignored the itchiness. I had a dermatologic antibiotic ointment and cream, which I rubbed over the itchy area. However, this did not relieve the itchiness. As I continued to think about the itchiness, skin bends came to my mind. However, I did not have mottled skin, and itchiness did not turn to pain on the torso. On Wednesday, the last day of diving, the first dive was at a depth of 120 feet (37 meters). The second dive was at a depth of 113 feet (34 meters). After the second dive, I again felt itchy. I made a third dive two hours later, touching 81 feet (25 meters). However, the major part of the dive was at 51 feet (16 meters). I came up from this dive and again was relieved of the itchiness. I'm uncertain if I was developing skin bends or becoming bent. I suppose the smartest thing to do when I felt I might be getting bent due to the itchiness was to request oxygen, which was available on the boat. I did not do this because I thought there might be an extra charge for using oxygen and also I would be prevented from diving for the remainder of the trip as a safety precaution. This was the most expensive dive trip I have ever taken and therefore I did not want to have to stop diving. However, good common sense would have dictated that it was better to stop diving than be flown to a chamber at excessively high cost.

Editor's comment: Mere itchiness without other signs or symptoms is not a common manifestation of DCS. Even so, if the diver suspected DCS, then there were a number of risk-reduction strategies that he might have considered, such as making shallower dives, ascending well before nearing his no-decompression limit, making fewer dives per day, and/or taking longer surface intervals between dives. DAN also recommends that every diver carry adequate insurance when taking a dive holiday, to greatly reduce economic concerns in situations such as this incident.

OUT-OF-GAS

CASE 824: POOR EYESIGHT LED TO MISREADING A DIVE COMPUTER AND RUNNING OUT OF GAS

I am a master instructor with >1,200 dives and was diving with a master diver trainee and a newly qualified instructor (<120 dives). The deckhand questioned if my tank had been changed. All day, they had swapped my tank as soon as I came on board. I told them it was good, that I'd checked my air and the tank pressure was 234 bar (3,394 psi). Off I went, and shortly after the other two followed. Down at 16 meters (52 feet) and still descending, I felt my tank going dry (it was increasingly harder to draw air), checked my gauge, and — yep! — I was out of air. I looked up, then looked at the girls, both about 4–5 meters (13–16 feet) away. I started tapping my tank; the instructor ignored me but the trainee looked up, so I gave the out-of-air signal. We swam toward each other, and I took her reg as she grabbed her octopus. We surfaced, and the instructor (who was my dive guide) came up with us. The surface crew swapped my tank, and off we went to finish our dive!

So what happened? Well, when I am overseas I use a dive computer with a tank contents transmitter. I am in my early 50s and recently started wearing +1.00 reading glasses. I don't need them underwater due to magnification, so as I was gearing up I did not have my glasses on, and when I checked my wrist watch/gauge and read 234 bar (3,394 psi), in fact it was 23.4 bar (339 psi). The decimal point on the display is minute, and I couldn't see it.

Editor's comment: There is no practical benefit to displaying cylinder pressures to one decimal place, since the pressure inside a tank will vary that much with changes in temperature. Dive computers with this level of detail likely increase the risk of an error when reading the pressure, as happened in this incident.

EQUIPMENT-FAILURE PROBLEM

CASE 856: A REGULATOR FAILED UNDER PRESSURE (BUT THE DIVERS DID NOT)

A group of students and I decided to plan a dive trip to a local inland dive site. As soon as I entered the water, my octopus hose started flying around, slapping the water and making a loud free-flow air sound. I didn't really know what was going on, and I was trying to grab my hose, but I couldn't see what was going on and was unable to grab it initially. My dive buddy, Matt, finally came to my rescue and turned off my air. This all happened on the surface. We found out that the plastic octopus regulator completely broke off from the hose. The regulator second stage fell to the bottom, and the hose was left in a free-flowing state. Thankfully, no one was hurt, but it was a little scary because obviously I was not expecting that to happen. Luckily, it was all caught on camera so that we could all relive the moment.

Editor's comment: All divers involved in this incident have given permission for the clip to be shared and this incident report to be published. See the incident video here: https://www.diversalertnetwork.org/diving-incidents/Regulator-explosively-failed-under-pressure-but-the-divers-did-not

In case it is not clear, the cause of this incident was a plastic second-stage octopus regulator breaking under pressure. In most regulators, the metal fitting at the end of the hose is attached to a metal part of the second stage, which contains the valve that opens when the diver inhales to deliver air to the diver. In this particular case, the attachment point was also plastic, and it gave way under the pressure in the hose. This diver and her buddy are very lucky that no one lost an eye, and we are grateful they are sharing this incident to warn other divers. It was also fortunate the regulator did not detach itself underwater, while the diver was at depth. Experiments have shown that a tank will empty far quicker if the low-pressure hose (for a regulator) bursts, rather than if a high-pressure hose (to the pressure gauge) bursts. This is because the low-pressure hose has a larger hole for air to pass through, where it screws into the first-stage regulator. All divers should regularly inspect their hoses for wear and tear, including every time regulators are rented or borrowed. In addition, many old plastic second-stage regulators now bear microfractures in the plastic and may fail when additional stress is placed on them (see Figure 3-5).

Figure 3-5. Plastic second-stage regulators with microfractures

LOSS OF CONSCIOUSNESS

CASE 738: WITHOUT WARNING, A DIVER FELT CRUSHING CHEST PAIN

Our group consisted of five divers; this issue happened to my father. We all geared up topside and entered the water, put our fins on, made sure everyone was set and began our dive. We leveled off at 60 feet (18 meters) and headed south along the reef, fluctuating between depths of 60–78 feet (18–24 meters). At the 14-minute mark, we were at a depth of 60 feet (18 meters). My dive buddy approached me and signaled that he was not feeling well; I repeated the signal back to him and he verified there was an issue. I signaled back, asking if he wanted to end the dive and ascend, and he acknowledged that we needed to end the dive and make our ascent. Once we hit the surface, I inflated his and my BCD, placed the diver on his back, located the exit point, and began to swim back. I did remove the regulator at one point so he could tell me tell me his symptoms, which were that it felt like there was an elephant sitting on his chest and he was in a considerable amount of pain, having difficulty breathing; then the regulator went back in to protect his airway. Before we reached shore, another diver in our group had made his way back to shore and informed a person there to call an ambulance.

Once we made it to shore, the diver's chest pains did not subside; he continued to breathe off the regulator. Since we were at a dive shop, I yelled for someone to bring oxygen. At this point, the diver was losing consciousness and could no longer communicate with us. The person from the dive shop arrived with the oxygen, and we swapped out the regulator for oxygen. The diver was unresponsive at this time, his eyes were barely open, but I repeatedly spoke to him, telling him to breathe. The ambulance arrived about 15 minutes within our reaching shore. They stuck an IV in the diver and began monitoring his oxygen saturation, assuring me the diver was breathing.

We contacted DAN within 30 minutes of getting to the hospital to open a case. As time passed, his condition improved, his color began to come back, and his speech improved. The EKGs and CT scan were all normal; they kept him overnight to repeat the blood work and EKG. All the tests came back normal, and they released him 24 hours after we arrived. No diving for the rest of the week for him, and they told him to seek out specialists when he returned to the States.

Editor's comment: The cause of this medical emergency is not yet fully understood, but these divers took the best course of action by seeking medical treatment immediately. The diver started his day with no reason to suspect this dive would be anything but fun. Then, when he started feeling unwell, he correctly signaled his buddy, they ascended in a controlled manner, and the buddy inflated both BCDs before towing the victim to shore. This case is a perfect example of why every diver should consider taking additional training in how to rescue a buddy.

On the shore, first aid was supplied swiftly and an ambulance was called and arrived soon, all while the patient deteriorated. There is no way to know how this might have ended if medical assistance had not been so readily provided. Then, once they were at the hospital, the dive buddy called DAN, a case was opened, and real-time medical advice was given.

IMMERSION PULMONARY EDEMA (IPE)

CASE 826: IPE OCCURRED IN AN OTHERWISE HEALTHY DIVER

Last Sunday I had a life-threatening dive accident. It was a dry-suit dive in 52°F (11°C) water. It was the best dive yet in my new drysuit. I felt like I was really getting comfortable in it. We got to the dive site in about 15 minutes, and we were at 70 feet (21 meters). I really hadn't expended any energy getting there, but I was suddenly out of breath. I stopped to catch my breath, but it got worse. In about two minutes I knew something was really wrong, and I signaled my buddy. He is a very experienced dive instructor. We also had a dive instructor student along. He immediately started a controlled ascent, and the two of them got me on shore and called the aid car. They not only saved my life but saved my drysuit by getting it off me before the fire department could cut it off me. Now these are good dive buddies! I was diagnosed with immersion pulmonary edema (my lungs filled with fluid).

The reason I am writing to you about this is that I read every DAN posting in Facebook, and I mentally practice skills and what to do in emergencies. On Sunday I did what I had practiced in my mind. When my buddy got to the hospital, he said I did everything right. So I have to credit DAN's daily Facebook postings for helping my buddies to save my life.

WEIGHT AND BUOYANCY PROBLEMS

CASE 716: A WEIGHT BELT FELL OFF AND CAUSED AN UNCONTROLLED ASCENT

Toward the end of the dive, at about 20-foot (6-meter) depth, my weight belt fell off (the buckle came loose from the strap). I exhaled and dumped air from my drysuit as quickly as possible and tried to flare my body to increase drag. My dive buddy tried to grab me, but I was dragging him up, too. I surfaced and power-inflated my BCD. Another diver in our party brought my weight belt up and I tried to put it on at the surface, and that is when I realized that the strap had come out on the female side. We therefore aborted the dive and did a surface swim to the exit point. I am fine and just glad it didn't happen at 66-foot (20-meter) depth.

CASE 706: AN INFLATOR CAUSED A RUNAWAY ASCENT UNDER THICK ICE

While diving in a frozen lake, the ring around my power inflator button started spewing bubbles and filling the BCD faster than I could dump the air. The hose connecting the BCD would not disconnect, as it was frozen. My rapid accent to the top resulted in a ruptured eardrum. I kept a cool head and did my best to slow my ascent by holding down the purge button; however, air was entering my BCD faster than it could escape. There was just under 3 feet (1 meter) of ice on the lake. I hit the ice overhead, then followed my line back to the hole. The power inflator button was still pliable; however, bubbles were coming out from around its rim, and depressing it did nothing. The vest continued to inflate and purge out of the overflow valve until my friends on the surface were able to disconnect the power inflator hose.

Editor's comment: Diving underneath ice, like cave-diving, requires specialty training, so that when the unexpected happens a diver will keep a cool head and react appropriately. In this case, when his BCD suddenly and unexpectedly started rapidly inflating, the diver kept his head and tried to slow his ascent. Even after his abrupt stop, the situation could have deteriorated if he had not maintained contact with his safety line. Even though his BCD was continually overinflating, wasting precious gas and holding him up against the ice, the diver focused on exiting the water to safety. He made it out via a hole through almost 3 feet (1 meter) of ice, where his friends were finally able to assist him.

CASE 686: A DIVE BUDDY EXPERIENCED A RUNAWAY FEET-FIRST ASCENT

The incident took place on the last dive of the final day of our six-day trip to a remote diving area. I and my buddy (both certified rescue divers with approximately three years' experience, 150 dives, mostly in drysuit cold-water conditions) did our predive checks. On this wall dive, our dive plan was to descend to about 90 feet (27 meters) and traverse the wall until our remaining no-decompression-limit time reached five minutes, or our pressure reached 1,500 psi (103 bar). All dives this week were on air, with dive computers, and safety stops were made on all dives. Water temperatures were in the low 50s F (10–12°C), so we wore drysuits.

We exited the boat and hit the water, then commenced our descent. When we reached 90 feet (27 meters), my buddy leveled off and I continued my descent to 100 feet (30 meters) to video the wall from below. We were five to six minutes into our dive, at 90–100 feet (27–30 meters) when a flash of light caught my attention. My buddy was about 20 feet (6 meters) away, above me and closer to the wall, and I could see she was trying to reverse a feet-first ascent by sculling with her hands. She had recovered an upright position, but her ascent was continuing. I could see from the air in her suit that a rapid ascent was likely. I began swimming over and up to her, clipping my camera off to a shoulder D-ring. I held my BCD inflator/deflator in my left hand, and my dive computer began to beep to warn that my ascent was exceeding 30 feet per minute (10 meters per minute). I added air to my BCD and kicked hard, my hand still on my inflator/deflator control. By now we were likely at 60 feet (18 meters).

I grabbed her fin with my right hand and dumped all the air from my BCD with my left. This was not enough to slow her down. At this point it was a pure runaway ascent. I feared an arterial gas embolism and began to hyperventilate — short inhale, fast exhale — and hope for the best. Suddenly the water around me was all chaos, as we shot up through the tiny bubbles of our own exhaust. When we were at 15 feet (5 meters) and still firing toward the surface, I made a calculated and conflicted decision. I decided to let go. My ascent immediately stopped, and my buddy went to the surface. I made a safe ascent from there, taking 20 seconds or so to reach the surface. She was responsive and alert, with no signs of DCS. Neither of us developed any symptoms following the incident.

VALVE NOT OPEN FULLY

CASE 710: A DIVER TURNED HER VALVE OFF INSTEAD OF ON

While diving with my dive buddy in Florida, I noticed that upon each inhalation the needle of my submersible pressure gauge (SPG) fluctuated. The needle dipped down with each breath, before returning to the correct psi reading for my tank. I continued diving while keeping a close eye on the gauge and, upon reaching a depth of approximately 55 feet (17 meters), it suddenly became very difficult for me to breathe. I looked at my SPG midbreath and saw the needle drop down to 0 psi, and it did not readily move back up. I felt like there was no more air available to me, even though I knew there was at least 1,200 psi (83 bar) in my tank.

I signaled "out of air" to my buddy and used her alternate regulator. We made a controlled ascent to the surface, and I was not injured. Upon inspecting my gear, I realized that instead of turning my tank all the way on and half a turn back, I had turned it all the way off and half a turn on. Upon reaching a depth below 33 feet (10 meters), I had experienced inadequate air pressure delivery from my tank to my regulator because the tank was barely on and could not continue to deliver the same volume of air at the increased pressure.

Editor's comment: It must have been disconcerting to suddenly be unable to breathe at 55 feet (17 meters). This diver kept a cool head, signaled "out-of-air" to her buddy, secured an alternate air source and made a controlled ascent. This is exactly what is taught in entry-level diver courses worldwide.

This incident also highlights a topic DAN is concerned about and that we wrote an article about in 2014, available here: http://www.alertdiver.com/Tank-Valves-and-Out-Of-Air-Emergencies

The days when we needed to turn our valve back half a turn are long gone, but some instructors still teach divers to do this. Why? The safest way to ensure you have adequate gas for any dive is to open your tank valve all the way, then look at your SPG while taking a couple of breaths. If your needle does not move, then your valve must be open, and if your needle goes down toward 0, then your valve must be closed. If you are in the habit of turning it back half a turn then, like this diver discovered, you might have enough gas to breathe normally at the surface but you could find yourself short of breath at depth. Remember, the safest practice is to turn your tank valve all the way open or all the way closed.

ALTITUDE DIVING

CASE 744: A DIVE AT HIGH ALTITUDE ENDED WITH A TRIP TO THE HYPERBARIC CHAMBER

A 48-year-old woman dove at an altitude of approximately 6,000 feet (1,828 meters). She was diving with her husband, who is a master diver. They were scuba diving, breathing compressed air, in water at a temperature of approximately 90° F (32°C). They dove to 64 feet (20 meters) for 40 minutes bottom time before ascending to 40 feet (12 meters) for a five-minute safety stop. They then ascended to 20 feet (6 meters) for a five-minute safety stop, then to 15 feet (5 meters) for a five-minute safety stop. They were both using dive computers, and neither of those alarmed or indicated omitted decompression at any time. No rapid ascent or unusual occurrences happened any time during the dive.

Approximately 45 minutes after surfacing, the diver experienced numbness and tingling in her right foot, which ascended to her right hip, resulting in weakness and numbness in her right leg. Her husband drove her to the emergency department (ED), where they arrived 1.5–2 hours after surfacing. In the ED, she was placed on 100% oxygen via a non-return face mask. The decision was made to transfer the patient for hyperbaric oxygen recompression therapy, and she was transported directly to the hyperbaric medicine chamber. Later, she was still on 100% oxygen and stated that her symptoms had almost completely resolved.

MISCELLANEOUS REPORTS

CASE 682: A PAIR OF DIVERS WENT SPEARFISHING, BUT A LIONFISH SPEARED THEM

While diving to 110 feet (34 meters) spearfishing, two divers were stung by a lionfish while attempting to harvest lobsters under a ledge. Both divers were maintaining proper buoyancy but were focused on the catch and did not see the lionfish swimming up to their location. Both divers got stung in the knee through their 5mm wetsuits but were able to ascend in a controlled manner. The trip back to shore took two hours, and both divers experienced extreme pain at the sting sites. One of the divers even experienced breathing problems. Both went to the local hospital and were treated for the stings before being released.

Editor's comment: Originally from the Indo-Pacific, lionfish, while beautiful, are an introduced species that has rapidly infested the East Coast of the United States, and divers are encountering them more frequently than ever before. DAN recommends keeping a careful watch for lionfish, especially when near reefs, man-made structures or harbors. When lionfish are spotted, divers should maintain a safe distance because, although they are not swift in the water, they may behave territorially. As the divers in this incident discovered, even a thick wetsuit offers little or no protection from the venomous fin rays of these aggressive predators. For more information on lionfish, including first aid for stings, see http://www.diversalertnetwork.org/health/hazardous-marine-life/lionfish-envenomation

CASE 692: A DIVER DEFOGGED HIS MASK WITH CONCENTRATED SHAMPOO, AFFECTING HIS VISION

During a recent holiday to Southeast Asia, I used shampoo for cleaning my mask to prevent it from fogging up during the dive. I have used shampoo before (e.g., in the Red Sea and Baltic Sea) without problems, but on this day I used shampoo supplied by the dive boat. Regrettably, the shampoo was a strong concentrate, and I did not completely rinse out my mask. During the dive, I felt only mild eye soreness. After ascending, I took the mask off, and that is when the irritation got stronger and very uncomfortable, so I wiped my eyes to clear the irritant away, but the situation only got worse. Back on shore, I learned there was no doctor on the island, and by now my left eye was stinging so bad that I had to take an emergency boat trip to the hospital on a larger island nearby.

Later, when I returned home, I visited my local doctor and was relieved to hear that no further treatment is going to be needed.

Editor's comment: This diver is lucky that his eyesight recovered fully. Nonetheless, this was a painful and frightening experience; it cut short his diving and cost hundreds of dollars for transport and treatment. When a mask is new, or when it has been in storage for a while, fumes may have settled on the inside of the lens, and toothpaste is a suitable gentle abrasive that can be used to scour off this residue. After cleaning the inside of the lens, make sure all the toothpaste is removed. Next, before diving, divers may want to smear a fine coating of detergent on the inside of the lens to stop microdroplets of water from forming on the glass. These microdroplets are what causes mask fogging, but they will not stick to detergent. Nonirritant commercial antifogging agents can be purchased from many dive centers, but we have a naturally occurring detergent in our saliva, so many divers prefer to spit in their mask, then wipe the spit over the inside of the lens before swilling out any excess. It goes without saying that this is yet another good reason for owning your own mask.

Whichever method you choose, remember to use clean hands to spread the detergent (smears of sunscreen, for example, will cause the lens to fog up). Lastly, while in theory other types of detergent, such as shampoo, might prevent fogging, not all shampoos are nonirritant, as this diver learned, and therefore it is the best practice to use either a commercial antifogging product or good old spit.

CASE 757: AN ELDERLY DIVER APPEARED CONFUSED

I was a guest on a dive trip and was paired with the buddy who invited me. We initially were told that the dive site was around 45 feet (14 meters) deep. The dive and current, however, led us into 80 feet (24 meters) of water. To my dismay, I saw the majority of divers making direct contact with the reef with their hands, bodies and fins. One elderly man, perhaps in his 70s, appeared to be the worst offender. I signaled to him to come up off the reef, but he was not responsive. I then gently tugged on his fins, so that he would take them off the reef, but within minutes he was lying on the reef again, with both hands fastened to coral heads. I noticed that he was largely unaware of the divers around him, and I could not ascertain who his buddy was.

Just short of 40 minutes, the majority of divers had started to surface. My buddy, the dive guide, the elderly man and I were the last four to ascend, at exactly 40 minutes, when the dive guide and I signaled that it was time to go up. We managed a slow ascent, with a deep stop at around 35 feet (11 meters), but noticed that the elderly man had barely lifted off the bottom. After a minute or two at 35 feet (11 meters), the three of us began another slow ascent to the safety stop. The elderly man remained below us and did not make eye contact with us during the ascent. We watched him in bewilderment as he came up to approximately 35 feet (11 meters); he seemed to be trying to equalize using the Valsalva maneuver, but then he began to descend again. He may have come up to 35 feet (11 meters) maybe one more time before we watched him sink again. He was barely moving, and I could not see his face from where we were. I banged my tank to get his attention, but he did not respond. All I could see was that he was sinking and drifting farther away from us. We were also nearing 50 minutes bottom time, which was well over the time we were supposed to surface. My buddy was also low on air and ready to surface.

I looked at the dive guide/instructor, who was carrying the float, and wondered if she would go and get him. She signaled to me that she would wait for him to join her, but, after seven minutes at the safety stop, it did not appear that that was going to happen. I decided then that I was going to get him. He wasn't swimming, he was sinking, he was alone, and he was not communicating with the rest of the group. I wondered if he was going to have enough air to make a safe ascent from the depth he was at.

I swam down and signaled that it was time to go up. He had a blank look on his face and was breathing but not doing too much of anything else when I made contact with him. He moved very slowly and just could not reciprocate any type of communication. I gave him the "up" signal, got behind him to grab his tank valve, and slowly ascended with him. He did not move or try to swim at all. At 20 feet (6 meters), I asked him again if he was okay, but he did not signal back. I signaled to him to inflate his BCD so that he wouldn't sink and that I wouldn't have to hold him in place at the safety stop, but he did not respond. His arms were just floating. So I held him from behind and inflated his BCD for him. I had to maintain contact because he was not swimming, nor could he keep from sinking. I did this as gently as I could; he didn't fight, just kind of floated there in "happy land" – so strange . . .

Under the circumstances, I felt it was safer to have him complete a safety stop than go straight to the surface. Once at the surface, he seemed to be fine and was able to get to the boat and up the ladder without incident. He was apologetic but offered no explanation for why he continued to sink or why he would not reattempt an ascent. He also acknowledged that he did not know or did not think to signal to anyone about any trouble he might have been having during his dive. He denied any other problems after questions by several other divers on the boat, but, by the decision of the dive leader, he did stay at the surface during the second dive.

Editor's comment: This case is mysterious, and we will likely never know why the elderly diver appeared unresponsive at depth. With the diving population gradually aging, we are hearing more reports of cardiac complications while diving, some of which may be transient and/or may result in momentary memory loss. Regardless of the cause, in this case another diver noticed something odd, weighed the circumstances (time at depth, remaining gas, overdue at the surface, etc.) and decided to act by assisting. As this diver discovered, being aware of other divers in the water need not be limited to just our buddies. Also, having the rescue skills to assist an unresponsive diver certainly helped this Good Samaritan with retrieving the elderly diver and then maintaining depth during the safety stop. Skills such as these are taught in dive rescue courses for just such emergencies.

IN CONCLUSION

The value of the DAN DIRS continues to grow each year. To recap, it appears as though the majority of reported incidents occurred during the first day of diving, often at an unfamiliar dive site, and the majority were reported by relatively newly trained divers. It must be remembered, however, that these reports were made voluntarily and, therefore, should not be thought of as a survey of random divers. Incidents apt to seem more important to divers are more likely to be reported, even though they may not be the most common incidents in diving. This may explain why the most commonly reported injury was decompression sickness when that is, in fact, much rarer than, for example, ear barotrauma.

Once again, reported equipment problems were largely those affecting buoyancy and breathing gas, and these two issues are of obvious importance to divers. As the case vignettes illustrate, many (but not all) such problems could have been avoided. The value of training is apparent, especially in the case of the diver reacting to the free-flowing low-pressure hose and in the rescue of the unresponsive diver. After training is over, DAN then recommends maintaining proficiency in the relevant skills through regular practice. Mentions in a few reports of rusty skills, such as with weight-belt adjustment, are also good learning points for divers to consider. And reports of injuries happening on boats remind us all to be safety conscious on the way to and from a dive site, not only when we are in the water.

DAN thanks all the divers who reported incidents to DIRS in 2015.

SECTION 4. BREATH-HOLD DIVE INCIDENTS

NEAL W. POLLOCK

4.1. INTRODUCTION

Breath-hold diving is defined as in-water activity involving some dive equipment but no self-contained or surface-supplied breathing gas. Breath-hold divers operate in a wide range of environments, pursue an assortment of goals, and wear various combinations and designs of suits, ballast weights, masks, snorkels and/or fins.

Common breath-hold activities include snorkeling, spearfishing, collecting, and freediving. Snorkelers may remain completely on the surface with no purposeful breath-hold, or they may use breath-hold in relatively limited surface diving efforts. Breath-hold spearfishing incorporates the act of underwater hunting for food into breath-hold exercises. Collecting generally refers to underwater hunting without spear devices. While maximizing breath-hold time and/or depth is generally not the primary motivation for either spearfishers or collectors, the challenge of the hunt, can encourage divers to push their limits. Freedivers are explicitly employing breath-hold techniques, with or without descent below the surface. Increasing their breath-hold time and/or the depth of their dives are common goals for freedivers. The nature of such dives will vary dramatically according to the individuals' skill and training level.

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

Extensive safety and disqualification protocols have kept the rate of adverse incidents in competitive freediving low. The same level of safety does not always exist outside of organized events, however. The risk of injury or death is higher for breath-hold divers who do not have proper training or who fail to ensure adequate safety backups. The sport's

Discipline	Description	Record Performances	
		Male	Female
Static: min:sec	Resting, immersed breath-hold in controlled water (usually a shallow swimming pool)	11:35	9:02
Dynamic, with fins: ft (m)	Horizontal swim in controlled water	984 (300)	778 (237)
Dynamic, no fins: ft (m)	Horizontal swim in controlled water	800 (244)	626 (191)
No-limits: ft (m)	Vertical descent to a maximum depth on a weighted sled; ascent with a lift bag deployed by the diver	702 (214)	525 (160)
Variable weight/ballast: ft (m)	Vertical descent to a maximum depth on a weighted sled; ascent by pulling up a line and/or kicking	479 (146)	427 (130)
Constant weight, with fins: ft (m)	Vertical self-propelled swimming to a maximum depth and back to surface; no line assistance allowed	423 (129)	341 (104)
Constant weight, no fins: ft (m)	Vertical self-propelled swimming to a maximum depth and back to surface; no line assistance allowed	335 (102)	236 (72)
Free immersion: ft (m)	Vertical excursion propelled by pulling on a rope during descent and ascent; no fins	406 (124)	302 (92)

Table 4.1-1 AIDA-recognized competitive freediving disciplines and current records (as of September 2, 2017)

minimal equipment requirements should not be equated with inherent safety; in fact, they mean that almost anyone can get in trouble if they are not informed of the sport's hazards. Breath-hold divers are susceptible to the physiological stresses of immersion, hypoxia, and hypercapnia, and, if they are diving vertically, potentially to immense squeeze forces. Loss of consciousness is the most obvious life threat associated with breath-hold diving, but it is not the only risk.

The active collection of breath-hold incident case data began in 2005 at the Center for Hyperbaric Medicine and Environmental Medicine, based at Duke University, then transitioned to DAN over the next few years. The initial effort included a retrospective review of cases beginning in 2004 (including those reported to DAN or found through active internet searches). Automated keyword searches were then established to capture new reports as soon as they appeared online. A database was developed to target the information of primary interest to dive safety experts. Details on the structure of the database can be found in the proceedings of a 2006 breath-hold workshop (Pollock 2006). Unlike the data analyzed by DAN for compressed-gas diving accidents, the breath-hold incident database includes cases without geographical restriction. Reviews of breath-hold incidents have been included in the DAN Annual Diving Report since 2005. Electronic copies of these reports are available for download, at no cost, at http://www.diversalertnetwork.org/medical/report. (Note that the information collected by DAN on fatalities and injuries associated with compressed-gas diving is also found in these reports.)

The number of cases captured from 2004 through 2015 was 763, with a mean±standard deviation of 64±17 and a range of 30 to 83 annually (see Figure 4.1-1). Eighty percent of the cases had fatal outcomes.

The purpose of incident data collection and analysis is not to assign blame but to learn from past events. Some accidents occur even when sound experience, planning, equipment, and support are in place. Such events serve as reminders of the fundamental risks of the activity and encourage us to evaluate and adjust our behaviors accordingly. Other accidents arise from flaws in equipment maintenance,

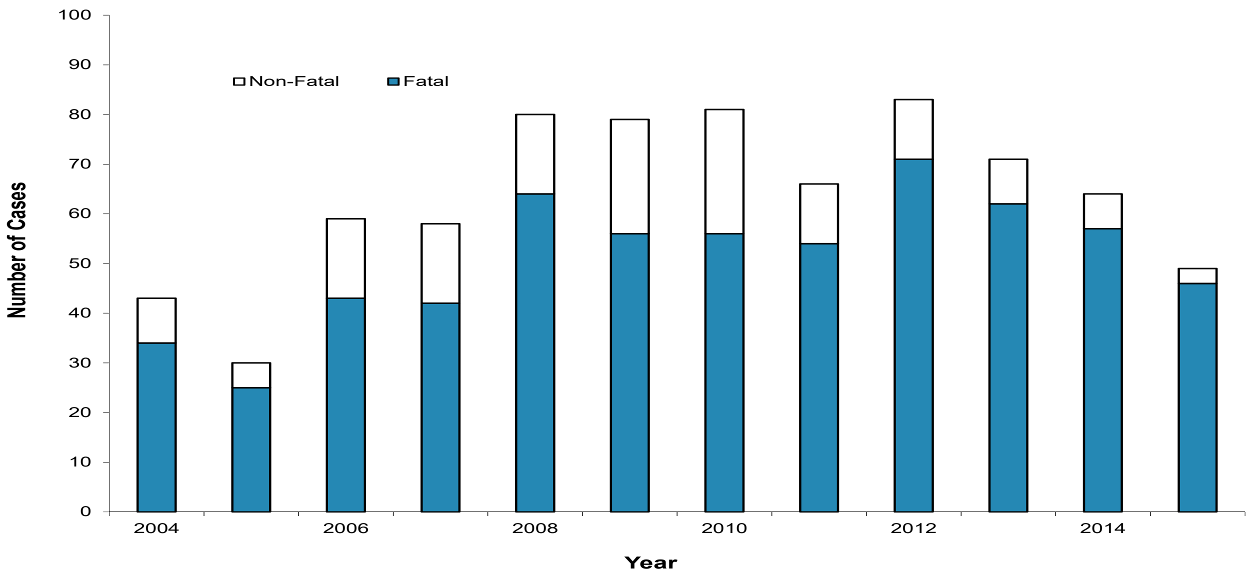

Figure 4.1-1: Breath-hold incidents, 2004–2015 (n=763; 80% fatal)

equipment use, training, or procedures. Incident analysis and program review can reduce future risks for all participants.

A fundamental challenge in the study of diving accidents is incomplete information. The investigative effort often requires a substantial amount of deductive reasoning and even some guesswork to interpret events. In this report, we summarize the available data and speculate when that is judged to be reasonable.

4.2. CASES IN 2015

Most 2015 cases were initially identified through automated internet searches, typically through online news articles. Some cases were reported to DAN directly by individuals involved in or aware of particular incidents. Complete details were rarely available.

A total of 49 breath-hold cases were captured in 2015 — 46 fatal (94%) and 3 nonfatal (6%). Incidents were reported from 12 different countries. Just over half (27, 55%) occurred in the U.S., in six different states: California (11 cases, 41%), Florida (6 cases, 22%), Hawaii (6 cases, 22%), Virginia (2 cases, 7%), New Jersey (1 case, 4%), and Rhode Island (1 case, 4%). The distribution among the top three states is similar to that seen in previous years and almost certainly reflects the popularity of water-related activities in those states, as well as, possibly, some reporting bias. It is highly unlikely, in any case, that our data on fatal cases reflects the true total numbers. It is almost certain that some fatal diving incidents involve breath-holding but are not reported in a way that makes that evident, meaning they cannot be captured in our database. This problem is even more marked in nonfatal cases. Our nonfatal case reports should thus be considered an anecdotal sample, useful for insight and illustration, but in no way representative of the frequency of such events.

The vast majority of the incidents captured in 2015 occurred in the ocean (45 cases, 92%); 3 occurred in swimming pools, and 1 in a lake. The primary activity most frequently associated with breath-hold incidents was snorkeling (24 cases, 49%); others included freediving (12 cases, 24%), collecting (11 cases, 22%), and spearfishing (2 cases, 4%). The value of these categorizations may be limited, however, particularly for fatal cases. The presence of specific equipment, such as a speargun, or of a history or communicated plan for a dive outing, may support the value of such categorizations, but the specific actions or events con-

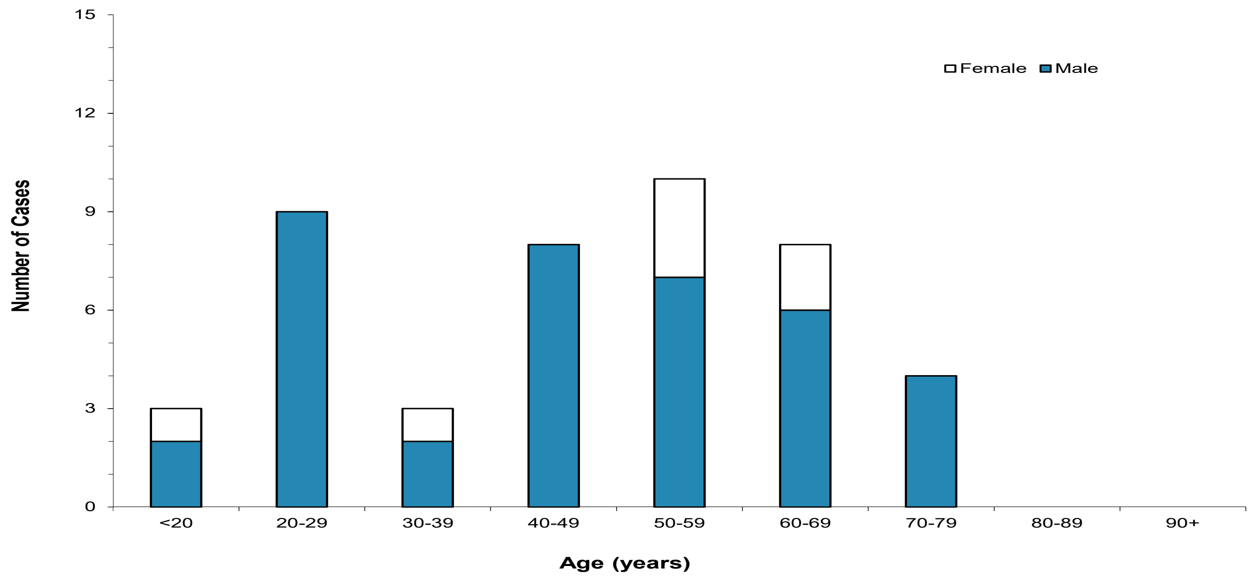

Figure 4.2-1. Age and sex distribution of breath-hold incident victims in 45 of 49 cases in 2015

tributing to an incident can easily confound categorical distinctions, as can reporter bias.

The sex and age breakdown for the 2015 cases is shown in Figure 4.2-1. The majority of victims were male (n=41, 84%). The mean age (±standard deviation) for both males and females was 47±18 years, and the range was from 14 to 77 years.

Information regarding the support available to affected divers was captured in 47 (96%) of the cases. The victims were diving with a group in 26 cases (55%), with a partner in 13 cases (28%), and solo in 8 cases (17%). Of course, there is no chance of anyone else being able to recognize a problem and render aid when someone is solo diving. Yet even when oversight is at hand, its effectiveness can be difficult to evaluate. But it is clear that a factor common to many accidents is a delay in recognizing a developing problem. And safety may be only somewhat improved if a diver's companions remain on shore or are not capable of completing a rapid rescue or recovery in the relevant diving environment. Effective supervision of a diver's status and immediate and appropriate action can resolve many potential problems before they become serious. This is typically best achieved when a partner or group provide close, in-water support. In group-diving situations involving just a casual association among divers, without close supervision, it can be very easy to miss problems as they develop.

Even when a stricken diver does receive assistance, it can be difficult to evaluate the effectiveness of the aid. Immediately bringing an otherwise healthy but unconscious breath-hold diver to the surface and then protecting the diver's airway from water entry (or further water entry) can be highly effective in preserving life. A slower recovery would typically be less effective, but determining the impact of a delay is challenging, as it is often not known exactly when the critical point in an incident occurred. And even a quick response might not make a difference for a medically compromised diver.

Overall, close and knowledgeable support is likely to improve outcomes. Informed partners or monitors can ask questions so as to more fully appreciate and be prepared for untoward events. There will almost certainly be a decline in informed supervision of breath-hold diving if, for example, efforts to ban the activity in swimming pools gain traction. It is easy for swimmers to hide such activities from lifeguards or other swimmers, leaving potential rescuers much less prepared to help if problems do occur. Rather than banning breath-hold diving, the prudent course would be to ensure that all swimmers, breath-hold divers, instructors, lifeguards and responsible parties appreciate the risks and the reasonable limits of the sport's safe practice. Understanding the factors that play a role in adverse incidents is one of the best ways to improve preparedness.

4.3. CAUSES OF DEATH OR INJURY AND CONTRIBUTING FACTORS

The cause of death is typically determined by a medical examiner assigned to fatality cases. The usefulness of the findings in breath-hold cases can be limited, however, particularly if the cause of death is determined to be drowning. More important to prevention efforts is the identification of root causes, triggers that initiate a cascade of events, factors contributing to an unchecked cascade, and/or specific disabling agents or injuries that lead directly or indirectly to the outcome. But the search for contributing factors is challenging, particularly in the case of unwitnessed events, because physical evidence is often not present or may be confounding.

It is difficult to determine the factors that inevitably lead to an adverse incident, but achieving a better understanding of those factors would be of great value in preventing future occurrences. The available information, as incomplete as it is, was reviewed to identify the primary disabling agents (see Table 4.3-1). The effort was not possible in 24% of cases, in some of which the body was not recovered and in others of which insufficient information was available.

Disabling agent	Number	%
Procedure/Behavior	12	32
Inadequate physical fitness	10	27
Medical health	9	24
Animal-involved injury	3	8
Environmental conditions	2	5
Boat strike	1	3
Total	**37**	

Table 4.3-1. Primary disabling agents associated with breath-hold incidents, 2015

The succeeding passages offer detailed facts and assessments regarding each of the disabling agents presented in Table 4.3-1.

PROCEDURE/BEHAVIOR

Procedural or behavioral errors stand as the most commonly identified class of disabling agent in the 2015 breath-hold incidents (n=12, 32%). This is commonly a leading class, even though its relative frequency has probably been reduced by the range of programs developed over the past 15 years to provide safety-oriented breath-hold training. In addition to the dedicated programs offered by Performance Freediving International (PFI) and Freediving Instructors International (FII), several traditional dive training agencies have developed or expanded apnea programs.

Even if the safety messaging is reaching the community, continued efforts are required to further minimize this high-risk, decision-based class of disabling agents. Such cases in 2015 included ineffective buddy operations, unsupported or unmonitored activities, and excessive efforts to prolong breath-hold time. The issue of excessive effort is the most challenging to document, since there is typically no physical evidence left behind. Combining inadequate support with excessive effort to increase breath-hold time can create huge risks. The lack of evidence makes it difficult to assess the scope of the problem, however. It is likely that some cases to which a disabling agent could not be assigned with confidence belong in this category, though that is speculation. In any case, sustained efforts to educate both new and experienced breath-hold divers are required.

It is likely that a substantial number of accidents in this data set were a consequence of intentional action, though the absolute number of such events is impossible to confirm. Outside of casual snorkeling, many breath-hold divers employ strategies to extend their breath-hold time, most notably hyperventilation. It does increase breath-hold time, but it does so by delaying or effectively deactivating the normal warning system that limits humans' breath-holding capability. The absence of physical evidence associated with fatal events involving apparently young and physically fit individuals has led some to speculate on the possibility of relatively exotic conditions like long QT syndrome, a disorder of the heart's electrical system, being a contributing factor. While such explanations are certainly possible, a much simpler and more likely explanation in most cases is that excessive hyperventilation was the underlying problem. The risk rises even higher if a diver chooses to employ such techniques when alone. And for the purposes of rescue, a diver is effectively alone if his or her partner or partners are not providing close supervision throughout a breath-hold dive. It is of note that close supervision requires the ability to act in response to a problem, not simply to observe it unfolding. A support team must be able to respond immediately and knowledgeably wherever a diver runs into trouble.

There is no simple formula to differentiate between safe and unsafe, excessive hyperventilation. Breath-hold divers must be sufficiently knowledgeable about the risks and then motivated to err on the side of safety. It is critical for all divers to realize that a loss of consciousness can develop without warning. Active avoidance is essential for the safe practice of breath-hold diving. Ignorance, or a misplaced belief that physiological hazards come with a warning, almost certainly contribute to many of the fatality cases we capture every year.

Each normal respiratory cycle is followed by a brief interruption of breathing (known as apnea) prior to the next inspiration-expiration cycle. The duration of the apnea period is primarily controlled by the partial pressure of carbon dioxide in the arterial blood. The range of its duration is fairly narrow during relaxed, involuntary respiration — from a high of 45-46 mmHg at the start of a respiratory cycle to a low of approximately 40 mmHg at the end of a cycle. Voluntary breath-holding can allow the carbon dioxide partial pressure to climb well into the 50 mmHg range or beyond, depending in large part on the diver's motivation. Eventually, however, a breakpoint is reached, when the urge to breathe is overwhelming.

Many breath-hold divers learn that ventilating the lungs in excess of their metabolic need — that is, hyperventilating — will flush carbon dioxide from the body and delay the point at which carbon dioxide accumulation reaches its breakpoint during a subsequent breath-hold. The accumulation of oxygen stores associated with hyperventilation is trivial in comparison with the clearance of carbon dioxide, since the normal concentration of carbon dioxide in the blood is 140 to 160 times the concentration found in the atmosphere. Without hyperventilation, there is a buffer in oxygen stores when the urge to breathe becomes intolerable. But any hyperventilation reduces carbon dioxide levels enough to erode that oxygen buffer. Limited hyperventilation will not erode the buffer enough to create a high risk of loss of consciousness, but there is a very fuzzy line beyond which excessive hyperventilation can delay the urge to breathe long enough for the oxygen partial pressure to fall below the level necessary to maintain consciousness.

Again, a crucial reminder: Loss of consciousness can develop before the urge to breathe is perceived. It is critical to understand that a loss of consciousness as a result of hyperventilation-augmented breath-holding can occur with absolutely no warning. There is no aura, instinct or innate superiority that will preserve consciousness — generally it is a result just of luck. But the problem with experiencing good luck is that it can reset one's sense of acceptable or safe practices. Bad luck can just as easily follow good luck, with devastating outcome.

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

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

The ability to categorize cases of blackout as being due to a general hypoxic loss of consciousness (HLOC) or, more specifically as hypoxia of ascent is frequently dependent on witness observations or on the presence of a dive computer that logs information at a fast sample rate. Confirming where the loss of consciousness developed is frequently not possible in unwitnessed events. A victim found on the bottom, for example, could have lost consciousness there, or could have lost consciousness near the surface and then subsequently sunk to the bottom due to a loss of airway gas and the positive buoyancy it provides.

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

It is very common for a diver rescued from a blackout to wake within seconds and have no memory of the event. Some may initially argue that they did not black out, until they realize that they came to their senses in surroundings different from where they last recalled being. Those who experience such events firsthand (as either a victim or a rescuer) realize how close one can be to loss of consciousness in a very unforgiving environment. Regardless of what some want to believe, neither training nor experience can produce a warning of impending blackout. Hopefully, divers can learn this prior to catastrophic events, and from then on reminding them to stay comfortably within their personal limits and ensure that they have adequate backup. The effect of hyperventilation on increasing the risks of breath-hold diving was described in the medical literature more than 50 years ago (Craig 1961a and 1961b), and yet divers are still being lost to its aggressive practice. Limiting hyperventilation to no more than the equivalent of two full ventilatory exchanges will still increase divers' breath-hold time but will likely not eliminate so much carbon dioxide that the urge to breathe is delayed long enough to threaten their consciousness. Hyperventilating in excess of this two-exchange limit escalates the risk that a diver's vital instinct to breathe will be problematically suppressed.

INADEQUATE PHYSICAL FITNESS AND ENVIRONMENTAL CONDITIONS

Separating physical fitness from environmental conditions as underlying factors in breath-hold incidents is difficult, since they are interdependent. Stated simply, a more physically fit diver is less likely to have problems with a given set of environmental conditions, but environmental conditions can also become severe enough to be unmanageable by even the most fit individuals. The associated hazards are compounded for those who tend to overestimate their own capabilities and/or underestimate environmental hazards. Inadequate physical fitness was identified as the primary disabling agent in 10 cases (27%), and environmental conditions were identified as overwhelming any practical level of physical fitness in 2 cases (5%). Many of the cases in which inadequate physical fitness was designated as the most important factor involved divers who were conducting seasonal harvesting dives in rough waters, often with strong currents. It is likely that interactions among limited physical capacity, demanding conditions, and possibly a lack of recent diving activity played a major role in the outcome. Physical fitness is rarely well documented in divers, but it strongly influences an individual's tolerance for adverse conditions. High levels of physical fitness create a reserve capacity that can be called upon when required. Addressing emergent needs quickly and without pushing one's physical limits can stop a cascade of events that might otherwise lead to a poor outcome. Individuals with limited physical capabilities should choose, or be encouraged to choose, to participate in water activities only under relatively benign conditions.

It should also be noted that it is important for divers with higher levels of physical fitness to appreciate that their capabilities may not be shared by everyone. Conditions that would be reasonable for them could be very stressful for those with lower fitness levels, particularly if they also have less in-water comfort and experience.

MEDICAL HEALTH

Medical health issues were designated as the third most common primary disabling agent in 2015 breath-hold incidents (n=9, 24%). This designation was most frequent among older victims. In many such cases, there was reasonable to strong evidence of cardiac involvement, and some cases appeared to combine cardiac issues with physical fitness issues. Data limitations make definitive determinations difficult. The associations among age, health and fatal diving accidents have been previously described (Denoble et al. 2008).

While water activities can be healthful, they also create a physiological strain that can be problematic for individuals with compromised health status, especially when added to the discomfort that can result from inexperience. Immersion in water, regardless of its depth, prompts an increase in the flow of blood to the heart that causes it to contract harder. Inspiration pressure increases in the water, as a result of both hydrostatic pressure and/or the urge to counteract the compressive force of a wetsuit. An individual's breathing resistance and physiological deadspace are further increased by the use of a snorkel. Wearing bulky equipment, particularly a weight belt, can also increase the strain of swimming, as can entry and exit requirements in rising seas or currents. One's initial immersion before any in-water activity is best done under benign conditions, with easy entry (and exit) options and no pressure to continue should discomfort arise. Yet it is not uncommon for vacationers to want to participate in once-in-a-lifetime activities that may expose them to more physiological stress than they had expected. Those who are medically or physically compromised can be at especially undue risk — a situation that ultimately may not be fully appreciated by either the divers themselves or the organizers of their diving expedition.

ANIMAL-INVOLVED INJURY

There were 3 breath-hold incidents (8%) in 2015 in which animal-involved injury appeared to be the primary disabling agent. All three were shark encounters. None of these divers were carrying speared fish, a factor that had been associated with shark attacks previously. The animal-involved category is a class of incident likely to be overrepresented in our database, given the potential for there to be physical evidence of the altercation and for substantial media attention to be given to such incidents. At the same time, it is also certain that many minor animal-involved injuries are not reported.

BOAT STRIKES

There was only 1 breath-hold incident (3%) designated as a boat strike in 2015. In this case, a windsurfer struck a solo snorkeler. While boat strikes are a class also thought to be overrepresented in our database, due to the presence of physical evidence and media attention, that does not appear to be the case in this year.

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

4.4. REDUCING BREATH-HOLD RISKS

Breath-hold diving encompasses a wide range of activities. Some are appropriately described as extreme and others as relatively benign. The margin of safety can be quite wide for casual, surface or near-surface activities by healthy individuals. But the margin of safety can become nonexistent in extreme-diving activities. During all in-water activities, appropriate safety precautions and backups are essential. The safety procedures employed in competitive freediving are usually effective. Yet away from the tight controls of the competitive field — or from the pursuits of medically healthy, physically fit and well-trained divers — the risks rise.

Individuals' medical health and physical fitness must be considered prior to their participation in any diving activity. Those with significant medical issues should be evaluated in advance and perhaps should be discouraged from participating in the sport. Those close to the low end of qualifying on the basis of physical fitness should participate under only the most benign conditions. For such individuals, orientation in a shallow pool or confined waters is much more appropriate than being dropped off the back of a boat in deep water, where currents, waves, weighting challenges, and/or anxiety may add to the risk factors. A thorough orientation to the activity for anyone with health or fitness concerns might encourage some to appropriately reconsider their participation in the activity — while enabling others to participate with more comfort and confidence.

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

The greatest risk is to divers who lack extensive backup support, whether they are unmonitored novices who just discovered hyperventilation or experienced spearfishers determined not to let their prey get away. Safety-oriented education and rational guidelines ensure that novice and experienced divers alike stay safe. Buddy diving in a one-up, one-down manner, in conditions of good visibility, and in water shallow enough for all divers to get to the bottom easily, can take a novice safely through the relatively high-risk phase of learning. A group of three (one-down, two-up) may be preferable as dive depths begin to increase. It is a typical rule of thumb to allow a recovery period of at least twice the duration of a dive for modest dives, with progressively longer recovery periods for deeper dives. A group of three or four, diving serially, can facilitate this sort of schedule and ensure that one or more of the divers available at the surface for backup is at least partially rested. This is important, since it is highly unlikely that optimal performance will be achieved during the stress of a rescue. Establishing safe habits in the beginning can help keep safe habits in place. Safety protocols become more complicated as dive depths are increased, potentially involving counterbalance systems or mixed-gas diver support, but a commitment to safety can keep personal and group practices evolving appropriately.

Freedivers should be defensively weighted — neutrally buoyant with empty lungs at 30 feet (9 meters) or deeper — to ensure that if they have problems at or near the surface, they are more likely to remain at the surface, where they can be found and assisted more quickly and easily. Overweighting can cause divers to sink, especially if gas is expelled from their airway at any point in the event. The momentum established during a good ascent can carry divers to the surface even if they lose consciousness.

Adequate support also requires an appropriate network of diving companions. Close support protocols — with divers shadowed during the final portion of their ascent and for the first 30 seconds of the postdive period — can address the majority of potential problems. It is important to remember that the risk of loss of consciousness continues post–breath-hold, until the oxygen in an inspired breath reaches the brain to counter hypoxia. The most critical aid for divers who have lost consciousness is to get their airway out of the water and keep it clear. If their airway is protected, consciousness is often quickly restored with no sequelae.

Another practice that creates some risk for breath-hold divers is a technique known as lung packing. A method of overfilling the lungs, it is used immediately before beginning a breath-hold dive to increase the volume of gas in the lungs above normal total lung capacity. While it can increase the duration of dives, it also increases the risk of pulmonary barotrauma (Jacobson et al. 2006). The hazards, not just the benefits, of all such techniques must be appreciated. They should be used thoughtfully and with caution foremost.

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

There are a couple of ways to strike a compromise. The simplest is to carefully restrict predive hyperventilation. Two deep inspiratory-expiratory exchanges prior to a breath-hold will still reduce the carbon dioxide levels in divers' blood and increase their breath-hold time, but without creating the high risk of hypoxia-induced blackouts that is associated with more extensive hyperventilation. The alternative is for divers to hyperventilate freely, but then limit their dive time. Butler (2006) reviewed the published data on this practice and concluded that limiting breath-hold time to 60 seconds could accommodate varying patterns of hyperventilation and physical activity with minimal risk of loss of consciousness. While this time limitation is too restrictive for some, it may be a good alternative for those who want to make safety their top priority.

Another alternative that preserves the individual freedom is the automatically deployed freediver recovery vest that are now available for breath-hold divers. These vests inflate automatically after a user-preset time at depth, at a maximum depth, or if a redescent immediately follows surfacing. While such devices do not eliminate the risk of blackouts, or guarantee divers' survival in case of blackouts, they can dramatically improve the odds of survival by returning divers to the surface, as long as they are not encumbered by an entanglement or an overhead obstruction.

Breath-hold divers spend a lot of time on the surface. To reduce their risk of problematic boat interactions, they should avoid boat-traffic areas whenever possible and clearly mark their dive site with high-visibility floats, flags and/or other locally recognized markers. In addition, they should wear high-visibility colors to make themselves as conspicuous as possible. The prevalence of equipment in dark colors or, more recently, camouflage patterns, runs contrary to visual safety practices. The safest choice is high-visibility throughout — suit, hood, snorkel, gloves, fins and whatever else might break the surface. Underwater hunters may argue for the benefits of reducing their visibility; but those who choose low-visibility or camouflaged gear need to rely even more heavily on the use of surface floats, support boats, and tenders to warn surface traffic of their presence.

All divers need to be aware of the hazards they face and of strategies that can reduce their risk. Receiving initial training from qualified individuals makes the transition into any new activity smoother and safer. Ongoing education, which includes learning from the mistakes of others, is important to ensure that the risk of participation in a potentially hazardous activity remains low. Further background on this subject can be found in a separate review (Pollock 2008). As a final note, it must be remembered that problems unrelated to diving, particularly health-related problems, can develop during diving activities. Appropriate and timely medical evaluation is prudent prior to engaging in a new activity, and also whenever an untoward circumstance arises. The important goal is not to unnecessarily limit participation, but to ensure good outcomes for all.

4.5. ONGOING RESEARCH

The greatest challenge in studying diving incidents is that complete details are rarely available. DAN maintains an online reporting system to expand its collection of cases — particularly regarding nonfatal events, about which more complete details may be available. It is expected that the additional insights gained through this effort will be extremely helpful in identifying additional factors that contribute to adverse incidents.

We encourage all divers to aid in this effort by using DAN's online incident-report form — see http://DAN.org/IncidentReport — to report any adverse events that they experience or witness. The continued effort to promote safety awareness among breath-hold enthusiasts and community leaders is essential.

4.6. CONCLUSIONS

A total of 49 breath-hold diving incidents were collected by DAN in 2015; 46 were fatal (94%) and 3 were nonfatal (6%). The victims were most often male (84%). The most commonly identified disabling agents were, in order of prevalence, procedural or behavioral errors (often involving support systems and likely excessive hyperventilation), inadequate physical fitness, medical health, animal-involved injury, environmental conditions and boat interactions. Improving appreciation among breath-hold divers of the hazards may offer the greatest defense against future adverse events. Sharing incident information is an important part of that process. We will continue our efforts to expand our collection of cases, both fatal and nonfatal, and to provide insights to the diving community.

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SECTION 5. IDAN INJURY SURVEILLANCE

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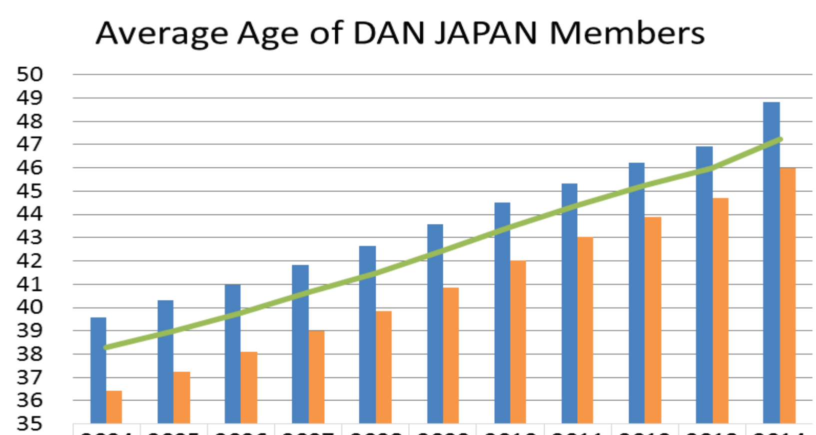
International DAN (IDAN) comprises various independent DAN organizations based all around the world. In this year's annual report, we are pleased to share detailed injury surveillance reports from four of DAN's global units. See page 5 for a list of all the IDAN-affiliated organizations.

5.1. RECREATIONAL DIVING-RELATED FATALITIES IN JAPAN, 2005–2015

INTRODUCTION

Recreational diving is one of the most popular activities in Japan. Over 40,000 new divers are certified each year (Buzzacott 2015). Commercial divers in Japan are required by law to have a regular medical examination for health



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Male	39.6	40.3	41.0	41.8	42.7	43.6	44.5	45.3	46.2	46.9	48.8
Female	36.4	37.3	38.1	39.0	39.8	40.9	42.0	43.0	43.9	44.7	46.0
Average	38.3	39.0	39.8	40.7	41.5	42.5	43.5	44.4	45.2	46.0	47.2

Figure 5.1-1. Average age of DAN JAPAN members, 2004-2014

management every six months. On the other hand, there is no regulation of health management for recreational divers, and such care is left to each diver's own responsibility. In recent years, the average age of Divers Alert Network Japan (DAN JAPAN) members has increased, from 38 years old in 2004 to 47 years old in 2014 (see Figure 5.1-1). That increase has generated concern about the possibility of an associated increase in diving-related injuries.

Analyses of diving-related fatalities have been conducted in many countries. A previous study in Japan, by Ihama et al. (2008), investigated autopsy data collected from 1982 through 2007 in Okinawa, a popular diving destination in southwestern Japan.

This study covers a more recent period and the whole country, analyzing recreational-diving–related fatalities in Japan between 2005 and 2015.

METHODS

The study was performed as a retrospective analysis. Fatality data was collected by the Japan Coast Guard (JCG) between 2005 and 2015 and by DAN JAPAN between 2005 and 2012.

DAN JAPAN is not a primary investigative organization, but it cooperates with the JCG, which deals with the majority of diving-related fatalities in Japan. DAN JAPAN has information on fatalities involving members through its insurance company.

There were 169 fatalities reported by the JCG and 11 by DAN JAPAN. Between the two groups, there were 10 duplicated cases. For this analysis, we targeted 164 cases, excluding six cases due to a lack of detailed information. An autopsy was performed in at least 20 cases; however, autopsy reports were not accessible. We investigated the profile of each diver, as well as the dive location, dive profile, event triggers and causes of death.

We classified dive style as group, buddy or solo. Group diving is a popular style for many divers in Japan. A group typically includes one or two instructors/dive masters and a few buddies.

We identified the triggers and causes of all fatalities according to the method described by Denoble (2008).

The study protocol was approved by the Institutional Review Board of DAN JAPAN and the Japan Marine Recreation Association (approval number **平成29年10月25日付第492号**).

This study was also conducted according to the principles of the Declaration of Helsinki.

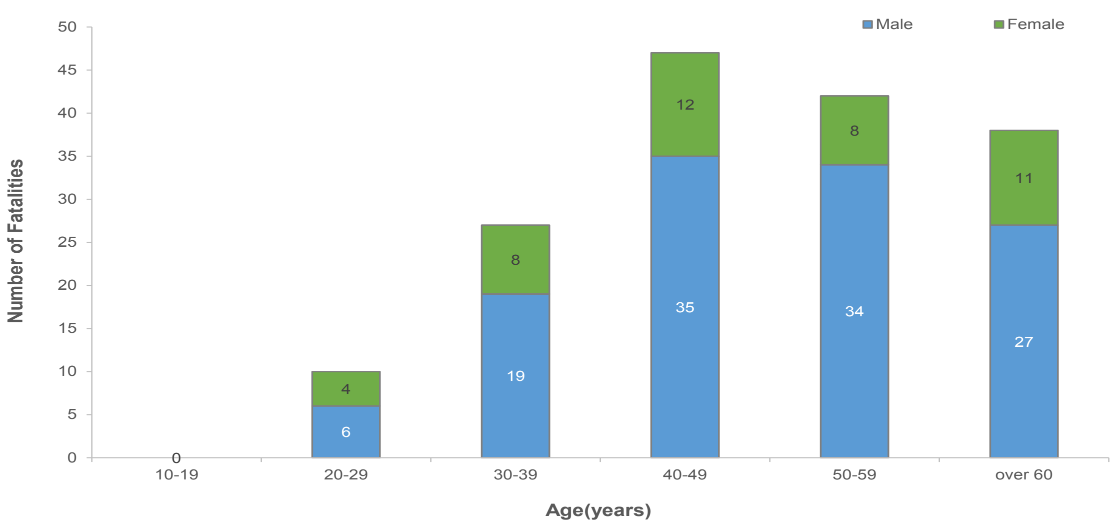


Figure 5.1-2. Age distribution of diving fatalities in Japan, 2005–2015

RESULTS

There were 121 males (74%) and 43 females (26%). Mean age is unknown because some cases are recorded in 10-year increments. There were 0 fatalities among divers in their teens, 10 among those in their 20s, 27 among those in their 30s, 47 among those in their 40s, 42 among those in their 50s, and 38 among those 60 or older. Of the 164 fatalities, 127 (77%) were in divers 40 or older, and 80 (49%) were in divers 50 or older (see Figure 5.1-2). The overall trend in the number of fatalities per year was flat (see Figure 5.1-3).

Figure 5.1-4 shows that the number of fatalities increases with the approach of summer and peaks around August. Figure 5.1-5 shows the geographic distribution of fatalities by prefecture. Okinawa and Shizuoka accounted for 73 (45%) of the 164 fatalities.

Trigger events were identified in 78 fatalities (48%); 21 cases involved cardiovascular disease, 11 loss of gas, 8 equipment trouble, 7 a weather/environmental factor, 4 alcohol, 3 entanglements, 3 water aspiration, 2 inexperience, 1 ear trouble and 18 some other trigger

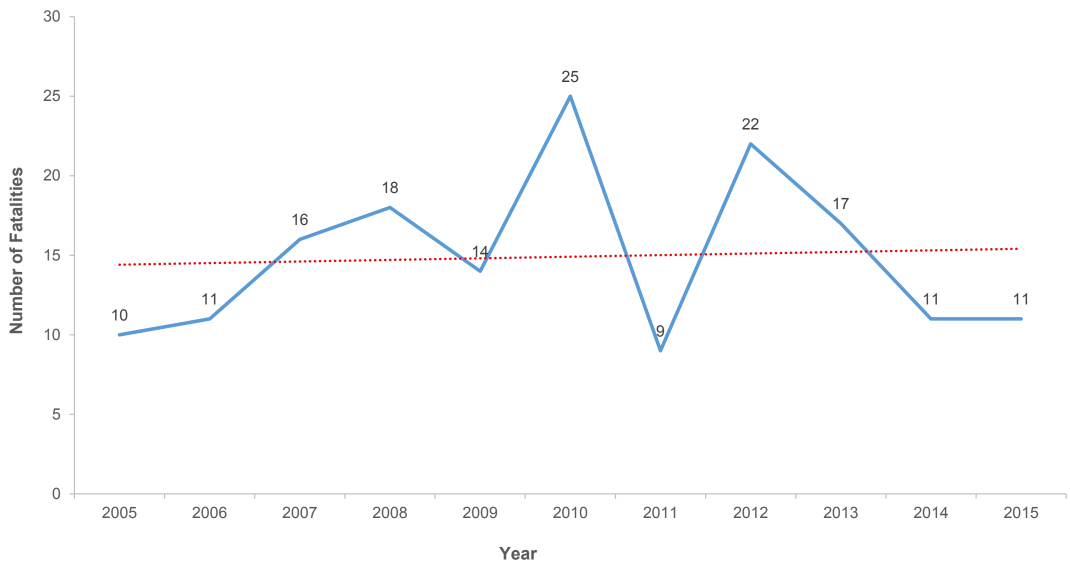


Figure 5.1-3. Number of fatalities by year in Japan, 2005–2015

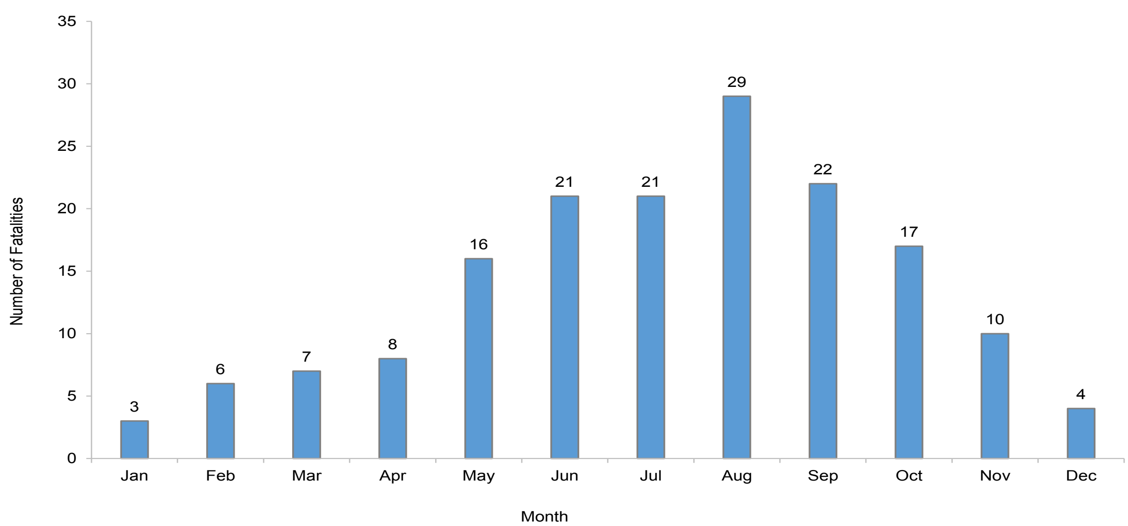


Figure 5.1-4. Distribution of fatalities in Japan by month, 2005–2015

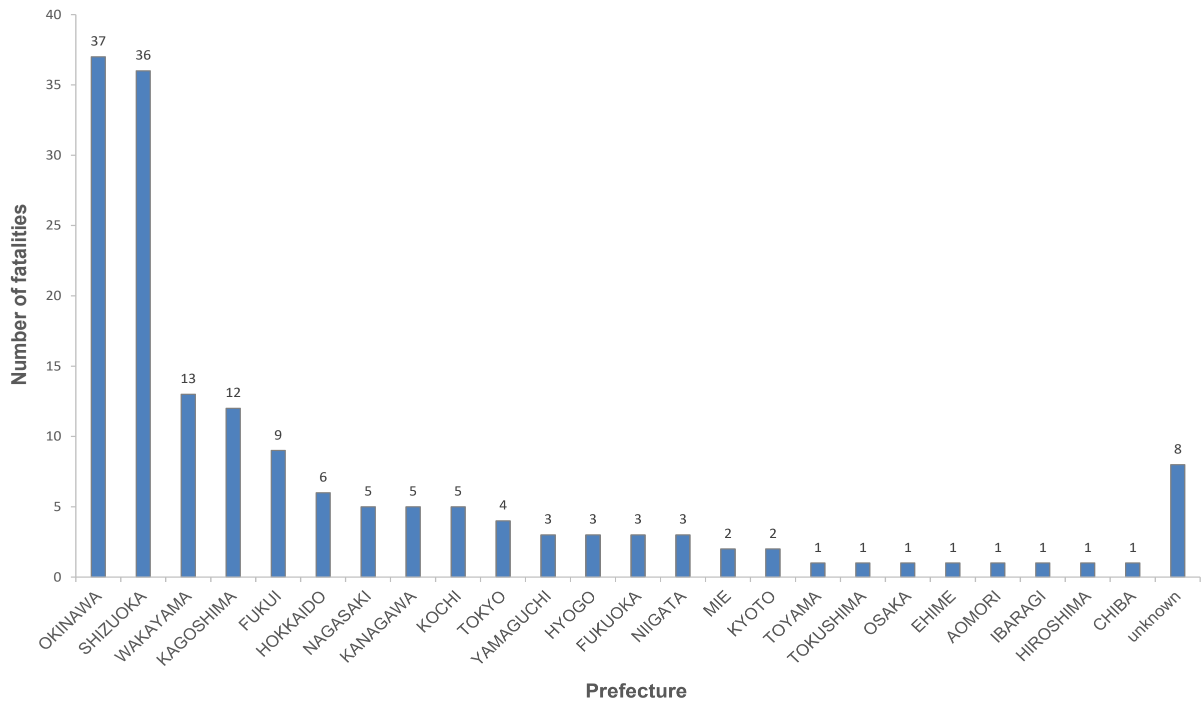


Figure 5.1-5. Prefecture where diving fatalities occurred in Japan, 2005–2015

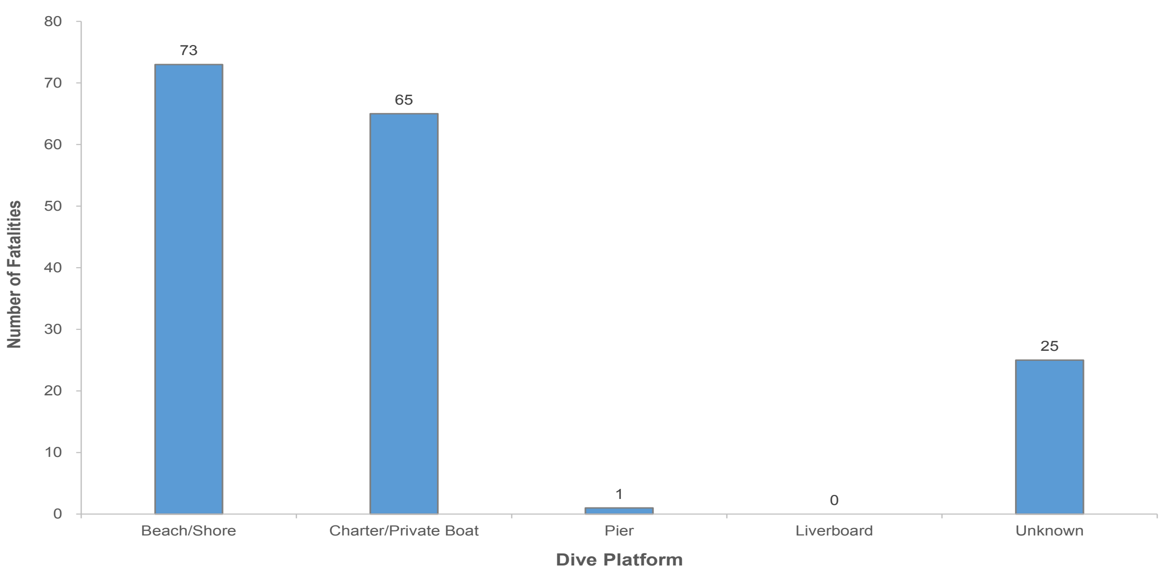


Figure 5.1-6. Dive platforms associated with diving fatalities in Japan, 2005–2015

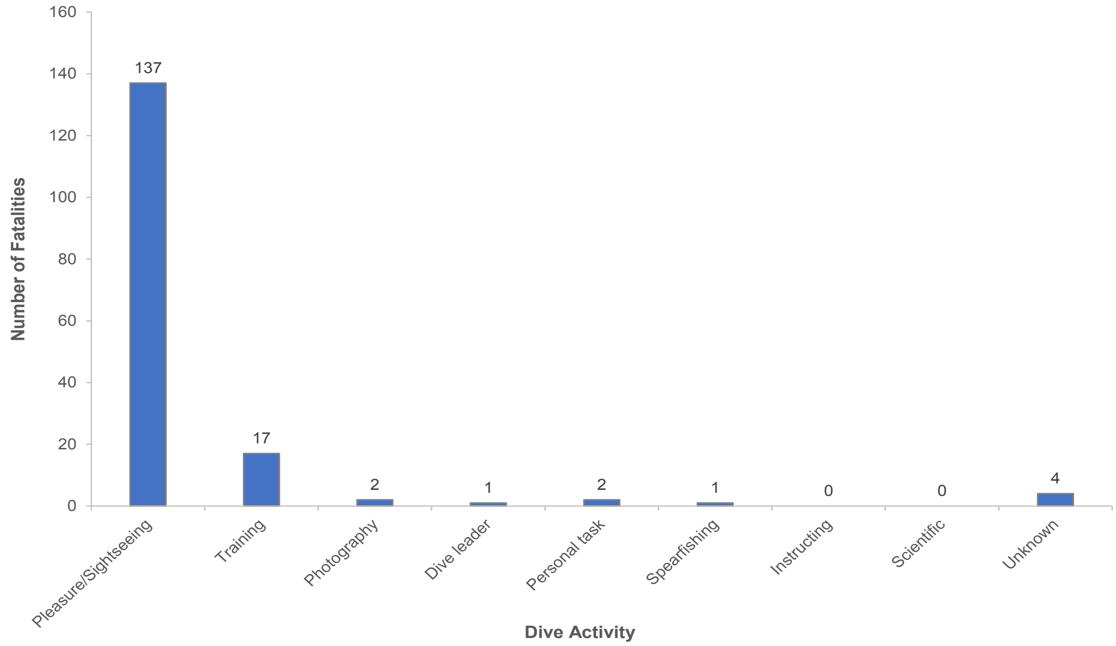


Figure 5.1-7. Dive activity during diving fatalities in Japan, 2005–2015

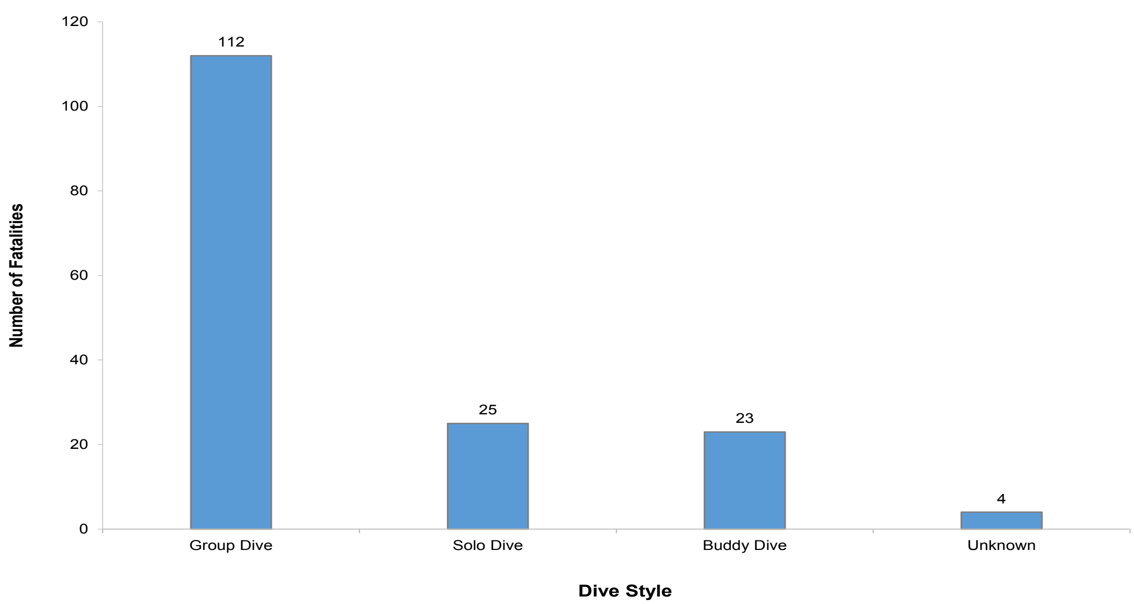


Figure 5.1-8. Buddy status during diving fatalities in Japan, 2005–2015

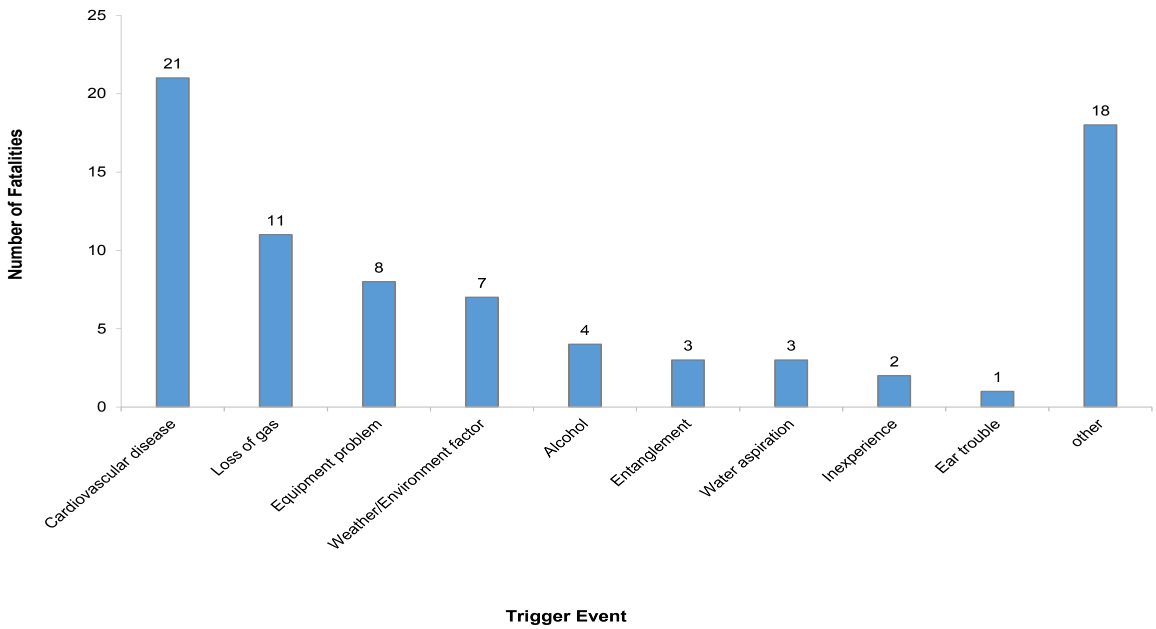


Figure 5.1-9. Triggers of diving fatalities in Japan, 2005–2015

(see Figure 5.1-9).

The cause of death is known for 103 fatalities (63%); 78 were due to drowning, 13 to cardiovascular disease, 6 to arterial gas embolism, 2 each to pulmonary barotrauma and pulmonary embolism, and 1 each to decompression illness and subarachnoid hemorrhage (see Figure 5.1-10). Panic was associated with 26 cases (16%). The triggers of panic are shown in Figure 5.1-11.

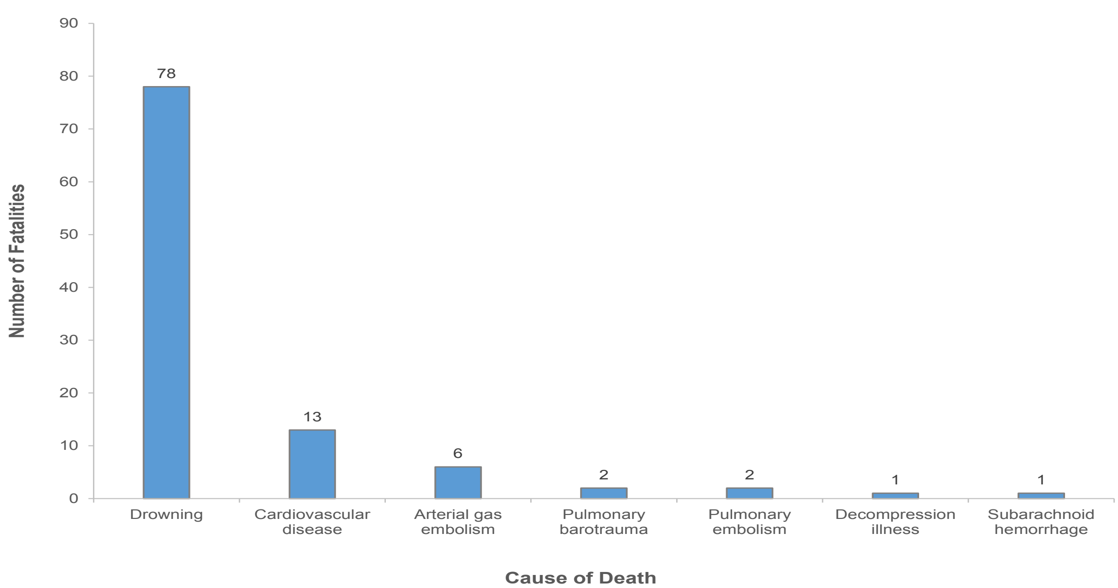


Figure 5.1-10. Cause of death in diving fatalities in Japan, 2005–2015

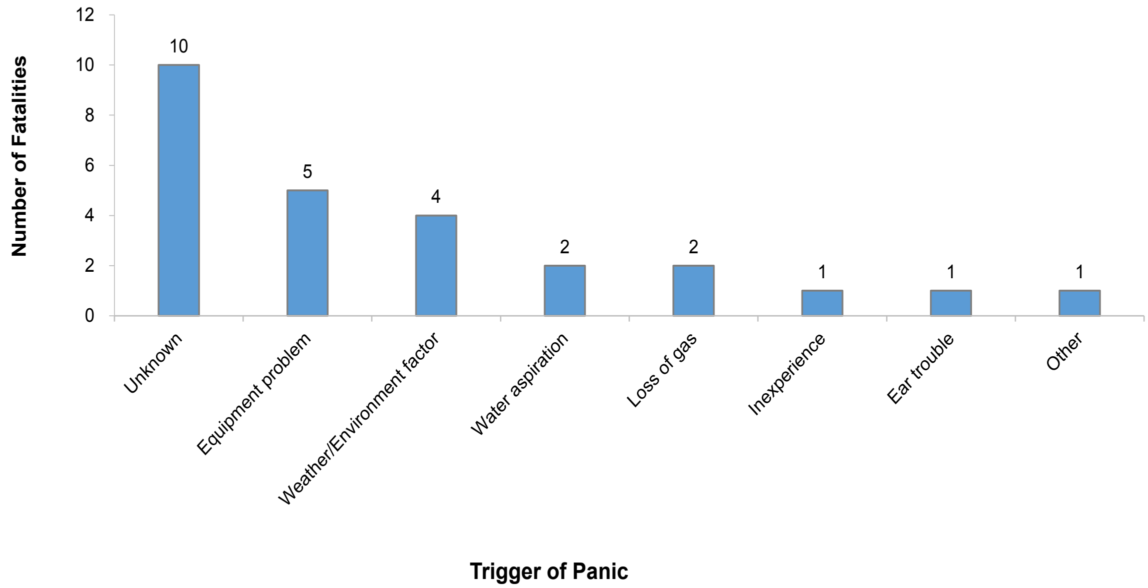


Figure 5.1-11. Triggers for panic in diving fatalities in Japan, 2005-2015

Figure 5.1-12 shows that 5 (45%) of the 11 loss-of-gas incidents involved solo divers, 4 (36%) involved buddy divers and 2 (18%) involved group divers.

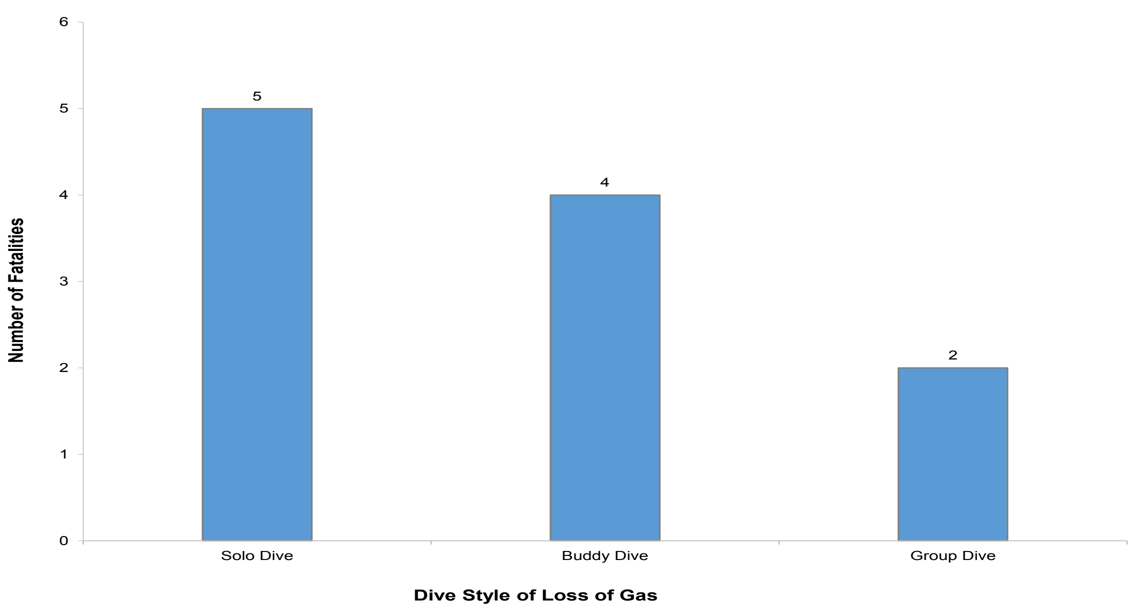


Figure 5.1-12. Buddy status in loss-of-gas fatalities in Japan, 2005-2015

DISCUSSION AND CONCLUSIONS

The majority of divers in this study who suffered fatalities were 40 or older and male, both of which are known risk factors for diving-related fatalities (Buzzacott 2015, Ihama et al. 2008). The mean age of DAN JAPAN members has increased from 38 years old in 2004 to 47 years old in 2014. However, there was no overall increase in the number of fatalities during the study period. The reason for that flat trend, despite the rising age of divers, is unknown.

The top three trigger events were the same as those identified by DAN America: cardiovascular disease, loss of gas and equipment problems (Denoble 2008). Drowning was the most common cause of death.

Panic was associated with 16% of the fatalities studied. The common triggers of panic were equipment problems and weather conditions. This points to the importance of completing a predive check.

The dive style of 112 fatalities (68%) was group diving. However, we cannot conclude that group diving is a risk factor, because of the popularity of group diving in Japan. The aim of group diving is to provide an added layer of safety. The leader of the group not only serves as a guide during the dive but also completes buddy checks, checks each diver's condition before the dive, and monitors each diver's remaining tank pressure during the dive. Of the 11 loss-of-gas cases, only 18% were during a group dive. The fatality rate of 0.69 per 10,000 member-years in Japan compares favorably with the DAN America fatality rate of 1.64 per 10,000 member-years and the British Sub-Aqua Club fatality rate of 1.44 per 10,000 member-years (Buzzacott 2015). These comparative statistics corroborate the safety of group diving.

LIMITATIONS

Even if our access to autopsy reports had not been restricted by the personal information protection law, the autopsy rate for diving fatalities during the study period was not high. And because identifying a cause of death can prove difficult without an autopsy, the reported causes of death may not be correct.

5.2 DAN SOUTHERN AFRICA DIVING MORBIDITY AND MORTALITY, 2016

Founded in 1996, DAN Southern Africa (DAN SA) is a public benefit organization that provides emergency medical advice and assistance to those who have suffered diving injuries, as well as a wide range of research, education and training programs that promote safe diving. The organization has just under 6,000 members. Its coverage region encompasses South Africa, Angola, Botswana, Comoros, Kenya, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, the Seychelles, Swaziland, Tanzania, Zaire, Zambia, and Zimbabwe, though inquiries are sometimes received from outside these borders. (Note the distinction in this report between South Africa, the country, and southern Africa, the region.)

DAN SA provides an emergency hotline service for diving and evacuation emergencies. Response staff and dive medicine specialists are on call 24/7/365 to assist with care coordination and evacuation. DAN SA also provides a diving medical information service, available to anyone. Data regarding diving fatalities in southern Africa are collected to the extent possible whenever they occur, and all medical inquiries are logged.

MORTALITY

In 2016, DAN SA learned of three diving fatalities in southern African waters — making a total of 18 from 2010 through 2016, inclusive, or an average of 2.6 per year (with a range of 0 to 4). All 18 known fatalities since 2010, except for one off Mafia Island in Tanzania's Zanzibar Archipelago, occurred in South African waters. The most common sites, likely reflecting their popularity with divers, were Sodwana Bay (n=4), Umkomaas (n=3) and Miracle Waters (n=3). Not surprisingly, there were fewer deaths during the winter (May to October, n=5) than during the summer (November to April, n=13), since many more divers take to the water in the summertime. See Figure 5.2-1 for a month-by-month breakdown of the fatalities from 2010 to 2016.

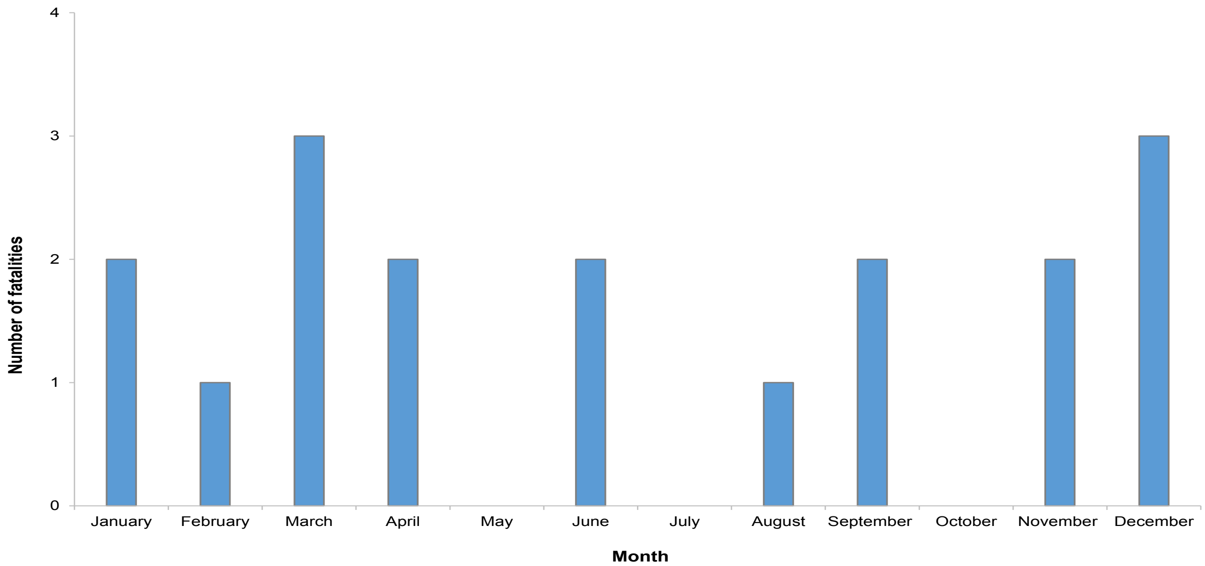


Figure 5.2-1. Monthly distribution of southern African diving fatalities, 2010–2016 (n=18)

The victims were male in 13 cases (72%) and female in 5 cases (28%). The age of the decedents ranged from 21 to 73. A majority (12, 67%) died while diving from a boat, 4 (22%) while diving in a quarry, and 1 each while diving in a pool and from the beach/shore.

Maximum depths were known in 13 cases (72%); 1 of those cases involved a diver in a pool, 6 involved divers using open-circuit compressed air, and 6 involved divers using rebreathers. The average maximum depth for the 6 open-circuit divers was 56 feet (17 meters), with a range of 26

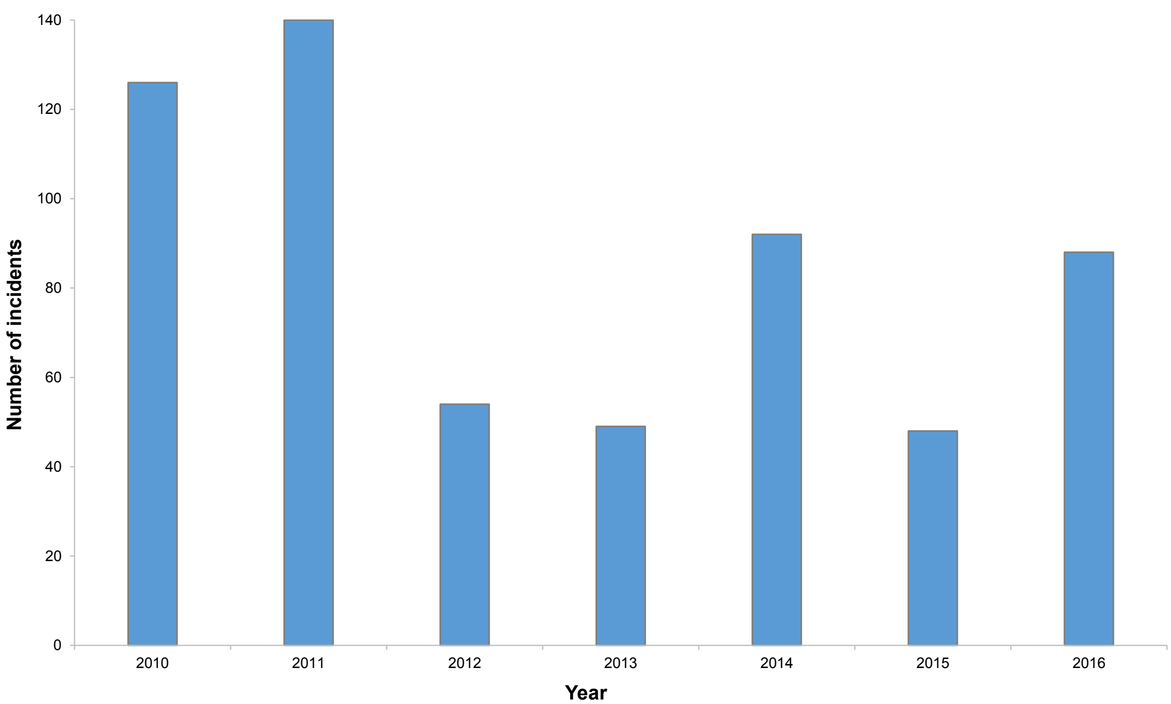


Figure 5.2-2. Number of DAN SA diving-related incidents by year, 2010–2016 (n=597)

to 72 feet (8 to 22 meters), whereas the average maximum depth for the rebreather divers was 210 feet (64 meters), with a range of 89 to 328 feet (27 to 100 meters). Of the 18 deaths, 5 (28%) occurred in freshwater and 13 (72%) in saltwater.

The most common cause of death was cardiac arrest (n=5, 28%), followed by arterial gas embolism (n=4, 22%) and drowning (n=3, 17%). These three conditions represent the most common causes of death in most, if not all, recreational-diving fatality studies. In two cases, anoxia was the leading cause of death; one was due to running out of air and the other was due to rebreather equipment failure. In the other cases, the leading cause of death was unknown. It should be noted, however, that out of the 18 fatalities, autopsy reports — and thus certainty regarding the cause of death — were available in only 3 cases (17%).

The certification levels of the divers involved in these fatalities ranged from student or basic open water certification through technical diver and/or instructor certification. DAN membership status was known for 16 of the 18 decedents; 10 (56%) were members, 5 (28%) were not, and 1 was a student.

MORBIDITY

In 2016, DAN SA received 108 incident-related calls, resulting in an average of 103 per year from 2010 to 2016 (with a range of 56 to 175). A significant majority of calls were diving-related, but some were nondiving-related. See Figure 5.2-2 (page 87) for a year-by-year breakdown of the diving-related calls from 2010 to 2016. Of the 108 incidents in 2016, 88 (81%) were diving-related and 20 (19%) were nondiving-related. The remainder of subsection 5.2 concerns only diving-related incidents.

South Africa lies between 35° and 22° latitude in the Southern Hemisphere's subtropical zone, and the other countries within DAN SA's purview extend north from there to just past the equator. The monthly distribution of diving-related incidents reflects this geographic reality, with calls peaking in the summer (November to April) and abating in the winter (May to October). This distribution is shown in Figure 5.2-3. A similar pattern is exhibited in the distribution of diving fatalities in southern African.

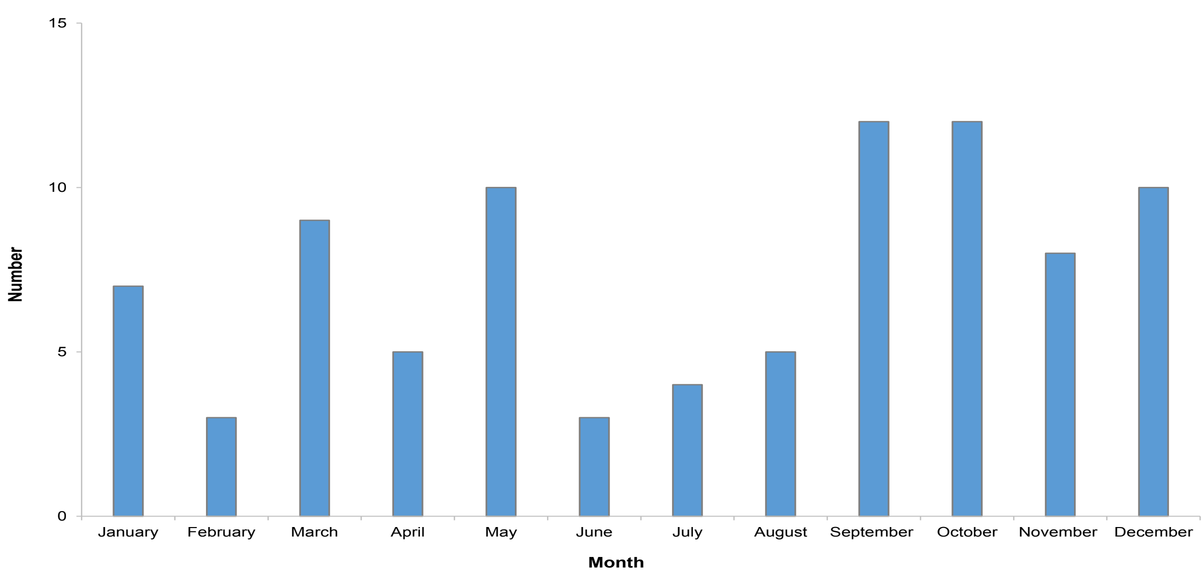


Figure 5.2-3. Monthly distribution of DAN SA diving-related medical incidents, 2016 (n=88)

Country of origin	n (%)
South Africa	362 (61)
Mozambique	90 (15)
Zanzibar	14 (2)
Egypt	12 (2)
Madagascar	9 (1)
Seychelles	6 (1)
Angola	6 (1)
Indonesia	5 (1)
Other	28 (5)
Unknown	65 (11)
Total	**597**

Table 5.2-1: Countries with ≥5 DAN SA diving-related incidents, 2010-2016 (n=597)

The countries of origin for diving-related calls are listed in Table 5.2-1. Because the numbers for countries outside of South Africa are very low in any given year, seven years of data are shown (from 2010 to 2016, n=597). The "Other" category includes countries from which fewer than 5 inquiries originated during the study period: Australia, Honduras, India, Indonesia, Israel, Kenya, Malawi, Maldives, Mauritius, Mexico, Micronesia, Namibia, Nigeria, Panama, Papua New Guinea, Philippines, Singapore, Tanzania, Thailand and the United States.

Almost half of all diving-related incidents involved DAN members (n=39, 44%); 45 (51%) involved nonmembers, and the callers' membership status in the remaining 4 incidents (5%) was unknown.

Reflecting the typical recreational diving population, the majority of incidents (55%, n=48) involved male divers, and 45% (n=40) involved female divers. In cases in which the diver's age was known (n=65 cases), there was a range of 16 to 68; the mean age was 37 for males (with a standard deviation of 15) and 36 for females (with a standard deviation of 12).

Table 5.2-2 shows the prevalence of the various different modes of evacuating injured divers. The most common mode was by the diver's own means.

Mode	n (%)
Own means	45 (51)
No evacuation needed	34 (39)
Ambulance	5 (6)
Boat	2 (2)
Commercial flight	1 (1)
Air ambulance	1 (1)
Total	**88**

Table 5.2-2. Mode of transport used for DAN SA medical evacuations, 2016

Of the 88 divers involved in the 2016 incidents, 56 (64%) received an outpatient referral or consultation, 15 (17%) received recompression therapy, and 16 (18%) required hospitalization. Table 5.2-3 lists the distribution of diagnoses in the 88 cases.

In conclusion, DAN SA receives reports of an average of 2.6 diving fatalities per year and around 85 inquiries regarding nonfatal diving-related incidents. The summer months are the busiest. At least a third of all diving-related inquiries originate outside of South Africa, and more than half of all diving-related incidents require evacuation, most often by the diver's own means.

Diagnosis	n (%)
Barotrauma, ear	10 (11)
Barotrauma, other	5 (6)
DCI/DCS, definite	19 (22)
DCI/DCS, possible	5 (6)
Fitness to dive after a recent diving incident	2 (2)
Hazardous marine life injury	3 (3)
Musculoskeletal condition	3 (3)
Other	33 (38)
Trauma	8 (9)
Total	**88**

Table 5.2-3. Diagnosis in 88 DAN SA diving-related incidents, 2016

5.3 BREATH-HOLD DIVING FATALITIES IN BRAZIL, 2002–2016

This study is based on data collected from January 2002 to December 2016 about fatal incidents involving breath-hold diving (also known as apnea diving or freediving) in Brazil. Evidence from prior to 2002 is scarce and imprecise. Previous statistics about this subject were published in the DAN Annual Diving Report – 2006 Edition.

The first reported breath-hold diving fatality in Brazil was in 1981, when a well-known national soccer team coach passed away while spearfishing in Rio de Janeiro. The incident attracted lots of attention, but it was probably not the very first.

Collecting such data is challenging. One challenge is that some cases involve publicly known individuals. Another is that it is difficult to collect precise information, since facts about such incidents come mainly from the media, press releases, web searches, and personal contacts and reports; that means details about many cases are incomplete. Also, authorities rarely investigate breath-hold incidents. Coroner reports are usually unavailable for examination, and are often inaccurate besides — listing the cause of death just as drowning, without defining an incident's incipient causes and sequence of events. Finally, the absence of witnesses is a factor in some cases. In addition, we believe the number of cases could be even greater than those reported here, as we suspect that many cases go unreported. The research is thus very dynamic; these statistics may be updated as unknown cases are revealed.

Several aspects of freediving (which is the most common term for the practice in Brazil) make it a popular sport there. One is the popularity of spearfishing, though there are no official statistics on the number of people who engage in that pursuit. Brazil has over 5,000 miles (8,500 kilometers) of coastline, over 5,500 miles (9,000 kilometers) of lake shore, almost 22,000 miles (35,000 kilometers) of inland waterways — and thus major scope for water-related activities. In addition, the country's largest population centers are adjacent to water. It is expected that a considerable number of the people who engage in water activities include freediving among those activities.

The simplicity of the equipment requirements, the wide availability of diving destinations and the decent fishing conditions in Brazil attract many divers to spearfishing there. The pastime started to catch on in the late 1960s — first in Rio de Janeiro waters, next in São Paulo, and then all around the country. In recent years, it's

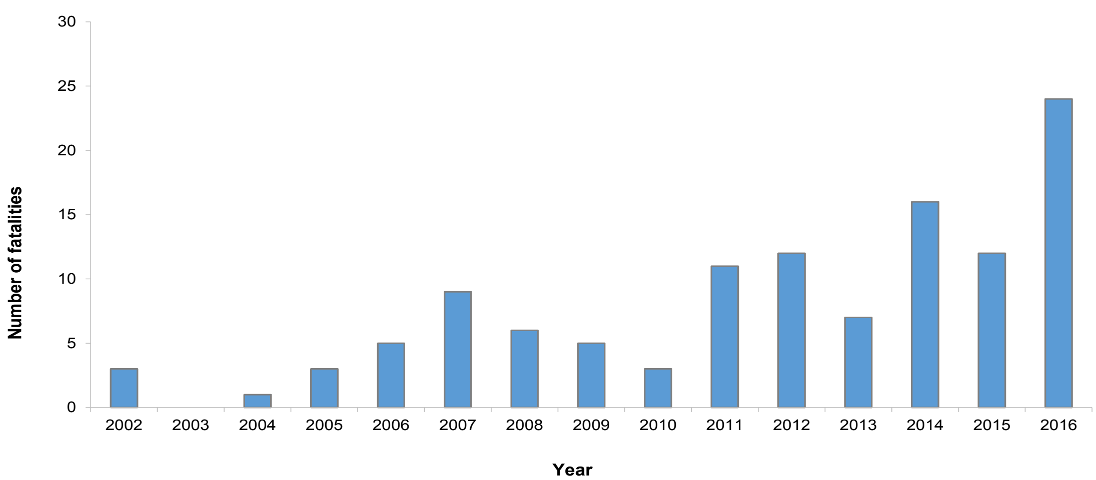


Figure 5.3-1. Breath-hold fatalities in Brazil by year, 2002–2016

been a popular sport in freshwater rivers and lakes as well as in saltwater. People engage in it as a cultural activity, a sport, a source of food and sometimes even a source of income. Competitive freediving to attain certified records is a much less popular reason for freediving. There has been a rapid increase in the popularity of spearfishing over the past 10 years, driven largely by the availability of online information about the sport.

Freediving is considered the most dangerous diving style because of the number of fatal incidents associated with the technique. Lack of formal training and of solid, progressive experience may be the main triggering factors for adverse incidents that involve behavioral factors, as the vast majority of participants engage in freediving without taking any courses or achieving certification. In recent years, people have had easy online access to informational and promotional videos and ads for gear sales and rentals, boat charters, and travel packages. This leads to increased risk, negligence, and technical mistakes such as excess hyperventilation. There are other contributing factors, too, including environmental considerations, solo diving status, attitudinal issues, underlying health problems (especially ones that may lead to loss of consciousness), and the simultaneous use of more than one diving technique (which increases the risk of an untoward incident).

It is suspected that the condition known as hypoxia of ascent (formerly called shallow-water blackout), preceded by hyperventilation, is the main cause of drownings associated with freediving. Other causes — in order of prevalence — are boat strikes, entanglements, underlying health issues, speargun wounds, entrapments, and electric shocks. No animal encounters were reported. All these causes were also implicated in nonfatal incidents, but the challenge of collecting detailed and reliable data about nonfatal cases is even greater.

Our research revealed 118 cases of death due to breath-hold diving in Brazil between January 2002 and December 2016; 93 of them (79%) happened while spearfishing.

In 116 cases, the subjects were men (98%), and in two the subject's sex could not be identified.

We also found that 79 cases (67%) occurred in saltwater and 39 (33%) in freshwater.

The age group most affected was those 30 to 39 years old, with 35 cases (30%). In 32 cases (27%), the decedent's age was not reported.

During 2014, 2015 and 2016, a total of 51 fatalities occurred. This span of only three years thus accounts for 43% of the 118 fatalities during the 15-year span of the entire study, show-

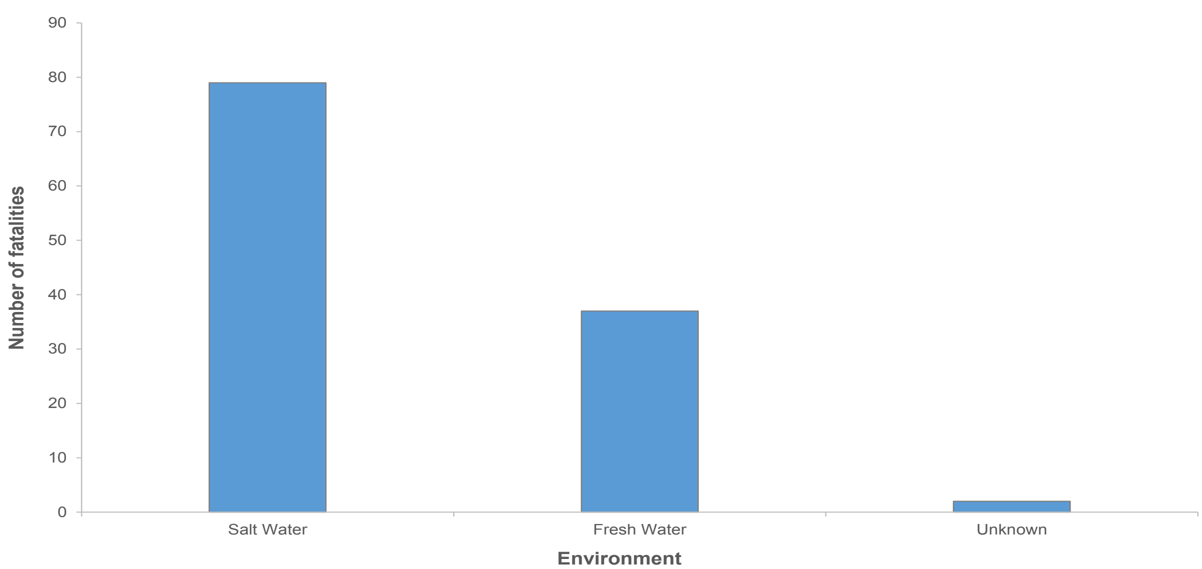


Figure 5.3-2. Environmental distribution of breath-hold fatalities in Brazil, 2002–2016

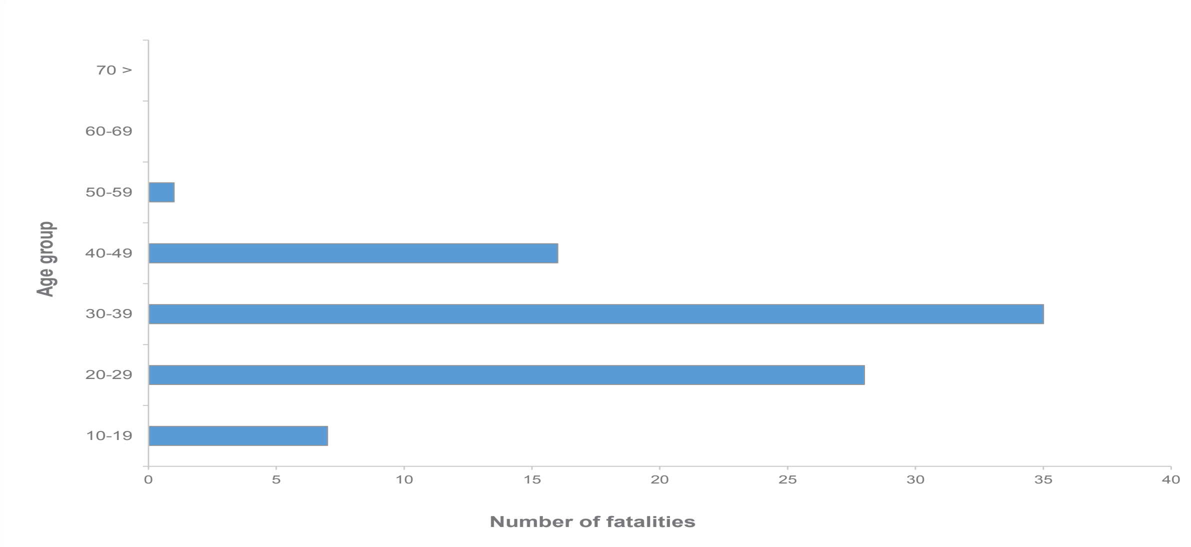


Figure 5.3-3. Age distribution of breath-hold diving fatalities in Brazil, 2002–2016

ing a significant increase in the number of fatal cases per year. In fact, there were 24 fatalities (20% of the total number) in 2016 alone — 12 of them during the first three months of the year, corresponding to the summer season in Brazil; this is the highest annual mortality figure since the beginning of the study. That figure compares to an average of just 4 fatalities per year (3% of the total) during the first nine years of the study period.

We emphasize, however, that we share these statistics not to point a finger at breath-hold diving, nor to suggest that the diving community refrain from it, but to show that there are risks associated with the sport. With appropriate training and care, however, divers can minimize those risks and avoid preventable deaths.

CASE 1: APPARENT HYPOXIA OF ASCENT WHILE SPEARFISHING

A diver was spearfishing while freediving in a group of four divers. Conditions were good, with clear visibility of over 66 feet (20 meters), warm temperatures of around 73°F (23°C), a bottom depth of 56 to 82 feet (17 to 25 meters), and a current of more than 1 knot.

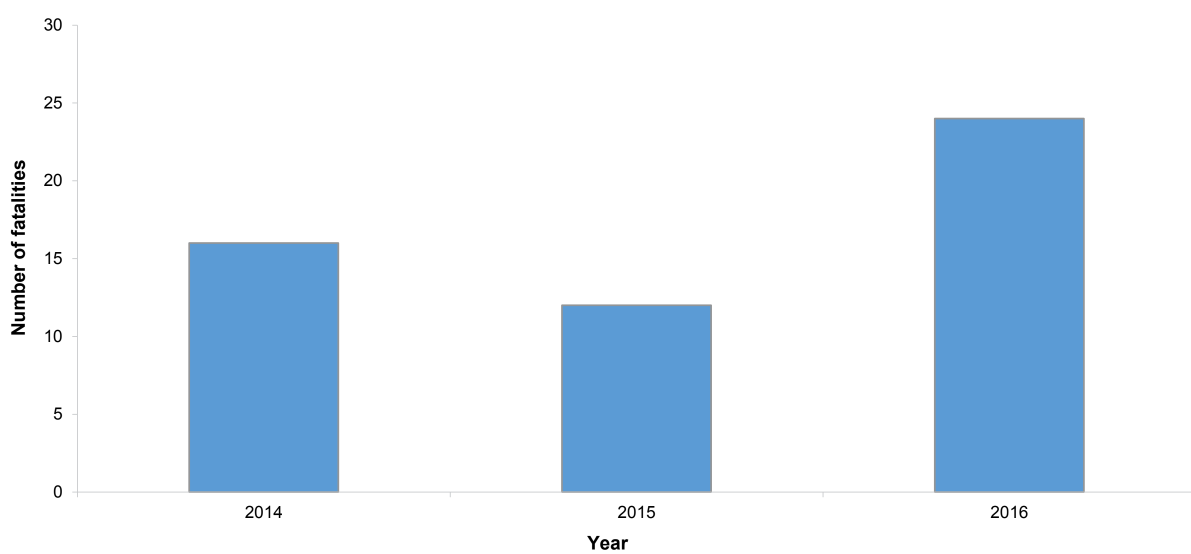


Figure 5.3-4. Breath-hold fatalities in Brazil, 2014–2016

The divers needed to hold a rope attached to the anchored boat while they were resting at the surface, in order to keep their position and save energy. During the dive, one diver disappeared.

When his body was recovered five days later, he still had his head camera on. An analysis of the video revealed the sequence of events leading to his death. He had made two long and deep dives, with a short surface interval between them of about 50 seconds. The audio revealed the sound of breathing while he was at the surface, suggesting that he hyperventilated for too long while resting. During his second dive, while he was swimming back to the surface, he apparently lost consciousness when he was close to the surface and, with his head still underwater, drifted away with the current without being seen by the other divers. He presumably suffered hypoxia of ascent, a condition that used to be referred to as a shallow-water blackout.

CASE 2: AN ENTANGLEMENT WHILE DIVING FROM A BEACH

A diver left shore from a beach for spearfishing. The conditions were average, with water visibility of around 16 feet (5 meters) and some swell. The bottom was shallow, at 16 to 33 feet (5 to 10 meters). The diver disappeared.

The emergency medical service (EMS) was called. EMS personnel started searching on nearby boats while waiting for rescue divers, and they noticed a resting fishing net. They pulled up the net and found the body of the missing diver entangled, wrapped in the fishing net. The use of rest fishing nets is a common fishing technique in Brazil, and the nets are usually poorly marked.

5.4 DIVING FATALITY REPORTING IN THE ASIA-PACIFIC

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

AUSTRALIAN FATALITIES

In Australia, the publication of diving fatality reports began formally in 1969, with a report by G.J. Bayliss on civilian diving fatalities between 1957 and 1967, inclusive. The reporting of fatalities in Australia continued with the introduction of Project Stickybeak by Douglas Walker, MD, who compiled data and reported on 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. Beginning in 2003, John Lippmann, on behalf of DAN AP, assumed re-

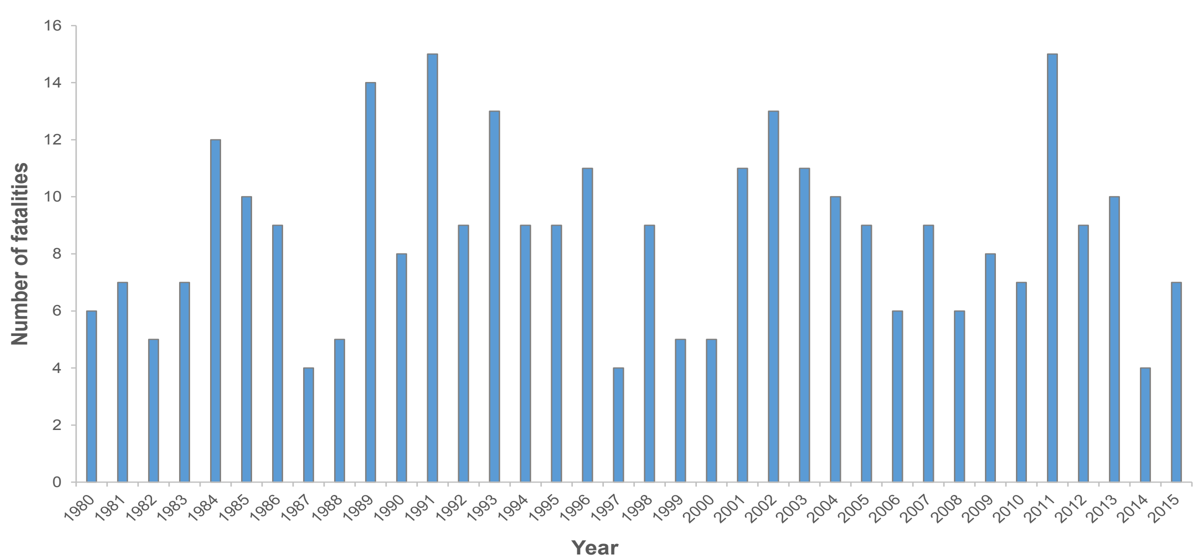


Figure 5.4-1. Recorded scuba diving fatalities in Australia from 1980-2015

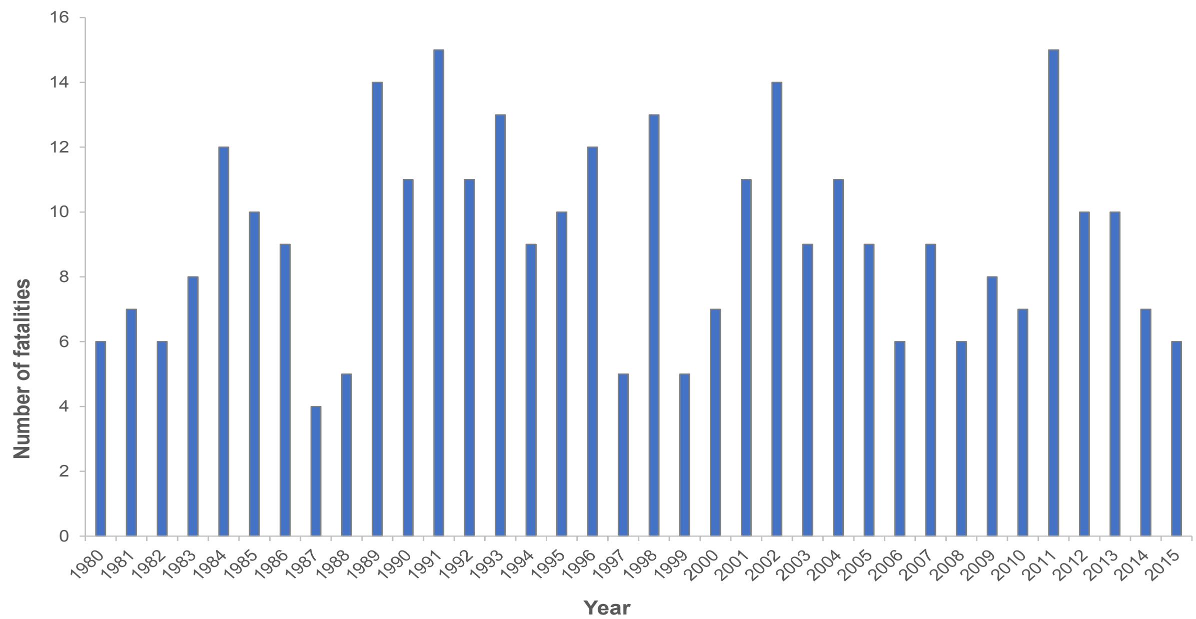


Figure 5.4-2. Recorded scuba-related deaths in New Zealand from 1980-2015

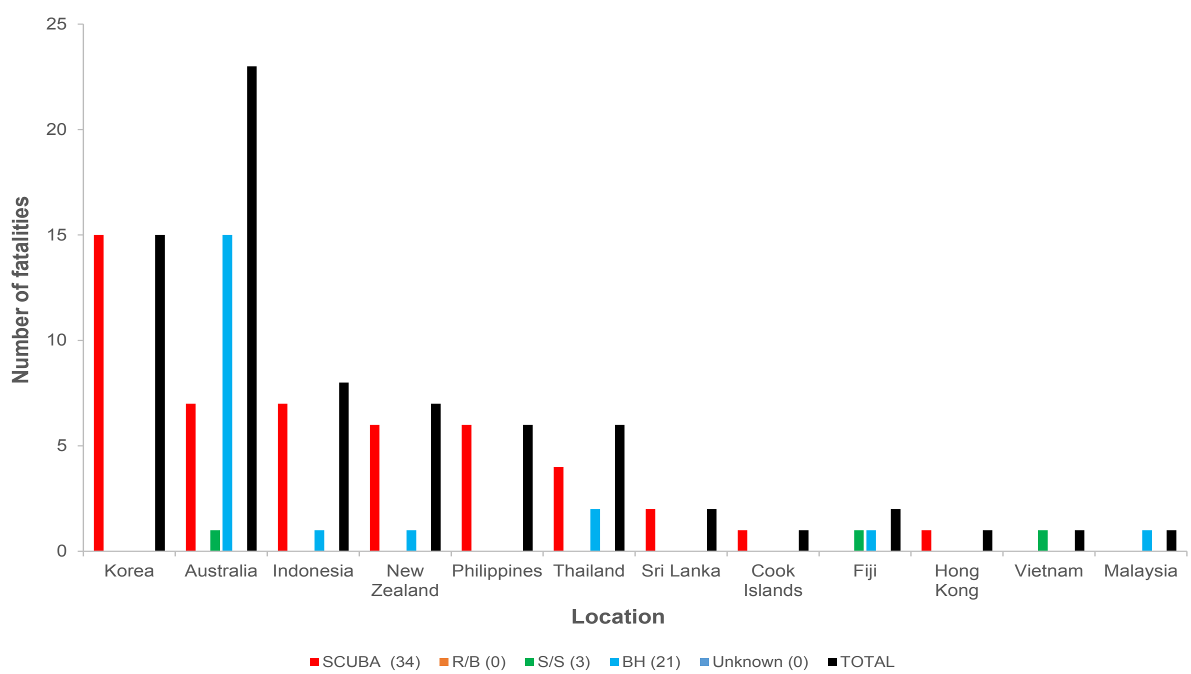


Figure 5.4-3. Recorded diving fatalities in the Asia-Pacific region by location, 2015

sponsibility for Australian dive mortality surveillance. Subsequent fatality reports have continued to be published in Diving and Hyperbaric Medicine. Initial accident data are collected by on-scene investigators, such as police and/or work- place, health, or safety officers. Autopsies are routinely conducted after diving fatalities in Australia, except in rare cases, such as when there is no familial consent or the victim's body was not found. This information, together with witness statements, is reviewed by relevant coroners, and a coroner's report is produced, with or without an inquest, as determined by the individual coroner.

The information sought and recorded includes the following:

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

The Australian National Coronial Information System (NCIS) was launched in 2000 and includes all deaths reported to a State or Territory coroner since that time. The information available for each case includes the coroner's report, a brief summary of the police report and, sometimes, the autopsy report. In order to obtain more complete data, DAN AP liaises with the State and Territory Coroners who often provide (under relevant ethics approvals) complete case files. These files generally include the full police reports, witness statements and often medical and diving histories and an equipment report. Key information from these files is recorded in the DAN database. DAN AP has constructed a database of all reported dive-related deaths in Australia since 1965.

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

Figure 5.4-3 shows all diving-related deaths of which DAN AP is aware in the Asia-Pacific region (excluding Japan) during 2015. These include fatalities involving scuba equipment, rebreathers (RB), surface supplied breathing apparatus (SS) and snorkeling/breath-hold diving (BH). However, it is very likely that there were significantly more deaths than shown here, since deaths in some countries often are unreported.

The map in Figure 5.4-4 (next page) shows the geographic distribution of all 2015 recreational scuba- related fatalities that were reported to DAN (n=181); those reports come thanks in large part to the efforts of the many regional DAN- affiliated organizations. In addition to reflecting reports from IDAN organizations, the fatality numbers shown on the map were also drawn from various media sources.

The numbers for certain countries are relatively accurate (e.g., USA, AU, NZ, UK, JP, and SA). However, the numbers for many other countries, especially less developed countries, are very likely understated.

The data from Europe (with the exception of the UK) is predominantly taken from insurance claims so is very likely to be an underestimate.

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Denoble PJ, Pollock NW, Vaithiyanathan P, Caruso JL, Dovenbarger JA, Vann RD. 2008. "Scuba injury death rate among insured DAN members." Diving and Hyperb Med 38(4):182-8.

Figure 5.4-4. Distribution by country of scuba fatalities compiled by John Lippmann and Scott Jamieson, 2015 (n=181)

APPENDIX A. THIRTY YEARS OF DAN INJURY SURVEILLANCE

ANNA MEASE, PETER BUZZACOTT, PETAR J. DENOBLE

INTRODUCTION

The Arab-Israeli war of the early 1970s led to an embargo on petroleum products to the United States and other countries. The price of oil doubled, tripled, then quadrupled. Soaring oil prices, coupled with a weakened U.S. dollar, led to an urgent need for the U.S. to gain greater energy independence. Oil and gas reserves on the continental shelf were going to be key in achieving that goal, and it was clear that divers would play an important role in developing those reserves. The National Institute for Occupational Safety and Health (NIOSH) organized a Diving Task Force and commissioned the Undersea and Hyperbaric Medicine Society (UHMS) to produce an overview of the state of diving and diving research. The report was submitted in 1976 and highlighted three recommendations:

1. That a civilian body be established to chart the course of nonmilitary diving research
2. That medical personnel be trained to care for divers on oil rigs and
3. That treatment facilities be established for injured divers

The UHMS commenced training medical personnel in collaboration with the U.S. Navy, then with the U.S. National Oceanic and Atmospheric Administration (NOAA), and established training for hyperbaric medical personnel in collaboration with the U.S. Department of Transportation and the National Registry of Emergency Medical Technicians (EMTs).

By 1997, civilian divers were being assisted 24/7 by LEO-FAST, a hotline located at Brooks Air Force Base in San Antonio, Texas, and directed by Colonel Jefferson Davis, MD. With the growth of recreational scuba diving, the load of calls became overwhelming for the volunteers at Brooks, so in September 1980 NOAA and NIOSH provided a two-year grant to Peter B. Bennett, PhD, DSc, to form the National Diving Accident Network (NaDAN) at the Frank G. Hall Hyperbaric Center at Duke University Medical Center in Durham, North Carolina (Vann 2007).

NaDAN (which was soon shortened to DAN) flourished over the course of its first five years. In 1987, the organization secured insurance for divers, and record numbers of divers signed up for DAN membership. In 1988, for the first time, DAN published what would eventually be called the DAN Annual Diving Report, based on 1986 and 1987 data (Dovenbarger 1988).

The purpose of injury surveillance is to inform decisions aimed at reducing injuries; this first report, typed by hand on a typewriter, was ahead of its time. Many respected national and even international injury surveillance systems started after DAN's first report, including the Australian Football League annual injury survey (launched in 1992), the Federation Internationale de Football Association (FIFA) surveillance system (1998), the England Professional Rugby Injury Surveillance Project (2002), the U.S.-wide National High School Sports-Related Injury Surveillance System (2005), the International Olympic Committee (IOC) injury surveillance system (2008), and the Major League Baseball Injury Surveillance System (2010) (Ekegren 2016).

Today, DAN has the largest collection of scuba-related injury and fatality records in the world. Other data DAN collects, or has collected, include hyperbaric treatment numbers, diving incident reports, and diving profiles (with outcomes) made by volunteer divers. The Annual Diving Reports also list both lay and scientific publications and presentations each year, and special topics are included as appendixes. Since 2015, the report has been indexed by the National Library of Medicine on its medical database, PubMed.

This year marks the 30th year of injury surveillance and Annual Diving Reports. The aim of this account is to review DAN's three decades of injury monitoring and prevention described in those reports.

METHODS

A hand search was conducted of every annual diving report published since 1988 (n=26). One report covered two years of data, one covered four years of data, and the remaining 24 reports covered one year of data each. The reports were originally called Diving Accident Reports, but the word "accident" was dropped in 1997, in line with the recommendation of the British Medical Journal that the word "accident" be avoided where possible (Davis 2001). Over subsequent years, the title of the report was occasionally revised to reflect changing surveillance priorities at DAN.

Prior to the U.S. Health Insurance Portability and Accountability Act (HIPAA) Privacy Rule of 1996, DAN was also able to collect data regarding the number of divers treated by U.S. hyperbaric chambers each year. Between 1999 and 2009, Project Dive Exploration, a prospective cohort study led by DAN, collected more than 150,000 recorded recreational dive profiles, and the growth of this data set was reported annually. In 2005, breath-hold data was included as a stand-alone section. Over the years, there have been a number of different editors and contributing authors for the Annual Diving Report, so varying inclusion and exclusion criteria, data collection methods, and report section authorship, as well as the expansion of the organization over the years, have affected which data were collected and how they were reported. These variables make it difficult to graph or compare reported injuries across the years. Looking at the available data though, some constants do emerge.

RESULTS

DIVING FATALITIES

DAN began to collect fatality data in 1989, and those data were included in DAN's 1989 Report on Diving Accidents and Fatalities. Fatality data from 1970 through 1988 were collected by and reports were compiled by John J. McAniff of the National Underwater Accident Data Center (NUADC) at the University of Rhode Island. Reports on fatalities for 1989 and 1990 were produced as a collaborative effort by DAN and NUADC.

The collection of fatality data has relatively simple inclusion and exclusion criteria, and this has resulted in largely consistent data collection methods over the years. Figure A-1 shows the number of fatalities that were reported to DAN annually from 1987 through 2015. Throughout the years, DAN has developed ever more robust methods of data collection, including online reporting forms (DARF, DIRF and the current DIRS [Diving Incident Reporting System]), internet and news searches, and calls to the DAN Emergency Hotline. Prior to 2003, the great majority of fatalities included in the Annual Diving Reports were ones that

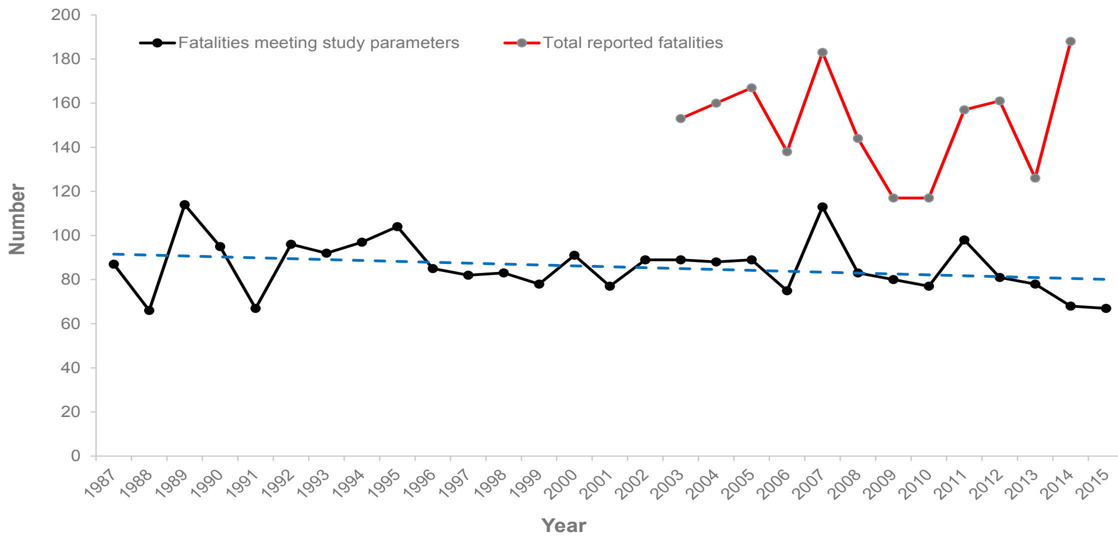

Figure A-1. Number of fatalities reported by DAN annually, 1987–2015 (n=3,341)

occurred in either the United States or Canada, or that occurred overseas but involved U.S. or Canadian citizens. This was largely due to the data-collection methods of the time, which included asking divers to mail in newspaper clippings, engaging a professional news clipping service (the pre-internet equivalent of a search engine) or fielding informational telephone calls. In the 2003 report, diving fatalities were described in a separate chapter, and the total number of fatalities reported to DAN, from anywhere, was also noted (see Figure A-1).

Over the 30 years of injury surveillance, the average number of annual recreational diving fatalities in the U.S. or Canada, or involving U.S. or Canadian citizens overseas, has declined from about 90 per year to about 80 per year, on average. From 1987 through 2015, Florida,

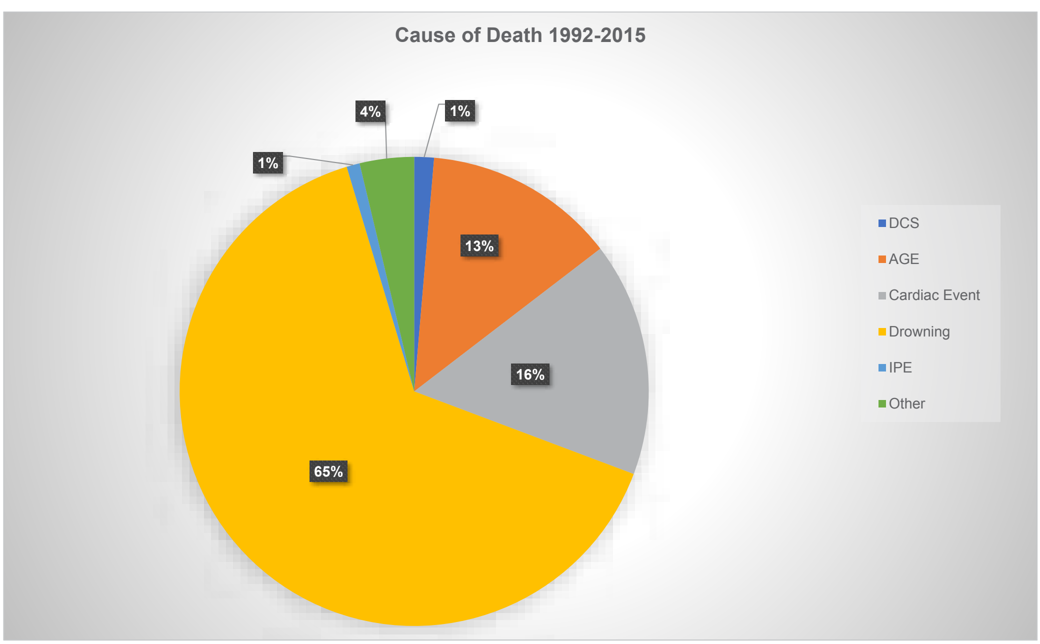

Figure A-2. Causes of death among divers, 1992–2015 (n=1,549)

California, Washington, and Hawaii had more fatalities than other U.S. states, likely reflecting their popularity as diving locations.

Figure A-2 shows the causes of death among divers from 1992 through 2015; a cause of death was attributed to 1,549 fatalities during that period. Drowning was the leading cause of death, at 66% of that total, followed by cardiac events at 16%, arterial gas emboli (AGE) at 13%, other conditions at 3%, and both decompression sickness (DCS) and immersion pulmonary edema (IPE) at 1% each. The "other" category includes events such as a gunshot wound to the head, sudden death, multiple organ failure, shark bite, carbon monoxide poisoning, pulmonary barotrauma, asphyxia, trauma, anoxic brain injury, and anoxic encephalopathy. Each of these events in the "other" category occurred 12 times or less over the 24-year period, and cumulatively they account for only 37 of these 1,549 deaths in the Annual Diving Reports. Drowning has steadfastly remained the leading cause of death among divers, killing at least 1,001 during those 24 years. Cardiac events were second, killing at least 250 divers in that period.

Fatality data by age were available for 2,267 deaths. That information is presented in Figure A-3. Males accounted for approximately 80% of every age group and averaged 82% of the 2,267 fatalities for which the decedent's age was known. Looking at the age distribu-

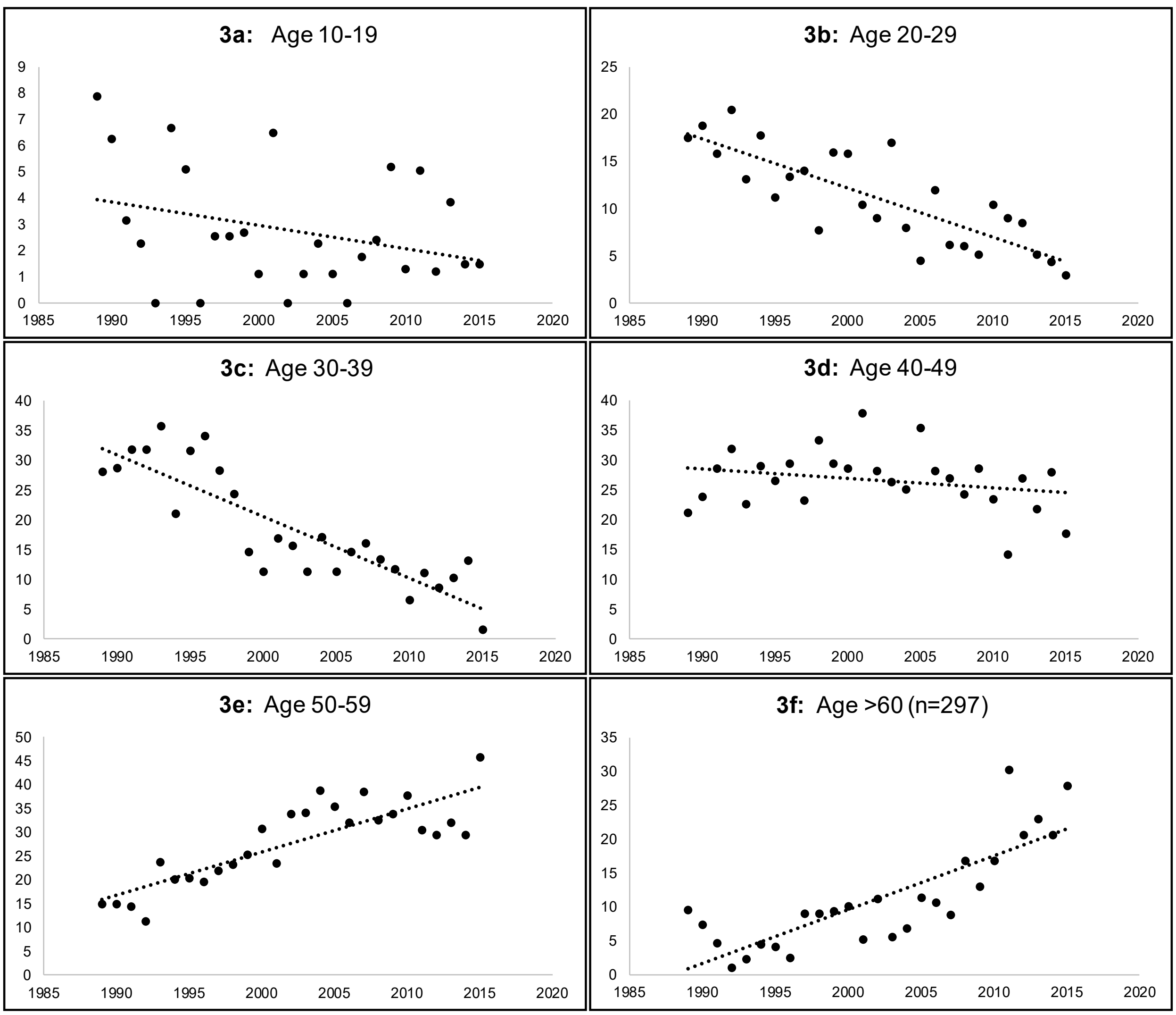

Figure A-3. Percentage of each year's fatalities by age-group, 1989–2015 (n=2,267) tions from 1989 through 2015, it is clear that fatalities steadily increased in age, as has been observed in living populations of recreational divers.

In Figure A-3a, it can be seen that the percentage of diving fatalities involving 10- to 19-year-olds decreased during the reporting period from an average of about 4% of each year's fatalities to an average of about 2%. The percentage involving 20- to 29-year-olds also decreased, from about 17% to about 7%. The percentage involving 30- to 39-year-olds showed the most noticeable decrease, dropping from about 30% to about 10%. The percentage involving 40- to 49-year-olds held steady, at between 25% and 30%. However, the proportion of diving fatalities involving 50- to 59-year-olds increased steadily, from about 15% to 35%. And fatalities among divers age 60 or older soared between 1989 and 2015, from about 5% to about 20%.

Data on body mass index (BMI) were available for 1,219 of the fatalities between 1992 and 2015 (see Figure A-4). BMI is classified by the U.S. Centers for Diseases Control (CDC) into four categories: underweight (<18.5), normal weight (18.5–24.9), overweight (25.0–29.9), or obese (≥30.0) (CDC 2016). Since the number of cases for which BMI has been reported vary by year, percentages are used here to display the data. In the early 1990s, there were more underweight and normal-weight decedents than has been the case in more recent years, and the proportion of diving fatalities involving overweight and obese divers has clearly increased.

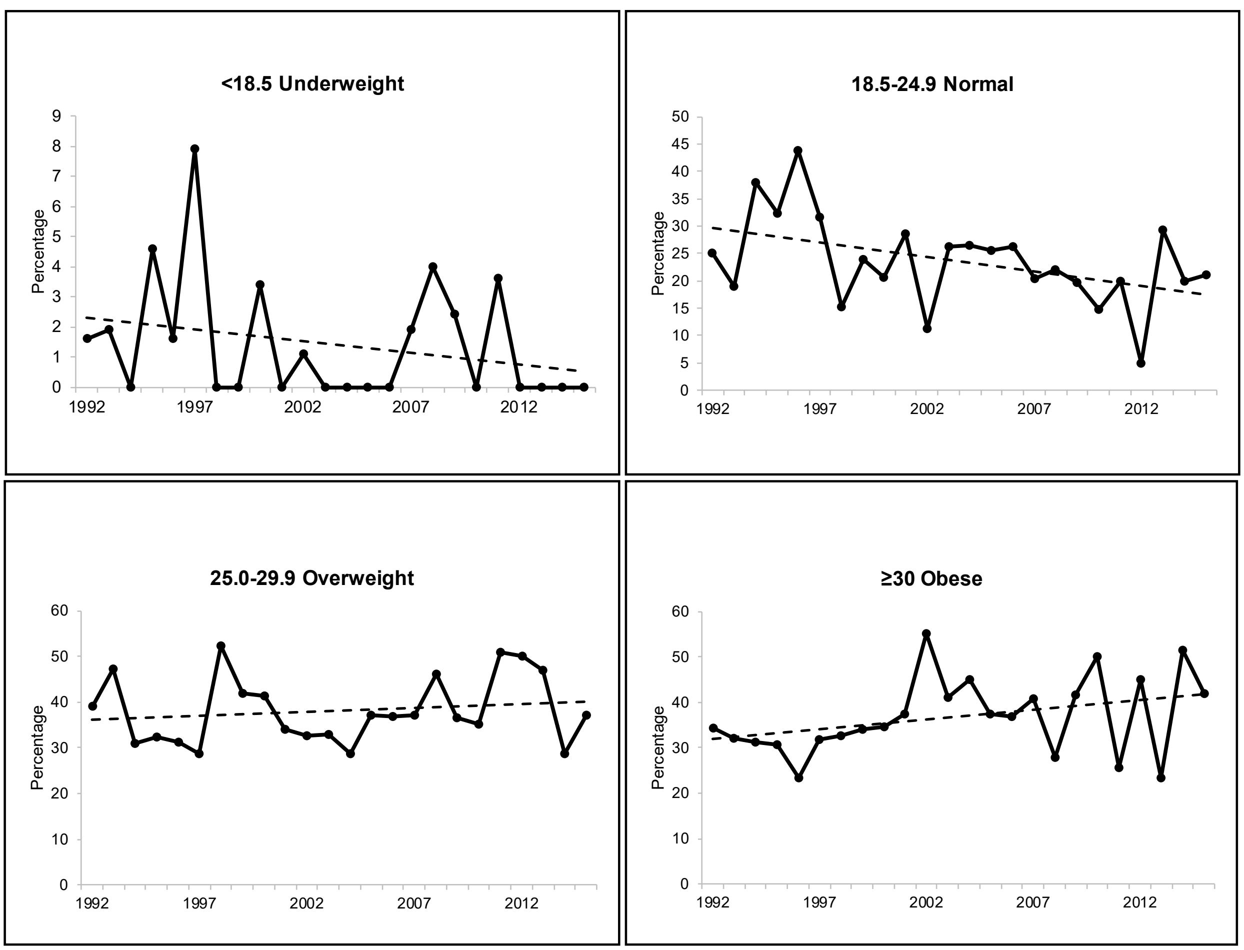

Figure A-4. Proportion of each BMI classification among recreational diving fatalities, 1992–2015 (n=1,219)

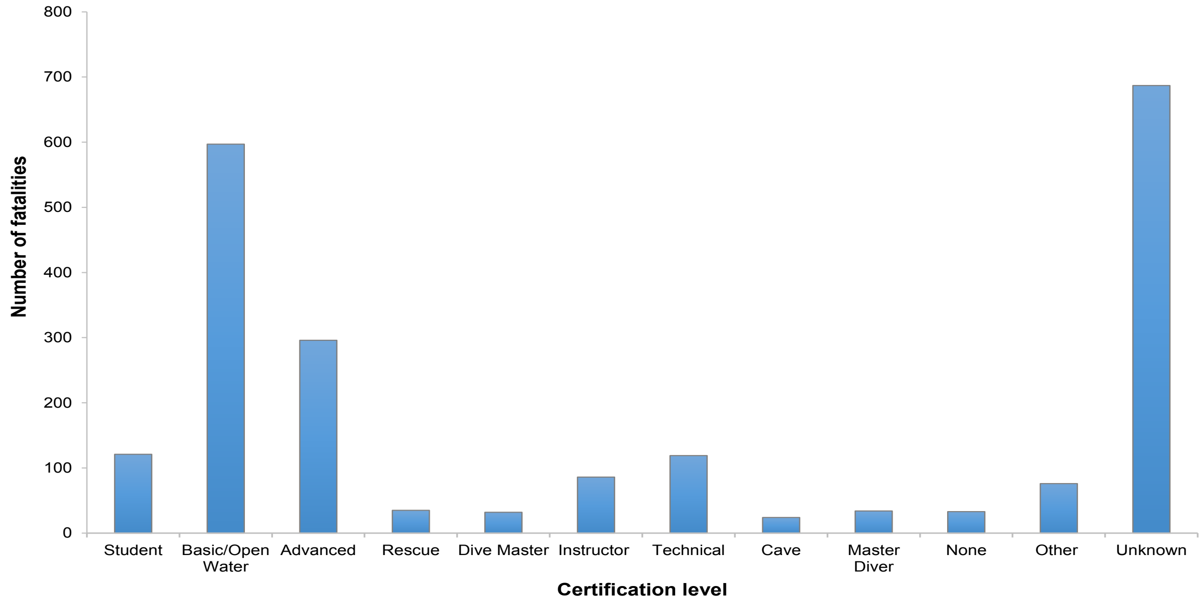

Figure A-5. Certification level in recreational diving fatalities, 1990–2015 (n=2,140)

The certification level of decedents was reported from 1990 onward. Figure A-5 shows fatalities by certification level; through 2015, 2,140 dive fatality reports included a mention of certification level, including a response of unknown (n=687, 32%). The most common certification level was basic open water diver (n=597, 28%), followed by advanced open water diver (n=296, 14%). Yet more than 100 fatalities involved dive professionals, including 32 divemasters/dive guides and 86 diving instructors.

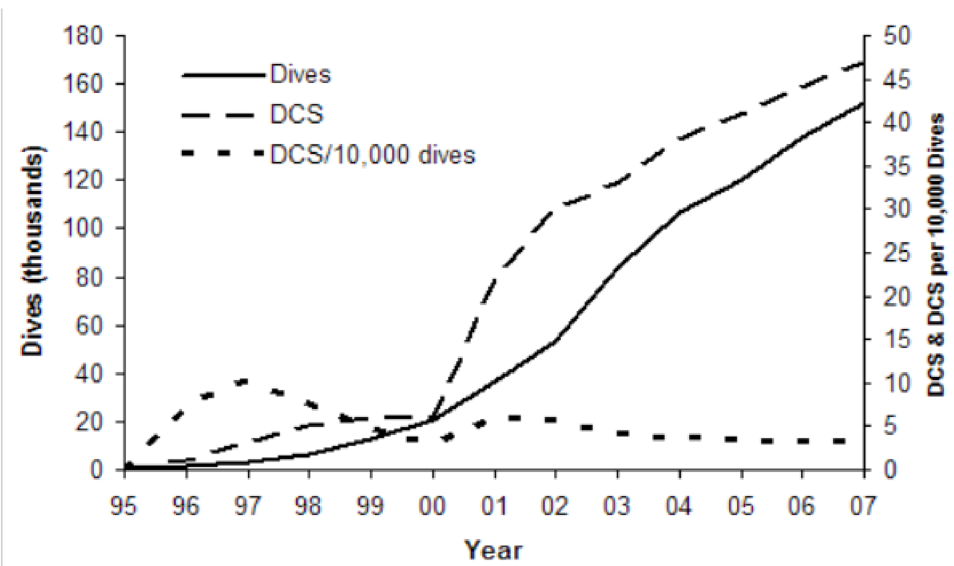

Figure A-6. Cumulative collection of Project Dive Exploration data, 1995–2007

PROJECT DIVE EXPLORATION

Project Dive Exploration (PDE), a prospective observational study of dive exposures and dive outcomes based on information recorded by dive computers during actual recreational dives, was launched in 1995. PDE data were included in the Annual Diving Report for the first time in 2001. Reports on decompression sickness, diving fatalities, and PDE have been included in every Annual Diving Report since then, through 2009. Figure A-6 shows the cumulative progress in collecting data through PDE.

Final PDE numbers for the period from 1995 through 2008, after cleaning up over 150,000 recorded dives, are as follows:

- 10,248 divers (71% male; 41.4 mean age)
- 122,129 dives (including 17,847 nitrox dives)
- 38 DCS cases

A comprehensive analysis of the data has been compiled and is in the process of being readied for publication.

MEDICAL ASSISTANCE

DAN began offering a medical hotline in 1981, to assist with both emergency and nonemergency medical information calls. In the first year, the hotline received 305 calls. Over the next few years, there was a steady increase in phone activity. In 1995, email inquiries began to be accepted as well; DAN received 115 emails in the first year and over 1,000 the second year. By the end of the 1990s, the hotline was receiving more than 10,000 calls and emails a year. In 2001, in recognition of the need and the impact the hotline was making, DAN extended its emergency call hours until 8:00 p.m. Today, DAN medical services are available 24 hours a day, 365 days a year. Over the past 10 years, DAN has received an average of more than 16,000 medical inquiries each year.

In total, during the 36-year period from 1981 through 2016, DAN medical staff have answered 86,336 emergency calls, 269,290 informational calls, and 64,830 emails — for a total of 420,456 inquires. It is predicted that DAN will answer its half-millionth medical inquiry sometime during 2020. DAN offers medical support not only to divers, but also to doctors and other medical personnel who are caring for divers. In 1987, about 100 inquiries (3% of all

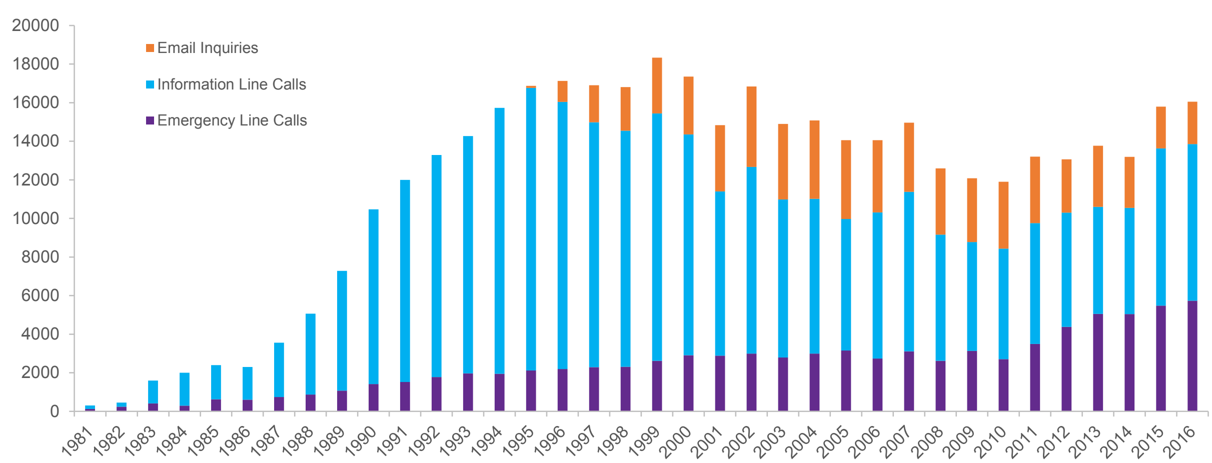

Figure A-7. Annual volume of inquiries to DAN Medical Services, 1981–2016 calls) came from medical professionals; today, sustantially more inquiries come from medical personnel, highlighting the confidence they have in DAN as a resource. Figure A-7 shows the increase in call and email activity DAN has experienced over the past 36 years.

DAN-SPONSORED WORKSHOPS AND SYMPOSIA

Based at least in part on the Annual Diving Reports and inquiries to DAN Medical Services, DAN has sponsored or cosponsored many research studies and workshops to address issues affecting the safety of divers. By 1995, diving with enriched air, or nitrox, was gaining popularity and had been adopted by large recreational diver-training agencies. To address misunderstandings about the use of nitrox and to discuss the available data, equipment, and training, as well as approaches to risk management, DAN convened a workshop focused on nitrox diving in November 2000. Concurrently, DAN was funding a series of human experiments at Duke University to examine when it is safe for divers to fly after single dives, repetitive dives, and multiday diving. In 2002, DAN held a workshop titled Flying After Diving, at which a consensus statement was developed that changed the guidelines for flying after recreational diving. In 2004, DAN jointly sponsored, with the UHMS, a workshop exploring the management of mild or marginal decompression illness in remote locations. The proceedings of that workshop set the standard for evacuation-related decision-making for the following decade.

Meanwhile, as shown in the tables on the previous pages, divers seemed to be getting older and heavier. In addition, DAN Medical Services were receiving more calls from divers with diabetes. In 2005, DAN cosponsored, again with the UHMS, a workshop focused on diabetes and recreational diving.

The following year, DAN and the UHMS jointly sponsored a third workshop, this one dedicated to breath-hold diving. Two years later, the pendulum swung to the other end of the spectrum, and DAN hosted a conference dedicated to technical diving, which had been experiencing extensive growth. Over two days, diving experts concentrated on four individual workshops — exploring physiology, decompression, rebreathers, and training. In 2010, DAN organized the first recreational diving fatalities workshop, featuring presentations by organizations and individual experts with direct experience in diving fatalities. In 2012, DAN cosponsored the third forum dedicated to rebreather diving, known as RF3, with the aim of furthering rebreather diving safety. This three-day conference drew hundreds of rebreather divers from around the world to Orlando, Florida.

In 2014, after including data on diving fatalities in the Annual Diving Report for more than a quarter of a century, DAN and the UHMS jointly convened a symposium dedicated to the medical examination of diving fatalities. The following year, in Montreal, Canada, DAN and the UHMS held a workshop aimed at reaching consensus regarding patent foramen ovale (PFO), a common cardiac defect, and fitness to dive. The proceedings of this workshop continue to inform both divers and physicians as they make decisions related to PFOs and diving, such as when surgery is being considered to close a PFO. In 2016, DAN cosponsored a workshop on artisanal diving, ahead of the UHMS Annual Scientific Meeting in Las Vegas. Most recently, DAN and the UHMS revisited the topic of managing mild and marginal decompression illness at a workshop in Naples, Florida. The proceedings of this and the 2016 workshop are yet to be published, but all other workshop proceedings are freely available for download from the DAN website.

DAN MEDICAL DEPARTMENT OUTPUT BETWEEN 1995 AND 2015

Between 1995 and 2015, the DAN Medical Department produced over 1,000 publications and presentations. Between 2011 and 2015 alone, at least 359 scientific and lay presentations were given by DAN medical and research staff, both within and outside the U.S. It is clear that DAN has increased its publication and presentation output significantly over the past 20 years (see Figure A-8). A breakdown of annual publications and presentations began in 2003. Between 2003 and 2015, the most commonly produced works by the DAN Medical Department were presentations (42%), lay publications (16%), and abstracts (13%). The "other" category includes edited books, media interviews, edited reports, research letters, audiovisual materials, editorial articles, published reports, booklets, review articles, blog posts, edited proceedings, books, published acknowledgements, and online publications. A given kind of item was placed in the "other" category if examples of it were produced 14 times or less from 2003 through 2015. Figure A-9 shows the breakdown of types of publications and presentations during that period.

Naturally, this output reflects the various research interests of DAN over many years.

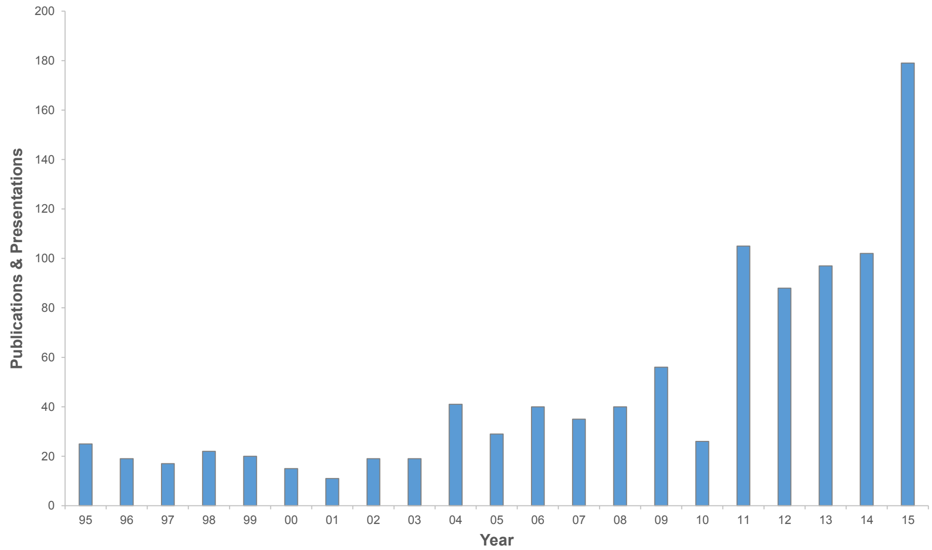

Figure A-8. Number of works produced by DAN Research, 1995–2015 (n=1,005)

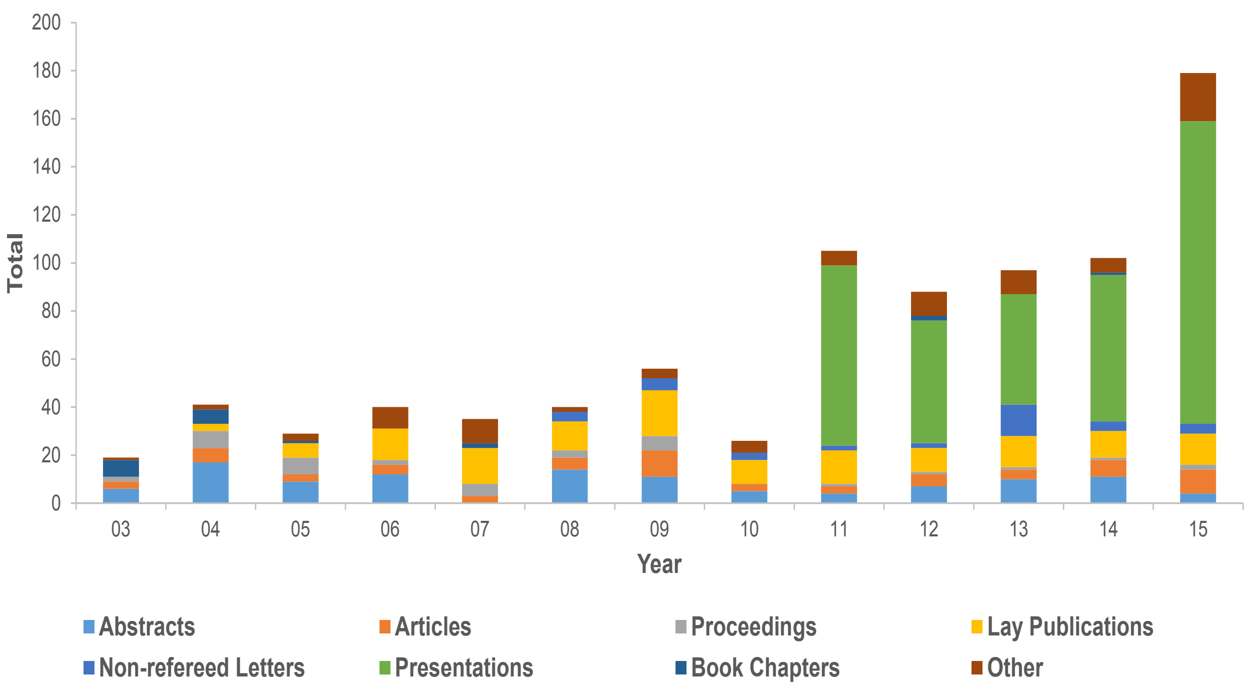

Figure A-9. Breakdown of DAN Research output, 2003–2015 (n=857)

DISCUSSION

DAN was formed before safety stops were a part of every open water diver course, before the first electronic dive computers hit the market, before "technical" diving was even a thing. The first Annual Diving Report came out in 1988 and was based on 1986–87 data. DAN Research was formed in 1992. To date, over 1,000 publications and presentations have promulgated dive safety advice and research, and nearly half a million people have been assisted by DAN medical experts, including more than 80,000 divers experiencing medical emergencies. This is an astonishing achievement.

We now share some reflections on all this data. Since we do not know the BMI of every diver, we cannot precisely estimate the effect that a higher BMI has on the risk of death while scuba diving. However, we do know that having a higher BMI is linked to heart disease, and since cardiac events are the second leading cause of death, after drowning (see Figure A-2), it can be presumed that individuals with a higher BMI may be at greater risk of injury, and injury can lead to death. Figure A-4 clearly shows that we, the dive community, are gaining weight. Figure A-3 indicates that we have concurrently aged. Taken together, these data suggest it is now more important than ever before that we divers eat a balanced diet and exercise regularly.

Basic open water and advanced open water certification are the most commonly earned certifications worldwide, and that's reflected in Figure A-5. But nearly 100 diving instructors have died while scuba diving, which highlights the fact that none of us are immune to risk and that each and every one of us should strive to minimize the hazards associated with venturing underwater.

Some of the limitations associated with long-term injury surveillance include the realities that technology has changed the way data are gathered and that staff turnover can lead to small changes in data-management practices. DAN has never claimed to have 100% complete data in any year, and we do occasionally receive new information regarding older cases — but the amount of new data declines sharply after two years have passed, which is when each Annual Diving Report is published. The numbers in Figure A-1 are those that were published in each of the Annual Diving Reports. If we were to assemble the number of fatalities for each of those years today, we would see slightly higher numbers overall. But the trend over time remains unchanged — and that has that the average annual number of fatalities is been in slight decline. All indications (fatalities, surveys, DAN memberships, etc.) suggest that the dive community is aging, so this decline may be a reflection of fewer dives being made each year. Then again, many older divers tell us they are making more dives than ever before, now that they are retired. So we cannot state with confidence whether diving is getting safer, or whether divers are at more risk now than they were 30 years ago, but what we can state is that the average number of diving deaths each year in the U.S. and Canada, or involving U.S. or Canadian citizens abroad, has declined slightly, from about 90 per year to about 80 per year.

DAN will continue to promote safe diving practices, DAN Research will continue to strive to make diving safer through research and dissemination of safety advice, and DAN medics will continue to answer thousands upon thousands of inquiries each year. We expect to hit our 500,000th inquiry within the next five years and to assist with our 100,000th medical emergency.

DAN is your buddy in dive safety.

1980 National Diving Accident Network (NaDAN) established

1981 Divers **hotline** established

1982 Medical information line added; name changed to **DAN** (Diving Accident Network)

1983 Changed name to Divers **"Alert" Network** (DAN) Membership launched ($10); First employee hired; *Alert Diver* vol 1 issue 1 published

1984 DAN Received 2000 calls to the **medical information line**

1985 First DAN Doppler bubbles monitoring field trips; first DAN oxygen kit produced; Diving Accident Reporting Form (DARF) designed

1987 Fatality data started being collected; first **Annual Diving Report** produced; DAN Insurance launched

1990 DAN became a not-for-profit **501(C)(3)** board of directors created

1991 **International DAN** (IDAN) organizations started; training department established

1992 Travel Assist Program was created; DAN research established; Flying After Diving trials

1993 Recompression Chamber Assistance Program (**RCAP**)

1994 Contact Lens Survey

1995 Website created and first email received; **Project Dive Exploration** commenced

1997 DAN moves to a new building and begins accepting collect calls (toll-free); Dive Accident Reporting Form (DARF) ended and Dive Injury Reporting Form (DIRF) created; **Diabetes** and Diving Study; Asthma Survey

1999 IT department created; Ascent Rate Study; first year of Research Intern Program

2000 DAN **nitrox** workshop

2001 Medical Services Call Center (**MSCC**) created; DAN emergency line hours extended

2002 FAD workshop; Flying after Recreational Diving Guidelines created

2003 DIRF ended; Scuba Epidemiological Research Form (SERF) was created

2004 UHMS/DAN Management of Mild DCI in **Remote Locations** Workshop

2005 **Freediving** injuries and fatalities included in the annual report; UHMS/DAN Diabetes and Recreational Diving workshop

2006 UHMS DAN Breath-hold diving workshop held

2008 DAN **Technical Diving** Workshop

2010 DAN Recreational Diving Fatalities Workshop

2012 AAUS/DAN/PADI **Rebreather**; Diving Incident Reporting System (DIRS) launched

2014 DAN/UHMS Medical **Examination of Diving Fatalities** Symposium

2015 DAN/UHMS **PFO** Workshop

2016 DAN/UHMS Harvesting and Aquaculture Divers Safety Workshop

ACKNOWLEDGEMENTS

The number of contributors to the Annual Diving Report over these 30 years is too great to allow us to list them all individually. But those people certainly deserve our thanks collectively, if not by name. In particular, DAN thanks the hundreds of medical examiners, coroners, detectives, sheriff's department staff, U.S. Coast Guard personnel, nurses, dive operators, dive professionals, dive buddies, and, sadly, the next of kin who have enabled DAN to conduct diving mortality surveillance over the past 30 years. A few individuals have made a substantial contribution over many years, including Joel Dovenbarger, Renée Duncan, Dr. Dick Vann, Dr. Petar Denoble and Dr. Neal Pollock, each of whom has edited multiple editions of this report. Also deserving of special mention are graphic designer Rick Melvin, who has worked on more than half of the front covers; Julie Ellis, who maintained the fatality database for many years, before leaving DAN; and Jeanette Moore, who has compiled the report for a number of years.

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APPENDIX B. BREATH-HOLD INCIDENT CASE REPORTS

NEAL W. POLLOCK, NILES W. CLARKE, PAYAL S. RAZDAN

The following reports are selected as illustrative cases from the incidents captured in 2015 to demonstrate problems identified in the breath-hold incident database. They are categorized under the factor deemed to be of primary importance, though it is common for multiple factors to play a role in a given event.

PROCEDURAL PROBLEMS

CASE F-15480: A DIVER SUCCUMBED AFTER EXCESSIVE HYPERVENTILATION

A 19-year-old male was an avid freediver and fisherman. He was out for a day of freediving in the ocean with several friends. They were competing to see who could freedive to the deepest depth when the accident occurred. The group had descended together, and they all surfaced, but the victim lost consciousness at that point and sank to the bottom in approximately 100 fsw (30 msw). Two of his companions dived to the bottom as quickly as they could, and they were able to bring him to the surface, but he did not regain consciousness.

This case is best described as a hyperventilation-induced hypoxic blackout, but there were two related critical problems at play — diver practice and team readiness. The diver-practice problem was excessive hyperventilation (that is, ventilation of the lungs in excess of the body's metabolic needs). Breath-hold divers quickly learn that hyperventilation increases their breath-hold time. It does so by reducing carbon dioxide levels in the blood. It is rising carbon dioxide levels that trigger the urge to breathe, not falling oxygen levels (also known as hypoxia). Excessive hyperventilation can depress carbon dioxide levels enough that a person can lose consciousness due to hypoxia, despite feeling no urge to breathe.

The risk is increased when dives are done through a vertical water column (as opposed to breath-holding at or near the surface). During vertical excursions, the rising ambient (surrounding) pressure during descent increases the oxygen available in the blood. Problematically, the falling ambient pressure during ascent causes a diver's blood oxygen levels to drop faster than they would through metabolic consumption alone, increasing the likelihood of problematic hypoxia. A combination of predive hyperventilation and substantial vertical travel through the water column can lead to hypoxia of ascent (HOA), a condition commonly known as shallow-water blackout. The fastest decline in blood oxygen levels occurs during the final (shallowest) stage of an ascent. A diver can be conscious at the surface, take in a breath of fresh air, and still lose consciousness if a critical level of hypoxia in the brain is reached before the oxygen from the fresh inspiration arrives. If victims are exhaling while or immediately after losing consciousness, their loss of positive buoyancy can make them sink quickly.

Team readiness also played an important role in this case. The most effective standby diver provides close support, remaining ready and able to respond to any sign of compromise in a diver. Assistance provided quickly is often much easier than that which is delayed, particularly in cases in which a victim may be sinking beyond the range of expeditious rescue. The divers in this case were all diving together, so while they could watch each other, the demands of the dive would likely compromise rescue abilities, making vigilance and fast response critical. The outcome for victims losing consciousness underwater is generally best if they can be immediately be brought to the surface and their airway protected from further exposure to water. Delays in getting victims to the surface can quickly lead to drowning.

The fundamental problem with hyperventilation is that there is no signal to show how much of the buffer is eroded between the initiation of the normal urge to breathe and the point of lost consciousness. It is generally held that hyperventilation limited to no more than the equivalent of two or three deep inspiration/expiration cycles results in a low risk of loss of consciousness under normal diving circumstances. As conditions become more extreme, however, either in terms of the diving depth or the availability of skilled, ready close-support divers, the use of hyperventilation should be increasingly conservative. A capable support diver watching closely should be able to bring a diver to the surface quickly if problems develop. Modifications for deeper freediving include having safety freedivers descend toward ascending divers and complete the ascent with them, to provide extremely close support. The details of both diver practice and team readiness must be worked out before the enthusiasm of the moment leads to unnecessary risk of life.

CASE F-15537: PAIR OF DIVERS HAD NO SURFACE SUPERVISION DURING POOL PRACTICE

Two divers, one 32 years old and one 34 years old, were practicing in a swimming pool to improve their breath-hold performance. They were working together, but without additional supervision. Both were medically healthy and physically fit. They were found unresponsive on the bottom, in close proximity to each other and near a ballast weight also on the bottom. They were recovered from the water, but resuscitation efforts were unsuccessful.

The unwitnessed nature of this case, combined with the lack of forensic evidence that is typical of breath-hold mishaps, limits the ability to recreate the sequence of events, but some speculation is reasonable. Given the divers' known goal of maximizing their breath-hold time, the absence of any known issues with the water or the facility, and their ultimate loss of consciousness, it is likely that aggressive predive hyperventilation was a primary factor and that it resulted in hypoxic blackout.

Absent other environmental events, it is almost certain that the divers were conducting their breath-holds simultaneously rather than using the one-up, one-down practice that is recommended for pool activity. If a diver with a partner providing close support loses consciousness in the controlled environment of a swimming pool, it is typically fairly easy for the safety diver to bring the victim to the surface and to protect their airway from prolonged exposure to the water. When this is done, consciousness is usually quickly restored. But if these two divers were using extreme predive hyperventilation to conduct a simultaneous contest, instead of serving as each other's close support safety, it would have been possible for both to lose consciousness with little or no urge to breathe and to subsequently drown without struggle.

The proximity of the two victims to each other and the presence of the ballast weight are consistent with the scenario that they were conducting static breath-holds together on the bottom. If they had been swimming dynamically, it is less likely that the timing of their loss of consciousness would be so similar that they would end up close together. While it is possible that their modest vertical excursion, combined with excessive hyperventilation, generated HOA, the simplest explanation is that the pair hyperventilated to such an extreme that they both experienced static hypoxic blackout even without the complicating factor of ascent.

A breath-hold diver is best protected by a safety diver who maintains close support throughout the breath-hold period. Vigilance and readiness to effect an immediate rescue to the surface are essential. This practice can be extremely effective in a pool environment for groups of two or three divers. A group of three provides enhanced protection, with one diver breath-holding, one recovering, and one fully rested and ready to provide immediate support. The roles can be rotated as the session progresses. Quick recognition of and response to a problem can reduce the time required to get a victim to the surface and restore an open airway. Survivability is much greater if the victim's airway is quickly cleared of water.

CASE F-15636: A SNORKELER STRUGGLED AND DROWNED

A 21-year-old male was snorkeling from a boat with friends when he reportedly got into difficulty on the surface. He was unable to remain at the surface and sank to the bottom. After some delay, he was recovered from the bottom. Efforts at resuscitation were unsuccessful. The death was attributed to drowning.

The details of this case are incomplete, but some speculation is possible. Young, muscular males will often have sufficient body density to be negatively buoyant in the water. While the use of fins can be effective at countering a negatively buoyant state, anything that compromises kicking ability, such as the onset of leg cramps, can make staying on the surface difficult, particularly for an inexperienced swimmer.

Thus even the absence of ballast weight, such as a weight belt, does not provide adequate protection for an individual who has substantial inherent negative buoyancy. Weak swimmers or nonswimmers are best protected by wearing properly sized personal flotation devices to ensure that they can maintain their position on the surface. If individuals who are negatively buoyant wish to dive, they can be protected by wearing a vest that can be inflated either manually or automatically to facilitate their return to the surface if they lose consciousness.

CASE F-15950: A DIVER WAS SHOT IN THE HEAD WHILE SPEARFISHING

A 21-year-old male was spearfishing with a partner when he was shot in the head with a speargun. The partner surfaced with the victim and was able to shout for help. Emergency medical services personnel transported the victim to the hospital, where he succumbed to the injury several days later.

High-powered spearguns pose a risk to divers, as well as to animals in the water. The risk can increase when multiple hunters are using spearguns simultaneously, when conditions are rough, or when visibility is low. Planning, communication, and constant situational awareness are required to minimize the risk of a diver moving into the field of fire.

MEDICAL HEALTH, PHYSICAL FITNESS, AND ENVIRONMENT

CASE F-15424: TWO SNORKELERS WERE RESCUED, BUT TOO LATE

A 60-year-old male and a 55-year-old female were snorkeling at a popular ocean shore site in conditions described as calm, when a nearby hiker saw the pair struggling. Lifeguards responded and brought both unconscious victims to shore. Cardiopulmonary resuscitation (CPR) was unsuccessful, and both victims were pronounced dead at the scene.

It is generally not well appreciated that even benign water conditions place a significant physiological load on snorkelers. Immersion in water causes a shift in blood from the body's peripheral to its central circulatory system, putting an additional burden on the heart, as it pumps harder to manage the increased volume. Using a snorkel also increases breathing resistance and adds ventilatory deadspace, further elevating the physiological workload. If ballast weight is worn, that is an additional burden that needs to be factored into any physical exertion.

Psychological stress arising from a lack of familiarity with the setting or problems generated by victims or their partners can add further strain. An initial problem can be as simple as unintentional aspiration of water or a leg cramp. There is no evidence regarding the events that preceded the victims' visible distress in this case, but it may be that a combination of normal stressors in conjunction with suboptimal medical health and physical fitness played a role in their demise.

CASE F-15520: A SNORKELER WAS FOUND FLOATING FACEDOWN

A 43-year-old male was on a day boat for a snorkeling trip with approximately 30 other snorkelers. The conditions were described as relatively calm. The victim did not have a specific partner. He was not seen to have any problems but was observed after a period of time to be unresponsive while floating face down in the water. He was brought back to the boat, and CPR was initiated. He was taken by speedboat to a local hospital, where he was pronounced dead on arrival.

The comments presented in the case above regarding the strain of immersion are relevant to this case, too. However, while the presence of a partner in the previous case may have played a role in creating or augmenting a stressful situation, this case demonstrates the risk of being "alone in a group." While medical health issues likely played a role in this case, it is possible that the presence of a partner, personal or assigned, could have resulted in faster recognition of a developing problem and thus faster intervention.

CASE F-15730: STRESS OF IMMERSION APPEARED TO RESULT IN DEATH

A 67-year-old male was in a group of five people entering the water from a dive boat, intending to collect abalone. They entered the water and were swimming toward the planned site when one diver noticed the victim floating listlessly at the surface. The victim was removed from the water and resuscitative efforts were initiated, but the efforts were unsuccessful.

It is likely that the combined strain of immersion, physical exertion, and medical compromise contributed to this event. The problem reportedly developed before the breath-hold diving began, but it is still appropriate to discuss this as a diving case, since at least part of the stress resulted from the diving activity. Medical issues can develop at any time, but the additional strains of being in the water and of aquatic activity should not be ignored.

It is important to maintain or build physical fitness reserves so that immersion produces relatively little strain relative to an individual's overall capacity. It is also important that medical fitness is evaluated on a reasonable schedule, more frequently as a diver's age increases and particularly prior to a diver's participation in new activities.

CASE F-15731: A DIVER IN DISTRESS WAS BROUGHT TO SHORE BUT CPR WAS UNSUCCESSFUL

A 56-year-old male was breath-hold diving with a partner for abalone in temperate waters and modestly demanding conditions, when the victim began to feel ill. Both divers dropped their weights, and the victim was assisted to shore by his partner. CPR was initiated on shore, but rescue attempts were unsuccessful.

See comments for the previous case.

ANIMAL-INVOLVED INJURY

CASE F-15530: A SNORKELER IS FOUND DEAD WITH EVIDENCE OF A SHARK ATTACK

A 65-year-old female was snorkeling in a group of three people. She became separated from her group and was found later, face-down, by other snorkelers. She was brought to the shore, and rescue personnel initiated resuscitation efforts, but they were unsuccessful. The events that immediately preceded this incident were unwitnessed, but the victim had severe injuries to one of her arms and her torso that were consistent with a shark attack.

Animals can be attracted to swimmers, snorkelers, or divers out of curiosity. The curiosity can change to active interest if the person is panicking, injured, or carrying injured prey with them. The victim in this case was not collecting or hunting, but it is unclear if she may have experienced an injury preceding the attack.

It is important to realize that the speed, power, and mobility of most aquatic predators is sufficient to put divers at a marked disadvantage. While sharks and other predators can often be observed with no untoward outcome, they remain wild animals that will follow their own motivations and drives. Caution and respect are essential. Counting on a benign response is not a wise strategy.

CASE F-15610: A SNORKELER SUSTAINS MULTIPLE SHARK BITES

A 50-year-old male was snorkeling with his wife from a boat with a group of friends. He was not carrying any animal catch and was not known to have any physical injuries. He was observed sustaining multiple bite wounds in a very rapid attack by a shark. He was recovered to the vessel after the shark left the immediate area. His injuries were too extreme for effective resuscitation efforts.

See comments for the previous case.

ENVIRONMENTAL CONDITIONS

CASE F-15523: ROUGH SEAS OVERPOWERED THREE DIVERS

A group of five male divers entered the water as part of a group that was intending to use breath-hold diving to collect abalone. The waters were temperate, the coastline was rocky, and the surf conditions were described as rough. The divers were not able to return to their entry point safely. Two divers were able to hold onto the rocks at the base of a steep cliff and were rescued. Three divers were overcome by the ocean conditions and drowned.

Incidents involving seafood harvesters are common, particularly in regions with demanding waters and short open seasons. The risk can be high if divers do not maintain their skills and physical fitness outside of the diving season. Time and competitive pressures can increase the risk to divers by inducing them to ignore questionable conditions and to fail to adequately assess their capabilities and readiness. Rough conditions create additional hazards, making it unsafe to be in the water.

Efforts should be made to ensure that divers possess appropriate skill and physical readiness in advance of every season opening. Conditions should be critically evaluated, erring on the side of caution when possible. If divers are caught in poor or worsening conditions, a rapid exit is generally best, avoiding rough terrain if possible. While diving in a group can sometimes provide protection, that margin of safety may be insufficient if conditions approach or exceed the capabilities of the individuals within the group.

BOAT STRIKE

CASE F-15831: A SNORKELER WAS STRUCK BY A WINDSURFER

A 32-year-old female was snorkeling approximately 80 feet (25 meters) from shore. She had experience with the site, but was not using a marker buoy or dive flag. While on the surface, she was struck in the neck by a windsurfer. She was transported to shore but died from excessive blood loss.

Breath-hold divers spend more time on the surface than compressed-gas divers do. The diver in this case may have been unaware of the hazard approaching her, since windsurfers do not make as much noise as most surface traffic. Furthermore, the blind spots and speed associated with windsurfing can make it very easy for windsurfers to be unaware of low-profile objects or swimmers in the water.

Vigilance is required in order to maintain surface safety. Protection from boat traffic can be increased if divers remain in protected areas or those with minimal surface traffic, and if they restrict their activities to the immediate vicinity of recognized dive flags, wear high-visibility gear, and remain continuously watchful. Public outreach can educate both divers and surface vessel operators, but surface swimmers will always have the greater personal risk, so they must be particularly vigilant to protect themselves.

APPENDIX C. PUBLICATIONS (2016)

JEANETTE P. MOORE

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APPENDIX D. PRESENTATIONS (2016)

JEANETTE P. MOORE

Pollock NW. “Extreme diving and diver protection.” Wilderness Medical Society student elective in Wilderness and Environmental Medicine, New Castle, Va. February 4–5, 2016.

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Buzzacott P. “Global burden of diving injuries.” OWU, Chicago, Ill. February 27–28, 2016.

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Trout BM. "Does Sex Matter in Diving?" Beneath the Sea, Seacaucus, N.J. April 2, 2016.

Trout BM. "From Incident to Fatality: Diving into DAN Data." Beneath the Sea, Seacaucus, N.J. April 2, 2016.

Martina S. "Perspectives on the eye and scuba diving." DAN Public Lecture Series, Durham, N.C. April 6, 2016.

Pollock NW. "Managing and measuring decompression stress." Department of Exercise and Nutrition Sciences, State University of New York at Buffalo, Buffalo, N.Y. April 20, 2016.

Pollock NW. "Decompression-induced bubbles — the known, the unknown, and the implications." TEKDiveUSA, Miami, Fla. April 23, 2016.

Pollock NW. "Future of technical diving" (panel). TEKDiveUSA, Miami, Fla. April 24, 2016.

Pollock NW. "Thoughtful management of decompression stress." TEKDiveUSA, Miami, Fla. April 24, 2016.

Pollock NW. "Decompression sickness during simulated low pressure exposure is increased with mild ambulation exercise" (oral presentation). Aerospace Medical Association Annual Scientific Meeting, Atlantic City, N.J. April 25, 2016.

Denoble PJ. "Prevention of scuba diving mishaps by using a predive checklist: A grouped randomized trial." South Pacific Underwater Medicine Society. May 2016.

Pollock NW. "Diving through the age continuum" (webinar). Float N' Flag Dive Centre, Burlington, Ontario. May 4, 2016.

Pollock NW. "Diving risk management." DAN-Undersea and Hyperbaric Medical Society (UHMS) Diving and Hyperbaric Medicine continuing medical education (CME) program, Cayman Brac. May 8, 2016.

Pollock NW. “Physical fitness and diving safety.” DAN-UHMS Diving and Hyperbaric Medicine CME program, Cayman Brac. May 9, 2016.

Pollock NW. “Thermal physiology.” DAN-UHMS Diving and Hyperbaric Medicine CME program, Cayman Brac. May 10, 2016.

Pollock NW. “Special population divers.” DAN-UHMS Diving and Hyperbaric Medicine CME program, Cayman Brac. May 11, 2016.

Pollock NW. “Altitude and diving.” DAN-UHMS Diving and Hyperbaric Medicine CME program, Cayman Brac. May 12, 2016.

Pollock NW. “Breath-hold diving.” DAN-UHMS Diving and Hyperbaric Medicine CME program, Cayman Brac. May 13, 2016.

Pollock NW. “Advancement and challenges in rebreather diving.” DAN Public Lecture Series, Durham, N.C. June 1, 2016.

Buzzacott P. “DAN Incident Reports: Murphy’s Law at Work.” Long Beach Scuba Show, Long Beach, Calif. June 4, 2016.

Buzzacott P. “Diving While Breathing Gases Other than Air.” Long Beach Scuba Show, Long Beach, Calif. June 4, 2016.

Buzzacott P. “Underwater Hunting: Research and Lucky Escapes.” Long Beach Scuba Show, Long Beach, Calif. June 4, 2016.

Pollock NW. “The world of harvesting and aquaculture diving” (workshop). Harvesting and Aquaculture Diving Safety, Las Vegas, Nev. June 8, 2016.

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Nochetto M. “Racional terapéutico.” DAN Academy of Dive Medicine, Base Naval ARC Bolivar, Catagena, Colombia. July 7, 2016.

Nochetto M. “Anamnesis y diagnóstico” (revisión de casos). DAN Academy of Dive Medicine, Base Naval ARC Bolivar, Catagena, Colombia. July 7, 2016.

Nochetto M. “Manejo de accidentes en locales remotos.” DAN Academy of Dive Medicine, Base Naval ARC Bolivar, Catagena, Colombia. July 8, 2016.

Nochetto M. “ED Buceo Comercial Empírico en las Américas.” DAN Academy of Dive Medicine, Base Naval ARC Bolivar, Catagena, Colombia. July 8, 2016.

Nochetto M. “Toxinología marina 1.” DAN Academy of Dive Medicine, Base Naval ARC Bolivar, Catagena, Colombia. July 8, 2016.

Nochetto M. “Toxinología marina 2.” DAN Academy of Dive Medicine, Base Naval ARC Bolivar, Catagena, Colombia. July 8, 2016.

Buzzacott P. “Risks and Hazards of Lobster Diving.” History of Diving Museum, Islamorada, Fla. July 20, 2016.
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Pollock NW. “Managing decompression stress.” St. Thomas diving community lecture, St. Thomas, U.S. V.I. July 20, 2016.

Pollock NW. “A quick and dirty review of gradient factors.” AllTek talk, Birmingham, England. September 21, 2014, at Eurotek 2014.

Razdan PS. “Making sense of CPR algorithms: ABC or CAB.” Durham Technical Community College, Durham, N.C. July 28, 2016.

Pollock NW. “Top articles in wilderness medicine.” 7th World Congress of Mountain and Wilderness Medicine, Telluride, Colo. August 2, 2016.

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Razdan PS. “Understanding CPR: ABC or CAB.” DAN Public Lecture Series, Durham, N.C. August 3, 2016.

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Pollock NW. "Managing decompression stress." Canadian Undersea and Hyperbaric Medical Society Annual Scientific Meeting, Vancouver, British Columbia. September 10, 2016.

Pollock NW. "Health and safety of inside tenders." Canadian Undersea and Hyperbaric Medical Society Annual Scientific Meeting, Vancouver, British Columbia. September 10, 2016.

Burman F. "Diving Safety Officer: Role and Responsibilities." 12th International DAN Diver's Day, Geneva, Switzerland. September 17, 2016.

Buzzacott P. "Expedition-level injury prevention" (oral presentation). National Speleology Society Cave Diving Section 2016 Mid-West Workshop, St. Louis, Mo. September 17, 2016.

Burman F. "Safety director course." ATMO course, San Antonio, Texas. September 19–21, 2016.

Burman F. "Acrylic Maintenance and Inspection." ATMO course, San Antonio, Texas. September 22, 2016.

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Pollock NW. "Physical fitness and diving safety." DAN-UHMS Diving and Hyperbaric Medicine Course, St. Lucia. September 26, 2016.

Pollock NW. "Thermal physiology." DAN-UHMS Diving and Hyperbaric Medicine Course, St. Lucia. September 27, 2016.

Pollock NW. "Managing and measuring decompression stress." DAN-UHMS Diving and Hyperbaric Medicine Course, St. Lucia. September 28, 2016.

Pollock NW. "Altitude and diving." DAN-UHMS Diving and Hyperbaric Medicine Course, St. Lucia. September 29, 2016.

Pollock NW. "Breath-hold diving." DAN-UHMS Diving and Hyperbaric Medicine Course, St. Lucia. September 30, 2016.

Nochetto M. "Como Funciona a DAN Emergency Hotline" (How does the DAN Emergency Hotline work). Professional Association of Diving Instructors (PADI) Dive Festival, São Paulo Boat Show, São Paulo, Brasil. October 2–3, 2016.

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Nochetto M. "Toxinological Aspects of Hazardous Marine Life." University of Campinas Poison Control Center, São Paulo, Brasil. October 3, 2016.

Scott S. “Diving Emergencies.” EMS World Expo, New Orleans, La. October 3–5, 2016.

Rowley B. “From incident to fatality: Diving into DAN data.” DAN Public Lecture Series, Durham, N.C. October 5, 2016.

Buzzacott P. “Epidemiology of recreational scuba diving morbidity and mortality.” University of Wales Bay Campus, United Kingdom. October 6, 2016.

Burman F. “Introduction to hyperbaric facility safety management.” Diving Medicine Diploma Course, Merida, Mexico. October 9–12, 2016.

Burman F. “Medical Gas Delivery Systems in Hyperbaric Facilities.” Diving Medicine Diploma Course, Merida, Mexico. October 9–12, 2016.

Burman F. “Safety Management of Hyperbaric Facilities, Part 1: Hazard Identification.” Diving Medicine Diploma Course, Merida, Mexico. October 9–12, 2016.

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Buzzacott P. “Epidemiology of Diving Injuries.” Diving Diseases Research Centre, Plymouth, United Kingdom. October 10, 2016.

Denoble PJ. “Patent Foramen Ovale and Fitness to Dive Consensus Workshop.” UHMS Pacific Chapter, San Diego, Calif. October 28, 2016.

Buzzacott P. “Inherent Hazards of Mixed Gas Diving.” Diving Equipment and Marketing Association (DEMA), Las Vegas, Nev. November 16 and 18, 2016.

Buzzacott P. “Nonfatal close calls and lessons learned from scuba diving incidents.” DEMA, Las Vegas, Nev. November 16 and 18, 2016.

Buzzacott P. “Thrill of the hunt and safety in lobster diving.” DEMA, Las Vegas, Nev. November 17 and 19, 2016.

Buzzacott P. “Trends in recreational diving injuries and fatalities.” DEMA, Las Vegas, Nev. November 17 and 19, 2016.

Denoble PJ. “Prepared diver program: The fundamentals of responsible diving.” DEMA, Las Vegas, Nev. November 16 and 17, 2016.

McCafferty M. “Navigating the internet and social media for diving information.” DEMA, Las Vegas, Nev. November 16 and 18, 2016.

McCafferty M. “Vanishing 24/7 chambers.” DEMA, Las Vegas, Nev. November 16 and 18, 2016.

McCafferty M. “When the chamber isn’t needed.” DEMA, Las Vegas, Nev. November 17 and 19, 2016.

Nochetto M. “Case series from the DAN Emergency Line: An interactive review of real cases.” DEMA, Las Vegas, Nev. November 17 and 19, 2016.

Nochetto M. “Delta P and barotraumas: How pressure affects gas-filled body cavities.” DEMA, Las Vegas, Nev. November 16 and 18, 2016.

Nochetto M. “Harvesting and aquaculture divers: Perils for those who bring us our seafood.” DEMA, Las Vegas, Nev. November 16, 2016.

Nochetto M. “Operational gas toxicities: How to mitigate risks.” DEMA, Las Vegas, Nev. November 17 and 19, 2016.

Pollock NW. “Advances and challenges in rebreather diving.” DEMA, Las Vegas, Nev. November 16 and 18, 2016.

Pollock NW. “Hydration and diving safety: Not as simple as you may think.” DEMA, Las Vegas, Nev. November 16 and 18, 2016.

Pollock NW. “Nutrition and diving.” DEMA, Las Vegas, Nev. November 17 and 19, 2016.

Pollock N. “Physical fitness for diving professionals: An at-risk community.” DEMA, Las Vegas, Nev. November 17 and 19, 2016.

Razdan P. “Impact of physiological stress on dive safety.” DEMA, Las Vegas, Nev. November 17–18, 2016.

Seery P. “DAN Instructor/Instructor Trainer 2017 Update.” DEMA, Las Vegas, Nev. November 16–18, 2016.

Seery P. “DAN Instructor Trainer Workshop.” DEMA, Las Vegas, Nev. November 18–19, 2016.

Seery P. “Make your DAN first-aid courses work for you.” DEMA, Las Vegas, Nev. November 16–18, 2016.

Pollock NW. “Dive readiness.” British Hyperbaric Association Annual Scientific Meeting, Cayman Brac. December 5, 2016.

Pollock NW. “The interaction between endocrine conditions and diving, part 1.” British Hyperbaric Association Annual Scientific Meeting, Cayman Brac. December 7, 2016.

Pollock NW. “The interaction between endocrine conditions and diving, part 2.” British Hyperbaric Association Annual Scientific Meeting, Cayman Brac. December 8, 2016.

APPENDIX E - RECENT RESEARCH POSTERS

PETER BUZZACOTT

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

Buzzacott P, Schiller D, Crain J, Marshall S, Denoble PJ. "Epidemiology of morbidity and mortality in U.S. and Canadian recreational scuba diving." Presented at the European Underwater and Baromedical Society annual scientific meeting in Ravenna, Italy, September 13–16, 2017.

Denoble PJ, Dunford RG, Sayer MDJ, Pollock NW, Nord DA, Vann RD. "Predicted probability of decompression sickness in 159 treated cases with documented dive profiles." Undersea Hyperb Med. 2009; 36(4): 247.

Denoble PJ, Vaithiyanathan P, Clark D, Vann RD. "Annual rate of decompression sickness based on insurance claims." Undersea Hyperb Med. 2009; 36(4): 333.

Denoble PJ, Vaithiyanathan P, Vann RD. "Annual diving fatality rates among insured DAN members." Undersea Hyperb Med. 2008; 35(4): 256.

Dovenbarger JA, Burman F, Pollock N. "Divers Alert Network Recompression Chamber Assistance Program." Undersea Hyperb Med. 2008; 35(4): 263.

Dunford RG, Denoble PJ, Vann RD, Shannon JS, Pollock NW, Howle LE. "The relationship of AGE and body mass index to Doppler-detected bubble grades." Undersea Hyperb Med. 2008; 35(4): 254-5.

Caruso JL, Uguccioni JE, Ellis JE, Dovenbarger JA, Bennett PB. "Diving fatalities involving children and adolescents 1989-2002."

Epidemiology of morbidity and mortality in US and Canadian recreational scuba diving

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Introduction

- Scuba diving is a popular recreational pursuit enjoyed by millions of divers in the US and Canada, though it exposes divers to stresses that sometimes result in injuries.
- The incidence of diving injuries in the US is unknown.
- It is important to know how common morbidity and mortality are in recreational diving, both for preventive interventions and to enable fairly-priced adequate insurance.
- This study investigates morbidity and mortality suffered by divers in the US and Canada.

Methods

- In the US the Consumer Product Safety Commission (CPSC) maintain the National Electronic Surveillance System (NEISS), a national register of Emergency Department (ED) presentations from around 100 hospitals in US and US Territories.
- The Canadian Hospitals Injury Reporting and Prevention Program (CHIRPP) supplied data concerning scuba diving injuries in children and adults presenting at emergency Departments at 11 pediatric and five general hospitals across Canada between 1990-2015.
- NEISS and CHIRPP were searched for scuba diving injuries.
- The Divers Alert Network (DAN) diving fatality database was searched for deaths and Sports and Fitness Industry Association (SFIA) estimates for diving were obtained from >383,000 completed annual surveys.
- Both the NEISS and SFIA data are publically available, the DAN fatality data was collected and analysed under approval from the Divers Alert Network Institutional Review Board (Approval #011-016) and the CHIRPP data were de-identified before analysis, therefore, the CHIRPP determined separate IRB approval was not required in this instance.
- SAS version 9.4 was used for the analysis.

Results

- There were 378 individual scuba-related ED presentations in the NEISS data out of 3,799,805 cases (0.0099%), equating to an estimated 13,943 cases nationally out of 140,624,966 (0.0099%), or 9.9 out of 10^5 cases.
- In the US there were an average 1,381 emergency department (ED) presentations annually for scuba-related injuries, (95% CI 570, 2335 estimated by Monte Carlo resampling and Central Limit Theorem).
- In Canada there were 98 cases of scuba-related injuries identified in the CHIRPP data.
- The majority (80%) of US cases were treated and released, or released without treatment, and less than 1% were dead on arrival or died in the ED.
- According to SFIA survey results, there were an estimated 306,174,386 dives made by US residents 2006-2015 and concurrently there were 563 recreational diving deaths in the DAN database, a fatality rate among US recreational divers of 0.18 per 10^5 dives and 1.8 per 10^5 diver-years.
- Regarding the location where each injury occurred, 332 (88%) occurred at places of recreation/sports, 11 (3%) at other public property, six (2%) in homes and 29 (8%) elsewhere or not recorded.
- In Canada, the prevalence of scuba-related injuries for CHIRPP patients aged 3-17 years was 1.5 per 10^5 cases, and the prevalence of scuba related-injuries to CHIRPP patients 18-62 years per was 16.5 per 10^5 cases.

Table 3: Disposition

Disposition	n (%)
Treated and released, or examined and released without treatment	305 (81)
Treated and transferred to another hospital	24 (6)
Treated and admitted for hospitalization (within same facility)	33 (9)
Held for observation (includes admitted for observation)	5 (1)
Left without being seen/Left against medical advice	8 (2)
Fatality, including DOA, died in the ED	3 (1)
Total	378 (100)

Table 1: Summary of data sets

Year	Total Interviews	US Population (person-years)	Estimated Number of Divers	Estimated Number of Dives	NEISS Estimate Total ED presentations	NEISS Estimate Scuba ED Presentations	Number recreational diving deaths	Foreign deaths in US	Non-recreational diving deaths
2006-15	383,389	2,844,972,894	30,444,000	306,174,386	140,624,966	13,943	563	8	87

Limitations

- Scuba diving is a geographically concentrated sport confined to locations with access to popular dive sites and, therefore, the NEISS may not accurately reflect the true distribution of scuba-related injuries in the US.
- Many diving injuries do not result in presentation to the ED and the overall burden of injury attributable to recreational scuba diving is likely greater than that resulting in presentations to the ED or death.
- Not all dives made by US residents were likely made within the US and many dives are made in the US by visiting divers.

Table 2: Body part affected by injury

Body Part Affected	n (%)
Ear [the most common injury in scuba diving, due to pressure changes]	127 (34)
All parts of body (> 50% of body) [for example, decompression sickness]	65 (17)
Trunk, upper (not including shoulders) [such as "skin bends"]	35 (9)
Others (<20 cases per body part) [no part of the body is exempt from injury]	151 (40)
Total	378 (100)

Conclusions

- In Canada and the US it is estimated only one out of every 10,000 ED presentations is due to a scuba–related injury.
- Among adults the scuba-related presentation rate was 16.5 cases per 10^5, more than ten times that among children presenting to the ED.
- The fact that there were 47 deaths in the US for every 1,000 estimated ED presentations speaks to the relatively unforgiving environment in which scuba diving takes place.
- At 1.8 deaths per million recreational dives, mortality in scuba diving appears nonetheless relatively low.
- The majority of divers presenting at the ED will be treated and released, or even released without treatment.
- Further research is needed to verify how many dives are made overseas by US divers, and how many are made in the US by international visitors.
- As with calls to the DAN Emergency Helpline, barotraumas were the most common injuries seen at the ED.

PREDICTED PROBABILITY OF DECOMPRESSION SICKNESS IN 159 TREATED CASES WITH DOCUMENTED DIVE PROFILES

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[1] Divers Alert Network (DAN), Durham, NC; [2] Dunstaffnage Hyperbaric Unit, Oban, UK; [3] Department of Anesthesiology, Duke University Medical Center, Durham, NC

INTRODUCTION

Decompression sickness (DCS) is a rare adverse outcome of diving.
Symptoms are mainly mild, although in some cases they may be severe and leave permanent damage or cause death.

The main recommended measure of DCS risk control in recreational diving is to limit the depth-time exposure to no-decompression (no-D) diving.

The no-D limits vary, and the compliance of divers with recommendations is not known. Thus, the success of this approach is difficult to evaluate.

In this study we used electronically recorded depth-time profiles to compare severities of exposures in symptom-free dives with dives resulting with DCS.

METHODS

Symptom-free, air and nitrox open-circuit dive profiles were obtained through DAN's Project Dive Exploration (PDE). Cases treated for DCS were provided by PDE, Dive Safety Lab (DSL) DAN Europe, DAN Medical Services Call Center (MSCC), and the Dunstaffnage Hyperbaric Unit in Scotland. DCS cases were classified as DCS I, DCS II and Ambiguous.[1]

The probability of DCS (P_{DCS}), as an index of severity of depth-time exposure, was calculated using probabilistic model.[2]

Differences in P_{DCS} values were tested by t-test (significance at p<0.05). We did not explore the compliance of divers with instructions provided by their dive computers.

RESULTS

Comparison of P_{DCS} in DCS-free group and in DCS group is shown in Table 1.

Table1. Comparison of P_{DCS} in DCS and DCS-free dives

Group	n	P_{DCS} (%)				
		mean	SD	min	max	median
DCS cases	159	1.31*	1.10	0.11	8.80	1.07
DCS-free	62,960	0.55	0.54	0.01	9.00	0.39

*p<0.05

The P_{DCS} in DCS cases was greater than in DCS-free dives. The distribution of P_{DCS} in two groups is shown in Figure 1.

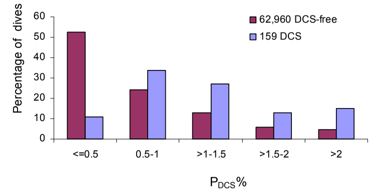

Figure 1. Distribution of P_{DCS} in DCS and DCS-free dives

Most DCS-free dives (77%) occur at P_{DCS} ≤1%, while only 45% of DCS cases had P_{DCS} ≤1%.

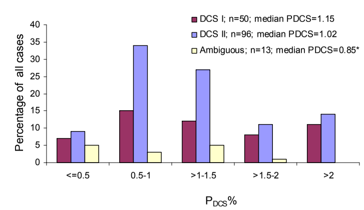

Figure 2. P_{DCS} by DCS type

DCS I and DCS II occurred at similar and Ambiguous cases at smaller P_{DCS} (Figure 2).

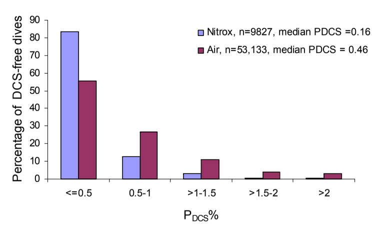

Figure 3. Comparison of nitrox and air DCS-free dives

Use of nitrox was associated with lower P_{DCS} in observed PDE dives (p<0.05).

DISCUSSION

DCS occurs for only a small fraction of recreational dives with P_{DCS} >1. Avoiding exposures with P_{DCS} >1 may reduce the occurrence of DCS to less than a half of current rates.

In recreational diving modifying dive practices would affect only 23% of dives; the use of nitrox also helps to reduce P_{DCS} values.

Safety margins could be increased by modifying dive depth-time profiles without necessarily affecting total dive time though bottom time may be reduced (e.g. Figure 4).

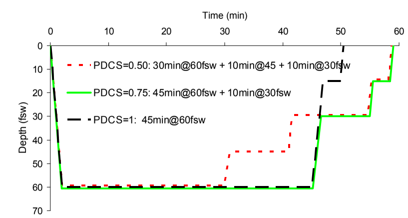

Figure 4. Effects of depth-time modifications on P_{DCS}

CONCLUSION

In most DCS-free dives, the estimated exposure severity was <1%, while most DCS cases resulted from dives of severity >1%.

Limiting dive exposure to P_{DCS} of 1% or less may significantly reduce DCS occurrence.

This could be achieved by modifying depth-time profile or by use of nitrox.

Dive computers enable multi-level diving which may help reducing rates of DCS.

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ANNUAL RATE OF DECOMPRESSION SICKNESS BASED ON INSURANCE CLAIMS

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INTRODUCTION

- Establishing and monitoring a DCS incidence rate may help evaluate trends in dive safety and effects of changes in dive technologies, practices and policies.
- We estimated the annual rates of DCS by calculating the rate of claims for DCS therapy among divers with DAN insurance.

METHODS

- The study was approved by the Duke University Medical Center Institutional Review Board.
- DCS claims (ICD-9 code of 993.3) submitted by insured DAN members in 2000-2007 were provided by insurance claims processing service.
- Data on all insured DAN members were available for the same period.
- The rate of DCS claims per 100,000 insured members was calculated for each year.
- The effects of age, sex, and calendar year on claim rates were tested by logistic regression ($p<0.05$).

RESULTS

- There were 1,401,864 insured member-years and 3,183 DCS cases.
- The distributions of insured DAN members by age and gender are shown in Fig. 1.
- The overall DCS claim rate was 227 (95%CI: 219-235) per 100,000 insured.
- Annual rates declined significantly from 285 in 2000 to 186 in 2007 (Fig. 2).
- Rates were higher in males (247; range 237-258) than in females (192; range 180-204).
- The relative risk for males to females was 1.29 (95% CI: 1.2-1.3).
- The rates declined with age and became similar for both genders above 40.

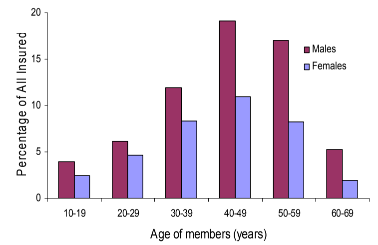

Figure 1. Distribution of Insured by Age and Gender

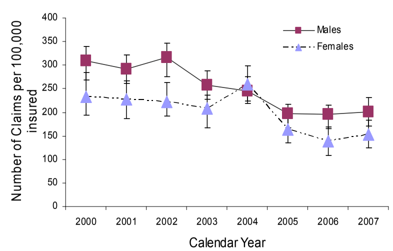

Figure 2. DCS Claim Rates by Year

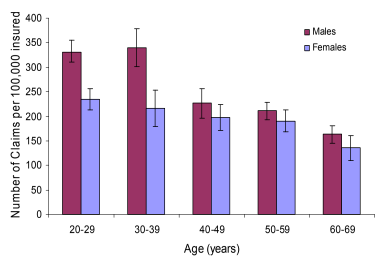

Figure 3. DCS Claim Rates by Age and Gender

RESULTS (continued)

- The risk for DCS claims decreased with increasing number of years of being insured relative to Year 2 (Fig. 4).
- After Year 2 (usually the first year of independent diving after certification), DCS claim rates steadily declined.
- The insurance renewal rates for divers who claimed DCS in first four insured years were greater than for those insured without claims.

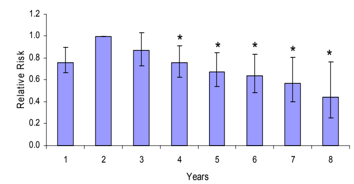

Figure 4. Relative Risk of DCS vs. Number of Insured Years. * Significant difference in comparison to Year 2 ($p<0.05$).

DISCUSSION

- Our data were from secondary insurance claims and may not represent all DCS cases in insured DAN members.
- However, no US primary insurance covers all DCS treatment expenses which would be an incentive for treated divers to file claims with DAN.
- Claim rates may overestimate true DCS rates if the diagnosis were later changed.
- Dive profiles were not available to test for differences in exposure by age and gender.
- Divers who suffer early DCS are often suspected to drop out of diving, but divers who claimed DCS in first year were more likely to renew their insurance consecutively for next four years than other divers. This suggests that early DCS was not a drop-out incentive.

ANNUAL DIVING FATALITY RATES AMONG INSURED DAN MEMBERS

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Introduction

The annual count of injury deaths in USA and Canada has been surveyed since the sixties. Peaking at 150 in mid-seventies, the death count has been fairly stable for more than one decade at 84±5 (range 77 – 91).

Without knowing the number of exposed persons, it is impossible to evaluate how the safety and riskiness of scuba diving change over time or to identify divers with greater than average risk.

Cardiovascular disease has also become increasingly recognized as a factor in the death in older divers but the association has not been tested due to lack of data.[1]

This study computed fatality rates among insured members of the Divers Alert Network (DAN), and tested effects of age and gender on overall rates and on cause specific rates.

Methods

Age, gender, and death while diving were extracted in de-identified form from about 150,000 insured DAN members for each year from 2000-2006.

Annual fatality rates were computed per 100,000 members.

Association with age and gender was tested with logistic regression ($p<0.05$).

The relative risks for divers <50 and ≥50 years of age for drowning, arterial gas embolism (AGE), and cardiac incidents were computed.

Results

Age of Insured DAN Members

There was a total of 1,141,367 insured member-years. Males made 64% and their mean age was three years greater than mean age of females. In seven year since 2000, mean age increased for three years for both genders.

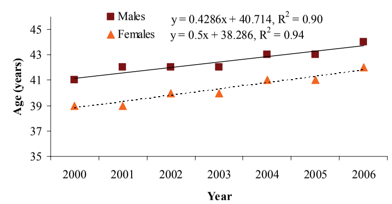

Figure 1: Mean age of insured DAN members.

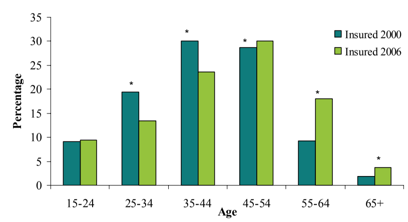

Figure 2: Age distribution of insured DAN members.

Annual fatality rates

Overall fatality rate was 16.4 (95% CI:14.2-18.9). Annual fatality rates varied from 12-23 per 100,000 with no trends during the observed period.

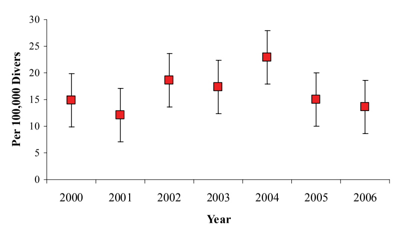

Figure 3: Annual fatality rates for DAN insured members

Age- and gender–specific fatality rates

The overall rate was greater for males (21.2) than for females (7.6) (2.8 OR, 1.9–4.5 95% CL). Rates increased with age both for males and females. The the difference in rates diminished with age, becoming similar after age 60.

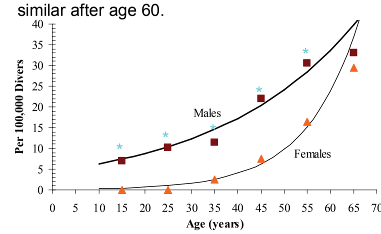

Figure 4: Fatality rates by age and gender

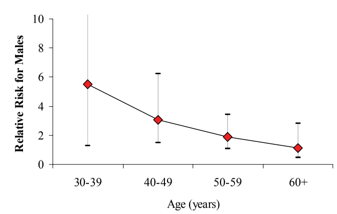

Figure 5: Relative risk for males in comparison to females

Cause-specific relative risks for older divers

In divers ≥50 years, cardiac disease is leading (37%) suspected cause of death while diving.
In the same age group, the relative risk of cardiac related scuba death is 12.9 times greater than in group under 50.

Table 1. Cause specific RR

Cause of Death	<50 years n=788,489	≥50 years n=352,878	RR	Lower Limit	Upper Limit
Cardiac	5	29	12.9	5.0	33.5
AGE	8	14	3.9	1.6	9.3
Drowning	15	17	2.5	1.3	5.1
Unknown	15	16	1.9	0.9	4.1
Other	7	3	1.0	0.2	3.7
Total	50	79			

Discussion

DAN insured divers may not be representative of all recreational divers but their aging seem to reflect similar trends in population.

Annual number of fatalities are small and thus random variations may affect year-to-year changes of fatality rates.

Relative increase of risk with age may be associated with prevalence of heart disease in population that increases with age, too.

Conclusions

In addition to specific risks in diving - AGE and drowning - older divers are exposed to additional, health-related risks.

Healthy life style and regular exercise may help reduce risk in diving.

Divers with risk factors for heart diseases should seek medical evaluation prior to diving.

References

Caruso JL, Bove AA, Uguccioni DM, Ellis JE, Dovenbarger JA, Bennett PB. Recreational diving deaths associated with cardiovascular disease: epidemiology and recommendations for pre-participation screening. *Undersea and Hyperbaric Medicine*. 2001;28 (suppl):75.

DIVERS ALERT NETWORK RECOMPRESSION CHAMBER ASSISTANCE PROGRAM

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Introduction

- The Recompression Chamber Assistance Program (RCAP) was developed as an outreach initiative to assist under-funded and/or under-supported hyperbaric facilities, usually located in remote areas and dedicated to the treatment of recreational diving emergencies.
  - Initiated by:
    - DAN America in 1993;
    - DAN Southern Africa in 1997;
    - DAN Europe in 2004.
- The program is designed to help ensure universal compliance to relevant international facility and treatment standards.
  - NFPA 99 Standard for Health Care Facilities.
  - ASME PVHO-1 Standard for Pressure Vessels for Human Occupancy.
  - International Classification Society Rules.
  - IDAN Risk Assessment Guide for Recompression Facilities.
- Additional goals are to expand the diving research base, increase the profile of facilities within local diving communities and to foster closer relationships within the diving industry.

Methods

- Facilities apply for RCAP support through an annual competitive process.
  - Primary selection criteria include financial need and intent to comply with minimum standards.
- Selected facilities are assessed by RCAP-funded engineering and operations professionals who complete risk, compliance with minimum industry standards, operations and documentation assessments.
  - Comprehensive reports are provided to aid facilities in compliance efforts.
- Direct support covers necessary equipment and facility upgrades, physician, nurse, and operational staff training and maintenance needs.
- The program effectiveness is evaluated for each facility by improvements in technical capability, staff and patient safety, and compliance with international standards.

Francois Burman conducting on-site chamber evaluations.

Results

- On-site assessment and support (1997-2006).
  - 54 facilities in 29 countries:
    - 91% multi-place, remainder monoplace;
    - 56% established primarily for HBO treatments;
    - 44% hospital-based;
    - 22% capable of mixed gas/USN TT6 treatments;
    - 20% had significant technical non-compliances.
  - 26 received training support.
    - on-site or travel/tuition awards.
  - 11 received equipment grants.
    - oxygen system components, essential maintenance spares, replacement acrylic windows, and patient monitors.
  - Approximately half received ongoing technical support.
- Locations included all DAN regions worldwide:
  - 46% America, 33% Europe, 15% Southern Africa, 6% Asia-Pacific.
- Subjective feedback indicates that participating facilities:
  - Are more motivated to maintain and improve facilities;
  - Feel they have access to a crucial resource to guide their efforts.
- RCAP is funded by:
  - Member donations - 61.5%;
  - Individual patron donors - 37%;
  - Extramural fundraising - 1.5%.
- RCAP was recently identified as a priority initiative for DAN America.

Discussion

- Involving all DAN regions could expand available support and further capitalize on regional experience and expertise.
  - Coordinating global training opportunities/schedule.
  - Pooling staff and providing referrals with staff rotation.
  - Expanding multi-center research opportunities.
  - Promoting advanced standardization of chamber operations and level of care.
- Improving international communication could improve local success.
  - Allowing new or troubled facilities to benefit from experience of sustainable facilities.
  - Promoting continued self-evaluation of operations.
  - Enhancing credibility and increasing local awareness.

Future Initiatives

- Increase funding base (breadth and scale) through greater public and industry awareness, better definition of needs, and improved networking with evacuation and treatment partners.
- Increase mutual program recognition through providing a common approach to assessment and then bringing facilities up to an acceptable level of minimum standards.

Conclusions

- The RCAP program has been used to support the operation and enhancement of injured-diver hyperbaric treatment facilities through all DAN regions worldwide.
- RCAP provides technical, resource and educational support for remote facilities that exist to aid divers in need.
- The program is a valuable outreach enterprise that helps to ensure that all such facilities meet or exceed minimum operational and professional standards. The program is expected to expand as directed and increase extramural fundraising for these efforts.

Acknowledgments

- Support provided by DANs America, Southern Africa and Europe, International ATMO Safety Director Program Scholarship, South Miami Hyperbaric Treatment Center and Miami Mercy Hospital.

THE RELATIONSHIP OF AGE AND BODY MASS INDEX TO DOPPLER-DETECTED BUBBLE GRADES

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[1]Divers Alert Network, Durham, NC; [2]Center for Hyperbaric Medicine and Environmental Physiology, Duke University, Durham, NC;
[3]Mechanical Engineering and Material Science Department, Duke University, Durham, NC.

INTRODUCTION

The US Navy reported on 2,491 dive trials in 1985.[1] They describe profiles by time-depth intervals, dive conditions and personal characteristics. Doppler monitoring was carried out on these dives but not reported. This study analyzes the Doppler results for dives using nitrogen and helium diluents.

METHODS

Trials were experimental dives conducted in a wet pot chamber environment for the purpose of developing decompression procedures. Included in this study are decompression and no-decompression profiles using helium-oxygen (n=1,502) and nitrogen-oxygen (n=707) for which Doppler detected venous gas emboli (VGE) data were collected. Ascent rates for helium dives were 60 fpm to the first stop as well as between stops where as nitrogen dives were 30 and 60 fpm respectively. Doppler results were obtained according to the DCIEM protocol at 30-60 and 60-90 minutes post-surfacing.

We analyzed the associations of age, body mass index (BMI; kg/m^2) and breathing gas on Doppler bubble levels. Highest score for any site was converted to a binary variable for high bubble grade (HBG) defined as HBG=0 for Spencer Grades 0-II or HBG=1 for Grades III-IV. Decompression stress was represented by the conditional probability of DCS (%P_{DCS}) estimated by the U.S. Navy multi-gas exponential-linear model (LEM)[2]. The LEM calibration database included, but was not limited to, the dives we investigated. Associations of the dependent variable (HBG) with the dichotomous age and BMI (<median, >=median), breathing gas and continuous %P_{DCS} were assessed by logistic regression using a level of significance at p<0.05.

RESULTS

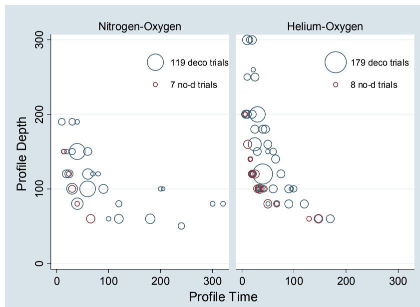

Figure 1. Frequency of dive exposures by nitrogen-oxygen and helium-oxygen breathing gases and by decompression and no-decompression profiles.

Table 1. Estimated odds ratio, p-values and 95% CI for multiple logistic regression model using dichotomous variables of age, BMI, breathing gas and continuous variable %P_{DCS}.

HBG	OR	95% Conf. Interval
%P_{DCS}	1.22	1.14 - 1.30
Age	1.48	1.24 - 1.77
BMI	2.06	1.72 - 2.47
He (vs.N_2)	1.91	1.57 - 2.33

Odds ratios indicate significance for all independent variables tested (p<0.05).

Table 2. Summary statistics for plotted values of logistic regression analysis. N_2 (n=707) and He (n=1,502) profiles.

	Inert Gas	Median	Range
Age	N_2	26	20 - 46
	He	28	20 - 44
BMI	N_2	24.7	20.4 - 32.4
	He	24.5	20.3 - 32.4
%P_{DCS}	N_2	4.3	1.7 - 7.1
	He	4.6	1.4 - 8.2

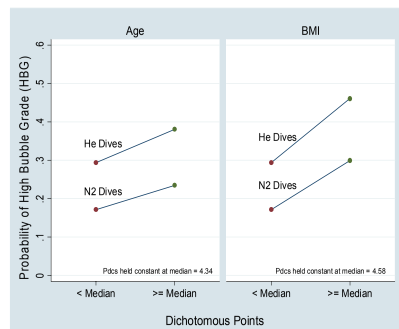

Figure 2. Probability of HBG for dichotomized variables age and BMI by breathing gas. Trials include decompression and no-decompression profiles.

DISCUSSION

There were 861 incidents of HBG in 2,215 trials (39% of exposures). Nitrogen dives had 27.7% HBG and helium 42.8%. Despite similar %P_{DCS} for helium and nitrogen dives, the probability of HBG was higher in helium dives for both age and BMI. This observed difference is unexplained but may be influenced in part by higher rates of ascent to the first stop and somewhat deeper dives for helium.

Divers with higher levels of BMI had more HBG than divers with lower levels. BMI does not discriminate fatness from muscularity. An assessment of body fat (three site skinfold measures on 78% of dataset) was included in a restricted model but found not significant. The effect of BMI on the probability of HGB is unexplained.

Older divers had more HBG than younger divers. Because measures of fat were found not significant, the effect of age on HBG may represent other changes possibly related to micro-vascular changes.

LIMITATIONS

This study takes into account neither the thermal status nor the exercise load of exposed divers.

Using skinfolds as a measure of body fat may have influenced the finding of non-significance.

CONCLUSIONS

There were significantly more HBG with helium-oxygen than with nitrogen-oxygen, and the HBG incidence increased with age and BMI.

REFERENCES

1. Thalmann, NEDU Reports 1-85 & 8-85
2. Parker, NEDU Technical Report 92-73

DIVING FATALITIES INVOLVING CHILDREN AND ADOLESCENTS: 1989-2002

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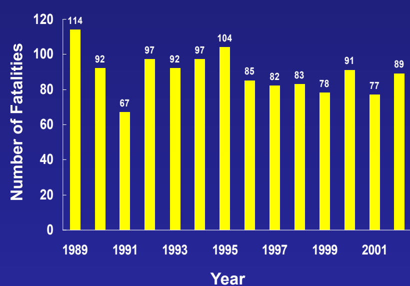
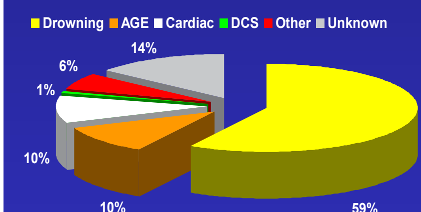
Divers Alert Network, Durham, NC

INTRODUCTION

In the past few years several dive-training organizations have made concerted efforts to attract younger individuals to recreational diving. Many dive medicine professionals feel that the younger diver may not possess the physical and emotional maturity to safely participate in recreational diving, particularly in emergency situations. The Divers Alert Network (DAN) collects and analyzes all available information on diving related fatalities and makes recommendations that promote safe diving.



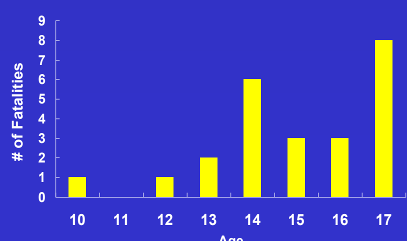
Total Fatalities

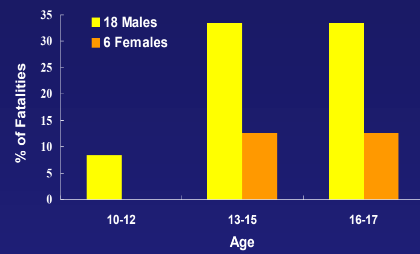


n = 1248

METHODS

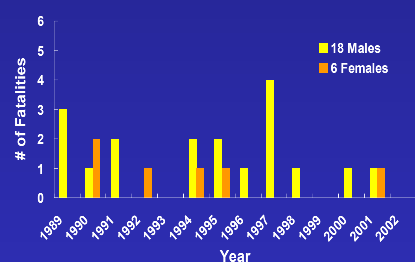
The DAN recreational diving fatality database was queried for dive fatalities involving individuals who were 17 years of age or younger at the time of death. DAN staff and a physician who is both a diving medical officer and a forensic pathologist reviewed all cases. The age of the diver, the cause and manner of death, the circumstances surrounding the dive accident, and the level of dive training and experience were examined.





RESULTS

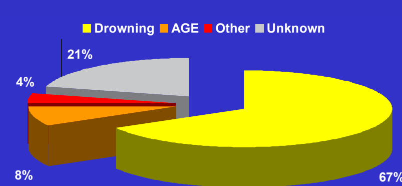
DAN collected data on 1248 diving fatalities for the years 1989-2002 inclusive. Twenty-four (1.9%) deaths involved individuals 17-years of age or younger (range 10-17). This included 18 males and 6 females. Every case was determined to be an accidental death. Drowning and/or air embolism was the cause of death in the vast majority of mishaps. Several of the young divers had no formal training; many died performing high risk (deep, altitude cave/wreck entry) dives.



CONCLUSIONS

A very small percentage of recreational diving fatalities involve individuals 17-years of age or younger. Only time will tell if increasing the number of active young divers will increase the number of fatalities in this age group. Most diving deaths are catastrophic events, but those involving younger divers result in a significant loss of productive years of life. Nearly all diving deaths involving children and adolescents are accidental in nature and theoretically totally avoidable.

Cause of Death



n = 24