ANNUAL DIVING REPORT

2007 EDITION

BASED ON 2005 DATA

DAN
DIVERS ALERT NETWORK

Annual Diving Report – 2007 Edition

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DAN works with a network of approximately 500 hyperbaric chamber facilities in the United States and around the world, of which approximately 200 provide annual reports on decompression illness (DCI) injuries. The DAN US network is divided into eight regions, each overseen by a Regional Coordinator.

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1. INTRODUCTION

1.1 The Diving Report

The DAN Annual Diving Report presents information on diving activity and incidents collected by DAN. The reports from 2001 forward are now available for download at no charge to all who are interested. It is our hope that the material provided can help to improve awareness of possible hazards and promote diving safety.

The data described in the 2007 report primarily reflect events occurring in 2005. This includes Section 2 (Project Dive Exploration [PDE]), Section 4 (Dive Fatalities), and Section 5 (Breath-Hold Dive Incidents). The exception is Section 3 (Dive Injuries), which presents data logged into the new Medical Services Call Center (MSCC) from April through December, 2006.

Case summaries are a popular tool in reviewing operational practice. Thumbnail reviews are available for dive injuries (Appendix 1), dive fatalities (Appendix 2), and breath-hold incidents (Appendix 3). A review of the sources of PDE data is found in Appendix D.

A list of publications authored or co-authored by DAN staff and affiliated investigators appears in Appendix E. Publications include peer-reviewed research reports (primary literature), book chapter reviews, research summaries presented at scientific meetings (abstracts), papers published in documents produced from scientific meetings (proceedings) and non-peer-reviewed articles (lay literature). Addressing as many levels as possible is an important strategy to communicate important messages regarding diving safety. Recent efforts to develop web-based training materials are also listed. Web-based training is likely to increase in importance as a tool for continuing education as well as to prepare individuals before they begin hands-on training programs. Further information on the DAN web-based programs can be found at http://www.diversalertnetwork.org/training/seminars/index.asp.

A glossary of terms used in this report is located in Appendix F.

1.2 Data Collection since DAN's Inception

The data discussed in this report can provide a good snapshot of events occurring in the recreational diving community, but it does not represent the complete range of activity or incidents associated with diving. The report includes only data made available to DAN and, in most cases, only data that can be followed up with a manageable effort. The majority of sections, therefore, are limited to residents or citizens of the United States or Canada. The exception to this is the breath-hold incident database which currently captures cases from wherever they are identified worldwide. As an initiative started in 2005, it was felt to be appropriate to start with a wide net to develop the program. Difficulties in collecting additional data from international cases may prompt a shift in focus or a strengthening of international collaborations in the future.

Figure 1.2-1 is the annual record of emergency calls, information calls and e-mail requests for information to DAN Medical Services since DAN started in 1981. Emergency calls and e-mail inquiries continue to rise gradually, slowly overtaking calls to the information line as the primary form of contact.

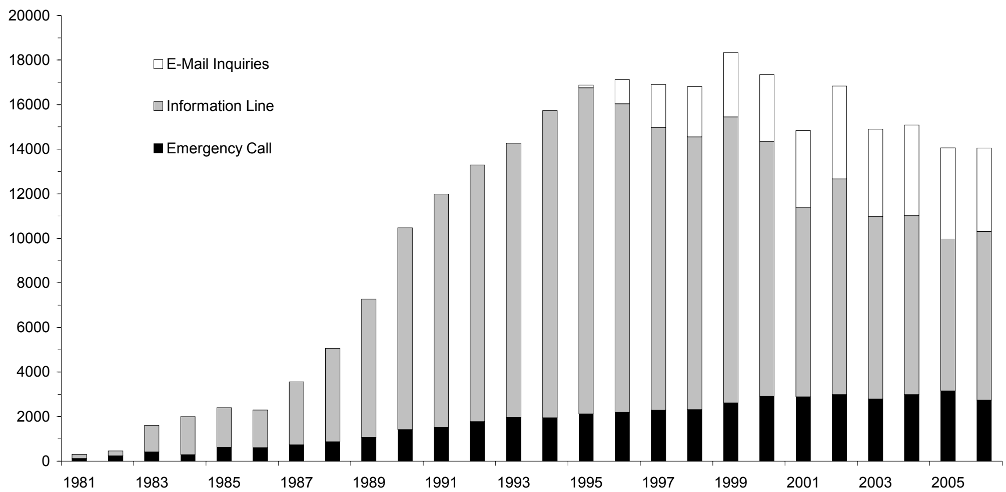

Figure 1.2-1 Emergency calls, information calls and e-mail requests for information

PDE is a prospective observational study of recreational diving dating from 1995, and Figure 1.2-2 is the cumulative history of PDE data collection. By the end of 2006, more than 11,000 divers had contributed data, a total of more than 137,000 individual dives. The overall rate of DCI in this sample is a little less than 3.1 cases per 10,000 dives, down from 3.6 cases per 10,000 dives reported in the last report (Vann et al., 2006). Details on the data available through 2005 are found in Section 2.

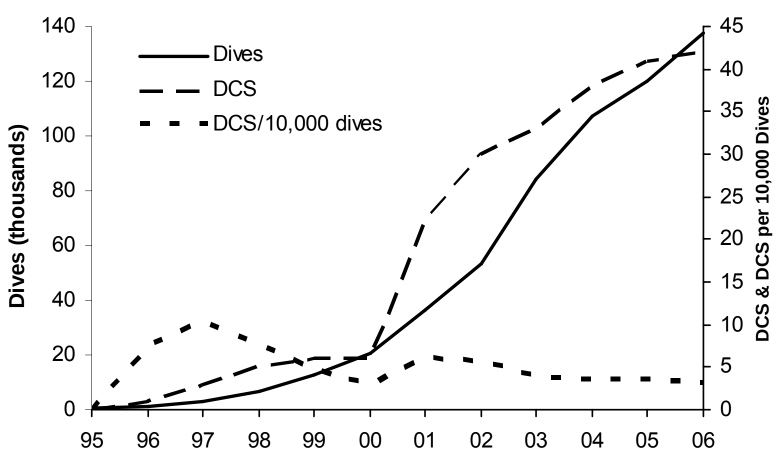

Figure 1.2-2 Cumulative Project Dive Exploration progress

Figure 1.2-3 is the annual record of US and Canadian diving fatalities that was started in 1970 by Mr. John McAniff of the University of Rhode Island and transitioned to DAN in 1989. The number of US and Canadian fatalities recorded annually has varied substantially from year to year. The annual count has been fairly stable in recent years, lower than the overall mean ± standard deviation of 98±21 (range 66-147), but still much higher than we would like to see.

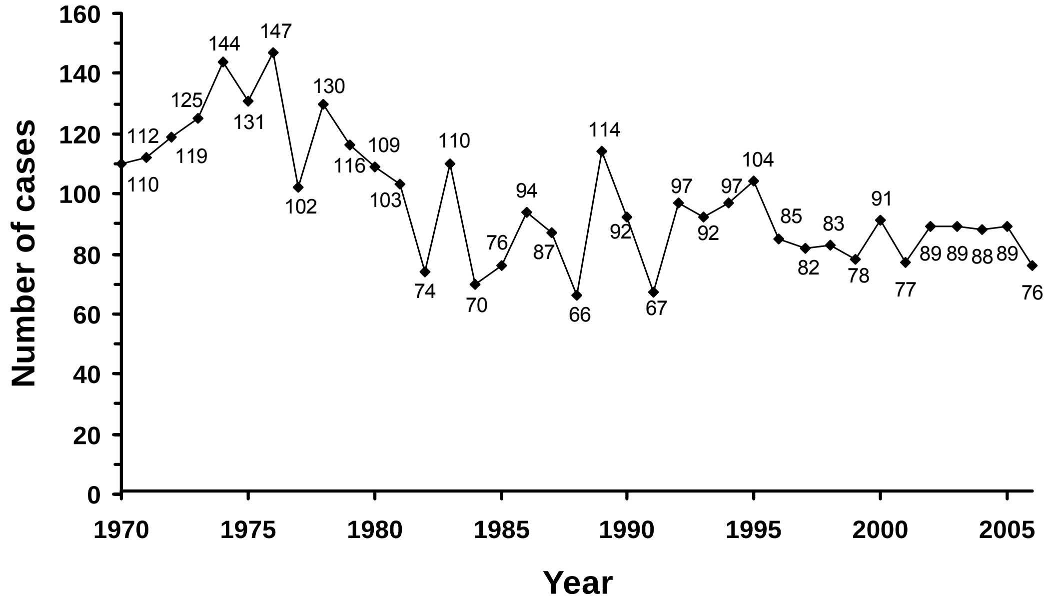

Figure 1.2-3 Annual record of U.S. and Canadian diving fatalities

The 2005 Report introduced a section on fatal and non-fatal breath-hold diving incidents that occurred anywhere in the world. These cases are distinct from the diving accidents described in Figure 1.2-3. Figure 1.2-4 represents the breath-hold cases recorded at DAN since 1993. The low numbers in the early years reflect the fact that these data were not actively sought. The visible increase seen in 1997 likely reflects improved accessibility to reports available through the Internet. The initial identification of cases is now facilitated by automatic keyword searches. The challenge remains in capturing details beyond the initial reports. One of the initiatives under way at DAN is the development of an online system to collect data on both fatal and non-fatal cases. We expect that the availability of this system will dramatically increase the number of cases identified, particularly for non-fatal events that might not otherwise be reported.

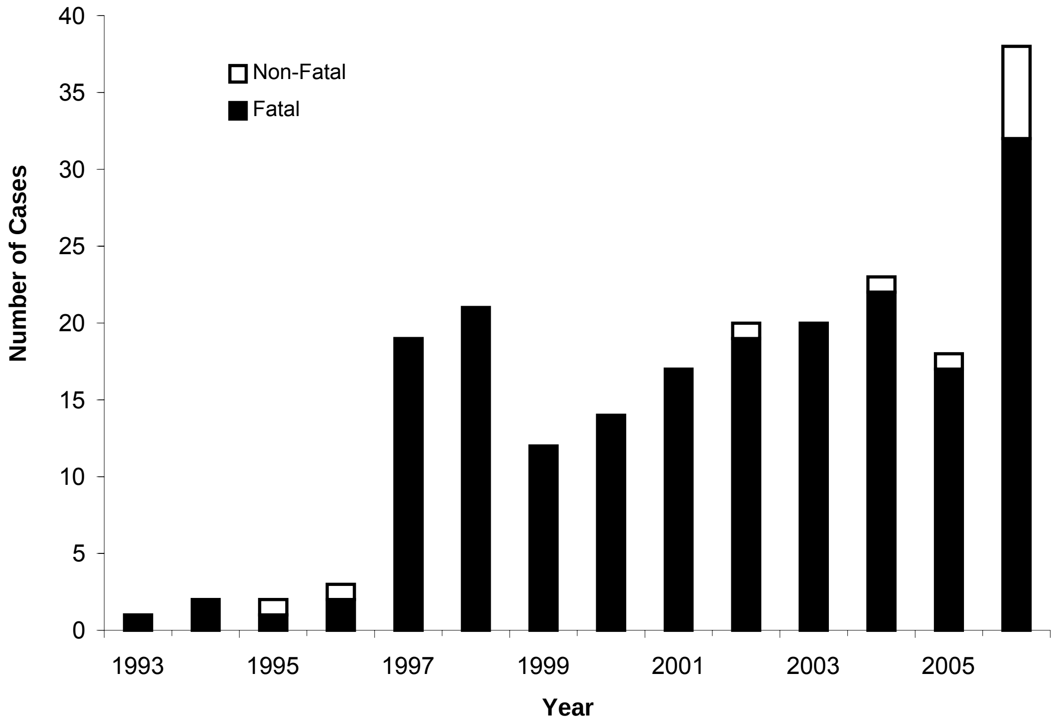

Figure 1.2-4 Annual record of breath-hold diving incidents

1.3 The Diver's Responsibility

Diving can provide a flexible foundation for a lifetime of enjoyment. The choice of environment, equipment and purpose create a range of opportunities to explore. It is the responsibility of the diver to ensure that he or she is ready for whatever diving is to be undertaken. This requires the maintenance of medical, physical and psychological fitness, knowledge and physical competence (Bennett et al., 2006). Since many of these elements can change over time, either acutely or chronically, it is important to re-evaluate readiness before every dive. Periodic medical evaluation and regular physical exercise can assist in the physical preparedness, and appropriate initial and continuing training and education can take care of knowledge and physical competence issues.

The initial evaluation for psychological fitness is part of medical clearance to dive. Maturity and sound judgment are critical. A common hazard in diving can be created when an individual is encouraged to dive by someone else who may be more enthusiastic, comfortable or capable. It is critical for each person to appreciate his or her strengths and limitations and choose accordingly when and where to participate. Respecting personal comfort limits, using appropriate equipment, establishing the availability of the right backup equipment and support, and then honestly appraising the actual conditions - of both divers and environment - before the planned dive are the final elements to help ensure problem-free activity.

The last two paragraphs cover a lot of ground. The diving enthusiast will commit a great deal of time mastering the physics, physiology, equipment and environment to be ready to go. Reading material like this annual diving report can also be extremely helpful. We learn a great deal through our mistakes, but we can also save ourselves from a lot of stress if we learn from the mistakes of others. Most situations that end badly are the result of a chain of events, a chain that can often easily be broken at several points during its development. Learning to recognize errors and patterns that can escalate into true emergent events is one of the most effective ways to ensure that unmanageable conditions do not arise. The tally of incidents described in this report should remind you that accidents can occur, and that they sometimes occur when least expected.

The most important form of readiness will often be flexibility, both mental and physical. We can memorize rules and practice skills until our responses are automatic, but there is always the chance that some surprise, small or large, will put us off balance. Case summaries can be a powerful tool by providing an opportunity to safely place you into a wide array of situations. The scenario can stimulate the important 'What if?' thoughts that can help you to critically evaluate your equipment, practices and decision making ability.

1.4 Personal Fitness Monitoring

Surprisingly little is known of the physical fitness of the typical recreational diver (Pollock, 2007). The major challenge is finding simple measures to generate a comprehensive picture with limited face-to-face contact. Many readers will be familiar with body mass index (BMI), a measure frequently used as a predictor of body composition. BMI is based on the relationship between height and weight, and as such, may not be a good predictor of body composition. Individuals with a disproportionate amount of muscle mass are penalized. Practially, however, BMI is a reasonable tool to assess trends on a population scale, when increases are more likely associated with increasing body fat than with increasing muscle mass.

Regular readers of the annual diving report may notice an increased presence of BMI values in the case data. Data gathered by DAN in recent years indicate that high BMI values are common in persons involved in incidents. The measures are included where available to allow further evaluation of this trend. As a point of personal awareness, BMI is a reasonable benchmark to monitor. Tracking your own score can help you keep your personal fitness efforts focused. Calculating your waist-to-hip ratio (WHR) will help to determine whether or not BMI is a good predictor for you. WHR is computed from the circumferences of your waist at the narrowest point and your hips at the widest point. Dividing the waist measure by the hip measure yields the ratio. Optimal target scores are ≤0.8 for men and ≤0.7 for women. Persons with relatively high BMI values and relatively low WHR values often have disproportionate amounts of muscle tissue, which also increases BMI, but in a good way.

1.5 References

Bennett PB, Cronje FJ, Campbell E, (with Marroni A, Pollock NW). Assessment of Diving Medical Fitness for Scuba Divers and Instructors. Best Publishing: Flagstaff, AZ. 2006; 241 pp.

Pollock NW. Aerobic fitness and underwater diving. Diving Hyperb Med. 2007; 37(3): 118-124.

Vann RD, Freiberger JJ, Caruso JL, Denoble PJ, Pollock NW, Uguccioni DM, Dovenbarger JA, Nord DA, McCafferty MC. Annual Diving Report: 2006 Edition. Divers Alert Network: Durham, NC, 2006; 99 pp.

2. PROJECT DIVE EXPLORATION

2.1 PDE in 2004

The reader is referred to the 2005 edition of the DAN Annual Diving Report for PDE objectives and methodology (Vann et al., 2005). During 2005, PDE collected data from 1,181 divers, 3,062 dive series and 15,056 dives. The total number of dives logged by PDE through 2005 is 122,071. Figure 2.1-1 shows cumulative data collection from 1995-2005. A summary of PDE data collected by DAN interns and independent field research coordinators (FRCs) is found in Appendix D.

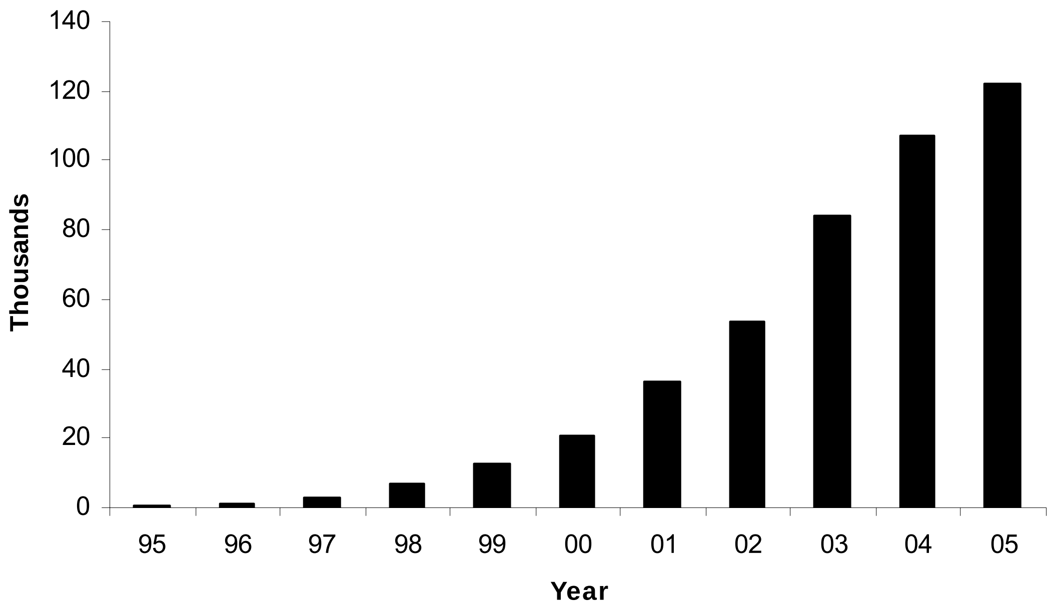

Figure 2.1-1 Cumulative number of PDE dives collected from 1995-2005 (n=122,071)

Table 2.2-1 shows dives in the groups who contributed PDE data from 2002-2005. DAN Interns collected the largest amount of data. The participation of Independent Divers has increased and they have become the second leading group in contributing dive data. The decrease in dives submitted by Liveaboard Collection Centers was due to a reduction of nearly 10,000 dives from Nekton Cruise boats. The contribution of the Recreational Dive Professionals decreased due to adverse weather in the Caribbean during 2005.

Table 2.1-1 Sources of PDE data

Source	2002	2003	2004	2005
DAN Interns	4,878	6,449	3,939	5,545*
Independent Divers	1,511	2,400	3,348	4,488
Liveaboard Collection Centers	6,593	13,046	12,040	2,874
Scapa Flow, Scotland	2,795	2,476	2,412	2,001
Recreational Dive Professionals (RDP)	1,283	2,396	2,173	150
Total	17,060	26,767	23,912	15,043

* 350 dives were from Scapa Flow

More dive logs were submitted directly to DAN by independent divers via the Internet using Cochran, DiveRite, Uwatec, and Suunto computers thanks to manufacturers who provided PDE-compatible dive computers. Check DAN website to learn more how you can contribute:

http://www.diversalertnetwork.org/research/projects/pde/index.asp

2.2 Divers

This section presents information about PDE divers including age, gender, certification, years since certification, and chronic and acute medical conditions. While 1,180 participants in PDE were volunteers from the general recreational diving population, they were not necessarily representative of this population. Most were 30 to 50 years of age and 31% were female (Figure 2.2-1). Twenty-seven percent were over age 50, which is an increase of five percent over the previous year.

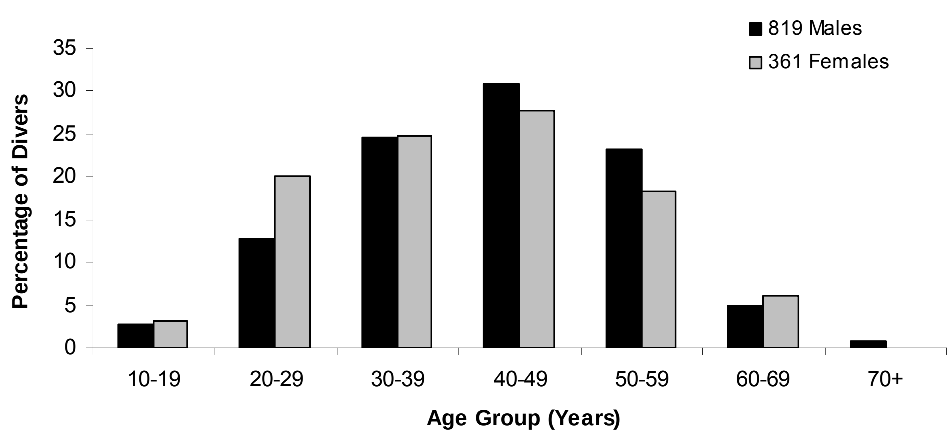

Figure 2.2-1 Age and gender of PDE divers (n=1,180)

Fifty-seven percent of divers held 'recreational' certifications (Open Water, Advanced Open Water, Specialty or Rescue). Twenty-one percent held leadership certification (Divemaster or Instructor) while only three percent held Cave or Technical certification. Seventeen percent of participants were student divers (Figure 2.2-2) and contributed eight percent of all dives.

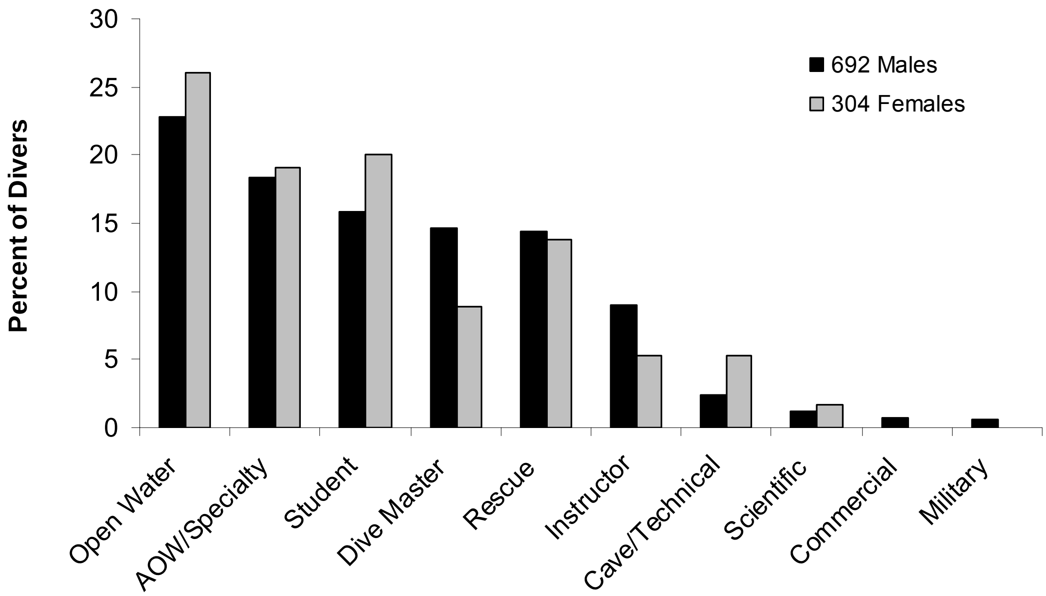

Figure 2.2-2 Percentage of 2005 PDE volunteers by certification of divers and gender (n=996)

Thirty-four percent were within five years of certification. This group has declined in size from about 42% since 1998 and 36% in 2004 (Table 2.2-1). Divers with more than 10 years since certification increased from about 26% in earlier years to 38% in 2004 and 40% in 2005 reflecting aging of the general diving population as seen elsewhere.

Table 2.2-1 Percentage of PDE volunteers by number of years since certification

Years of Diving	1998	1999	2000	2001	2002	2003	2004	2005
1	19.3	16.4	17.9	15.5	15.6	10.7	11.9	4.5
2	4.8	7.1	9.8	6.4	6.4	8.6	6.2	6.9
3	7.8	7.9	7.1	10.9	7.1	5.9	8.4	7.1
4	6.0	7.9	6.3	6.0	6.6	4.4	7.1	7.8
5	4.4	3.5	5.4	3.8	5.1	6.7	5.4	8.2
6-10	25.3	23.7	21	19.4	18.4	20.5	23.4	25.4
> 10	26.7	26.2	29.3	26.3	30.1	35.6	37.6	40.2

Allergy, high blood pressure, and ear or sinus problems (six to 16%) were the most common chronic health conditions (Figure 2.2-3) as in previous years. Less common conditions (two to three percent) included asthma, heart disease, previous DCI, and diabetes.

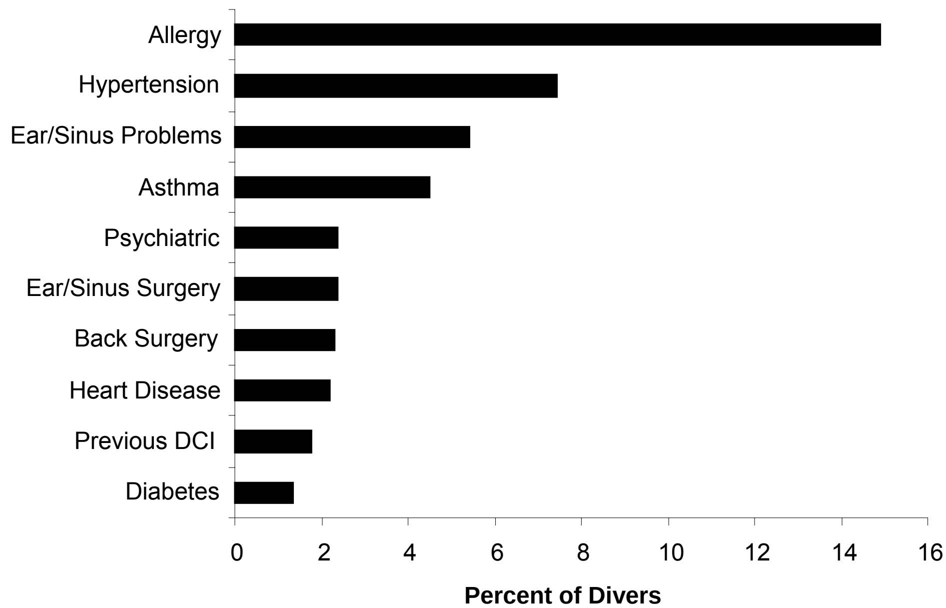

Figure 2.2-3 Chronic health conditions reported by PDE volunteers (n=1,180). Acute health conditions that were reported (Figure 2.2-4) included seasickness (10% of divers) and orthopedic problems (joint and muscle pain, back pain, injuries – nine percent). Common cold-like conditions were reported by less than two percent, but use of decongestants was reported by seven percent of divers reflecting, possibly, a preventive use of decongestants.

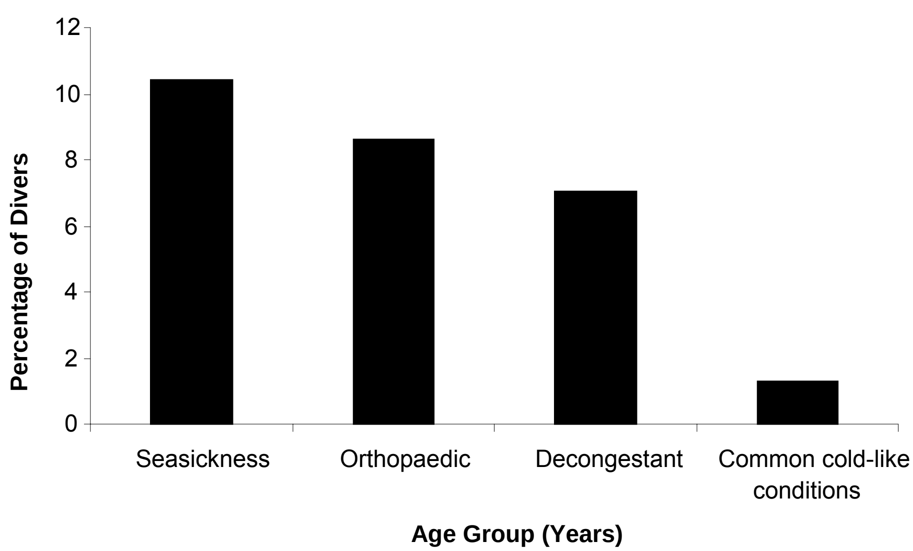

Figure 2.2-4 Acute health problems before diving reported by PDE divers (n=1,180)

2.3 Dive Conditions

This section reviews the diving environment, dive platform, breathing apparatus, reasons for diving, thermal protection, subjective thermal comfort, and subjective work rate.

Ninety-three percent of PDE dives were collected in saltwater while a little over two percent came from freshwater and only a half percent of dives (74 dives) were in caves or caverns. Two-thirds of the dives were from day-boats (small) and 21% from liveaboard boats (Figure 2.3-1). In previous years liveaboards usually contributed two-thirds of all collected dives. Ninety-eight percent of the dives used open-circuit breathing apparatus, rebreathers in 1.2%, and surface-supplied in 0.02%. Eighty-six percent reported sightseeing as the purpose of the dive. Activities were described as student-related in eight percent of the total. Miscellaneous activities including photography, proficiency, spearfishing, or non-professional work were declared in fewer than one percent of the cases.

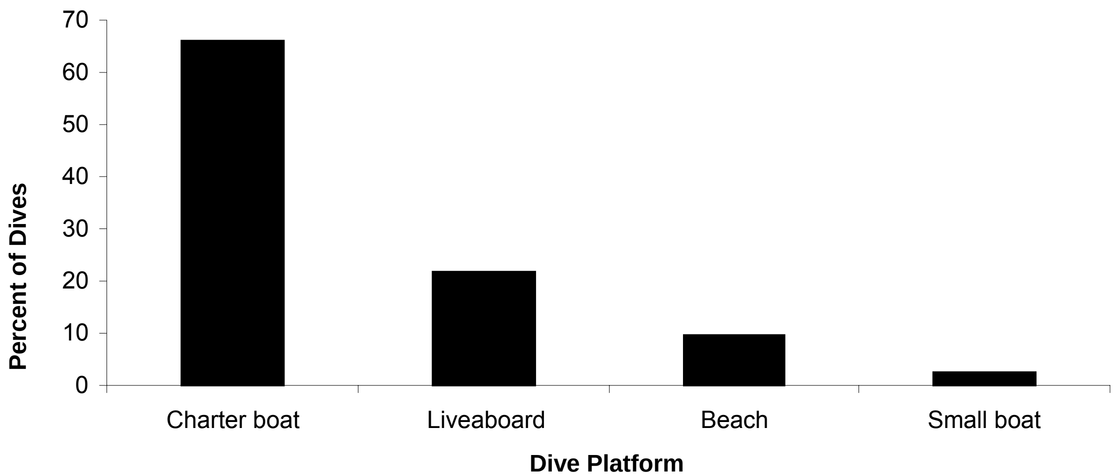

Figure 2.3-1 Percentage of the PDE dives by dive platform (n=14,828)

Thermal protection depended on the geographic area. Sixty-five percent used wetsuits, 15% drysuits, and the remaining 20% lycra, diveskin or swimsuit. Most divers indicated they were comfortably warm (Figure 2.3-2). Scapa Flow divers reported being cold on 20% of dives and hot on 17%, whereas the other dive groups were generally more comfortable (Table 2.3-1).

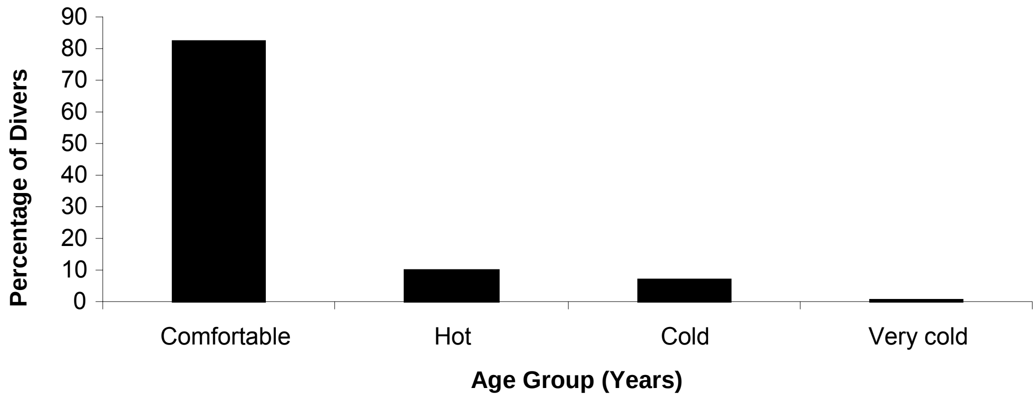

Figure 2.3-2 Subjective thermal comfort of PDE divers (n=12,878)

Table 2.3-1 Reported thermal comfort in PDE dive groups (n=15,043)

Thermal Comfort	Dive Group (%)			
	Liveaboard	Day boat	Scapa Flow	Beach
Hot	12	9	17	2
Comfortable	80	86	60	90
Cold	6	4	21	4
Very cold	0	0	1	1
Not reported	1	1	<1%	3

More than 84% of PDE divers reported doing light work and 16% reported moderate or heavy work (Figure 2.3-3). Scapa Flow divers reported moderate or heavy work more often than did the other divers (Fisher Exact p<0.001) (Table 2.3-2).

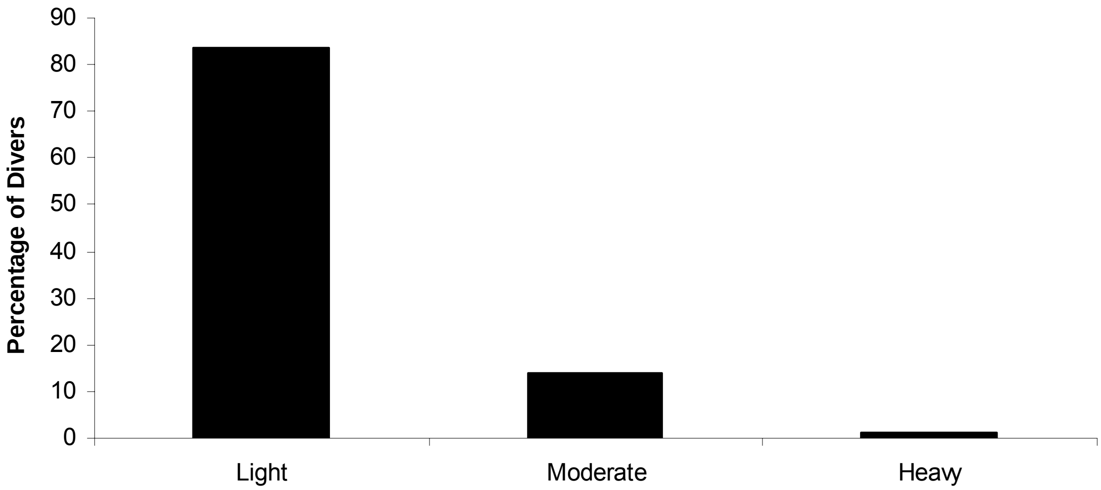

Figure 2.3-3 Percentage of the PDE sample reporting the indicated subjective workload (n=12,835)

Table 2.3-2 Reported work rate in PDE subgroups (n=12,829)

	Group (%)			
Work Rate	Liveaboard	Day boat	Scapa Flow	Beach
Light	86	85	74	94
Moderate	12	14	24	6
Heavy	2	1	1	<1

2.4 Dive Profiles

Section 2.4 describes the breathing gases, repetitive dive status, number of days in the dive series, number of dives in the series, maximum dive depths, deepest and last dives in the series, maximum depth for each day of multiday series, dive planning methods, decompression stops, and altitude exposure.

The breathing gas was reported as air in 65% of PDE dives, nitrox (a nitrogen-oxygen mix with greater than 21% oxygen) in 33%, and a mix containing helium in two percent. Forty-six percent of the dive series were multiday, 27% were single-day repetitive, and 27% were single dives (Figure 2.4-1).

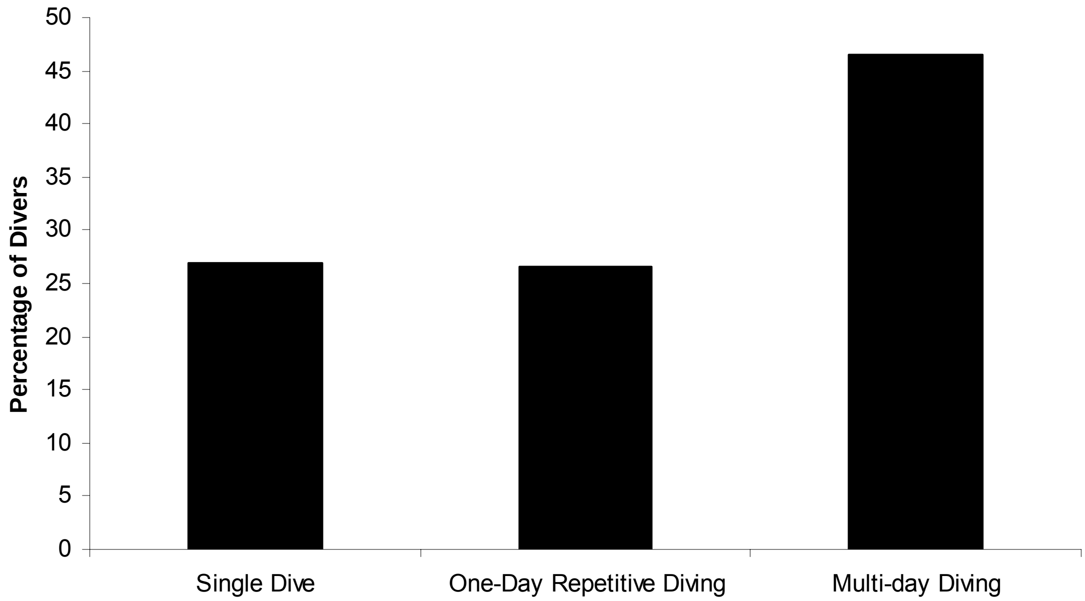

Figure 2.4-1 Single, repetitive, and multiday PDE dives (n=3,056)

Fewer multiday dive series and more single dives and one day diving may be a consequence of decreased number of liveaboard dives and an increased number of students. Fifty-three percent of all dives occurred in one day-dive series (Figure 2.4-2). Similarly, the number of dives in the series decreased in comparison to previous years (Figure 2.4-3).

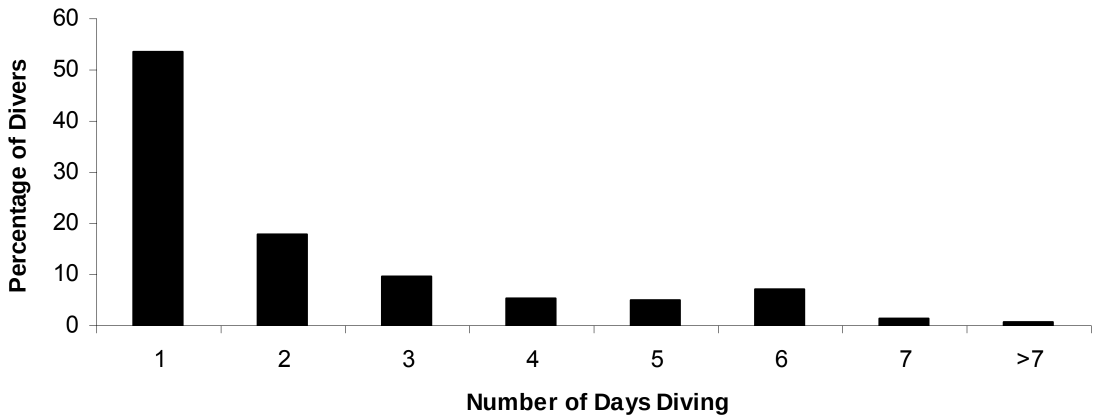

Figure 2.4-2 Number of days in PDE dive series (n=3,056)

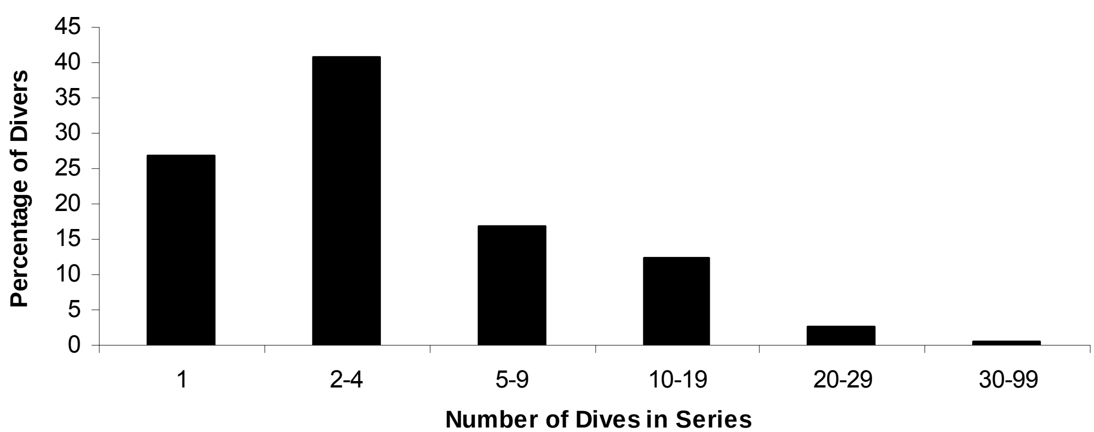

Figure 2.4-3 Number of dives in PDE dive series (n=3,056)

Twenty-eight percent of the dives were deeper than 90 fsw (27 msw) (Figure 2.4-4) compared to 20% in 2004, and the last dives of the series were to lesser depths than the deepest dives (Figure 2.4-5).

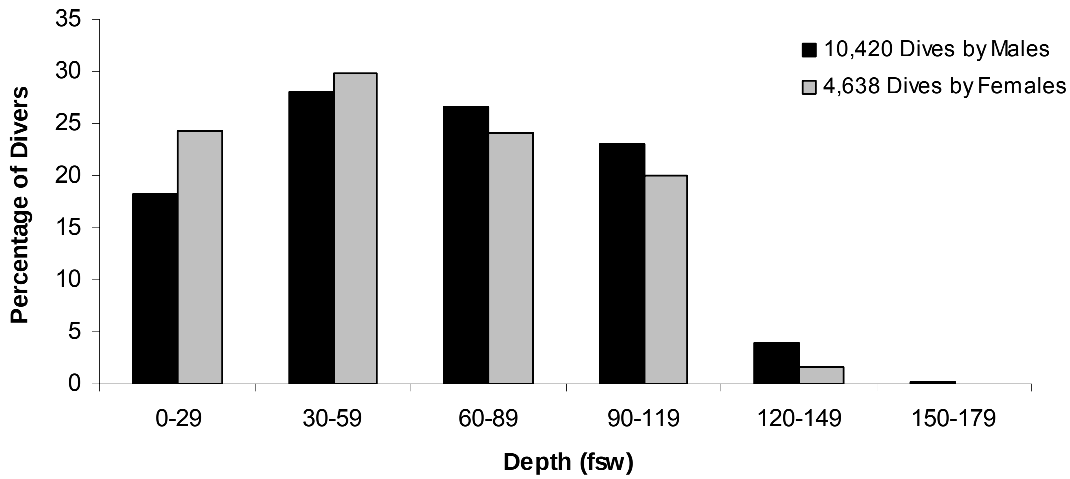

Figure 2.4-4 Maximum depths of PDE dives (n=15,039)

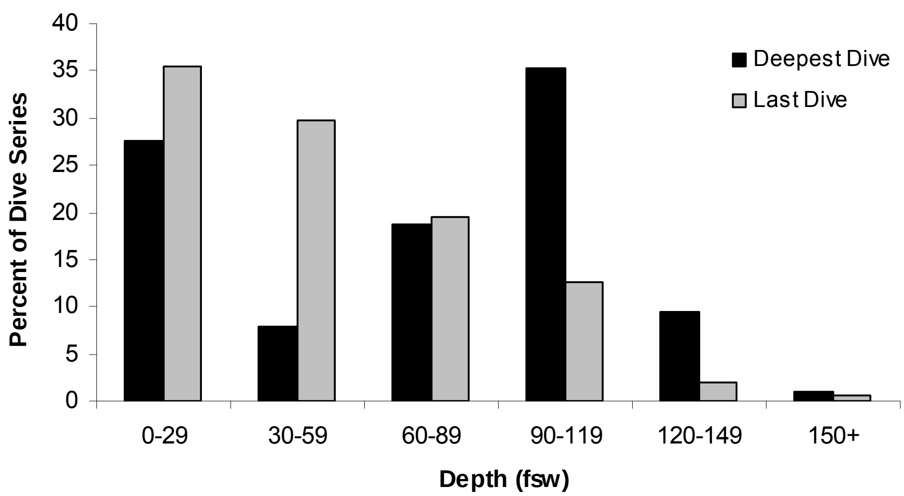

Figure 2.4-5 Depth of deepest and last dive in PDE dive series (n=3,056)

The dive depth decreased with each dive in a repetitive dive series (Figure 2.4-6).

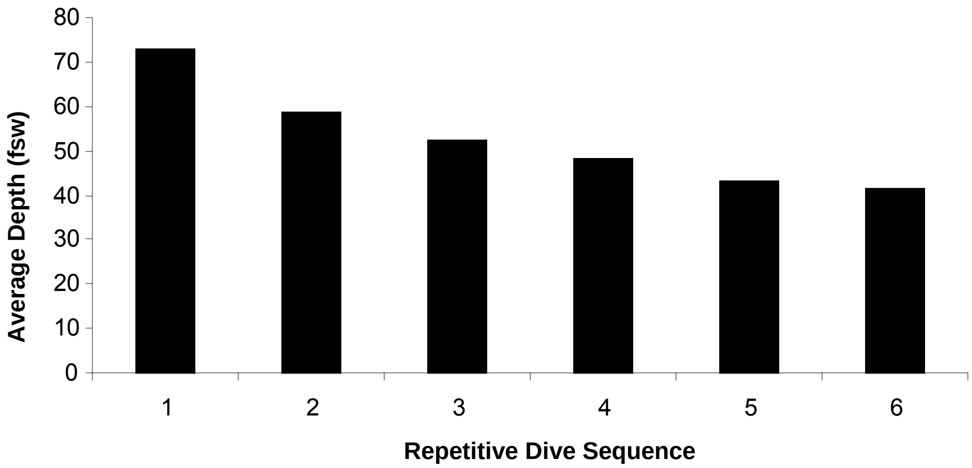

Figure 2.4-6 Dive depth by repetitive dive sequence in PDE dive series (n=14,966)

Scapa Flow dives and dayboat dives were deeper than liveaboard and beach dives (Figure 2.4-7)

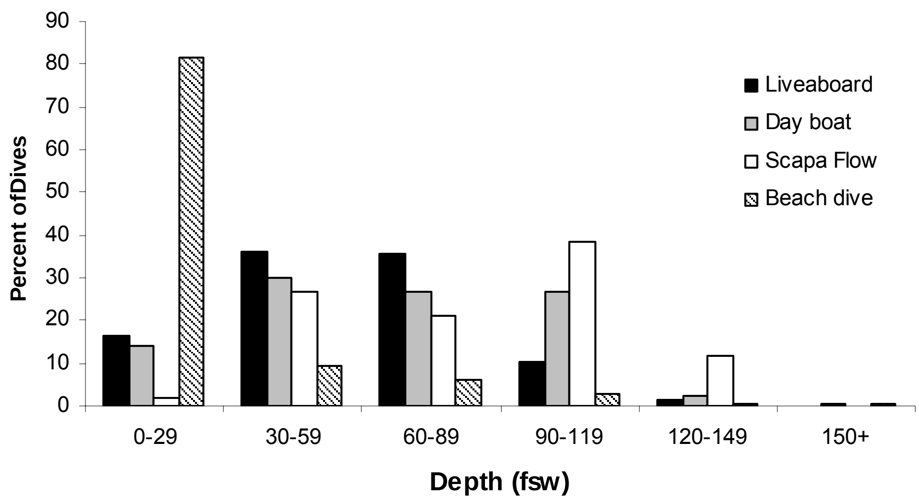

Figure 2.4-7 Distribution of dive depths among PDE subgroups

Dive computers were used for 79% of the PDE dives. Thirteen percent reported using tables and eight percent followed somebody else (Figure 2.4-8). An increase in the reported use of tables may be due to increased number of student participants.

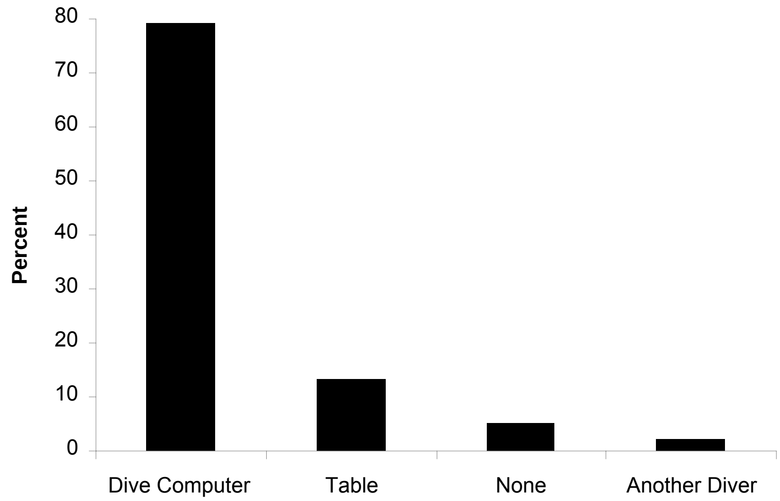

Figure 2.4-8 Number of PDE dives by dive planning method (n=15,046)

Fifty-three percent of PDE divers reported flying after diving (Figure 2.4-10). Nine percent participants did not return 48-hour reports. The improvement in reporting was achieved due to increased self-reporting (individual divers using electronic dive log with an explicit field to report flying after diving) and interns who were able to follow up with their divers.

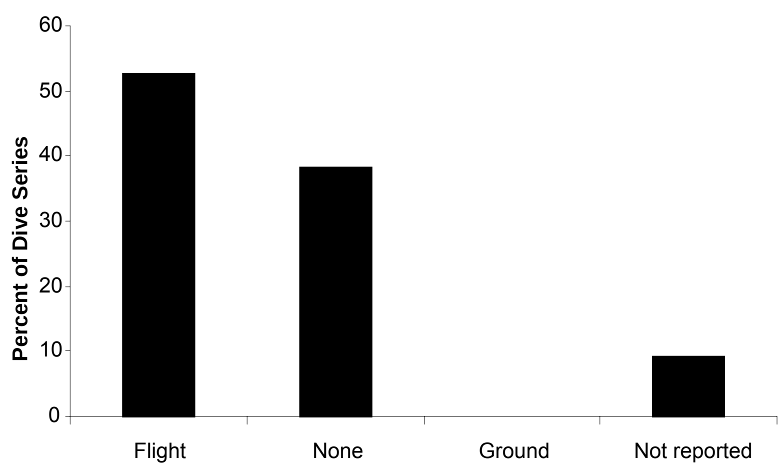

Figure 2.4-10 Percentage of PDE divers reporting altitude exposure after diving (n=3,062)

2.5 Dive Outcomes

Because there are no certain methods of diagnosing decompression illness (DCI, which includes AGE and DCS), we offer operational definitions for six possible outcomes of the PDE dives. The outcomes were based on reports by PDE volunteers of events, symptoms, and signs in daily logs or in the 48-Hour Report. Reports that were potentially decompression related were followed up with the diver or recompression facility. As a measure of decompression stress, the DCS probability (P_{DCS}) was estimated from the dive profile based on the method described by Gerth and Vann (1997).

Definitions of the six possible outcome categories were:

Uneventful

Events, signs, or symptoms were denied.

Incident

Incidents include procedural problems or equipment problems that did not result in major harm. Equalization problems are included here, such as temporary ear pain or discomfort. These were not reported as injuries. Potentially hazardous procedural or equipment events were reported but signs or symptoms were not reported.

Non-DCI Injury or Symptoms

These included injuries, signs, or symptoms unlikely to be DCI upon review of medical history.
Pulmonary barotrauma (pneumothorax, mediastinal emphysema, subcutaneous emphysema) in the absence of neurological or cardiopulmonary signs or symptoms.
Headache in the absence of other signs or symptoms described by the Perceived Severity Index (PSI, see page 48 in the 2005 edition of the DAN Diving Report).
Seasickness and transient vertigo.
Injuries, signs, or symptoms not attributable to AGE after a single dive to less than 30 fsw (10 msw).
Sign or symptom onset times longer than 24 h after the last dive or altitude exposure.

Ambiguous

Applied if any of the following criteria were present:
Insufficient exposure (single dive to less than 30 fsw [10 msw]).
Signs or symptoms that could be ascribed to a non-DCI cause.
Confounding medical conditions that could explain the symptoms.
Spontaneous symptom resolution after less than 20 minutes with surface oxygen or less than 60 minutes without oxygen.
Inadequate information.

Arterial Gas Embolism (AGE)

Applied if all three criteria were present:
Symptom onset time of less than 15 minutes post-dive.
Presence of cerebral neurological signs, symptoms, or findings.
Symptom duration greater than 15 minutes.

Rapid ascent, out-of-gas, cardiopulmonary symptoms, pneumothorax, or mediastinal or subcutaneous emphysema increase the confidence of an AGE diagnosis.

Decompression Sickness (DCS)

Onset of signs or symptoms within 24 h of diving or altitude exposure after diving.
Signs or symptoms in accordance with PSI categories.
Type I DCS (DCS I) included PSIs of Pain, Skin/Lymphatic, Constitutional/Non-Specific.
Type II DCS (DCS II) included PSIs of Serious Neurological, Cardiopulmonary, Mild Neurological.
Other PSIs could also be present.

Table 2.5-1. Summary of outcomes

Outcome		# of Dives
Uneventful Dives		14,197
Incidents		846
Non-DCI Symptoms		87
Ambiguous		3
	DCS I	3
DCI	DCS II	1
	AGE	0

2.5.1 Incidents

PDE divers reported 95% of their dives to be uneventful. Incidents (procedural and equipment) were reported in five percent (Figure 2.5.1-1 and Table 2.5.1-1). The most common procedural problems were related to buoyancy at 0.8% followed by 32 cases of rapid ascent (0.25%), 21 cases out of air (0.2%), eight cases of shared air and seven cases of missed decompression.

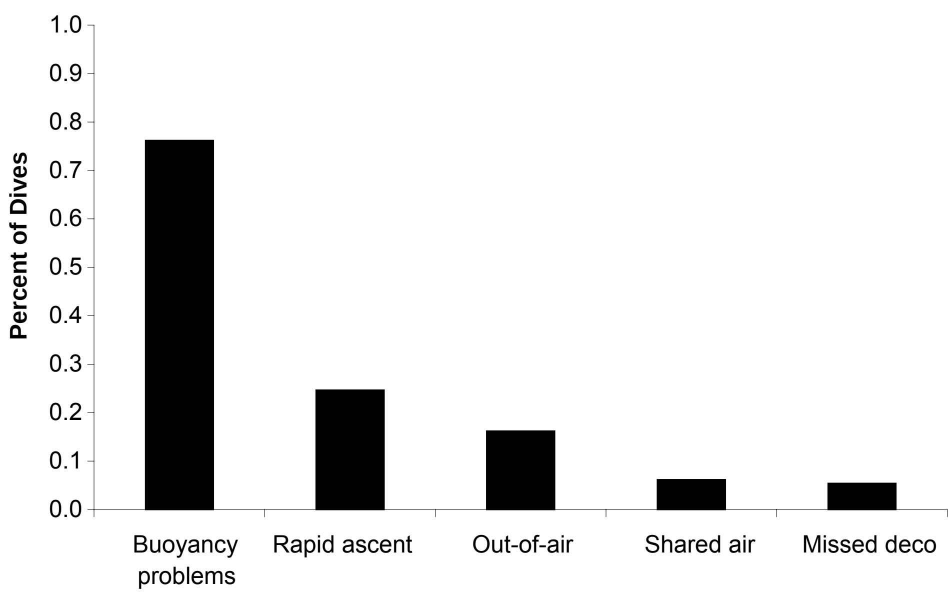

Figure 2.5.1-1 Percent of PDE dives with reported procedural problems (n=15,056)

Table 2.5.1.3-1 summarizes the PDE dives with reported equipment problems. There were a total of 345 dives (2.3% of all dives) with reported equipment problems. The face mask was the most common equipment problem (0.89% of all dives) followed by thermal protection (0.35%). The following incidents were of note. None were associated with injury.

- Low pressure hose blew off on ascent within five fsw (two msw) of the surface.
- Caught in monofilament line upon reaching bottom. Had to cut it off.
- Snagged on rope of a large fishing net upon reaching the bottom. Buddy cleared the rope then became entangled in monofilament line.
- Oxygen supply ran out during a rebreather dive. Bailout regulator malfunctioned. Used buddy's octopus regulator until he fixed his own regulator and breathed on his bailout trimix.
- O-ring failure on descent.
- Regulator free-flow.
- Valve o-ring problem ended dive early.

Table 2.5.1-1 Percent of PDE dives with reported equipment problems

Equipment Problem	Frequency	Percent
Mask	115	0.89
Thermal protection	45	0.35
Fins	38	0.29
BC	29	0.22
Regulator	28	0.22
Computer	22	0.17
Weight belt	20	0.15
Breathing apparatus	20	0.15
Decompression reel	9	0.07
Mouthpiece	8	0.06
Pressure gauge	4	0.03
Depth gauge	3	0.02
Valve	2	0.02
Other	31	0.24

2.5.1.1 Rapid Ascent

Among 32 cases with reported rapid ascent, we discuss three cases reported by divers at Scapa Flow.

Case 1

A female diver made eight dives in seven days. The profile for the last two days appears in Figure 2.5.1-1. On her last dive, she reported she was "sucked into a wreck" after which she put up a deco bag, lost one fin, became tangled in the line, and made an uncontrolled ascent at 90 fsw·min^{-1} (27 msw·min^{-1}) for the last 30 fsw (9 msw). She reported no symptoms.

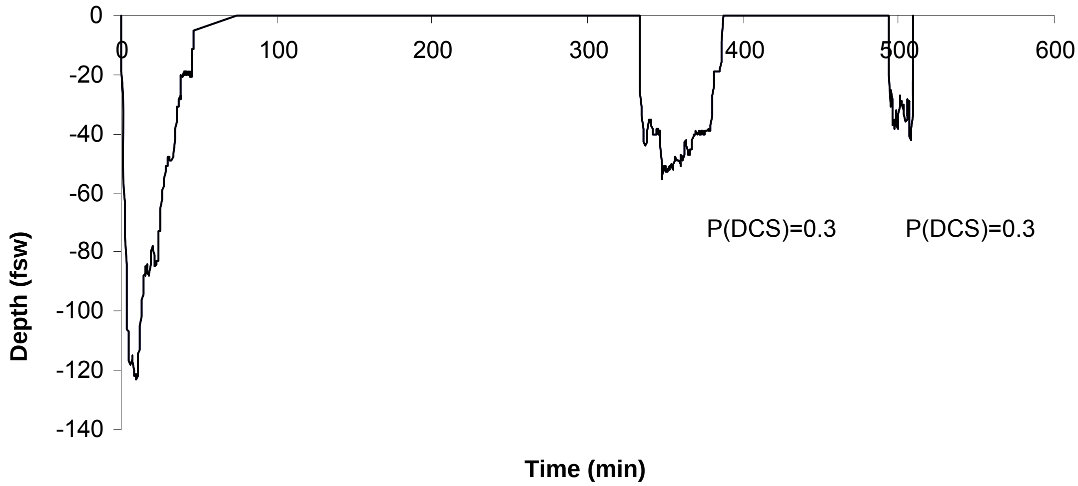

Figure 2.5.1.1-1. Diver was "sucked" into a wreck on the last dive, lost one fin, was tangled in the decompression buoy line and ascended at 90 fsw·min^{-1} (27 msw·min^{-1}). No symptoms were reported.

Case 2

On his third day of wreck diving while venting air from his drysuit, a diver developed a mask squeeze using an unfamiliar mask and made a rapid ascent at 150 fsw·min^{-1} (46 msw·min^{-1}) from 39 fsw (13 msw) (Figure 2.5.1-2). When back on board, he felt sick and breathed oxygen for 20-30 minutes. He resumed diving the next day without further incident.

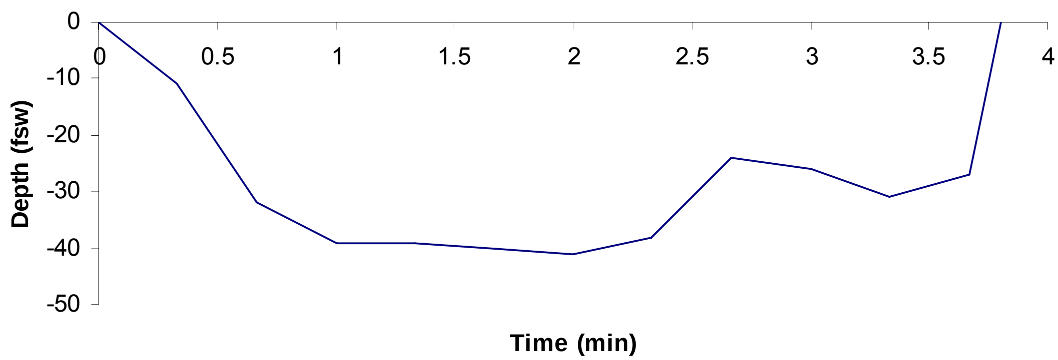

Figure 2.5.1.1-2 Rapid ascent at 150 fsw·min^{-1} (46 msw·min^{-1}). No symptoms.

Case 3

On the second dive of the third day, a diver using a closed-circuit rebreather was at a 75 fsw (23 msw) decompression stop with 11 minutes remaining when his decompression reel became tangled and he was pulled to the surface. He freed himself and returned to 46 fsw (16 msw) for 16 minutes and ascended to 12 fsw (4.5 msw) for nine minutes with an oxygen setpoint raised to 1.6 atm. The ascent and descent occurred too quickly to be recorded by the dive computer. No symptoms were reported.

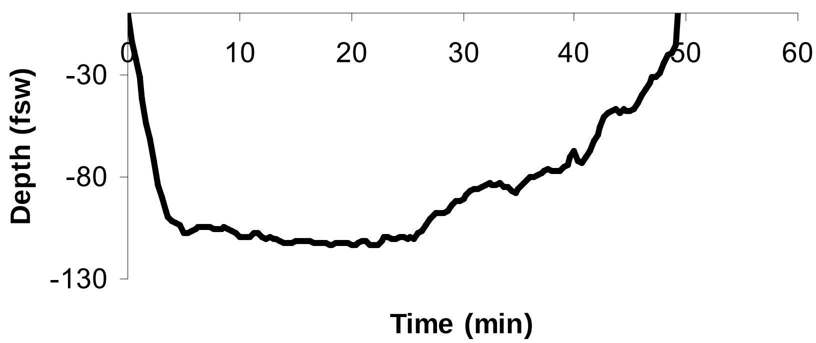

Figure 2.5.1.1-3 Rapid ascent from a decompression stop. No symptoms reported.

2.5.1.2 Omitted Decompression

Five Scapa Flow divers were transported to hyperbaric chambers for omitting 12 to 23 minutes of decompression after wreck diving. All received first aid oxygen on the boat and in the ambulance during transportation to a local hyperbaric chamber. No symptoms developed, and no one was recompressed. The reasons for omitted decompression were unknown. Figure 2.5.1-4 shows the profile of a diver who reported 19 minutes of omitted decompression. The estimated DCS risk was 1.7%. In four other cases with reported omitted decompression, the estimated risk was between 1% and 1.3%.

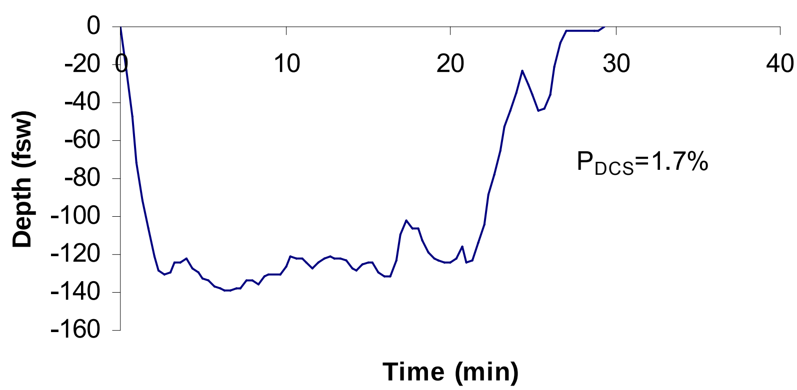

Figure 2.5.1.2-4 Nineteen minutes of omitted decompression with an estimated P_{DCS}=1.7%

2.5.2 Non-DCI Injury or Symptoms

The most frequent non-DCI injury, difficulty equalizing the middle ear pressure, was reported in 397 cases or three percent of the PDE dives (Figure 2.5.2-1). Seasickness was reported on 46 dives and transient vertigo on 32 dives. Five divers reported headaches.

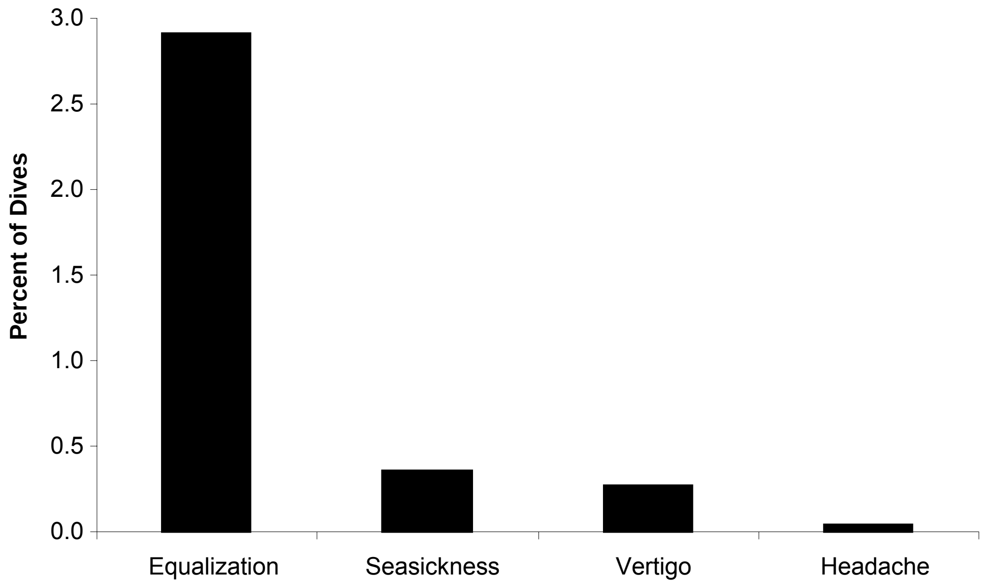

Figure 2.5.2-1 480 Non-DCI injuries or symptoms in 15,056 PDE dives

2.5.3 Ambiguous Cases

A 53-year old, healthy female diver reported tenderness of the breast and kidney region (severity '5' on a scale of 0 to 10) at one hour after two dives to 80 fsw (24 msw) and 54 fsw (16 msw). She did not seek medical attention and continued to dive for four more days.

A male diver reported shoulder and neck pain he said was related to a previous injury.

A male diver reported leg pain but continued diving and did not seek medical help.

A 45-year-old female diver had a history of asthma (using Ventolin®), back pain, nervous system disorder, and acute seasickness. During her fourth day of diving as deep as 108 fsw (32 msw), she was fatigued after a 112 fsw (34 msw) dive and cancelled a second dive. She had recovered by the next day and continued diving for two more days as deep as118 fsw (35 msw).

2.5.4 DCS

There were four DCS cases for an annual incidence of 2.8 cases per 10,000 dives. Three cases were classified as DCS I and one DCS II. All received first aid oxygen and were recompressed. All cases resolved completely.

Case 1. Pain in right shoulder (DCS I).

The diver was an experienced, 40-year-old male with no reported health problems. He made six dives in five days from a charter boat wearing a drysuit and breathing nitrox with 24 to 30% oxygen. He developed pain in his left shoulder the evening after his fifth dive but ignored it and went diving the next day. The last dive profile, which had an estimated P_{DCS} of 1.2%, is shown in Figure 2.5.4-1. When the pain got worse post-dive, he reported it and received first aid oxygen and intravenous fluids on the boat. All symptoms resolved after recompression on USN TT6.

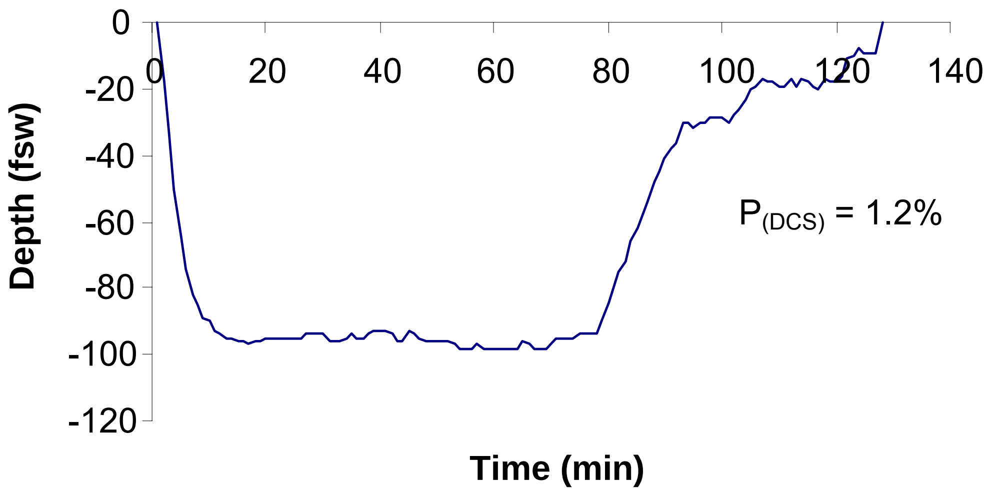

Figure 2.5.4-1 Pain in right shoulder relieved by recompression (DCS I)

Case 2. Left upper arm pain (DCS I).

A 31-year-old male diver, certified three years earlier, had more than 150 dives. He made a series of eight wreck dives in six days from a charter boat. His last five dives were on nitrox. On the fifth day, he dived to 50 fsw (5 msw) and 80 fsw (24 msw). On the sixth day, he did a multi-level dive to of 116 fsw (35 msw) with a brief stay on the bottom and a total underwater time of 49 minutes (Figure 2.5.4-2). The estimated P_{DCS} was 0.4%. His second dive was to 110 fsw (33 msw) with 25 minutes of decompression at 20-10 fsw (6-3 msw) with a P_{DCS} of 1.0%. Shortly after surfacing, he developed dull pain in his left upper arm. He was breathing oxygen within 30 minutes and was seen in a local chamber within one hour after diving. All symptoms resolved during treatment on USN TT6.

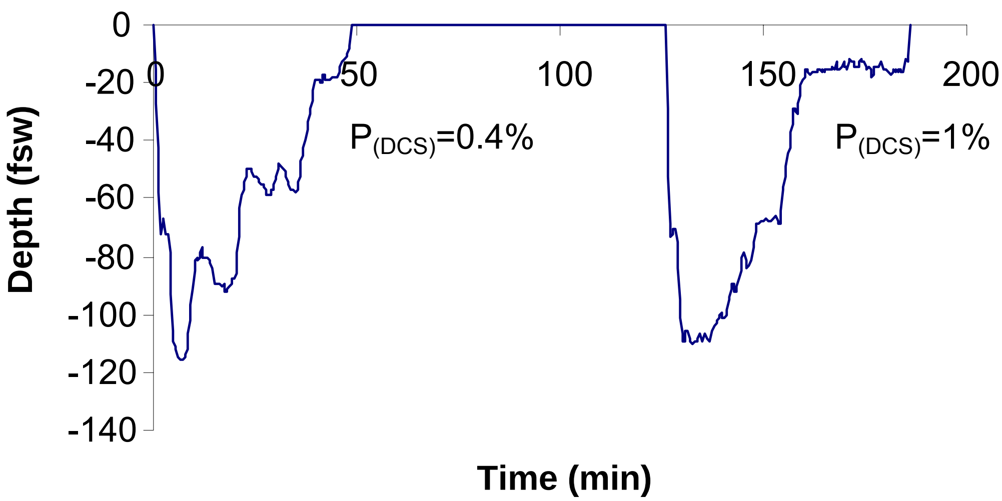

Figure 2.5.4-2 Pain in right upper arm relieved by recompression (DCS I)

Case 3. Skin bends and cerebral symptoms (DCS II).

A female diver in her late twenties had been certified for four years and made 250 dives, 100 within the last year. She was classified as obese by body mass index (BMI 36.5 kg·m^{-2}) with a history of allergy and asthma requiring the use of inhalers. In this series, she made 11 wreck dives on nitrox in six days with the estimated P_{DCS} often exceeding 1.0% (Figure 2.5.4-3). On the last day, she dived to 137 fsw (41 msw) (the deepest of the series) and then to 116 fsw (35 msw). Twenty minutes into this dive, her drysuit started leaking and she aborted the dive, omitting planned decompression stops with an oxygen-rich nitrox breathing gas. The estimated P_{DCS} risk for the dive with omitted decompression was 2.3% (Figure 2.5.4-4). Upon surfacing and taking a hot shower, she noticed a dark red, marbling rash over her chest and upper arms. One hour later she was admitted to the local hyperbaric chamber where she was recompressed on a USN TT6. The rash resolved during the treatment. The next day, she drove home, transiently reaching an altitude of 1,200 ft (366 m) while crossing a pass. Two days later, she felt unwell and noticed a decrease in her typing proficiency. She also had difficulty speaking (dysphasia). At the hyperbaric chamber, she could not walk heel-to-toe or touch her finger to her nose with closed eyes. These manifestations suggested cerebral DCS, and she was treated with a USN TT6 followed by a COMEX Table CNx12 (nitrox at 12 msw for 2.5 hours). Symptoms resolved.

A test for patent foramen ovale (PFO) was negative, but she was told that there was an indication of a pulmonary shunt. (A pulmonary shunt would allow bubbles in the venous blood to bypass the lung filter and enter the arterial circulation.) While a PFO or pulmonary shunt could increase the risk of DCS, the decompression stress indicated by the estimated P_{DCS} was 2.3%, which is quite high. Most safe PDE dives have a P_{DCS} of less than 1.0%. The diver soon returned to diving and has had no problems in two years since.

For more information about PFO and pulmonary shunt, see: "Patent Foramen Ovale: what is it, and what are its implications for scuba divers?" by Richard E. Moon, and John Rorem at the web address: http://www.diversalertnetwork.org/medical/articles/article.asp?articleid=50.

There is also an article of PFO by Moon and Bove on the website (http://www.diversalertnetwork.org/medical/articles/article.asp?articleid=70).

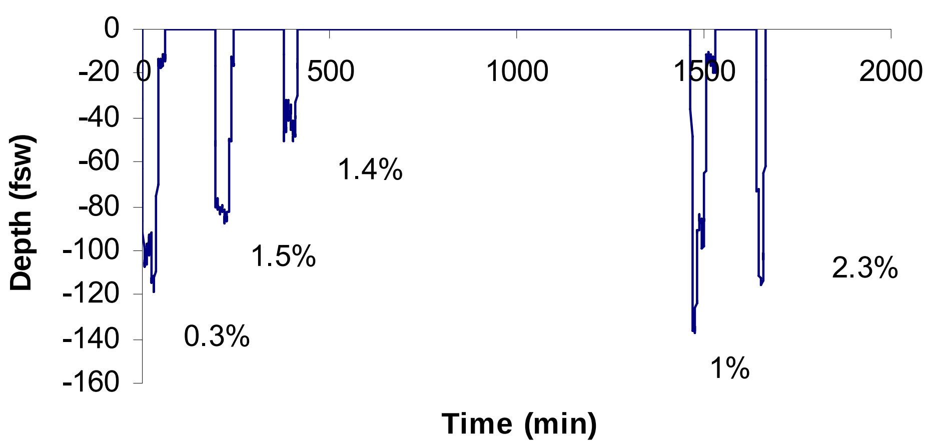

Figure 2.5.4-3 Last two days diving. Skin rash on chest. Cerebral symptoms (DCS II)

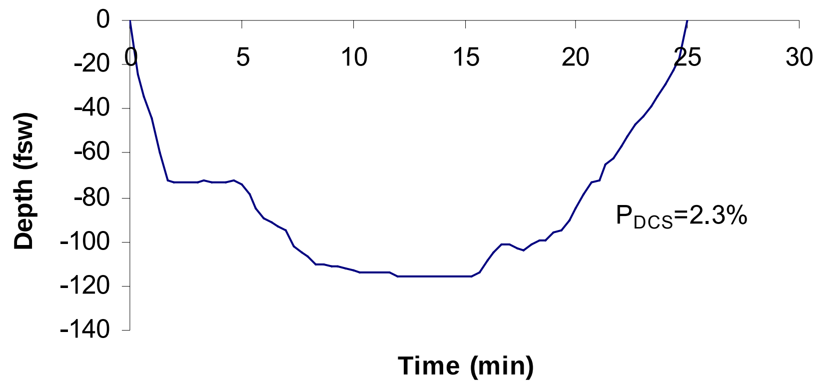

Figure 2.5.4-4 Aborted dive with omitted decompression. P_{DCS}=2.3%

Case 4. Left shoulder pain (DCS I).

A 21-year-old female diver (height 66 in [1.67 m], weight 125 lb [57 kg], BMI 20.1 kg·m^{-2}) was certified three years previously and had made a lifetime total of 18 dives. The present series was a Divemaster class with two days of training and a total of six dives using open-circuit scuba with air. On the second day, her first dive was to 112 fsw (34 msw) for a total time of 29 minutes. After a 30-minute surface interval, the next dive was to 24-28 fsw (7-8 msw) for another 50 minutes including a five minute surface interval. The estimated P_{DCS} was less than 0.7%. Three and a half hours post-dive, she developed left shoulder pain which she did not report. She completed the pool sessions the next morning as part of her class, but the shoulder pain had not subsided, and she was evaluated at a local clinic. After an X-ray and examination of her shoulder, the physician recommended that she seek treatment in a recompression chamber. Several hours later, she was admitted to a hyperbaric chamber with pain of severity '5' on a 0 to 10 scale. She was recompressed, and the pain resolved after 10-20 minutes at pressure.

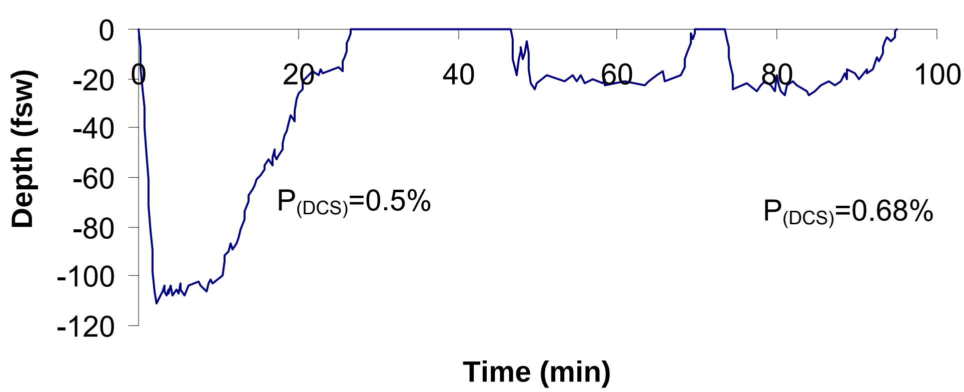

Figure 2.5.4-5 Shoulder pain. Type I DCS

2.6 References

Gerth WA, Vann RD. Probabilistic gas and bubble dynamics models of decompression sickness occurrence in air and N2-O2 diving. Undersea Hyperb Med. 1997; 24: 275-92.

Vann RD, Freiberger JJ, Caruso JL, Denoble PJ, Pollock NW, Uguccioni DM, Dovenbarger JA. Report on Decompression Illness, Diving Fatalities and Project Dive Exploration: DAN's Annual Review of Recreational Scuba Diving Injuries and Fatalities Based on 2003 Data; 2005 Edition. Divers Alert Network: Durham, NC, 2005.

3. DIVE INJURIES

3.1 Introduction

The investigation of recreational diving injuries is an important part of DAN's mission to improve diving safety, and DAN has collected information on recreational scuba diving injuries since 1987. The Health Insurance Portability and Accountability Act of 1996 (HIPAA, Title II), however, significantly affected how DAN could collect clinical data. HIPAA has changed not only the way in which DAN collects data but also how DAN manages calls to the Emergency Medical Hotline. To make this process both HIPAA-compliant and more efficient, DAN has developed a new online system, called the Medical Services Call Center (MSCC). With appropriate security authorizations, the MSCC allows medics, physicians, chamber staff, and evacuation services in different geographic locations to communicate quickly over the Internet and so improve the speed and safety with which injured divers are triaged and delivered to care. DAN implemented a prototype version of the MSCC in the spring of 2006; it has already reduced the data entry workload and improved reliability. The MSCC includes an electronic version of the Scuba Epidemiology Report Form (SERF), the replacement for the Diving Injury Report Form (DIRF), and allows chambers to enter and retrieve their own case data online.

The primary purpose of the MSCC is to ensure clinical quality assurance. The attending physicians at the Duke University Center for Hyperbaric Medicine and Environmental Physiology review the calls and the medic's responses on an ongoing basis. However, by design, the MSCC also captures information needed to address key questions for diving injury research. The Injury Section of the 2007 Diving Report falls within the HIPAA-mandated transition to the MSCC from the previous injury collection systems. When the transition is complete, clinical data from the MSCC will be stripped of patient-identifying information to make it compliant with HIPAA regulations. This research data will be available as de-identified cases (contains no identifying information) with information about dive profiles, symptom onset and severity, therapies, and resolution of residual symptoms. Longitudinal analysis of these data allow assessment of the probability and severity of decompression injury for a given dive profile, the natural history of DCS and AGE injury resolution, and the effects of therapeutic interventions.

3.2 Data Sources, Case Classification and Diagnostic Confidence

<u>Sources:</u> DAN receives hotline calls from throughout the world, from divers, chamber operators and physicians. A total of 5,645 calls or emails were logged into the MSCC system by DAN medics from April 6 through December 31, 2006. The frequency distribution of call origin is shown in Table 3.2-1. The primary mission of the DAN hotline is to advise divers in need of medical assistance, and DAN America provides this service to all callers without taking into account DAN membership status. The majority of all calls to DAN involve requests for information, particularly information about medical fitness to dive. Questions about DCS and barotrauma make up a large part of the remaining inquiries. DAN also fields requests for information on a large range of other topics including questions about hyperbaric medicine to advisories about travel to remote locations. When a caller reports a situation involving an actual injury, the call is classified as a case. Almost 31% of all calls involved actual cases of injury to either a diver or a non-diving DAN member from April 2006 through Dec 31, 2006.

Table 3.2-1 Origin of DAN calls entered into the MSCC in 2006

		Frequency	Percent
	Email	949	16.8
	Information Line	2,965	52.5
	Emergency Line	1,525	27.0
	Referred from Travel Assist	205	3.6
	Total	5,644	100.0
Missing		1	0
Total		5,645	100.0

<u>Classification:</u> The topic categories addressed by these calls as indicated by the medic's assessment included in Table 3.2-2 and Figure 3.2-1.

Table 32-2 Topic of DAN calls entered into the MSCC in 2006

		Frequency	Percent
	Information (non-specific)	1,316	29.2
	Fitness to dive	1,314	29.2
	DCS	509	11.3
	Middle ear barotrauma (BT)	305	6.8
	Trauma or infection	247	5.5
	Possible DCS	221	4.9
	Envenomation	133	3.0
	Pulmonary BT	101	2.2
	Sinus BT	91	2.0
	AGE	33	0.7
	Immersion pulmonary edema	8	0.2
	CO	3	0.1
	Other	226	5.0
	Total	4,507	100.0
Missing		1,138	
Total		5,645	

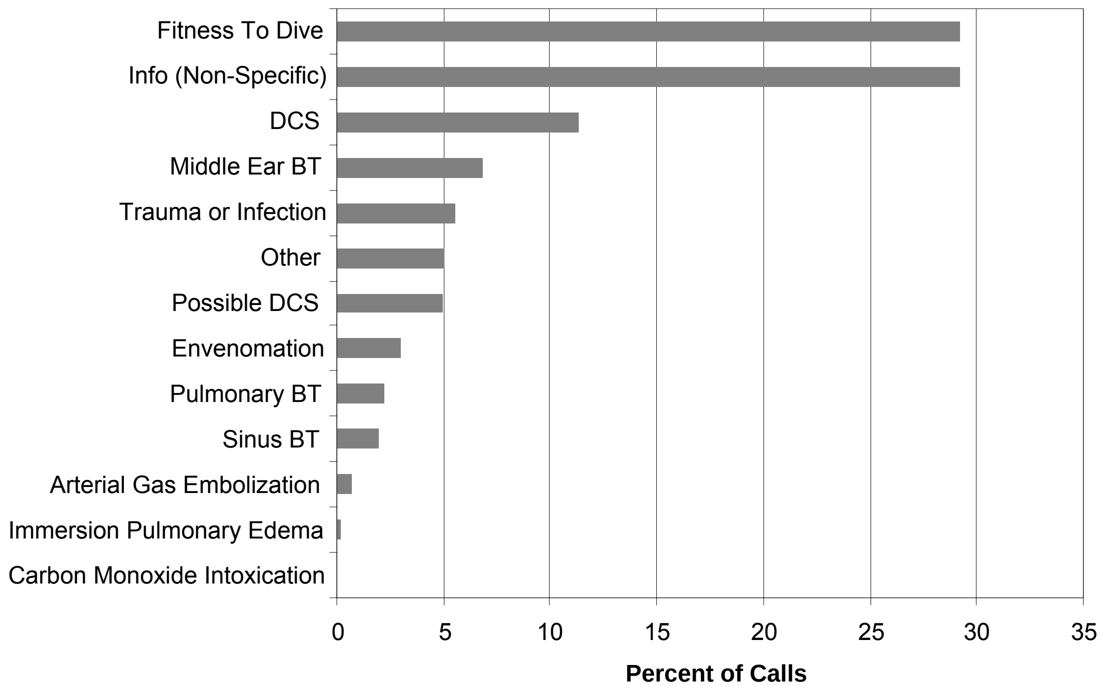

Figure 3.2-1 Percentage of calls by topic (n= 4507)

3.3 DAN Diagnosis

Each call logged by the MSCC is assigned a working diagnosis by the medics or physicians who field the calls. The management of cases, potentially including referrals and evacuation, is directly influenced by this assessment. During the daily morning report, cases are reviewed by the DAN physician staff for quality assurance purposes and long-term follow-up is assigned and completed where appropriate. A breakdown of the diagnoses recorded by the hotline medics and physicians using the first version of the MSCC is shown in Table 3.3-1 and Figure 3.3-1.

Table 3.3-1 Diagnosis of cases as assigned by DAN medic (n=935)

		Frequency	Percent
	Barotrauma	259	27.7
	DCS	216	23.1
	Non-Diving Related	171	18.3
	Trauma	70	7.5
	Envenomation	69	7.4
	Other	150	16.0
	Total	935	100.0
Missing		802	
Total		1,737	

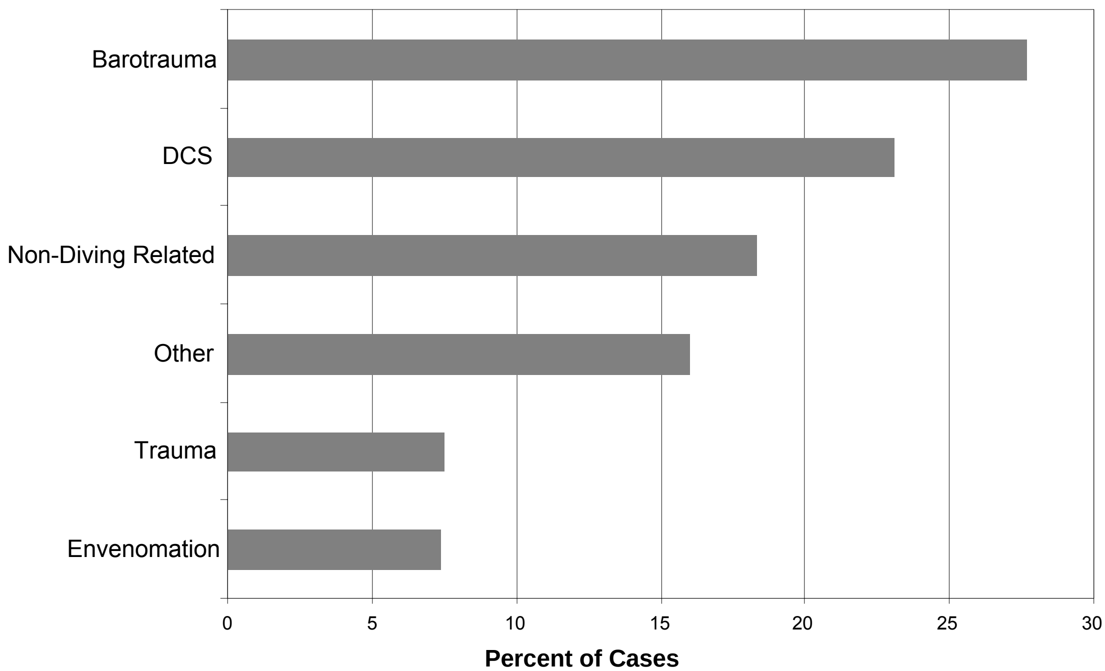

Figure 3.3-1 Diagnosis of cases as assigned by DAN medic (n=935)

3.4 Confidence in Diagnosis

The fact that a diver received hyperbaric therapy does not guarantee that a decompression-related injury occurred. There are no objective diagnostic tests for DCI. Most reporting chambers treat fewer than 10 cases per year. This makes it difficult for clinicians to acquire significant diagnostic experience. Because hyperbaric treatment is generally benign, many divers are treated for uncertain indications when DCS or AGE appears possible. The SERF and MSCC allow treating physicians to express their diagnostic confidence. Table 3.4-1 shows the treating physician judged the diagnosis to be confident for only approximately two-thirds (61.8%) to three-quarters of their patients. Diagnostic accuracy can be determined during follow up for quality assurance purposes.

Table 3.4-1 Confidence in Assessment (n=498)

		Frequency	Percent	Valid Percent	Cumulative Percent
	High	308	17.7	61.8	61.8
	Low	19	1.1	3.8	65.7
	Moderate	168	9.7	33.7	99.4
	N/A	3	0.2	0.6	100.0
	Total	498	28.7	100.0	
Missing		1,239	71.3		
Total		1,737	100.0		

3.5 Diver Characteristics Associated with Injuries

Age. The age of the divers in our case population was normally distributed with a mean of 43±12 years, similar to the 42±12 years age of all PDE divers (Figure 3.5-1). Table 3.5-1 shows the age distribution for case-related calls and indicates that some injured divers continued to dive well into the eighth decade. Sixty-five percent of the case calls involved males (n=1,301).

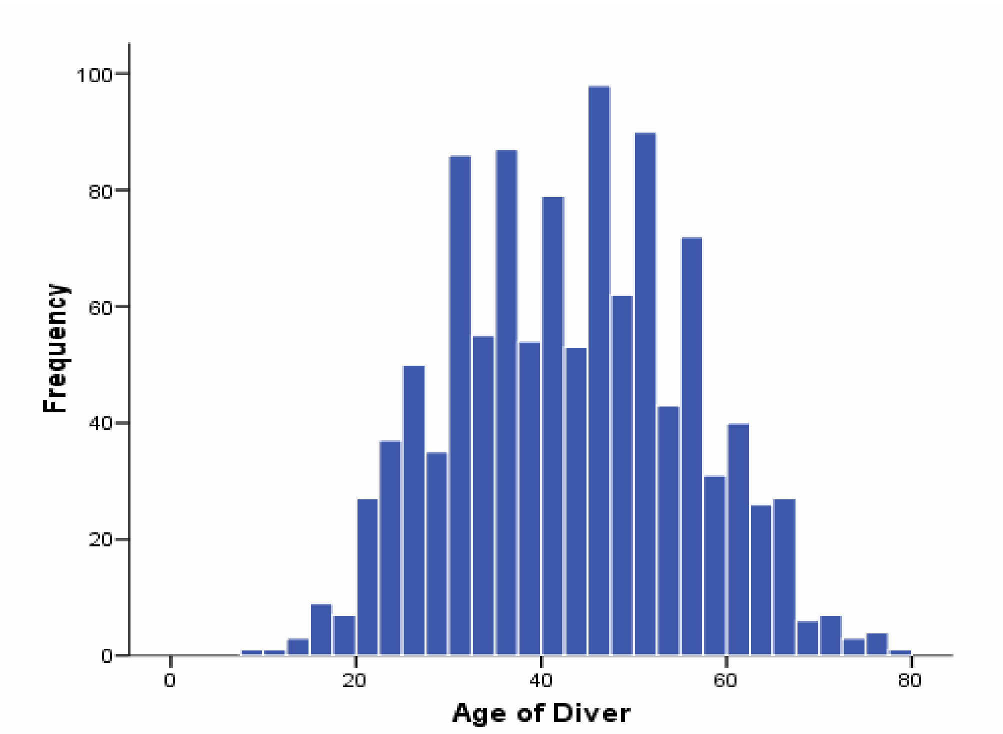

Figure 3.5-1 Age of divers (n=1,094)

Table 3.5-1 Age of divers involved in case calls

Number	Valid	1,094
	Missing	643
Mean		42.9
SD		12.6
Median		43.0
Minimum		8
Maximum		79

The distribution of subjects by gender appears in Table 3.5-2.

Table 3.5-2 Gender of Divers

		Frequency	Valid Percent
	Female	453	34.8
	Male	848	65.2
	Total	1,301	100.0
Missing		436	
Total		1,737	

Medical Problems. Medical history information was recorded in 514 of the injury cases and in 413 of these instances it was noted to be unremarkable (Table 3.5-3). Of the 101 cases where significant past medical history was recorded, cardiovascular disease predominated. Because of the low recording frequency it is not possible to make assumptions about the significant past medical history of the divers represented by these calls.

Table 3.5-3 Reported past medical history (n=101)

None	413
Cardiovascular	52
Previous DCS	20
Psychiatric	10
Respiratory	9
Neurological	6
Diabetes	4
Total Reporting	514

3.6 Dive Exposure Characteristics Associated with Injuries

Limited dive profile data in the form of diver-reported depths and times were available for a little more than a third of all injury cases. The reported profiles are summarized in Table 3.6-1. It should be noted that not all injury cases were associated with a dive. Table 3.6-2 summarizes reported profile values by DAN medic-assigned diagnosis. Dives associated with DCS were significantly deeper ($p<0.001$) and longer ($p=0.059$) by the non-parametric Kruskal-Wallis test than those associated with other diagnoses. Dive profile-related data other than depths and times were recorded with less frequency. Of all of the injured divers reporting, 95 divers admitted having made a rapid ascent, 30 divers surfaced with a decompression obligation and 88 divers admitted to having had symptoms before making their last dive.

Table 3.6-1 Depths and times of dives associated with cases

Values in fsw		Maximum Depth of Dive Series	Maximum Depth of Last Dive	Total Dive Time (min)
Number	Valid	710	728	656
	Missing	1,027	1,009	1,081
Mean		83.0	70.0	39.0
SD		46.0	44.7	22.3
Median		80.0	60.0	36.0
Minimum		6	6	1
Maximum		320	320	200

Table 3.6-2 Dive characteristics by diagnosis (n=479)

Diagnosis		Max Depth of Dive Series (fsw)	Max Depth of Last dive (fsw)	Duration of Last Dive (min)
DCS	Number	175	182	173
	Mean	106.5	91.6	41.9
	SD	45.2	46.9	20.6
	Median	95.0	80.0	40.0
Barotrauma	Number	105	107	97
	Mean	61.3	50.6	38.0
	SD	35. 3	30.5	25.2
	Median	60.0	45.0	32.0
Envenomation	Number	5	5	4
	Mean	58.2	42.6	35.0
	SD	30.9	18.9	10.0
	Median	68.0	35.0	30.0
Trauma	Number	35	36	32
	Mean	68.5	57.8	45.6
	SD	50.5	50.1	30.9
	Median	60.0	40.0	38.0
Non-Diving Related	Number	99	98	89
	Mean	70.4	58.2	36. 6
	SD	35.9	34. 6	18.5
	Median	71.0	50.0	30.0
Other	Number	97	97	84
	Mean	71.1	57.9	37.9
	SD	38. 9	36. 6	23.2
	Median	65.0	55.0	35.0

3.7 DCS Symptom Characteristics

Experts report that in making the diagnosis of DCS they consider the following factors: 1) was there a significant inert gas exposure as manifested by the depth and time parameters of the dive, 2) were the diver's symptoms consistent with DCS, 3) was the onset of symptoms sufficiently close to the end of the dive, and 4) was the response to treatment (surface or hyperbaric oxygen) as expected (Freiberger et al., 2004). Of the 1,737 cases in the database, 692 cases had symptoms recorded. Table 3.7-1 and Figure 3.7-1 present the frequency of symptoms reported by 692 callers in this sample. For ease of analysis, the symptoms are arranged hierarchically in order of severity; therefore only the most severe symptom is listed although other less severe symptoms may have also been present.

Table 3.7-1 Symptoms reported in DAN cases (n=692)

Symptom	Frequency	Valid Percent
Pain (any)	308	44.5
Paresthesia	148	21.4
Constitutional Symptoms	57	8.2
Respiratory Symptoms	40	5.8
Cortical Changes	31	4.5
Motor Weakness (any)	30	4.3
Vertigo	22	3.2
Cerebellar Symptoms	13	1.9
Headache	10	1.4
Skin Rash	10	1.4
Bowel or Bladder Dysfunction	9	1.3
Hearing Impairment	8	1.2
Tinnitus	4	0.6
Nystagmus	2	0.3
Total	692	100

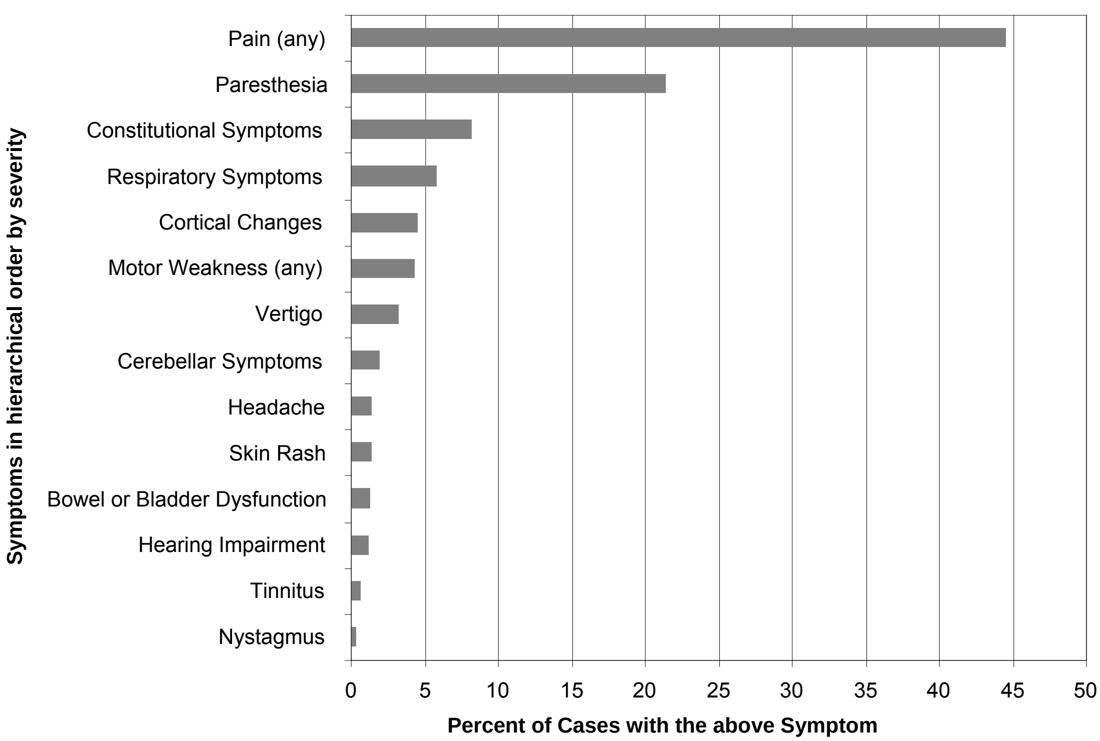

Figure 3.7-1 Symptoms reported in DAN Cases (n=692)

Pain and sensory symptoms (paresthesias) were the most common complaints reported for all case reports. Of the 692 cases where symptoms were recorded, 462 divers were assessed by the DAN staff as having had DCS. In 462 divers assessed as specifically having DCS, the symptom distribution is depicted in Table 3.7-2 and Figure 3.7-2.

Table 3.7-2 SERF symptoms in divers assessed as having DCS (n=462)

Symptom	Frequency	Valid Percent
Pain (any)	181	39.2
Paresthesia	145	31.4
Motor Weakness (any)	29	6.3
Constitutional Symptoms	24	5.2
Cortical Changes	22	4.8
Cerebellar Symptoms	17	3.7
Vertigo	13	2.8
Respiratory Symptoms	10	2.2
Skin Rash	10	2.2
Bowel or Bladder Dysfunction	7	1.5
Nystagmus	2	0.4
Headache	2	0.4
Total	462	100

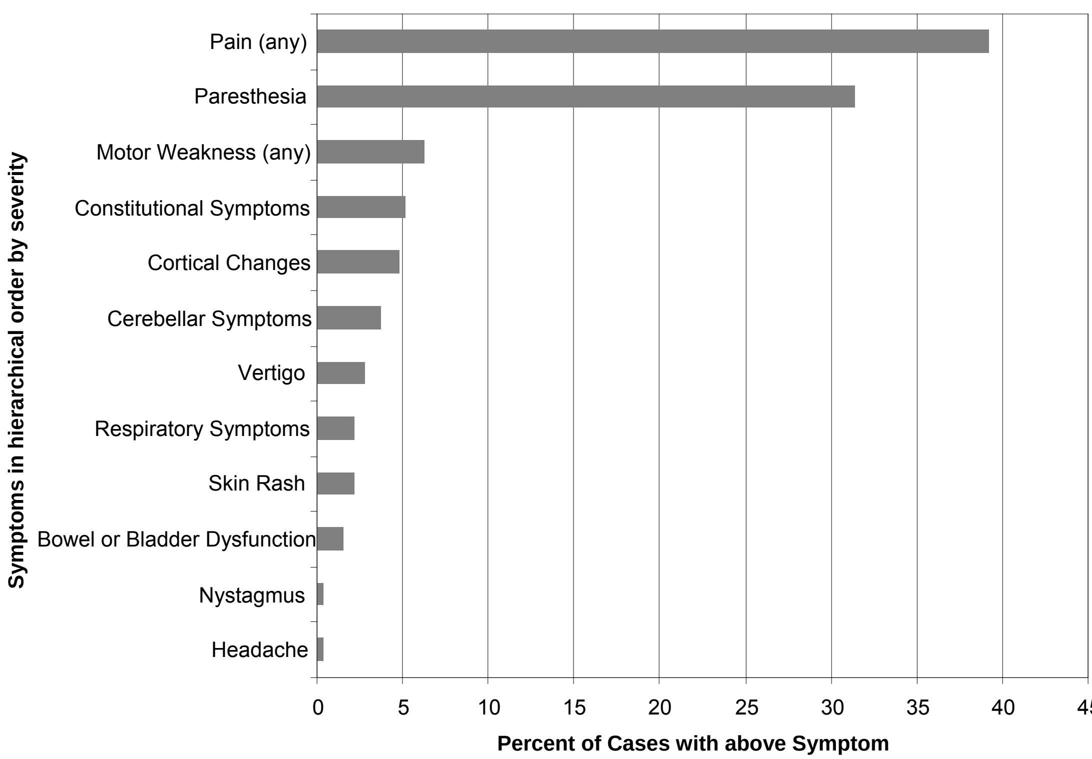

Figure 3.7-2 Symptoms reported in DAN cases (n=462)

It is interesting to note that motor weakness, cerebellar symptoms (ataxia) and cortical changes were reported in four to six percent of the DCS cases. It is also important to note the following: Even in this sample representing less that one year's worth of data, seven divers suffered from bowel or bladder involvement after their dives that was presumably due to DCS.

Pain was the most common symptom reported in DCS and as has been noted previously, the upper extremities were more frequently involved in the recreational diving population. Table 3.7-3 and Figure 3.7-3 depict the location of pain in 229 divers reported in our sample reported.

Table 3.7-3 Pain distribution in divers assessed as having DCS

	Frequency	Percent
Arm	142	19.5
Trunk or Abdomen	35	4.8
Leg	23	3.2
Head or Face	17	2.3
Chest	12	1.6
Total	229	31.4
Missing	501	68.6
Total	730	100

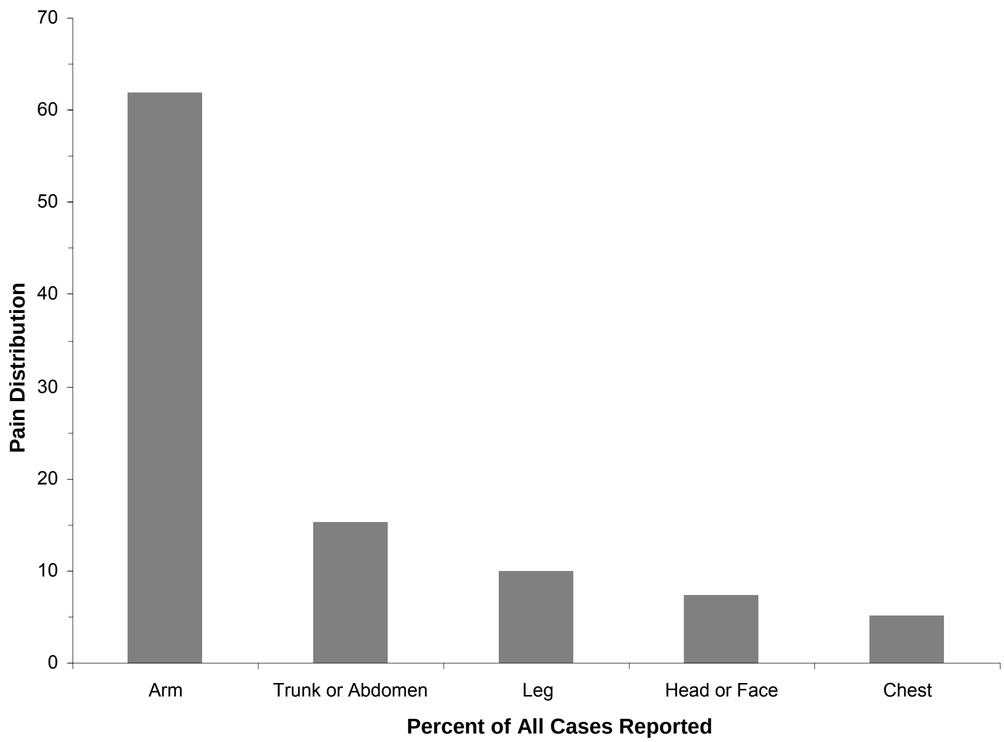

Figure 3.7-3 Pain distribution in assessed with DCS

3.8 Symptom Onset Time

Symptom onset time in DCS was different depending on the type of symptom reported. Table 3.8-1 and Figure 3.8-1 show the median symptom onset times for cases assessed as having DCS. Except for the more minor and often neglected symptoms of paresthesia, pain and constitutional malaise, the median time for symptom onset in DCS was under one hour. As a general rule the more severe symptoms received earlier treatments. This tendency, and its detrimental effect on outcome analysis, has been reported previously (Freiberger and Denoble, 2005; Longphre et al., 2007).

Table 3.8-1 Onset time, time to first aid oxygen and time to recompression by symptom type (n=363)

SERF Symptoms		Symptom Onset Time	Time to First Aid O_2	Time to Recompression
Headache	Mean	0.0		
	Number	1		
	SD			
	Median	0.0		
	Minimum	0.0		
	Maximum	0.0		
Vertigo	Mean	0.8	1.8	3.0
	Number	7	3	1
	SD	0.7	0.4	
	Median	0.8	2.0	3.0
	Minimum	0.0	1.3	3.0
	Maximum	2.0	2.0	3.0
Bowel or Bladder Dysfunction	Mean	0.9	1.4	10.4
	Number	5	4	3
	SD	1.7	2.4	8.5
	Median	0.1	0.2	10.3
	Minimum	0.0	0.2	2.0
	Maximum	4.0	5.0	19.0
Respiratory Symptoms	Mean	0.9	15.6	21.4
	Number	10	7	6
	SD	1.0	35.6	29.7
	Median	0.6	2.0	13.0
	Minimum	0.0	0.1	0.5
	Maximum	3.0	96.0	80.0
Nystagmus	Mean	1.1	0.4	4.0
	Number	2	1	1
	SD	1.2		
	Median	1.1	0.4	4.0
	Minimum	0.3	0.4	4.0
	Maximum	2.0	0.4	4.0
Cerebellar Symptoms	Mean	1.4	0.6	8.8
	Number	12	6	9
	SD	1.6	0.4	7.9
	Median	0.5	0.5	6.8
	Minimum	0.1	0.2	1.0
	Maximum	4.0	1.3	24.0

SERF Symptoms		Symptom Onset Time	Time to First Aid O_2	Time to Recompression
Cortical Changes	Mean	1.6	4.7	20.0
	Number	20	13	13
	SD	3.0	8.4	38.5
	Median	0.6	0.4	3.2
	Minimum	0.0	0.0	0.4
	Maximum	12.5	24.0	144.0
Motor Weakness (any)	Mean	4.3	2.5	6.0
	Number	23	12	6
	SD	10.9	5.2	9.4
	Median	0.3	0.4	2.5
	Minimum	0.0	0.1	0.4
	Maximum	48.0	18.0	25.0
Paresthesia	Mean	10.2	8.4	35.4
	Number	118	31	23
	SD	19.1	12.9	45.6
	Median	2.0	1.0	17.0
	Minimum	0.0	0.1	1.8
	Maximum	144.0	48.0	207.0
Skin Rash	Mean	10.4	4.0	3.2
	Number	5	1	1
	SD	21.0		
	Median	2.0	4.0	3.2
	Minimum	0.0	4.0	3.2
	Maximum	48.0	4.0	3.2
Pain (any)	Mean	10.8	10.2	52.2
	Number	139	29	26
	SD	29.1	15.3	112.7
	Median	2.0	4.0	20.0
	Minimum	0.0	0.1	1.0
	Maximum	264.0	72.0	578.0
Constitutional Symptoms	Mean	19.4		
	Number	21		
	SD	17.9		
	Median	16.0		
	Minimum	0.5		
	Maximum	72.0		
Total	Mean	9.2	7.2	30.5
	Number	363	107	89
	SD	22.2	14.4	68.5
	Median	1.5	1.0	12.0
	Minimum	0.0	0.0	0.4
	Maximum	264.0	96.0	578.0

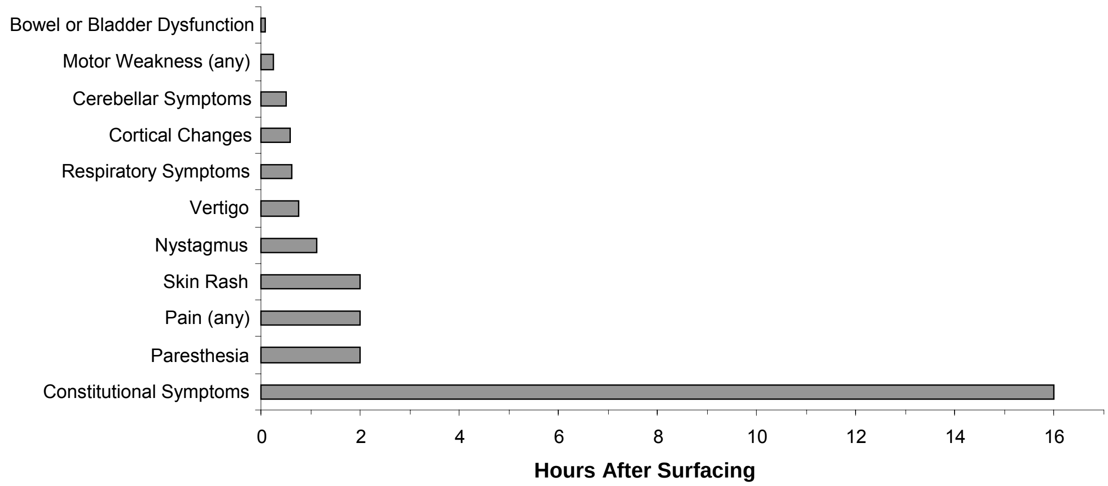

Figure 3.8-1 Median symptom onset time in hours (n=363)

3.9 DCS Treatments and Outcomes

Detailed treatment and outcome information was not available for this first year where we were fully dependent on the MSCC for data. The hyperbaric treatment table was recorded in 269 cases assessed to have DCS. The treatments administered are listed in Table 3.9-1. Where the information was available, most divers were given one or two hyperbaric treatments (Table 3.9-2). Some divers in our sample reported receiving as many as eight treatments over as many days. DAN plans to begin reporting more detailed follow-up of divers treated for diving injuries in the upcoming versions of this report.

Table 3.9-1 Treatments (n=243)

Treatments Recorded	
TT6	175
TT6 ex	55
TT6A	2
TT5	29
Hart	6
Comex 30	2
Other	24

Table 3.9-2 Number of treatments received (n=112)

Number of Treatments	Number of Divers in Category
1	47
2	31
3	15
4	5
5	3
6	7
7	3
8	1

3.10 References

Freiberger JJ, Denoble PJ. Is there evidence for harm from delays to recompression treatment in mild cases of DCI? In: Mitchell SJ, Doolette DJ, Wachholz CJ, Vann RD, eds. Management of Mild or Marginal Decompression Illness in Remote Locations Workshop Proceedings. Durham, NC: Divers Alert Network, 2005: 70-89.

Freiberger JJ, Lyman SJ, Denoble PJ, Pieper CF, Vann RD. Consensus factors used by experts in the diagnosis of decompression illness. Aviat Space Environ Med. 2004; 75(12): 1023-1028.

Longphre JM, Denoble PJ, Moon RE, Vann RD, Freiberger JJ. First aid normobaric oxygen for the treatment of recreational diving injuries. Undersea Hyperb Med. 2007; 34(1): 43-49.

4. DIVE FATALITIES

4.1 Introduction

Recreational scuba diving deaths are rare events, but the risk is never insignificant and vigilance is required to keep it as low as possible. DAN has maintained a recreational diving fatality surveillance system since 1989 to help learn why divers die and how deaths might be prevented.

The DAN fatality surveillance system has two components: an external voluntary notification system and an internal investigation process. Voluntary notification comes from divers who may have witnessed an accident, family members, dive businesses, investigative agencies, and government agencies. DAN also actively monitors the Internet including newspapers, scuba forums and websites for news about diving fatalities. Once a notification is received, DAN researchers start an inquiry to collect all the available relevant data. This inquiry is limited to recreational scuba fatalities that involve U.S. and Canadian residents diving in USA, Canada or abroad. Despite all investigative efforts, information on fatalities is often incomplete, especially in cases that occurred abroad.

Fatality surveillance data for 2005 are presented in this chapter. One year surveillance data does not enable researchers to evaluate statistically for possible causative and contributing factors.

4.2 Fatality Statistics

DAN received notification of 167 deaths during scuba diving in 2005. Three involved commercial divers, 75 foreigners and 89 recreational US and Canadian divers. Table 4.2-1 shows the frequency of deaths by country for all known recreational incidents.

Table 4.2-1 Frequency of accidents by country (all known recreational incidents)

Country	Non US/Can	US & Canada Residents
Antilles	1	3
Australia	8	1
Austria	1	
Belize		1
Canada		12
Cayman Islands		3
Chile	1	
Croatia (Hrvatska)	1	
Egypt	4	
Ecuador		1
Fiji	2	
France	3	
Honduras	1	1
Indonesia	1	
Ireland	1	
Malaysia	2	
Malta	1	
Mexico	1	4
Netherlands	1	
New Zealand (Aotearoa)	5	
Northern Mariana Islands	2	
Norway	1	
Panama	3	
Philippines	3	
Poland	1	
Romania	1	1
Saudi Arabia	2	
South Africa	11	1
Spain	3	
Switzerland	1	
Turks and Caicos		1
United Kingdom	12	
United States	1	59
Virgin Islands (British)		1
Total	75	89

The 89 cases discussed in this report were US or Canadian recreational divers (79 male and 10 female).

Eighty percent (n=71) of these cases occurred in the U.S. or Canada and 34% (n=30) abroad. Table 4.2-2 shows the geographic distribution of U.S. and Canadian fatalities by state or province. Most cases occurred in Florida (24%) and California (13%)

Table 4.2-2 Distribution of US and Canadian fatalities by state and province (n=70)

State or Province	Number
Florida	17
California	9
British Columbia	5
Washington	5
New York	4
Ontario	4
Hawaii	3
Massachusetts	3
North Carolina	3
Nova Scotia	3
Texas	3
Illinois	2
Pennsylvania	2
Connecticut	1
Maine	1
New Jersey	1
Oregon	1
Rhode Island	1
South Carolina	1
Vermont	1

Autopsy reports were available for 33 cases, not available for 23 cases and unknown or not performed in 26 cases. A coroner's summary or death certificate was available for five of the cases with unknown or not performed autopsies. There were no witnesses to the critical event in 35 cases. The body was not recovered in five cases.

4.3 Characteristics of Divers Who Died

Figure 4.3-1 shows the age distribution for dive fatalities. Eighty-two percent of males and 80% of females were 40 years or older. The range of males was from 18-71 years, with a median of 50 years. The age range of females was 28-58 years, with a median of 43 years.

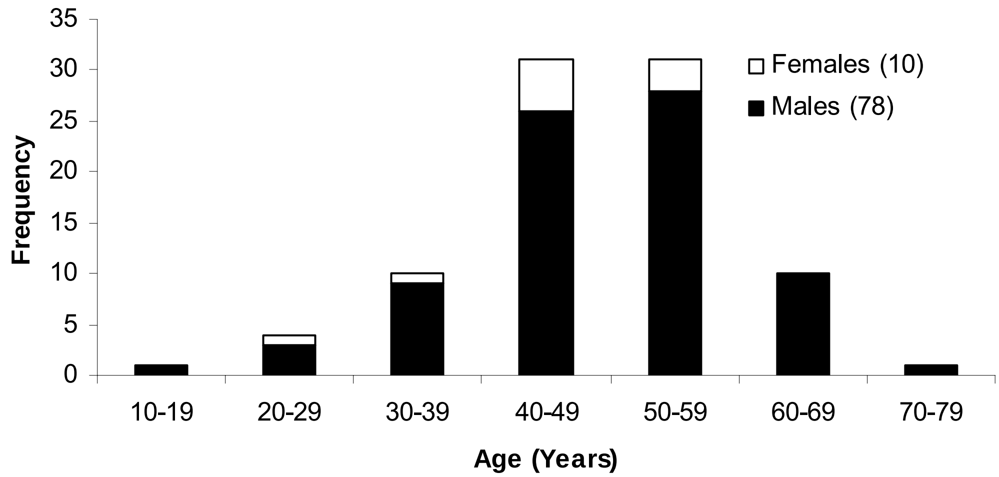

Figure 4.3-1 Distribution of fatalities by age and gender

Medical history was available in 35 cases (40%), although rarely complete. The most frequently reported medical conditions were high blood pressure (14 cases, 15%) and heart disease (13 cases, 14%). Four decedents had back pain. Three had diabetes, one of which had known kidney disease, a sign of progressive chronic damage by diabetes. Two had asthma and two had prostate cancer. One decedent had known fatigue on exertion. Other health conditions included advanced cancer of lungs and bones, hemochromatosis, thrombocythemia, ALS, panic attacks and cirrhosis. Smoking history was known for 30 cases; 25 were non-smokers and five were known smokers.

Figure 4.3-2 depicts height-weight proportionality in the fatality population as indicated by body mass index (BMI; weight in kg divided by height in meters squared). Disproportionately large muscle mass will raise BMI but high values are more frequently associated with fatness on a population basis. BMI data available for 43 fatality victims indicated that 26% were classified as normal weight (18.5-<25.0 $kg \cdot m^{-2}$), 37% were overweight (25.0-<30.0 $kg \cdot m^{-2}$), 28% were obese (30.0-<40.0 $kg \cdot m^{-2}$) and nine percent were morbidly obese (≥40 $kg \cdot m^{-2}$).

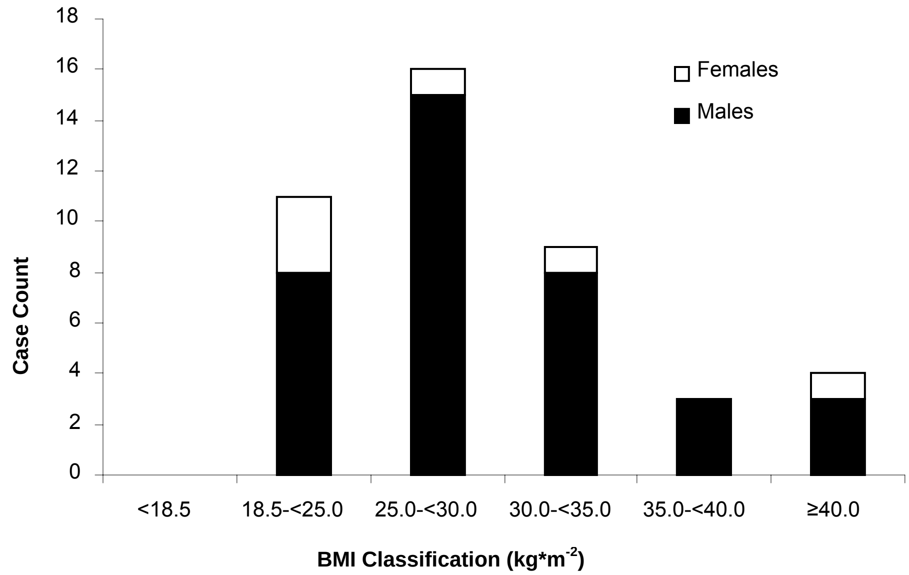

Figure 4.3-2 Classification of fatalities by BMI (n=43)

The percentage of divers with the BMI of 25.0 kg·m^{-2} or greater among fatalities (81%) appear greater than reported by the National Center for Health Statistics for U.S. adults aged 20 years and older (65%) (1999-2002 National Health and Nutrition Examination Survey).

Seventy-one of the victims were known to be certified but information on the certification level was missing in half of the cases. The half with information included one student, nine with open water certification, 13 with an advanced or specialty certification and 22 with higher certification.

Figure 4.3-3 shows the number of years since initial certification. Fifty-two percent had been certified 10 years or more, and 26% one year or less. This pattern can change dramatically from year to year. Evaluation of the specific risk factor is not possible based on a one year of data.

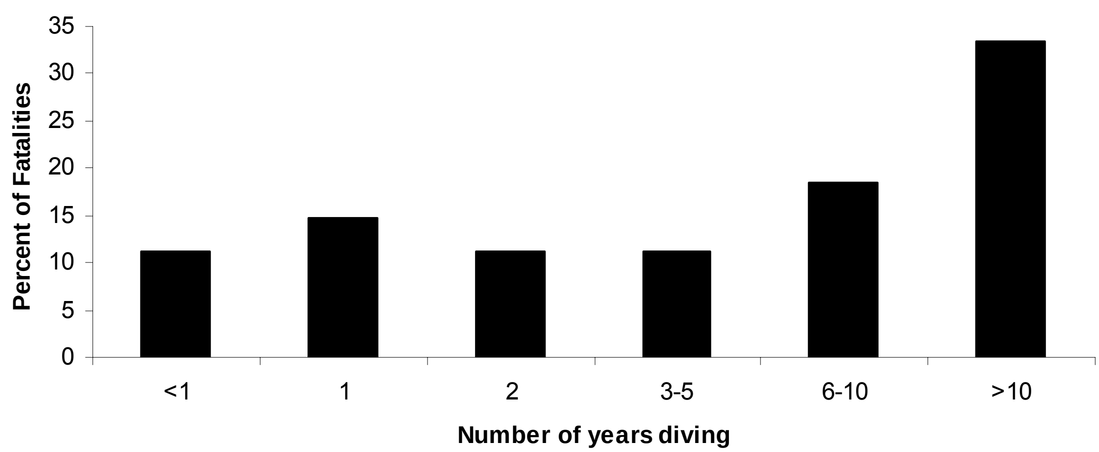

Figure 4.3-3 Number of years since initial certification of divers who died (n=54)

The time between the most recent previous dive day and the day of the accident was known for only 29 fatalities. In five cases, the victim had not dived for more than one year prior to the fatal dive day.

4.4 Characteristics of dives

Figure 4.4-1 shows the month of death. As expected, most fatalities occurred during summer months when most diving is conducted in North America.

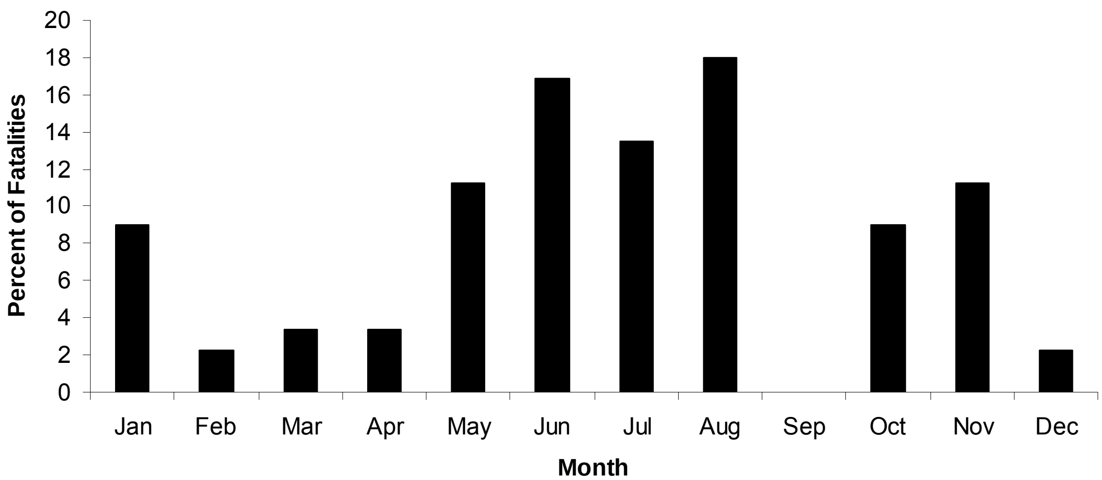

Figure 4.4-1 Month when diver deaths occurred (n=89)

Most diving deaths occurred during daylight. Only three deaths occurred during night diving and two occurred at dusk. Seventy-nine percent occurred in the sea or ocean, 15% in lakes or quarries, four percent in rivers, and two percent in swimming pools. Both pool accidents (separate) involved experienced divers who were testing their rebreathers in four to six feet of water and died of hypoxia.

Figure 4.4-2 shows the reason for diving. Sixty-four percent of fatal dives (53 cases) involved pleasure or sightseeing (including three wreck and one cave dive), 14% (12 cases) involved spearfishing, hunting or collecting game, 10% training and four percent (three cases) underwater photography. One diver died while retrieving an anchor, one while trying to attach a chain to a buoy, and one while surveying his sunken boat in a river.

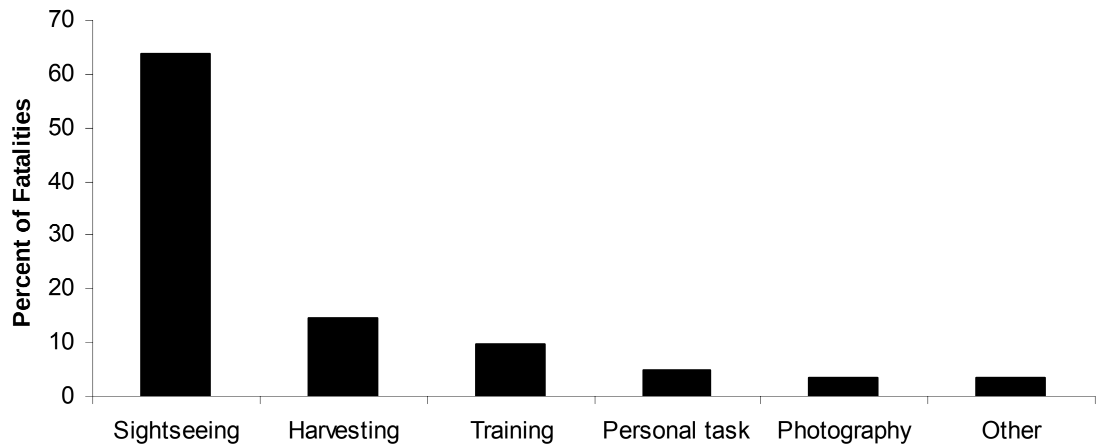

Figure 4.4-2 Diving activity (n=83)

Figure 4.4-3 shows the platform from which the fatal dives began. Sixty-four percent began from a charter or private vessel, consistent with previous reports. Thirty-one percent dived from shore and three percent from a live-aboard. Strong current or rough seas were contributing factors in at least 25% of all cases and more often in diving from shore (37%).

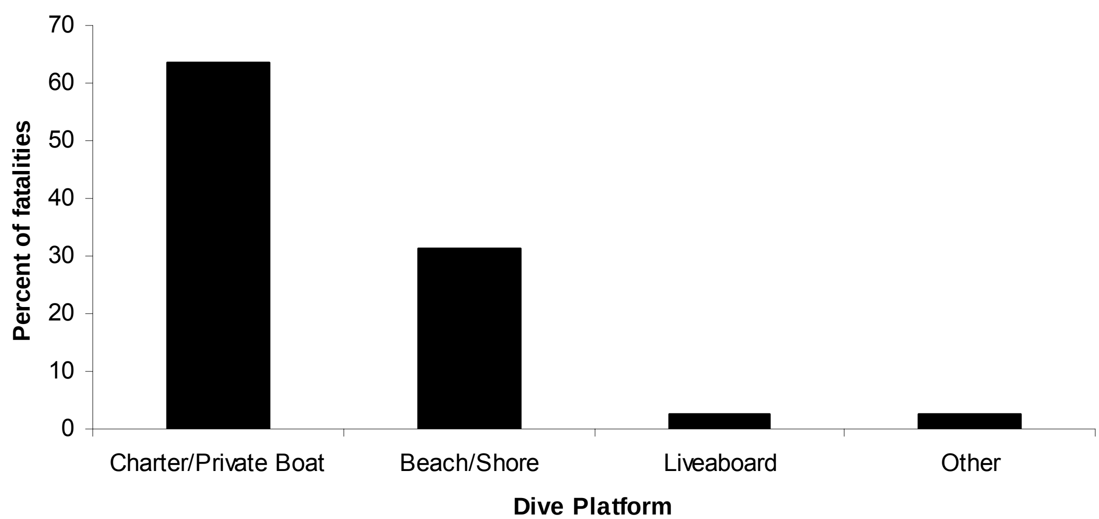

Figure 4.4-3 Dive platform (n=77)

Contrary to the 2004 pattern when 37% of decedents wore drysuits, they were used in only 10% of the 2005 cases.

Figure 4.4-4 shows the maximum dive depth reported for 60 fatalities. Six cases (seven percent) occurred on the surface before diving. The median reported depth of underwater accidents was 60 fsw (18 msw). Twenty-five percent of cases occurred in 20 fsw (6 msw) or less and 25% in 100 fsw (30 msw) or deeper.

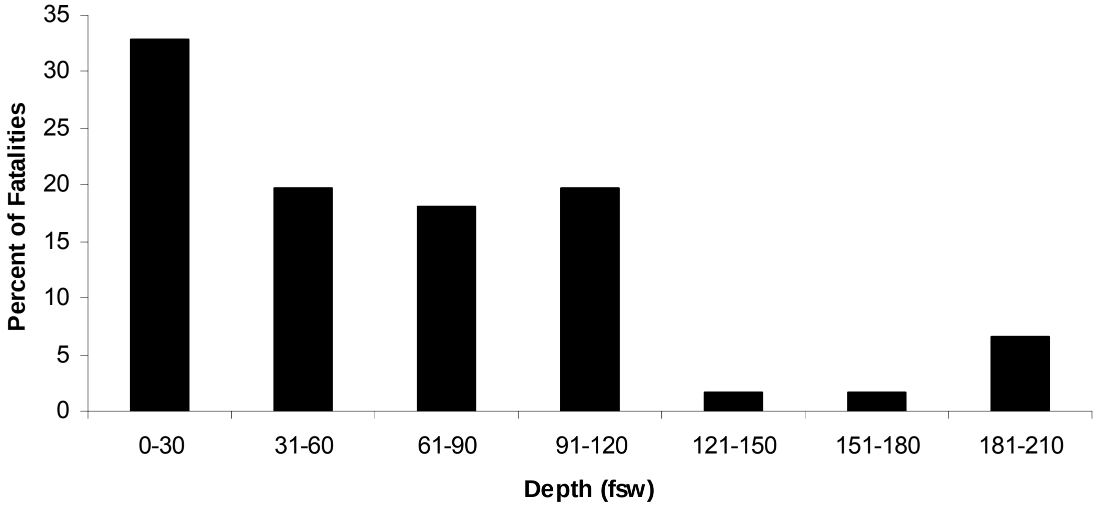

Figure 4.4-4 Maximum depth of accident dive (n=60)

Out of 53 cases with a known sequence, 87% of deaths occurred on the first day of diving and 13% on the second to fourth day of diving. The fatal dive was the first dive of the day in 82% and the second in 18% of the 55 cases with available data.

Figure 4.4-5 shows breathing gear and breathing gas. Scuba was used in 92% of cases (n=78) and most frequently with air (82%). Nitrox was used in scuba in 10 cases and rebreathers in six cases.

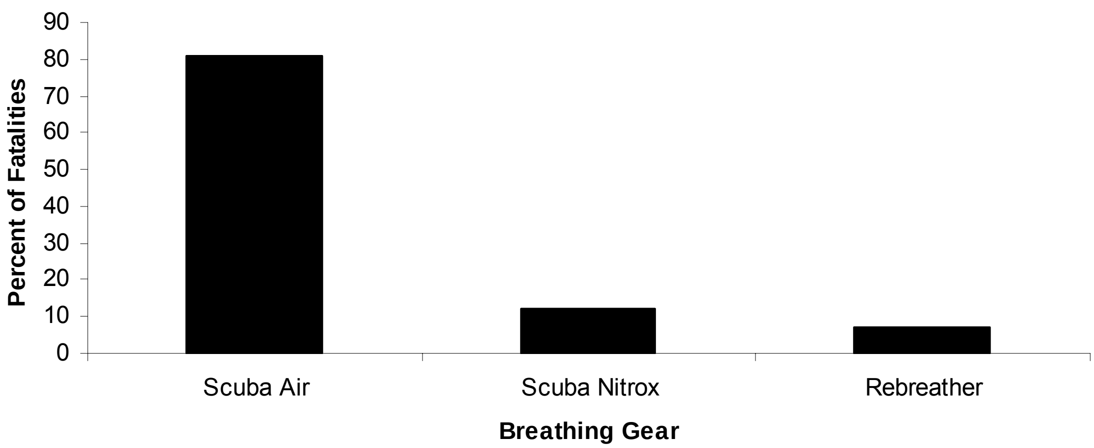

Figure 4.4-5 Breathing gear and gas (n=84)

4.5 Analysis of Situations and Hazards

We explored each case according to: a) the phase of the dive in which it occurred; b) the chronological chain of events ending in death; and c) the buddy system used.

Cause of death (COD) was usually the best defined characteristic of a diving fatality, but preceding events were frequently more relevant to understanding what happened. In reverse chronological order, we defined the key events as COD, disabling injury, disabling agent, and trigger and, where possible, we identified these components for individual cases. The disabling injury was not necessarily the COD but was ultimately responsible for death. The disabling agent was the cause of the disabling injury, and the trigger was the event that began the sequence that ultimately culminated in death.

4.6 Fatalities by Dive Phase

Dive phases included: a) on the surface before diving, b) descent, c) on the bottom, d) ascent, and, e) on the surface after diving. We include in this analysis all fatalities that occurred from the moment when a scuba equipped diver entered the water. Figure 4.6-1 shows the distribution of fatalities by dive phase when the problem became obvious.

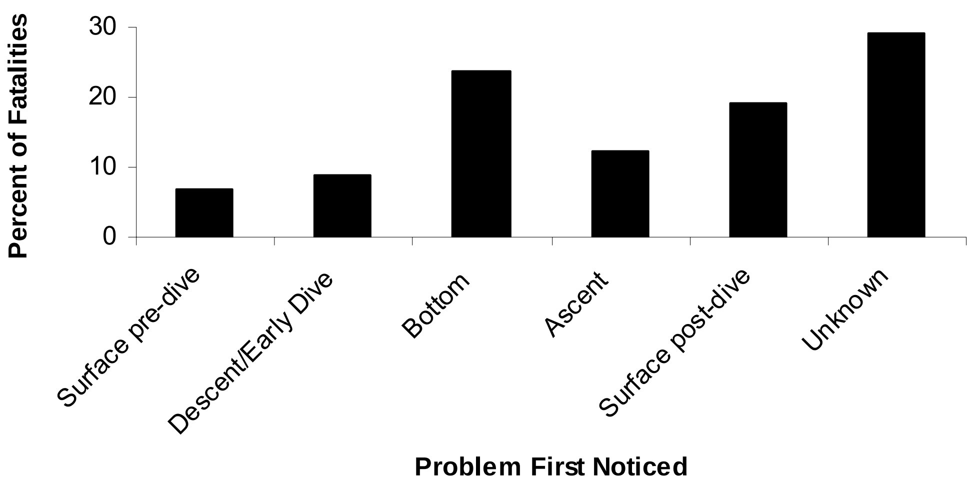

Figure 4.6-1 Dive phase when it became obvious that dive has a problem (n=89)

Witnesses were not present in 29% of fatalities. Six divers (seven percent) developed problems even before descent and eight (nine percent) during descent or soon thereafter. Problems were most often noticed at the bottom (24%) and at the surface post-dive (19%). Figure 4.6-2 shows the distribution of fatalities by the phase in which diver lost consciousness.

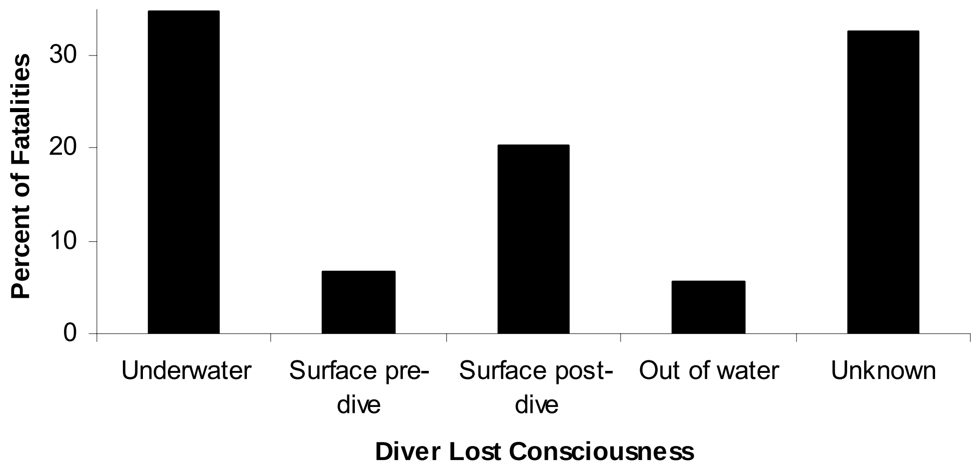

Figure 4.6-2 Dive phase when diver lost consciousness (n=89)

Most divers losing consciousness did so underwater (34%). Five divers lost consciousness upon exiting (or being retrieved from) the water.

Fatalities often began and evolved over several dive phases. Table 4.6-1 shows the phase when problems started and when the diver lost consciousness.

Table 4.6-1 Accidents by stage of dive

	Diver Lost Consciousness					
Problem Started	Out of water	Surface pre-dive	Under water	Surface post-dive	Missing data	Total
Surface pre-dive		5			1	6
Descent/Early Dive		1	4	1	2	8
Bottom	3	1	13		4	21
Ascent			5	4	2	11
Surface post-dive	1		2	11	3	17
Missing data			7	2	17	26
Total	4	7	31	18	29	89

Surface pre-dive. Trouble began on the surface before submersion in six cases. Sometimes it was associated with waves, surf or strong currents but in other cases conditions appeared normal. Accidents that occurred before descent and most of the cases that occurred at the surface post-dive, indicate that it is the swimming that sometimes causes accidents rather than diving itself. Here are brief descriptions of cases:

- Diver in mid-sixties, with 70 dives in five years of diving, experienced breathing problems while swimming at the surface just before his second dive. He lost consciousness quickly. He was brought aboard and provided CPR but never revived. The suspected cause of death was a cardiac event.

- Diver in late-fifties with a history of heart attack and irregular heartbeats went to hunt lobsters after a year of not diving. While swimming out from the beach he got into distress and drowned.

- Diver in late-forties, not very experienced, went for a shore dive with couple of friends to collect lobsters at night. They all waded out into shoulder deep water but rip currents were so strong that victim decided to return to shore. Buddies kept sight of him until he reached waist deep water and then lost him. He was found later dead, floating several hundred yards offshore.

- Female diver in mid-forties was knocked down by a wave as she was backing into the surf to start dive. She was found dead, with a regulator in her mouth. The cause of death was head trauma.

- Student in mid-fifties was on a training dive from the beach with his instructor and a group of other students. He did not feel well and decided to return to shore by himself. Witnesses on the beach saw him struggling and went to help but he lost consciousness and was floating face down before they reached him.

- Experienced diver in late-sixties had buoyancy problems and got entangled in the mooring line. In an attempt to disentangle, he removed his BCD and started swimming towards the boat still wearing his mask and weight belt. He sank in front of witnesses.

On descent or early in dive. Trouble began on descent or at an early stage of the dive in many cases:

- Diver with a rebreather started a dive without opening the tanks. Lost consciousness early in descent due to hypoxia.
- Diver on scuba for his third dive of the day, lost by buddies from the beginning. Diver was found at the bottom with his tank turned off.
- Diver was witnessed trying to reach his spare regulator immediately after descent. His main tank was empty.
- Diver in a drysuit sank quickly after purging his suit and was never found.
- Diver in a drysuit sank faster than usual. He had difficulty with his drysuit and drowned. Sealing cap and coupling for drysuit hose were found pushed out of position.
- Diver lost consciousness early in the dive. Suspected aneurism.
- Vertical current propelled diver quickly to the surface. Pulmonary barotrauma and AGE.
- Two divers in separate incidents were on rebreathers in a shallow pool and died of hypoxia.
- One diver went to over 130 fsw (40 msw) on air. He was seen having trouble early in the dive. He did not come back and was never found. The other diver went to 168 fsw (51 msw) and back in less than 20 minutes. He died of DCI soon after surfacing.

At the bottom. Divers lost consciousness at the bottom in 34% of cases (n=31). Four may have had heart problems, four lost consciousness for unknown causes, three were entangled, three may have suffered hypoxia, and one was trapped.

Ascent. Trouble started during the ascent in 12% of cases (n=11). Heart problems were suspected in four cases. Autopsy indicated lung barotrauma and AGE in three cases. There was no obvious explanation for the other cases.

Surface post-dive. In a number of cases the problems were not noticed until the diver surfaced. These are the most difficult cases in which to distinguish between injuries during ascent or on the surface. The longer a diver is at the surface without symptoms, the less likely it is that death was due to injury on the bottom or during ascent. Autopsy may help clarify the cause of death.

- An inexperienced female diver in her early-fifties, missed the tag line after surfacing, drifted away and sank. She was found unconscious at 60 fsw (18 msw) with her regulator out of her mouth and her tank empty. It seems that she had a little time for rescue action. She may have been trying to inflate her BC and sank before realizing that she was out of air. An early aspiration may have produced panic that prevented her from releasing her weight belt.

- A 60-year-old, experienced male diver was diving with a buddy. Ten minutes into the dive, his buddy experienced some problems with his regulator. They both ascended orderly to 15 ft (4.6 msw) and after a five minute safety stop surfaced along the anchor of their dinghy. The buddy swam to the back and entered the dinghy. The victim complained that he was too tired to do the same. He was losing strength progressively while his buddy supported him from the boat. He died within 20 minutes, before help arrived. The autopsy identified a weakened artery (aneurism) in his brain that accidentally ruptured.

- An inexperienced swimmer and diver in his fifties, with less than 10 lifetime dives and reportedly prone to panic, decided to swim with buddy from shore the length of the pier and back. They decided to abort the dive because of poor visibility and return to shore. The victim was swimming ahead of his buddy but never reached the shore. Once the buddy was on shore, he realized that his companion had disappeared.

- A diver in his early fifties with a history of cardiac surgery, three stents and on nitroglycerin, completed two shallow dives with a group of divers. After a normal ascent from the second dive he started swimming toward the boat. He was seen then to be in distress and was retrieved from the water but did not respond to CPR.

Lost consciousness after exiting water, post-dive, out of water. Four deaths occurred after dive, out of water.

- An experienced female diver in her forties, healthy, lost consciousness aboard boat after a non-complicated dive. In retrospect, one witness said that she looked ill at the safety stop.
- A female in her late-fifties, morbidly obese with Type II diabetes, signaled that she was having trouble breathing and was tired while diving at 25 fsw (7.6 msw). Instructor assisted her in a slow ascent and put her on board. She vomited, lost consciousness soon after and died several hours later in hospital. Reportedly, she died of a stroke.
- An experienced male diver in early-fifties, with Type II diabetes, aborted a dive and ascended to the surface in front of the boat. He complained he could not catch his breath and was helped onboard. Assistant went for an oxygen kit and when he turned back the victim was unconscious and never recovered. Victim had a recent checkup and all was okay other than diabetes. Heart and kidney disease was found on autopsy.
- A male in his early-sixties experienced difficulty breathing or hyperventilation 20 minutes into a dive to 53 fsw (16 msw). A dive guide assisted the victim to the surface and onto the dive boat. The victim collapsed, vomited, and CPR was started, but the victim was never revived.

Death while spearfishing, lobster hunting or harvesting. Six fatalities involved hunting lobsters, three spearfishing, one harvesting scallops and one harvesting crabs. Together they made up 14% of all fatalities. Three occurred in each of California and Florida, two in North Carolina and one in each of Washington, New Jersey, Massachusetts and Nova Scotia. All cases had in common that the diver dived alone or in a small dive party, usually from a small boat. In most cases there was no surface support. Lobster hunting seems to offer an unreasonable attraction since few of the decedents were fit for diving by any reasonable criteria and did not dive for some time prior to the fatal dive. Several incidents were unwitnessed since most hunters prefer to dive alone. The deaths of others were classified as drowning.

Based on available data in these accidents it is not possible to discuss specific causes of death, but it appears that there were some common hazards that victims may have ignored.

1. Hunting and harvesting involves much more swimming than simple sightseeing. It may be too much for divers with heart problems (known or unknown).
2. Buoyancy variations and intentional ascents and descents during shallow water hunting and harvesting, expose divers to relatively large pressure changes that may cause harm.
3. The additional weight of catch may be overwhelming for a diver with marginal fitness.
4. Lack of surface support exposes divers to additional exertion needed to reach the boat or shore and exit the water.
5. Big game may drag a hunter in any direction. Hunting while on a rebreather may not be a good idea since rapid changes in depth may produce substantial changes in the oxygen partial pressure in rebreathers.
6. Hunting areas are often shared with surface fisherman. This may result in entanglement and collisions.
7. The prospect of catch may raise the risk that a diver is willing to accept. This may include poor decisions regarding personal health or minimum gas supply.

4.7 Cause of Death (COD)

Figure 4.7-1 shows the distribution of causes of death (COD) as reported by coroners and medical examiners. Twenty-eight cases (51%) were designated as drowning, and nine cases (16%) acute heart condition. Asphyxia (eight cases), as reported by medical examiner, equates to drowning. Arterial gas embolism, lung expansion injury or extra-alveolar air syndrome were reported in five cases (nine percent). One case of sudden death was suspected to be caused by a cardiac event.

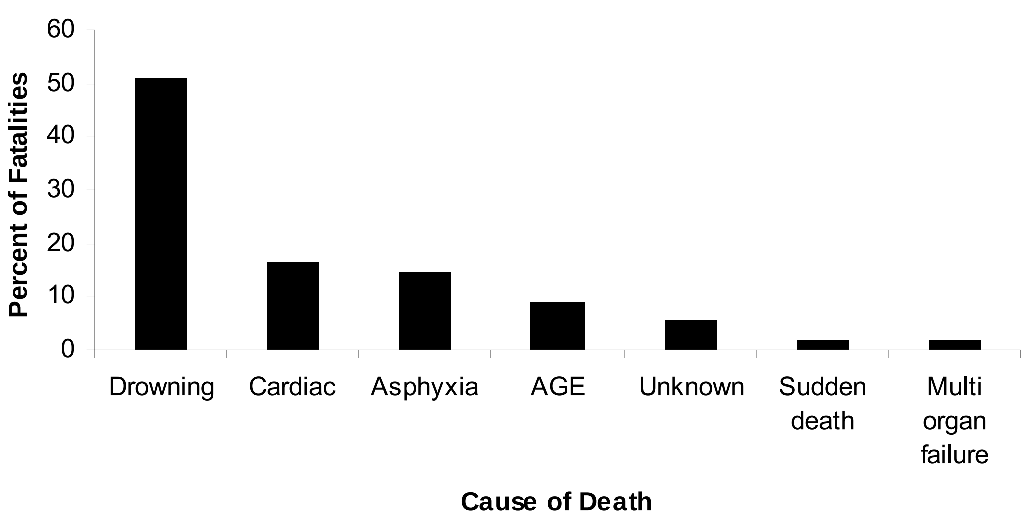

Figure 4.7-1 Cause of death (n=55)

4.8 Buddy System

Only 14 cases involved intentional solo diving. However, in very few cases did divers comply with a reasonable buddy system dive practice. In one case, a dive guide died trying to save diver who became unconscious. In several instances a buddy retrieved an unconscious diver who subsequently died, most likely from a natural disease like myocardial infarction or aneurism rupture. Most of the time victims got into trouble after separating from a buddy and there was neither witness to the accident nor help when it was needed.

The value of buddy diving cannot be judged by on this report alone. However, it is realistic to state that:

1. Reliable buddy support provides piece of mind.
2. The presence of a buddy may help to calm down a diver dealing with an emergent event.
3. A buddy may be able to share air if needed.
4. A trained buddy may assist an unconscious diver to the surface.
5. An incompetent diver cannot be expected to provide adequate buddy support. A dependent diver should be paired with a professional guide.

4.9 Conclusion

Death in recreational diving is rare, but it may affect any diver in any diving environment and at any point in the pre-dive, dive, or post-dive timeline.

Diving skills and physical fitness can not be replaced by experience. All three are very important.

Each diver is responsible for his own safety, but diving with an organized group may increase the safety margin by providing assistance in an emergency. The assistance may be expected only from able, willing and prepared divers. It has to be discussed and agreed upon in advance.

Ask dive guides and more experienced local divers about pre-dive hazards and risk analysis for a specific dive site and current dive condition. Provide them honest information about your skills and fitness level, if you are asking them for help in evaluating risks. Ultimately, the decision to dive or not is your responsibility. Use it wisely.

5. BREATH-HOLD DIVE INCIDENTS

5.1 Introduction

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

Freediving, a form of breath-hold diving, has experienced a marked growth in popularity as an underwater sport. A great deal of interest has been generated by the burgeoning field of freediving competition. There are numerous competitive classes recognized by the International Association for the Development of Apnea (AIDA; http://www.aida-international.org/) (Table 5.1-1).

Table 5.1-1 AIDA-Recognized Competitive Freediving Disciplines

Discipline	Description
Static	resting, immersed breath-hold in controlled water (usually a shallow swimming pool)
Dynamic	horizontal swim in controlled water; with and without fins categories
Constant Weight/Ballast	vertical self-propelled swimming to a maximum depth and back to surface; no line assistance allowed; with and without fins categories
Free Immersion	self-propelled vertical descent and ascent on a line to a maximum depth; no fins
Variable Weight/Ballast	vertical descent to a maximum depth on weighted sled; ascent by pulling up a line and/or kicking
No Limits	vertical descent to a maximum depth on a weighted sled; ascent with a lift bag

Additional disciplines have also been established for competition, although they are not yet recognized by AIDA. The rate at which record-setting performance is documented has drawn many to the sport. The advancement in one category – No Limits – in which freedivers reach the greatest depths, is shown in Figure 5.1-1. The current male record is 702 ft (214 m), set by Herbert Nitsch of Austria in June 2007. The current female record is 525 ft (160 m), set by Tanya Streeter, originally from Britain, in August 2002. The current record for static breath-hold is 9:08 min:s, set by Tom Siestas of Germany in May 2007.

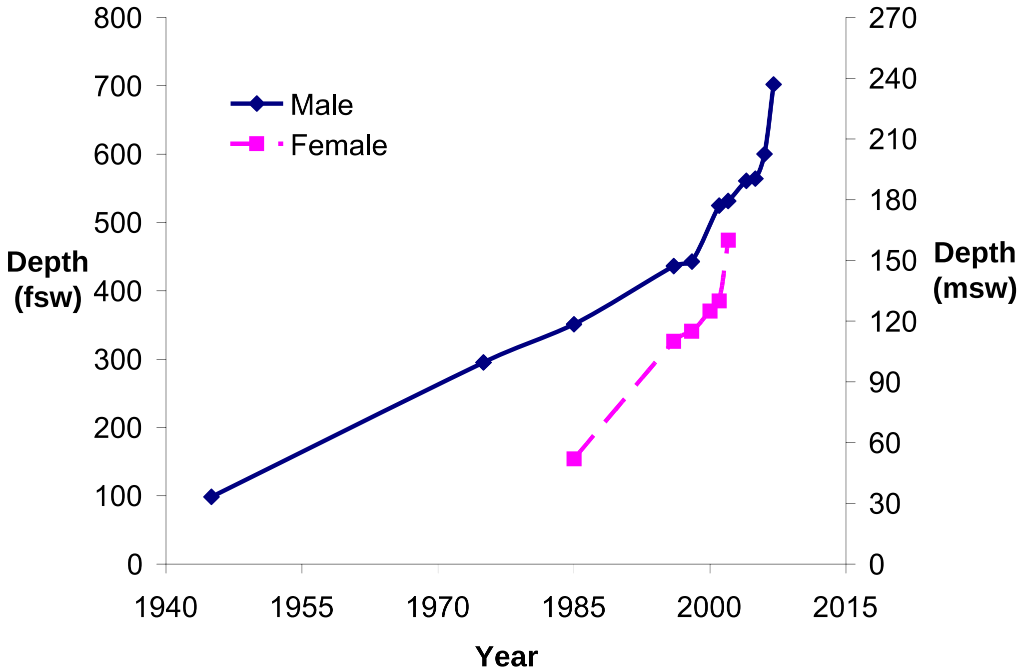

Figure 5.1-1 World record depths in freediving No Limits competition

Extensive safety protocols and procedures have kept the incidence rate in competitive freediving extremely low. The rising profile of freediving may encourage involvement at all levels, from casual through competitive. The risk of injury or death that exists with breath-hold is higher for individuals who do not have proper training or who fail to ensure the presence of adequate safety back-ups when pushing their limits. Though enjoyable and safe when participants are informed and reasonable care is taken, the potential remains for any in-water activity to be physically challenging, and accidents do still occur.

DAN established a dedicated breath-hold incident database in 2005 to collect and disseminate information from both fatal and non-fatal events to improve awareness, training and procedural development. Details on the structure of the database can be found in the proceedings of the 2006 breath-hold workshop (Lindholm et al., 2006). The case intake from 2004 through 2006 (79 incidents) is included in the depiction of DAN-held records (Figure 1.2-4). The annual totals were 23, 18 and 38, respectively. Unlike the data analyzed by DAN for compressed-gas diving accidents, the breath-hold incidents include cases from around the world.

As the first year of active data collection, the 2005 effort was not well advertised in the diving or freediving communities. Virtually all cases were found by keyword capture of reports appearing on the Internet. It is likely that many relevant cases were either not reported on the Internet or did not include the targeted keywords. It is expected that our capture rate will increase as recognition of the effort grows.

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

The greatest challenge in the study of accidents is incomplete information. The investigative effort can require a substantial amount of deductive reasoning and occasionally some guesswork to interpret events. In this report, we summarize the available data and speculate when reasonable. The case summaries found in Appendix C provide brief descriptions of each event.

5.2 Cases in 2005

Most cases were initially identified through automated Internet searches, typically from online newspaper articles. Few cases were reported to DAN directly by individuals involved in the incidents. Cases were excluded if the available information was too limited to be fairly evaluated. Complete details were rarely available, particularly for international cases.

Eighteen cases are included in this summary, 17 fatal (94%) and one non-fatal.

Incidents were reported from eight different countries. Half (n=9) occurred in the United States. The U.S. incidents occurred in three states: Hawaii (56%; 5/9), and California and Florida (each with 22%; 2/9). The concentration on U.S. incidents likely reflects a bias in the available reports rather than a true worldwide pattern. The distribution of U.S. incidents may partially reflect the popularity of breath-hold activities in certain states but could also include a reporting bias. It is anticipated that case identification will improve in all areas as our data collection program is recognized by breath-hold divers and support groups.

Details on the diving environment were available for all of the known cases. Most (89%; 16/18) occurred in the ocean. One case occurred in a freshwater spring and one in a lake.

Categorical descriptions of the primary activity of the incident victim are shown in Figure 5.2-1. Snorkeling remains the most commonly applied designator. Snorkelers may remain completely on the surface with no purposeful breath-hold, or they may use breath-hold in typically limited surface diving efforts. Freedivers direct their activity to breath-hold diving from the surface. Increasing dive depth and/or breath-hold time are common goals. The nature of the dives will vary dramatically with the individual skill and training level of participants. Spearfishing incorporates the act of underwater hunting for food into the breath-hold exercise. Collecting generally refers to underwater hunting without spear devices. Maximizing breath-hold time and/or depth is generally not the primary motivator for either spearfishing or collecting. The challenges of the hunt, however, can encourage divers to push their limits. The proportion of incidents with the primary activity described as freediving climbed from a minority position at 4.5% in the 2004 data to 28% in 2005. It is unclear if this reflects a true refocusing of activity or an increased sensitivity in activity labeling in incident reports.

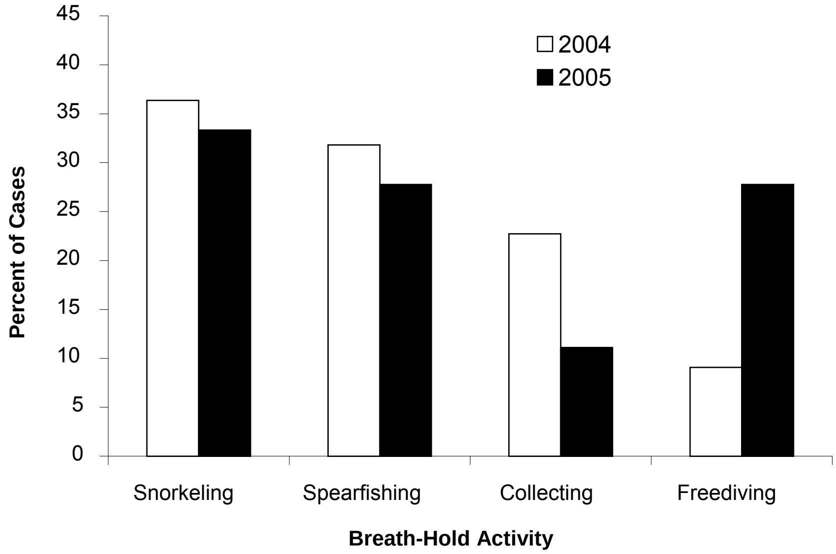

Figure 5.2-1: Distribution (percentages) of described primary activity for breath-hold incident casualties in 2004 and 2005 (n=22 and 18, respectively)

Figure 5.2-2 describes the gender and age of all known victims. All were male. This pattern is not surprising. Only one of the 23 victims identified in 2004 was female. The average age (± standard deviation) was 38±15 years, ranging from 18 to 68 years, similar to previous patterns.

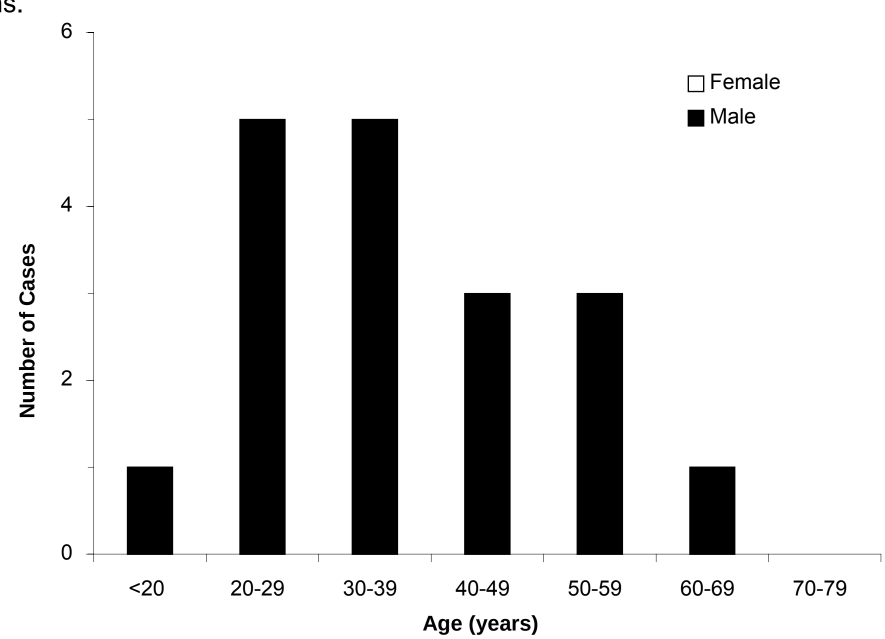

Figure 5.2-2: Age and gender distribution of breath-hold incident victims in 2005 (n=18)

Information regarding the support available to the diver was determined in all of the known cases. One or two other dive partners were present in 50% (n=9) of cases, and no partner/support was present in 33% (n=6) of cases. 'Other support' (poorly documented for larger group activity) was described for 11% (n=2) of the known cases.

Information regarding the availability of eyewitness accounts was determined in all of the known cases. Witnesses were present in less than half (44%; n=8) of the cases. The availability of assistance to the victim was established in all but one of the known cases. Timely assistance was provided in 47% (n=9) of known cases.

Information on casualty recovery was available for all of the known cases. Bodies were recovered in all but two cases. Casualties were most frequently recovered from the bottom (50%; n=9), then from the surface (28%; n=5), and only infrequently intercepted within the water column (11%; n=2).

The type of dive platform used was documented in 94% (n=17) of the known cases. Beach- or shore-based activities represented 59% (n=10) of cases, day boats 18% (n=3), kayaks 12% (n=2), liveaboards six percent (n=1) and cruise ship six percent (n=1).

The casualty's level of experience in the breath-hold activity was established in 44% of the known cases (n=8). More than half were described as 'Advanced' (n=5), one-quarter as 'Intermediate' (n=2) and one as 'No Experience.'

Time of day was known in 83% (n=15) of the known cases. All but one occurred in daylight hours. The last case was unwitnessed, occurring some time in the early morning hours.

The presence or absence of an overhead environment was established in 89% (n=16) of the known cases. There was only one case associated with an immovable overhead environment; this involved a person who was a competitive swimmer and freediver who died while diving solo in a springwater cave.

5.3 Cause of Death and Contributing Factors

The cause of death is typically determined by medical examiners assigned to fatality cases. The usefulness of the finding is often limited, particularly if the cause of death is determined to be drowning. More important is the effort to identify the problem or problems that created the situation in which drowning, for example, could occur. The search for contributing factors can be challenging, particularly in the case of unwitnessed events. Starting with 2006 data, complete fatality case files will be forwarded to a medical examiner experienced in diving medicine who will review all the data to confirm or, if warranted, expand upon the conclusions drawn by the initial medical examiner. Secondary medical examination was not completed with the current cases.

Records from initial medical examination were available for one-third (n=6) of the known fatal cases. In each of these cases, the primary cause of death was described as drowning or asphyxia due to drowning.

Additional insights into factors believed to contribute to an incident were available for most of the known cases. The case summaries are categorized into hazard clusters. The overwhelming concern is hypoxia-induced blackout, believed to be a primary factor in half of the cases known from 2005. While many people think that oxygen controls our breathing activity, carbon dioxide is the primary regulator in healthy individuals. We tend to be relatively insensitive to oxygen levels under most conditions.

Each of our respiratory cycles is followed by a brief period of breath-hold (apnea) prior to the next inspiration-expiration pair. The duration of the apnea is primarily controlled by the partial pressure of carbon dioxide in the arterial blood. The range is fairly narrow during relaxed, involuntary respiration, from a high of 45-46 mm Hg at the start of the respiratory cycle to a low of approximately 40 mm Hg at the end of the cycle. Voluntary breath-hold can allow the carbon dioxide partial pressure to climb well into the 50 mm Hg range or beyond depending in large part on motivation. Eventually, however, a breakpoint is reached when the urge to breathe is overwhelming. Many breath-hold divers know that taking a series of rapid breaths in excess of metabolic need (i.e., hyperventilation) will flush carbon dioxide from the body and delay the point at which carbon dioxide accumulates to the breakpoint during a subsequent breath-hold. The accumulation of oxygen stores associated with hyperventilation is far less than the clearance of carbon dioxide since the concentration of carbon dioxide in the blood is much higher than that found in the atmosphere. Delaying the carbon dioxide trigger to breathe can be problematic since the oxygen partial pressure may fall below the level necessary to maintain consciousness before any urge to breathe is felt. Effectively, the loss of consciousness that can follow hyperventilation-augmented breath-hold may occur with absolutely no warning. Occurring at or near the maximal depth of the dive, this would be described simply as a hypoxia-induced blackout.

A major effect of the increasing pressure of depth is an increase in the partial pressure of gases in the lungs and bloodstream. This makes more oxygen available to the cells and shifts the carbon dioxide concentration closer to breakpoint. The carbon dioxide partial pressure may still be far below breakpoint if a substantial amount of hyperventilation was employed to lower it pre-dive. The more critical evolution occurs during surfacing, when the ambient pressure reduction makes the partial pressure of oxygen fall at a faster rate than by metabolic consumption alone. A state of problematic 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 reduced by the reduction in ambient pressure and therefore unlikely to stimulate a strong urge to breathe. Effectively, the risk of hypoxia-induced loss of consciousness 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 (before the oxygen in the first inspired breath has time to reach the brain). Again, the loss of consciousness will be without warning. Many will describe this condition as 'shallow water blackout' but since that name was first used to describe another condition it is falling out of favor.

Problems with loss of consciousness were known to develop or strongly suggested in one-half of the known cases (n=9). Hypoxia of ascent was evident through witness reports in three cases and by the location of the casualty on the surface in another case. Five other victims were found underwater following unwitnessed events. The details are limited, but it is possible that each is explained by underwater blackout or hypoxia of ascent. Once becoming unconscious, a negatively buoyant diver would either sink, making the point of loss of consciousness difficult to know. It must be added that the medical examiner suggested that one of the unwitnessed fatalities might have been precipitated an asthmatic reaction, but since the history of asthma was limited to childhood and the victim was 42 years of age, the hypoxia-driven alternative that was also suggested seems more likely.

Two cases were associated with boat strikes, one fatal and one non-fatal (see case summaries). Two more fatal cases were associated with pre-existing health conditions (in addition to the case of possible asthma discussed above). The details are limited in the case of a 59-year-old who may have experienced a cardiac event. The autopsy of a 44-year-old with a history of seizures and stroke who drowned while freediving solo did not confirm whether his medical conditions led to his drowning or if this might have been another case of blackout.

Two cases of fatal animal attacks were identified. One diver was taken by a great white shark while spearfishing with a partner, and the other was believed to have been taken by a crocodile while snorkeling out of sight of his partner. A single case of entanglement was identified in which a spearfisher's net and weight belt became entangled on a rock.

The final two cases did not include enough information to categorize. A 59-year-old male was found unresponsive at the surface while solo diving for abalone. A 68-year-old male with no snorkeling experience disappeared shortly after entering water that was rougher and had a stronger current than expected.

5.4 Reducing Breath-Hold Risks

Breath-hold diving can be less forgiving than compressed-gas diving in that the shift from 'fine' to 'in trouble' can be extremely fast. There are a number of strategies that can reduce the risk of problems or increase the likelihood of a positive outcome if a problem arises. The risk of blackout will be markedly reduced by avoiding or severely limiting pre-dive hyperventilation. A total of one, two or at most three deep inspiratory-expiratory exchanges prior to breath-hold will still reduce the carbon dioxide levels in the blood and increase breath-hold time but are less likely to promote a significant risk of hypoxia-induced blackout. The fact that half of the fatal incidents appeared to involve a loss of consciousness should encourage an extremely cautious approach to hyperventilation.

The presence of an appropriate support network is critical when problems do arise. The finding that two-thirds of the victims had some form of support indicates a positive effort. The finding that more than half (56%) of the reported incidents were unwitnessed, however, suggests that the system used may not always be adequately employed. Effective direct supervision requires close monitoring throughout the breath-hold and 30 seconds post-breath-hold periods. (The risk of loss of consciousness continues post-breath-hold since it takes time for the oxygen in an inspired breath to reach the brain.) Optimally, an awareness of the diver's activity during the pre-breath-hold period would also be helpful to ensure safe pre-dive practices.

Direct supervision does not have to be onerous; it can be easily fit to many situations. A simple two-person, one-up-one-down buddy team with committed direct supervision can provide effective protection for shallow diving situations. A group of three (one-down, two-up) may be preferable as dive depths increase. Allowing a recovery period of twice the dive duration is a reasonable practice. It also ensures that one of the divers available at the surface for backup is at least partially rested.

The risk of a bad outcome following loss of consciousness increases when negative buoyancy is an issue. Many divers might first think to wear extra weight to minimize the effort associated with breath-hold descent. The benefit during descent, however, is overshadowed by the undesirable effects. If a wetsuit is worn and loses buoyancy under pressure, a significant degree of negative buoyancy may exist at depth. This will increase the effort required to ascend (increasing the rate of oxygen consumption). A diver that is negatively buoyant near the surface will also rapidly descend if consciousness is lost in the ascent. This will make it difficult, or in some cases impossible, for immediate rescue to be completed. For safety reasons, it is recommended that divers are weighted to be neutrally buoyant at a depth of approximately 15 ft (4.6 m).

A safety vest is currently under development for breath-hold diving; it will automatically inflate after a preset time at depth unless actively turned off by the wearer. While such a device would not eliminate the risk of underwater blackout or hypoxia of ascent, it could have been beneficial in almost three-quarters of the 2005 cases in which the victims were not found on the surface. Automatic surfacing would not guarantee survival, but it would definitely improve the chances. A number of streamlined vests are available now that can be inflated either manually or through deployment of a small compressed-gas cylinder. Both automatic and manual systems are worth considering for general use.

Since a great deal of time is spent on the surface, breath-hold divers must prepare to reduce the risk of interactions with boats. These include site selection outside of high traffic areas, use of large high-visibility flags and surface floats (or boats), and high visibility hoods, vests and other clothing that might be visible above the water. The spearfishing community might be least willing to wear high contrast clothing. Adequate protection through surface floats, boats and tenders then becomes more important.

Spearfishers face an additional risk of animal interactions while they carry their prey. The single case of shark attack in this series involved a pair of spearfishers. Divers should avoid carrying catch with them whenever possible.

Increasing the awareness of those involved in or supporting breath-hold activity holds the potential to significantly reduce incident rates. Educational opportunities include further development of training programs and continued communication of incident reports and insights.

5.5 Conclusion

A total of 18 breath-hold diving incidents occurring in 2005 were collected by DAN; all involving males and all but one fatal. Hypoxia-induced loss of consciousness remains the greatest problem. Increasing the awareness of those involved in or supporting breath-hold activity holds the potential to significantly reduce incident rates. Our efforts will continue to expand case collection, both fatal and non-fatal, and to provide insights to the community.

5.6 References

Lindholm P, Pollock NW, Lundgren CEG, eds. Breath-hold diving. Proceedings of the Undersea Hyperbaric Medical Society/Divers Alert Network 2006 June 20-21 Workshop. ISBN #978-1-930536-36-4. Durham, NC: Divers Alert Network; 2006; 165 pp.

APPENDIX A. DIVE INJURY CASE REPORTS

Case 1

This diver was a 42-year-old male in excellent health with a history of several years of diving in the Pacific Northwest. He recently trained in drysuit use and was performing his fifth and sixth drysuit dives, both while breathing a 32% nitrox mix.

The two scheduled dives were in cold water to gain drysuit experience. His first dive was to 64 fsw (20 msw) for 47 min, followed by a one-hour surface interval time (SIT) and then a 58 fsw (18 msw) dive for 43 min. Both dives were complicated by rapid ascents from about 20 fsw (6 msw) to the surface.

Approximately one hour after exiting the water, after removing and storing his gear, the diver began to feel soreness and a light tingling in his left arm with a slight red rash and itching sensation on his skin. This spread to his shoulder and the fingers of his left hand over the course of the evening. He thought about the possibility of decompression illness and looked at an article on the Internet. He decided to wait until the following day to see if his symptoms resolved.

After a call the next day into DAN, he decided to be evaluated by a DAN referral physician. On a scale of 0-10 with '0' being no symptoms and '10' being the worst ever experienced, he rated his symptoms as a '3.' Twenty-seven hours after the onset of his first symptoms, he received a Hart-Kindwall oxygen treatment table, often used with monoplace chambers. This is a 2.5 hour schedule that includes sequential stays at 60 fsw (18 msw) and 30 fsw (9 msw) with a slow rate for all decompression travel (1.0 $ft{\cdot}min^{-1}$ [0.3 $m{\cdot}min^{-1}$]). Both symptoms improved to a barely noticeable sensation after the treatment and completely resolved by the fifth day post-treatment.

Case 2

This diver was a 29-year-old male in very good health. He had a history of a fractured left wrist as a young child, a secondary injury causing a shoulder dislocation and some history of numbness believed to be from nerve impingement. He was a scuba instructor and nitrox certified.

The diver scheduled two sequential days of diving. He used 32% nitrox and his drysuit on the first day. His first dive was to a maximum depth of 90 ffw (27 mfw), multi-level with a total bottom time of 45 min. After a 1:30 h:min surface interval he dived to a maximum depth of 45 ffw (14 mfw) for one hour. He had no difficulties with the dives and did not notice any symptoms. His second day of diving was with air, using a wetsuit to complete a dive to 23 ffw (7 mfw) dive for 63 min. Although the dive was without incident he was chilled during the dive and fatigued afterwards. He felt he may have been dehydrated from the previous day of diving.

Approximately three hours after the final dive, his left hand began tingling. He noticed this because his hand near the old fracture site felt different than the rest of his skin. Three hours after the onset of the tingling he began to notice a mild pain in the joints of his left arm and his entire arm felt numb and tingly. Since he had experienced similar symptoms previously he decided to wait and see if they improved.

The following day he called DAN and was directed to the local referral doctor. On exam he stated his pain was a '2' on a 0-10 scale and his numbness was about the same as the previous day. The examining physician also found some weakness in the left arm. The patient received an extended US Navy Treatment Table 6 (USN TT6) and his symptoms resolved. He returned to diving in six months.

Case 3

This diver was a 28-year-old male with no health issues. He had never had decompression illness. He was an active diver and frequently worked as a divemaster with classes from his shop. He had been certified for 20 years and completed more than 100 dives each year. Most of his dives were on nitrox.

Weekend checkout dives were scheduled at a location 5,000 ft (1,524 m) above sea level. Over three days he performed 14 dives between 36 ffw (11 mfw) and 81 ffw (25 mfw), working with both basic and advanced open water classes. He completed eight dives on the first day using a 36% nitrox mix. He had one emergency ascent but the remaining dives were uneventful and the day finished without further incident or symptoms. On the second day he did four dives, two to between 50 and 55 ffw (15 and 17 mfw) on air and two to the same depths on 36% nitrox. All dives were within the no-decompression limits of his computer and the day was uneventful.

The third day of diving he did two dives on air. The first to 81 ffw (25 mfw) for 23 min and the second to 36 ffw (11 mfw) for 25 min. He waited four hours before returning home which involved driving over a mountain pass of 7,800 ft (2,377 m).

He was fine until he woke up the next morning, 23 hours after surfacing from the last dive, when he experienced a painful stinging sensation in his lower abdomen. At its worst the stinging was a '7' on a 0-10 scale. Two hours later he noticed an additional area with mild tingling, about a '3,' on his anterior thighs. Despite no previous similar symptoms he chose to wait until the next morning to call DAN and ask questions about decompression illness. He was then directed to the local DAN referral physician.

Upon examination the physician found a slightly abnormal Rhomberg, and the diver subjectively felt the stinging and tingling symptoms had lessened somewhat since first noticed. The patient was treated with a USN TT6 during which all symptoms resolved. He remained symptom free when reevaluated the following day. He was advised to wait four to six weeks before returning to diving.

Case 4

This diver was a 43-year-old male with no current health concerns, on no medications and a non-smoker. He had always wanted to try scuba diving and decided to do an introductory course while on vacation in Mexico.

After an introductory pool session he completed two open water dives to a maximum depth of 50 fsw (15 msw) for roughly 45 min each. The dives were guided, easy and uneventful. He began to experience lower back pain approximately 1.5 hours after the second dive. The pain was unusual in that he had never experienced similar pain before and he could not find a position of comfort. At its worse, the pain was a '5' on a 0-10 scale. He checked with the local divemaster but deferred going to see the local dive physician as he felt it was musculoskeletal in nature.

The diver flew home two days later at the end of his vacation. The pain had not improved but it was not significantly worsened by his flight. He saw his personal physician after getting home and was put on several medications for pain relief and muscle relaxation. He made a second visit to his physician five days after his initial visit with no real improvement in his pain. The office nurse, who was a diver, consulted DAN and the patient was referred to a local physician and referral chamber, now nine days out from symptom onset.

The examining dive physician found no neurological symptoms and ruled out other known causes and conditions associated with lower back pain. The diver was then compressed on a US Navy TT6 and within 10 min on oxygen his pain was reduced by half. At the end of his recompression treatment he rated his back pain as less than a '1' and he felt dramatically improved.

On follow up the next day he still had mild back pain and was given a shorter 90 min treatment that completely cleared his discomfort. He remained symptom free.

Case 5

This diver was a 59-year-old male technical-certified, recreational dive instructor on a live-aboard dive vessel. On the first day of his dive vacation he completed a series of four multilevel nitrox dives. Profiles follow: Dive #1-106 fsw (32 msw) for 53 min followed by a SIT of 1:49 h:min; Dive #2-123 fsw (37 msw) for 68 min with a SIT of 2:27 h:min; Dive #3- 91 fsw (28 msw) for 75 min followed by a 1:35 h:min SIT; Dive #4- 93 fsw (28 msw) for 43 min, exiting the water at 1830 local time. The dives were considered uncomplicated and each included routine safety stops.

Within 10 min of surfacing and boarding the boat from the last dive, the diver experienced bilateral shoulder pain throughout the areas where the straps of his buoyancy compensator contacted his body. He ignored these symptoms and proceeded to dinner where he then complained of unusual dizziness. Following dinner, he began complaining of numbness throughout his left shoulder and elbow and retired to his cabin where he attempted to rest. He emerged from his cabin within one hour appearing pale and complaining of generalized weakness and difficulty walking and nearly collapsed on the deck of the boat. He was assisted to breathe 100% oxygen for 35 min at which point the shoulder and elbow numbness was resolved and he stated that he then felt fine. His prior medical history was notable for hypercholesterolemia, asthma and gastroesophageal reflux disease. His medications at the time were Ibuprofen, Zocor (simvastatin), Asthmacort and imiprozol.

The local hyperbaric medical team was summoned while the diver was transported to a shore-based chamber. Although surface oxygen had reduced his symptoms and chief complaint, the diver was examined and found to be ataxic and unsteady on his feet. He entered the chamber four hours after symptom onset for treatment with a standard USN TT6 with no extensions. He reported resolution of all symptoms by the end of the treatment and returned the following morning for evaluation. Because he had experienced a return of mild numbness to the left arm during the night, he was retreated on a USN TT5 for a period of 2.5 hours with full resolution.

The diver returned to diving four weeks later and has since completed greater than 500 dives without further incident. Following the incident, he limits his diving to stay within the recreational no-decompression limits on nitrox and focuses on staying well-hydrated at the time of his diving.

Case 6

This diver was a 50-year-old female experienced recreational diver (>500 lifetime dives) on vacation in Mexico. She had completed a series of six dives over a three-day period; two dives per day. Her final day dive profiles were as follows: Dive #1-89 fsw (27 msw) for 42 min followed by a SIT of 33 min. Dive #2- 56 fsw (17 msw) for 52 min exiting the water at 1230 local time. There were no reported complications or problems with the dives and all dives included safety stops. However, she stated that she may have ascended rapidly from her safety stop on her final dive. Almost immediately upon exiting the water on the final dive she began complaining of a tingling sensation throughout her hands and arms which then progressed within moments to include numbness throughout both legs. The boat arrived at shore within 10 min, where she was unable to ambulate from the boat and required assistance. At shore she was placed on surface oxygen and transported directly to the local hyperbaric center where, on examination, she was also discovered to be hyper-reflexive with positive clonus findings. She received a standard USN TT6 with no extensions. She emerged from the chamber at 1830, having regained her ability to ambulate, but still with residual symptoms of tingling throughout her toes. She was scheduled for a follow-up exam the next morning and was discharged back to her hotel. She and her companion departed the facility for dinner and then returned to the hotel where 2.5 hours later she complained of distended lower abdomen and difficulty with urination, as well as bilateral lower extremity weakness. The diver was transported immediately back to the chamber where she was re-evaluated, catheterized and retreated with hyperbaric oxygen for a second USN TT6, this time fully extended.

Evacuation assistance to a major hyperbaric facility in Florida was provided. The patient then received two additional USN TT6 treatments with progressive improvement of lower extremity strength. Bladder function returned to normal following her third treatment. All symptoms were resolved and full strength restored in both lower extremities at the end of the fourth treatment. Following a two-day period of observation, the patient returned home. The patient had not returned to diving when follow up was completed two years later.

Case 7

This diver was a 12-year-old male who was snorkeling at a local freshwater spring. He performed a breath-hold dive to approximately 24 ffw (7 mfw). He encountered a “talk box;” an inverted box filled with compressed air to provide an air space for divers to be able to communicate verbally without returning to the surface.

He reportedly took at least two breaths inside the box and then swam to the surface. According to his father, he was exhaling continuously. Immediately upon reaching the surface the diver stated “I don’t feel good.” Bystanders reported that the young man appeared to lose consciousness and exhibited what was reported as seizure activity.

Local emergency medical service was contacted and they arrived within minutes to the scene. By this time the young man had regained consciousness but remained confused and weak. He was transported to the local hospital where a chest X-ray revealed pneumomediastinum without any sign of a pneumothorax. The patient was neurologically intact at this time. The patient was treated with oxygen and admitted to the pediatric intensive care unit (ICU).

The following day the pediatric ICU physician contacted DAN for consultation. The patient did not have any neurological symptoms and the pneumomediastinum was resolving. A computed tomography (CT) scan of the patient’s head showed no problems. The physician was concerned with the possible cause of the reported seizure activity as the patient was a normal healthy 12-year-old without history of seizure or neural deficit.

The consulting hyperbaric physician opined that the most likely cause for the symptoms was an AGE. The circumstance surrounding the injury, the initial onset of symptoms and the resulting pneumomediastinum made the diagnosis of AGE highly likely. While the patient’s condition and neurological status had returned, a USN TT6 was recommended to prevent latent symptoms or undetected secondary injury. The patient was discharged post-treatment having completely recovered.

APPENDIX B. DIVE FATALITY CASE REPORTS

B.1 Proximate Cause: Air Embolism

05-08 Certified, experienced diver, completing second dive of the day, buddy assisted her from safety stop to surface where she surfaced unconscious.
Cause of Death: Air Embolism due to Pulmonary Barotrauma due to Scuba Diving

This 40-year-old female was a certified diver with 75 lifetime dives. She was completing a second uneventful dive for the day when she signaled that she did not feel well while at the safety stop. Her dive buddy assisted her to the surface where she was noted to be unconscious before being brought onto the boat. Resuscitation efforts were unsuccessful. The autopsy disclosed gas in the carotid arteries and circle of Willis as well as mediastinal emphysema. Some of the characteristic findings associated with drowning were not present. The death was most likely due to an air embolism.
BMI = 23.7 $kg{\cdot}m^{-2}$

05-21 Experienced advanced open-water diver with no dives in preceding two years, no health problems, diving with buddies on two uneventful dives, lost consciousness on surface swim to boat
Cause of Death: Air Embolism due to Pulmonary Barotrauma due to Scuba Diving

This 72-year-old male was an experienced diver with advanced open-water certification. He had completed more than 300 dives but none in the preceding two years. He was diving from a liveaboard with two buddies. After completing two uneventful dives, the decedent lost consciousness during the surface swim back to the boat. The autopsy report was not available for review but it was reported that the diver had sustained an air embolism secondary to pulmonary barotrauma. The diver had an entirely negative health history and the autopsy did not disclose any evidence of significant natural disease processes.
BMI = na

05-50 Experienced technical diver, on third dive of the day from boat, surfaced with mass under his skin, taken to chamber but could not complete treatment, died next day, limited information.
Cause of Death: Air Embolism due to Pulmonary Barotrauma due to Scuba Diving

This 44-year-old male had technical diver certification and 25 years of diving experience. He was completing his third dive of the day from a boat when he noticed a mass under the skin of his shoulder as he surfaced. The decedent felt the mass move from his shoulder to his neck. There are few details regarding the case but the decedent was transported to a hyperbaric chamber where he became too unstable to complete recompression therapy. He died the next day. The death was likely due to an air embolism secondary to pulmonary

barotrauma based on the history of subcutaneous emphysema developing on ascent. An autopsy report was not made available.
BMI = na

05-75 Public safety diver, medical history of heart disease and obesity, made solo task dive to sunken boat with friend topside in boat, wearing drysuit, overweighted, surfaced and spoke but then lost consciousness and sank, out of air.
Cause of Death: Air Embolism due to Pulmonary Barotrauma due to Insufficient Air

This 49-year-old male had multiple medical problems, including hypertension, morbid obesity, ischemic heart disease, and elevated serum lipids. He was a certified diver and an active member of the local sheriff's dive team. The diver made a solo dive from a boat to look at how to salvage a sunken boat from the bottom. A friend waited topside in the boat. The diver was using a drysuit and was overweighted. He surfaced after 30 minutes at 50 ft (15 m) and said something to the person in the boat but then lost consciousness and sank below the surface. An examination of the diver's equipment revealed that his tank was empty. The autopsy disclosed cardiomegaly and focally severe coronary artery disease, but also intravascular and subcutaneous gas. The medical examiner felt that the diver died of a cardiac event but the dive history and empty tank make an air embolism likely.
BMI = 39.6 $kg{\cdot}m^{-2}$

05-85 Diver with advanced open-water certification, intermediate level experience, medical history for prostate cancer and hypertension, made dive with buddy on nitrox, surfaced fatigued after safety stop, panicked during surface swim and lost consciousness.
Cause of Death: Air Embolism due to Pulmonary Barotrauma due to Insufficient Air

This 60-year-old male had advanced open-water diving certification with approximately 25-30 lifetime dives. His medical history included prior surgery for prostate cancer, hypertension, and depression. The diver and a buddy went to 97 fsw (30 msw) for 17 minutes on nitrox. After the safety stop, the diver surfaced and complained that he was tired. He panicked during the surface swim and lost consciousness. The decedent's buddy brought him to the boat where resuscitation efforts were unsuccessful. The autopsy disclosed evidence of pulmonary barotrauma, intracardiac and intravascular gas, and mild coronary artery disease. An evaluation of the equipment showed that the decedent was low on air and he had 20 lb (9 kg) of integrated weights still in his buoyancy compensator. The case was signed out as an air embolism.
BMI = 28.7 $kg{\cdot}m^{-2}$

05-10 Inexperienced diver, diving with buddy, ran out of air and shared with buddy on emergency ascent, lost consciousness on ascent.
Cause of Death: Air Embolism due to Insufficient Breathing Gas

This 62-year-old male was a certified diver with 26 lifetime dives who was diving with a buddy from a liveaboard. The diver exhausted his air supply and he and his buddy shared air during an emergency ascent. The decedent lost consciousness during the ascent and could not be resuscitated. The death was reported to be due to "cardiac arrest," which is an inappropriate term to use on a death certificate as a cause of death. Given the circumstances and the experience level of the diver, this was much more likely a death due to air embolism.
BMI = na

05-58 Diver with unknown certification and experience, diving with buddy to wreck, buddy ran out of air and victim offered to share air, buddy pulled hose from regulator, did emergency ascent, victim lost consciousness at surface, buddy treated.
Cause of Death: Air Embolism due to Insufficient Air

This 49-year-old male was making a dive to 90 fsw (27 msw) to look at a wreck. The diver's buddy ran out of air and the diver offered to share air with him. The diver's buddy pulled the hose off the regulator and the two made an emergency ascent. The diver lost consciousness on the surface and could not be resuscitated. The decedent's buddy was treated for his injuries and survived. This was an air embolism due to an emergency out of air ascent.
BMI = na

05-67 Experienced diver with medical history of cancer, on chemotherapy and radiation, made shore-entry dive with buddy, became separated at safety stop, found on bottom unconscious.
Cause of Death: Air Embolism due to Insufficient Air

This 45-year-old male was a very experienced diver with more than 400 lifetime dives. He had a medical history that included metastatic lung cancer for which he was receiving chemotherapy and radiation therapy. In fact, he had received a radiation treatment on the day of this dive mishap. According to the investigation report, his physician advised him that diving would increase his oxygenation and therefore would be good for him. The decedent made a shore-entry dive to 84 fsw (26 msw) for 30 minutes with a buddy, and they ascended to the safety stop. The two divers became separated at the safety stop and the buddy found the decedent unconscious and on the bottom. The medical examiner determined the cause of death to be drowning secondary to an air embolism.
BMI = na

05-44 Experienced diver with unknown certification level, history of deep dives with no safety stops, made dive with buddies, diver went deeper alone, made rapid ascent and lost consciousness at surface, out of air
Cause of Death: Air Embolism due to Rapid Ascent due to Insufficient Air

This 59-year-old male was reported to be an experienced diver, though his certification level is unknown. The diver had a history of making deep dives, often to depths of 130-180 fsw (40-55 msw), without any safety or decompression stops. The decedent and two buddies made an ocean dive with the buddies staying at 70-80 fsw (21-24 msw) and the decedent making a deep excursion to 184 fsw (56 msw). He lost consciousness after breaking the surface, and an investigation revealed that his tank was empty. The death was from an air embolism secondary to a rapid ascent provoked by running out of air.
BMI = 23.5 $kg \cdot m^{-2}$

B.2 Proximate Cause: Drowning/Air Embolism

05-06 Certified diver with unknown experience and medical history of asthma, made repetitive bounce dives with buddy to collect artifacts, separated from buddy, panicked and sank, pulled unconscious from the water by his buddy.
Cause of Death: Drowning due to Air Embolism due to Scuba Diving

This 27-year-old male was a certified diver with an unknown amount of diving experience. He and a buddy were making repetitive bounce dives to 15 ft (5 m) in a river, searching for artifacts. They used ankle weights for the dives. The decedent had a medical history that included asthma, and he used an inhaler just prior to making the dives. During one of the bounces, the decedent separated from his buddy and ascended in a panic. He sank back below the surface and was pulled unconscious from the water by his buddy and brought to shore. The autopsy disclosed intravascular, intracardiac, and subcutaneous gas. The decedent's tank still contained 1000 psi (69 bar). The death was ruled a drowning secondary to an air embolism. The possible contribution of asthma to this death cannot be determined with certainty, but asthma is a known risk factor for pulmonary barotrauma.
BMI = 20.5 $kg \cdot m^{-2}$

05-37 Inexperienced advanced open-water certified diver, history of asthma with inhaler use, made uneventful dive day before, diving with buddy, they surfaced, diver lost consciousness and sank below the surface, and buddy got him to surface.
Cause of Death: Drowning due to Air Embolism due to Scuba Diving

This 54-year-old male had advanced open-water certification but had made fewer than 20 lifetime dives. He had only been a certified diver for a year. The diver had a history of asthma for which he used an inhaler. A day earlier the diver made an uneventful dive to 103 (31 msw) for 27 minutes. On this day the diver went to 103 fsw (31 msw) for 36 minutes. His buddy went up to find the boat, returned to depth, and then they both surfaced. The decedent pointed to his regulator and then to his chest before losing consciousness and sinking below the surface. His buddy assisted him to the surface but resuscitation efforts were unsuccessful. The autopsy disclosed changes associated with drowning, extensive intravascular gas, and pleural adhesions. The death was ruled a drowning secondary to an air embolism. Asthma may have contributed to this death.
BMI = 24.9 $kg \cdot m^{-2}$

05-22 Certified technical diver with unknown experience, made wreck dive with group, separated from and surfaced before other divers, did not drop weights and disappeared after struggling on the surface, found two hours later
Cause of Death: Drowning due to Air Embolism due to Rapid Ascent due to Insufficient Air

This 44-year-old male was a certified technical diver making a wreck dive in a group of four divers. He had a habit of going off on his own during dives. The seas were rough and the decedent surfaced ahead of the other divers. He grabbed onto a buoy but did not drop his weights and eventually let go. The diver drifted away from the boat and disappeared after struggling on the surface. His body was found two hours later. The medical examiner ruled the death a drowning due to an air embolism as a consequence of a rapid ascent. The diver had been low on air and toxicology was positive for diphenhydramine.
BMI = 26.3 $kg \cdot m^{-2}$

05-88 Certified but inexperienced diver, medical history positive for depression, on medication, made shore entry solo dive in poor visibility, found unconscious, equipment evaluation tank mounted backwards, out of air, computer showed rapid ascent with missed decompression stop.
Cause of Death: Drowning due to Air Embolism due to Rapid Ascent due to Insufficient Air

This 29-year-old male was a certified diver with fewer than 25 lifetime dives. His medical history included depression for which he was on prescription medication. The diver made a solo dive in freshwater using a shore entry. Visibility was poor. He was found unconscious on the surface by other divers in the area and could not be resuscitated. The autopsy disclosed changes consistent with drowning but the report did not address the possibility of pulmonary barotrauma. An examination of the equipment revealed that the tank was mounted backwards and the air had been exhausted. The dive computer showed that the decedent had descended to 163 ft (50 m) for a bottom time of 25 minutes. He then made an extremely rapid ascent, omitting at least four minutes of obligated decompression time. This was most likely an air embolism secondary to a rapid, out-of-air ascent. Nitrogen narcosis may have been a factor.
BMI = 22.4 $kg \cdot m^{-2}$

05-43 Inexperienced advanced open-water diver, smoker with several medical conditions, diving with buddy who had trouble equalizing, aborted first dive, and on second dive at depth, victim went into distress and lost consciousness, assisted to boat.
Cause of Death: Drowning due to Air Embolism due to Pulmonary Barotrauma due to Insufficient Air

This 50-year-old male had been certified one year. He possessed advanced open-water certification, with 43 lifetime dives. His medical history included hypertension, hemochromatosis, and cigarette smoking. The decedent was diving with his 13-year-old daughter who had trouble equalizing. They aborted the initial descent but then made it down to 35 ft (11 m). The decedent began thrashing about and lost a fin. The regulator fell from his mouth and he lost consciousness. After being assisted back to the boat, resuscitation efforts were unsuccessful. The autopsy disclosed extensive extra-alveolar gas and changes associated with drowning. The cause of death was determined to be drowning due to an air embolism.
BMI = 29.6 $kg \cdot m^{-2}$

05-53 Experienced obese diver with multiple certifications, medical history of hypertension on medication, made wreck dive with buddy in strong current, mask flood on ascent, panicked at safety stop and made rapid ascent to surface, lost consciousness.
Cause of Death: Drowning due to Air Embolism due to Pulmonary Barotrauma; due to Rapid Ascent due to Insufficient Air

This 47-year-old male was an experienced diver with multiple certifications. His medical problems included morbid obesity and hypertension treated with medication. The diver and a buddy made a wreck dive to 105 fsw (32 msw) for 26 minutes in a strong current. There were no problems until the ascent when the decedent's mask flooded at approximately 55 fsw (17 msw). The two divers went up to the safety stop where the diver panicked and made a rapid ascent to the surface. The diver's computer ascent rate violation rang. On the surface the dive buddy offered the stricken diver an alternate air source, which he may have used briefly but then he lost consciousness and could not be resuscitated. The autopsy disclosed changes associated with drowning as well as abundant intravascular and intracardiac gas and cardiomegaly. Toxicology was positive for morphine; administration during the resuscitation attempt cannot be excluded.
BMI = 49.8 $kg \cdot m^{-2}$

05-61 Diver certified for one year, experienced, made dive with buddy to barge, ran out of air, shared air and both ran out of air, both made an emergency ascent, victim was unconscious at surface, buddy had hyperbaric treatment.
Cause of Death: Drowning due to Air Embolism due to Pulmonary Barotrauma due to Rapid Ascent

This 50-year-old male had been certified for one year but allegedly had attained a fair amount of diving experience. He and a buddy made a dive in a lake down to a barge located at 112 ft (34 msw). The decedent ran out of air and the two divers shared an air source. Soon they were both out of air and they made an emergency ascent. The decedent went up ahead of his buddy and was unconscious upon reaching the surface. Resuscitation efforts were unsuccessful. The diver's buddy was treated at a local hyperbaric medicine facility and recovered. The autopsy disclosed changes associated with drowning as well as pulmonary barotrauma. This was a drowning death secondary to an air embolism caused by a rapid, out-of-air ascent.
BMI = 29.2 $kg{\cdot}m^{-2}$

B.3 Proximate Cause: Cardiac

05-03 Certified diver with unknown experience level, made wreck dive with buddy, had difficulty at depth, assisted to the surface, pronounced at local hospital.
Cause of Death: Cardiac Dysrhythmia

This 41-year-old male was a certified diver; his level of experience is not known. The diver made a wreck dive with a buddy to an unspecified depth and had a problem on the bottom. He was brought to the surface and then to a local hospital where resuscitation efforts were unsuccessful. An autopsy report was not made available, but the death was ruled to have been due to a cardiac event.
BMI = na

05-12 Experienced diver, made shore dive with group, thought to be removing his fins at the end of dive in shallow water, but victim was unconscious, died next day.
Cause of Death: Cardiac Dysrhythmia

This 64-year-old male was a certified, experienced diver who made a shore-entry dive with three other divers. At the end of the dive, the other divers thought the decedent was removing his fins in shallow water but they soon noticed that he was unconscious. He was transferred to a local medical treatment facility where he died the next day. The autopsy report was not released but the death was most likely due to a cardiac event.
BMI - na

05-34 Experienced advanced open-water diver, possible heart condition, diving with drysuit on wreck with group and left them to dive solo, did not surface and was found two hours later.
Cause of Death: Cardiac Dysrhythmia

This 33-year-old male had advanced open-water certification with five years of diving experience. He made a dive on a wreck with a large group but went off on his own as a solo diver. He allegedly practiced unsafe diving habits in the past. When he did not return to the boat after 90 minutes, a search was begun and his body was recovered from the bottom (85 fsw [26 msw]) 30 minutes later. The diver had been wearing a drysuit with a full face mask, using mixed gas. At least one report states that he was low on gas. The medical examiner

ruled the death as natural and likely due to a cardiac event. The decedent has been on an anticoagulant medication, which may indicate that he had a chronic heart rhythm problem.
BMI = na

05-25 Experienced diver preparing to make a shore-entry dive in rough seas, knocked down by a wave and lost consciousness with regulator in mouth, died four days later.
Cause of Death: Cardiac Dysrhythmia due to Scuba Diving

This 43-year-old female was an experienced, certified diver making a shore-entry dive in a rough sea state. According to the investigative report, she was knocked down by a large wave during the shore entry and lost consciousness. The regulator remained in her mouth. The diver was taken to a local hospital where she died four days later of complications from her injuries. The medical examiner ruled the cause of death as commotio cordis, which means an abnormal heart rhythm caused by a force applied to the chest wall. The circumstances fit that conclusion. The autopsy also revealed mild coronary artery disease.
BMI = 22.3 $kg \cdot m^{-2}$

05-78 Experienced diver, made dive with buddy in poor visibility, recording video, using rebreather, separated and found ten minutes later.
Cause of Death: Cardiac Dysrhythmia

This 43-year-old male was an experienced, certified diver who was using a rebreather on a dive with a buddy. They were recording a video in a lake with poor visibility. He and his buddy separated and the decedent was found unconscious approximately 10 minutes later in 13 ft (four meters) of water. A year after the death, the coroner certified the death as due to a cardiac event.
BMI = na

05-27 Certified diver with moderate diving experience, poorly conditioned with positive medical history for diabetes, hypertension and depression, on several medications, diving with instructor from boat, overweighted, difficulty breathing minutes into the dive, surfaced and lost consciousness at boat.
Cause of Death: Cardiac Dysrhythmia due to Coronary Atherosclerosis, Focally Severe

This 58-year-old female was a certified diver with moderate experience making a dive from a boat with an instructor. She was overweighted for the dive. The diver's medical problems included morbid obesity, diabetes, hypertension, and depression. She took several medications. The decedent complained of difficulty with breathing and fatigue approximately 15 minutes into the dive. She surfaced with the instructor and lost consciousness after returning to the boat. The diver was brought to a hyperbaric chamber where she was pronounced dead. The autopsy disclosed focally severe coronary artery disease and an enlarged heart. The death was determined to be due to a cardiac event.
BMI = 43.7 $kg \cdot m^{-2}$

05-28 Certified diver with unknown amount of experience, medical history positive for obesity, heart disease, diabetes and kidney problems, diving with two buddies, became short of breath and lost consciousness.
Cause of Death: Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 53-year-old male was a certified diver with an unknown amount of experience making a dive with two buddies. The decedent had a medical history that included heart disease, diabetes, and kidney problems. He was also overweight. After spending 13 minutes at 43 fsw (13 msw), the diver surfaced early because he did not feel well. Once back in the boat the diver complained of shortness of breath, began coughing, and then collapsed. The autopsy

disclosed coronary atherosclerosis and cardiomegaly. The cause of death was ruled to be a cardiac event.
BMI = na

05-36 Experienced, rescue diver did first uneventful dive with group, fatigued, short of breath and lost consciousness before second dive, pulled into boat but could not revive, severe coronary disease on autopsy.
Cause of Death: Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 64-year-old male had been certified five years and had attained rescue certification. He completed an uneventful dive to 52 fsw (16 msw) for 40 minutes with a large group of divers. The diver said he was fatigued and short of breath prior to the second dive. Before he descended for the second dive he lost consciousness and was pulled into the boat. Resuscitation efforts were unsuccessful. The autopsy showed focally severe coronary artery disease, pulmonary emphysema, and toxicology positive for diphenhydramine. The death was determined to be due to a cardiac event.
BMI = na

05-84 Certified diver with unknown experience level, multiple medical problems including obesity, respiratory episode after diving one week prior, made dive with buddy, problem at safety stop and surfaced in distress, lost consciousness.
Cause of Death: Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 54-year-old male was a certified diver with an unknown amount of diving experience. His medical history included obesity, hypertension, elevated cholesterol, and depression. He apparently had an episode of respiratory distress after surfacing from a dive one week earlier. The diver and a buddy went to 105 fsw (32 msw) for 24 minutes, and during the safety stop the diver began to have some sort of problem. He surfaced in distress and lost consciousness after calling for help. Unfortunately the medical examiner declined to perform an autopsy and signed the case out as a cardiac death. Given the history, an air embolism cannot be excluded.
BMI = 25.6 $kg \cdot m^{-2}$

B.4 Proximate Cause: Drowning/Cardiac

05-04 Experienced, obese technical diver, had difficulty at depth, buddy attempted to share air but diver had lost consciousness.
Cause of Death: Drowning due to Cardiac Dysrhythmia

This 62-year-old male was a very experienced technical diver who ran into difficulty at 60 fsw (18 msw) during a dive. His buddy tried to provide an alternate air source but the diver had lost consciousness. An autopsy was likely not performed but the death was ruled as a drowning due to a cardiac event. The deceased had cardiac risk factors including being overweight.
BMI = na

5-20 Experienced diver made wreck dive with buddy in strong current, buddy had equipment problem, surfaced, victim was fatigued and died at surface
Cause of Death: Drowning due to Cardiac Dysrhythmia

This 60-year-old male was an experienced, certified diver making a wreck dive to 75 ft (23 m) in a strong current. His buddy had a regulator problem so they surfaced. The diver was

fatigued at the surface and could not get into the boat under his own power. They had performed a safety stop. His buddy held the decedent's head above the surface but the stricken diver lost consciousness and could not be resuscitated. The autopsy report was not made available but the death certificate states that this was a "probable drowning due to an air embolism." The history is much more consistent with a cardiac event, however.
BMI = 30.2 kg·m^{-2}

05-30 Diver with one year certification and unknown diving experience, medical conditions include asthma, heart disease and back pain, smoker, made solo shore-entry dive, found floating unconscious minutes later, toxicology positive for opiates
Cause of Death: Drowning due to Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 43-year-old male had been a certified diver for one year, with an unknown amount of experience. His health history included asthma for which he used an inhaler, ischemic heart disease, and chronic back pain. He was also a smoker. The diver made a shore-entry dive by himself and was found floating unconscious 20 minutes later. The autopsy disclosed focally severe coronary artery disease and changes consistent with drowning. Additional findings included a simple renal cyst, and a patent foramen ovale. Toxicology was positive for opiates and diphenhydramine. The death was determined to be a drowning secondary to a cardiac event.
BMI = 21.1 kg·m^{-2}

05-32 Diver training in initial open-water course with group, could not continue dive and headed for shore, struggled on surface and lost consciousness, autopsy reported heart disease
Cause of Death: Drowning due to Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 53-year-old male was making a shore-entry dive with a group under instruction in what appears to have been an initial open-water certification course. During the dive he informed the instructor that he could not continue and headed toward shore. The diver was seen struggling on the surface and assistance was rendered but he lost consciousness and could not be resuscitated. The autopsy disclosed coronary artery disease, cardiomegaly, evidence of previous myocardial ischemia, and changes consistent with drowning. The medical examiner ruled the death a drowning due to a cardiac event.
BMI = 28.5 kg·m^{-2}

05-33 Certified but inexperienced, obese diver, diving with group, surfaced complaining of leg numbness, lost consciousness and disappeared, recovered two hours later.
Cause of Death: Drowning due to Cardiac Dysrhythmia due to Coronary Atherosclerosis, Focally Severe

This 44-year-old male had been a certified diver for 15 years but had little diving experience. He was diving in a large group and surfaced 10 minutes into the dive, complaining of leg numbness. During the surface swim back to shore he loses consciousness and his body was recovered two hours later approximately two miles from shore. The autopsy revealed changes associated with drowning as well as focally severe coronary artery disease and evidence of previous myocardial ischemia. The decedent was also morbidly obese. The medical examiner determined that the death was a drowning due to a cardiac event.
BMI = 39.3 kg·m^{-2}

05-47 Unknown certification and experience, training for unknown course, medical history of hypertension, obesity and gastric reduction, diving with buddy, became separated and found unconscious at depth, cardiac disease found on autopsy.
Cause of Death: Drowning due to Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 58-year-old male was a certified diver with an unknown amount of experience who was under instruction for an unknown training evolution. The diver's medical history included hypertension, morbid obesity, and a previous gastric reduction procedure. The diver and his buddy became separated during the dive and the diver was found unconscious at depth. Resuscitation efforts were unsuccessful. The autopsy disclosed moderate coronary artery atherosclerosis, marked cardiomegaly, and changes associated with drowning. The cause of death was drowning due to a cardiac event.
BMI = 47.1 $kg{\cdot}m^{-2}$

05-71 Experienced diver with rescue certification, diving with group and buddy on nitrox, began descent and ascended alone for unknown reason, found unconscious on bottom with regulator out of mouth.
Cause of Death: Drowning due to Cardiac Dysrhythmia due to Coronary Atherosclerosis

This was the second dive of the day for this 62-year-old male who had rescue diving certification and significant diving experience. He was in a group of five divers, including a designated buddy. The others descended the mooring line down to the anchor but the decedent went down a short ways and then ascended for an unknown reason. The diver was later found on the bottom, unconscious and with his regulator out of his mouth. He had a full tank of nitrox. The autopsy showed changes consistent with drowning as well as moderate coronary atherosclerosis. The medical examiner ruled the death a drowning with coronary artery disease a contributing factor.
BMI = 27.2 $kg{\cdot}m^{-2}$

05-80 Unknown certification and experience level, obese and heavy smoker, made shore-entry night dive in strong current with group to collect lobster, aborted dive and began swim to shore alone, found floating unconscious.
Cause of Death: Drowning due to Cardiac Dysrhythmia due to Coronary Atherosclerosis

The certification status and experience level of this 48-year-old male was unknown, but according to the investigation he had not been diving for several years. He was a heavy smoker and overweight. The diver made a shore entry night dive in a group of three divers to collect lobster. There was a strong current present. The decedent left his buddies to return to the beach because he felt it was too rough. He was later found floating unconscious by his buddies. The autopsy disclosed coronary artery disease with a ruptured plaque, cardiomegaly, pulmonary emphysema, and fatty change of the liver. The medical examiner determined the cause of death to be drowning secondary to a cardiac event.
BMI = 30.5 $kg{\cdot}m^{-2}$

05-81 Advanced open-water certified diver with unknown level of experience, last dive one year prior, medical history positive for heart disease and obesity, made dive with buddy who returned to boat for forgotten gear, victim struggled at surface, lost consciousness.
Cause of Death: Drowning due to Cardiac Dysrhythmia due to Coronary Atherosclerosis

This 48-year-old male had advanced open-water certification with an unknown amount of diving experience; his last dive was a year previously. The diver's medical history included a previous myocardial infarction, a persistent irregular heartbeat, and morbid obesity. The diver and his buddy swam out on the surface but the buddy decided to return to the boat to retrieve forgotten gear. As that occurred, the decedent was seen to struggle on the surface and the

buddy headed over to render aid. The decedent lost consciousness and did not respond to resuscitation efforts. The autopsy disclosed coronary artery disease, cardiomegaly, evidence of esophageal reflux, and changes consistent with drowning. The medical examiner determined the cause of death to be drowning secondary to a cardiac event.
BMI = 35.0 kg·m^{-2}

05-70 Diver with advanced open-water certification and unknown amount of experience, multiple medical problems on medications, made dive with group, signaled to buddy to ascend, separated at safety stop, found just beneath surface, unconscious, regulator out of mouth.
Cause of Death: Drowning due to Cardiac Dysrhythmia due to Cardiomegaly

This 52-year-old male had advanced open-water diving certification with an unknown amount of dive experience. He had multiple medical problems and took several medications including antidepressants and narcotics. The diver made a dive from a boat with a large group and utilized a buddy. After a period of time he notified his buddy that he wanted to go up. They were together at the safety stop but then separated. The boat crew found him just below the surface, unconscious, and with the regulator out of his mouth. The autopsy revealed a very thick left ventricle of the heart as well as changes associated with drowning. The death was likely due to a cardiac event that resulted in drowning.
BMI = 29.4 kg·m^{-2}

05-13 Poor conditioned, morbidly obese diver with unknown certification and experience, medical history significant for heart disease/surgery and medication for this condition, diving with group on second dive, surfaced and lost consciousness
Cause of Death: Drowning due to Acute Myocardial Infarction due to Coronary Atherosclerosis

This 52-year-old male had a past medical history that is significant for severe coronary artery disease treated with bypass surgery and stents. He still carried nitroglycerin for ischemic episodes. The decedent was also morbidly obese. His dive certification status and level of experience are unknown. The diver was in a large group and after surfacing from the second dive of the day with his dive buddy, he lost consciousness. Resuscitation efforts were unsuccessful. The diver was wearing 30 lb (14 kg) of weights which were not ditched during the mishap. The autopsy disclosed an acute thrombus of a coronary artery with plaque rupture. Additionally, the deceased had cardiomegaly and evidence of prior ischemic damage to the heart. Toxicology was positive for the beta blocker medication Metroprolol.
BMI = 37.7 kg·m^{-2}

B.5 Proximate Cause: Drowning/Insufficient Air

05-31 Diver with minimal diving experience, medical history of obesity and hypertension, made dive from boat with buddy, separated on bottom, found unconscious on bottom, overweighted, toxicology positive for cannabinoids.
Cause of Death: Drowning due to Insufficient Air due to Scuba Diving

This 54-year-old male received initial dive certification a year earlier and had made some dives in the distant past but overall he had minimal diving experience. He made a dive from a boat with his buddy but they became separated on the bottom. The decedent had been low on air at the time they separated and he was found unconscious on the bottom at 85 fsw (26 msw). The diver's past medical history was significant for hypertension and morbid obesity. The cause of death was determined to be drowning. Additional autopsy findings included coronary atherosclerosis, evidence of previous myocardial ischemia, a tongue contusion, and toxicology that was positive for cannabinoids. The diver also was overweighted for the dive.
BMI = 41.5 $kg \cdot m^{-2}$

05-39 Experienced diver had made dive with rebreather apparatus, using the remaining gas in his rebreather, he made a solo dive in a pool and was found unconscious on the bottom, out of air.
Cause of Death: Drowning due to Insufficient Air due to Scuba Diving

This 51-year-old male was an experienced, certified diver who had been out diving with a rebreather apparatus and wanted to use the remaining gas in his rig. He entered a swimming pool alone and was found unconscious at the bottom of the pool. Resuscitation efforts were unsuccessful. The medical examiner ruled the death a drowning due to an exhausted gas supply.
BMI = na

05-55 Certified, inexperienced diver, overweighted and advised to decrease weight but replaced weight with same amount, surfaced and could not inflate BC, out of air, sank and found two hours later, weights still in place.
Cause of Death: Drowning due to Insufficient Air

This 52-year-old female was a certified diver with only 10 lifetime dives. Prior to making a dive from a boat she configured her integrated weights with a total of 30 lb (14 kg) and when the divemaster advised her to decrease this she took six pounds (2.7 kg) from the integrated weights and replaced them with an equal weight in her BC jacket pocket. The diver surfaced from the dive and missed the tag line. She could not inflate her buoyancy compensator because she had exhausted her air supply. The diver sank below the surface and her body was recovered two hours later at 60 fsw (18 msw) with all 30 lb (14 kg) of weight still in place. The cause of death was ruled drowning.
BMI = na

05-60 Experienced dive instructor, spearfishing with group using rebreather, separated from group at depth, seen later with large fish on his spear, then shortly found unconscious, out of gas source, inadequate back up equipment.
Cause of Death: Drowning due to Insufficient Air

This 30-year-old male was a very experienced dive instructor with multiple specialty certifications. He was using a rebreather rig in a group of seven divers to spearfish. The decedent separated from the other divers at 190 fsw (58 msw) and was later seen with a large fish on his spear. Shortly after that he was found unconscious at 160 fsw (49 msw). The

stricken diver's buoyancy compensator was inflated by his buddy and he was brought to the surface where resuscitation efforts were unsuccessful. An inspection of the decedent's equipment provided the explanation for his death. The primary gas source had been exhausted and his bailout bottle was not configured in a usable manner; there was no regulator attached to it. In addition to changes associated with drowning, the autopsy disclosed mild coronary artery disease and a ruptured left eardrum.
BMI = 31.4 $kg \cdot m^{-2}$

05-73 Diver with unknown certification and moderate experience, poorly conditioned with health problems, made numerous dives with group but no buddy, to hunt lobster, continued dive with little air, surfaced in distress, lost consciousness.
Cause of Death: Drowning due to Insufficient Air

This 54-year-old male was a certified diver with moderate experience. His medical problems included morbid obesity and chronic hepatitis C with cirrhosis of the liver. He was making numerous excursions to the bottom of a shallow area (8-10 fsw [2-3 msw]), hunting lobster with a group of divers. It does not appear that the diver had a dedicated buddy. He went back to the boat but did not change tanks before continuing his diving. The diver abruptly surfaced in distress and lost consciousness. In addition to changes associated with drowning, the autopsy demonstrated coronary artery disease and cirrhosis of the liver.
BMI = 34.2 $kg \cdot m^{-2}$

05-79 Experienced diver, on second shore dive of day with buddy to collect lobsters, descended and separated, poor visibility, overweighted, body recovered later just below surface, air was not turned on.
Cause of Death: Drowning due to Insufficient Air

This 44-year-old female was a certified diver with ten years of diving experience. She was making a second dive of the day using a shore entry with a buddy in order to collect lobsters. The diver entered the water with her buddy and they swam to a buoy before descending. The two divers left the surface together but immediately became separated at 13 fsw (four msw), which was the bottom. Visibility was poor and the decedent was overweighted. The decedent's body was recovered 1.5 h later, just below the surface. An investigation revealed that the decedent entered the water without turning her air on. The death was ruled a drowning due to insufficient air.
BMI = 32.3 $kg \cdot m^{-2}$

05-11 Certified diver with unknown experience level, completed two uneventful dives with a buddy, then did a solo dive with minimal air, to retrieve a crab pot, found entangled in lines, weight still in place.
Cause of Death: Drowning due to Insufficient Breathing Gas due to Entanglement (Rope)

This 54-year-old male was a certified diver with three years of diving experience. He completed two uneventful dives with a buddy but entered the water for a third dive without a buddy. The purpose of the dive was to retrieve some crab pots, but the diver began the dive with minimal air in his tank. When rescue divers recovered the diver's body, he was entangled in the lines in a manner that prevented him from ditching his weights. The death was ruled a drowning.
BMI = na

05-23 Experienced diver with multiple medical conditions, game collection dive at night with group in kelp, separated and found unconscious with weights still on, tangled in kelp
Cause of Death: Drowning due to Insufficient Air due to Entangled (kelp)

This 49-year-old male was an experienced, certified diver on a night dive, collecting lobster with two other divers. His medical history included past alcohol dependence and chronic hepatitis C for which he was taking interferon. The diver became low on air and separated from the group. He was found unconscious and entangled in kelp, with weights that could not be ditched. The diver was taken to a hyperbaric facility where he was pronounced dead on arrival. The autopsy revealed changes consistent with drowning, moderate coronary artery disease, evidence of past myocardial ischemia, fatty liver, and an arteriovenous malformation involving the brainstem. The medical examiner thought that the arteriovenous malformation likely had a contribution to the death but the circumstances do not really substantiate that. Also, interferon therapy has numerous side effects and should be considered incompatible with safe diving.
BMI = 27.0 $kg{\cdot}m^{-2}$

05-51 Experienced and certified cave diver, diving with buddy in cave, silt out in cave, buddy had free-flow, shared air, buddy surfaced, body recovered next day, one tank empty and the other had closed valve.
Cause of Death: Drowning due to Insufficient Air due to Entrapment in a Cave

This 43-year-old male was a very experienced diver and certified cave diver. He and a buddy entered a freshwater cave and experienced a siltout 25 minutes into the dive at 109 ft (33 m). While exiting, the decedent's buddy had a free-flowing regulator and the two shared air. The decedent abruptly pulled his alternate air source back from his buddy and the buddy surfaced. The decedent's buddy used his own regulator to exit the cave. The decedent's body was recovered the next day. The death was ruled a drowning. An examination of the tanks used by the deceased revealed one empty tank and one tank with 2000 psi (138 bar) with the valve closed. One theory investigators proposed is that the valve was turned to off by rolling across the top of the cave.
BMI = 27.8 $kg{\cdot}m^{-2}$

05-69 Experienced diver with advanced open-water and cavern certification, made shore-entry dive into complex cave system, left spare air bottle at safety stop, out of air, buddy gave him his spare, did not surface, body recovered next day.
Cause of Death: Drowning due to Insufficient Air due to Entrapment (Cave)

This 34-year-old male was an experienced diver with advanced open-water and cavern diving certifications but no certification in cave diving. He and two other divers made a shore entry into a complex freshwater cave system. All three had spare gas bottles the decedent decides to leave his back at the safety stop. The decedent ran out of air at 184 ft (56 m) and one of his buddies gave him a spare gas bottle. The other two divers make it to the safety stop, but the decedent did not. His body was recovered later that day. The death was a drowning due to entrapment in a cave with an exhausted gas supply.
BMI = na

05-52 Instructor who took risks, including deep solo dives, heavy smoker, diving with advanced open-water student to wreck in poor visibility, entered restricted area and tight passageway, buddy surfaced, instructor found entangled in wreck pipes, out of air.
Cause of Death: Drowning due to Insufficient Air due to Entrapment in a Shipwreck

This 49-year-old male was an instructor who was known to take chances and make some high risk dives, including deep solo dives. He was also a heavy smoker and significantly

overweight. The diver was with a large group and informally took an advanced open-water student down to a shipwreck as a buddy. Visibility was poor and they entered a restricted area of the wreck at a depth of 105 fsw (32 msw). A hatch they opened had previously been welded shut and they entered a confined space without a line. Their light flooded and they were running low on air at the 74 minute mark of the dive. The decedent went through a tight passageway that his buddy could not follow him through and the buddy ascended to the surface. The instructor was recovered two days later entangled in some pipes in the boiler room of the ship. He had several tanks with him; all were empty. The autopsy disclosed mild coronary artery disease, a thickened left ventricular wall, a benign kidney tumor, and changes consistent with drowning.
BMI = 29.9 $kg \cdot m^{-2}$

05-56 Inexperienced, recently certified diver, training in advanced open-water class, had buoyancy problems, ran low on air, panicked, instructor attempted to share air, lost consciousness at depth.
Cause of Death: Drowning due to Insufficient Air due to Panic

This 57-year-old male was a recently certified diver with fewer than 20 lifetime dives. He was under instruction in an advanced open-water course. During the dive he had persistent buoyancy problems, ran low on air and panicked. The instructor tried to share air with the student but was unsuccessful. The student lost consciousness at depth and could not be resuscitated after being brought to the surface. The autopsy report was not made available. The cause of death was drowning but a contributing natural disease processes cannot be completely excluded.
BMI = na

B.6 Proximate Cause: Drowning/Various Causes

05-29 Certified diver with unknown experience level, diving with three others from boat in rough seas and poor visibility, boat malfunctions and on swim to land victim disappeared, found two days later.
Cause of Death: Drowning

This 28-year-old female was a certified diver with an unknown amount of experience making a dive from a boat in rough seas and poor visibility. She was with three other divers. While transiting to a dive site the boat engine died and the four divers decided to head for land. The other three divers were rescued after three days adrift at sea. The decedent's body was recovered two days after the divers entered the water. An autopsy was performed and the cause of death was determined to be drowning.
BMI = na

05-72 Double fatality, diver had problem at depth, divemaster drowned also, limited information.
Cause of Death: Drowning

There is little information available on the death of this 49-year-old male. He had some kind of problem on the bottom and both he and the divemaster who came to his aid reportedly drowned. This case is limited to a single fatality in the tally since the divemaster was a non-American/non-Canadian national for which little information was available.
BMI = na

05-74 Diver with advanced open-water certification and intermediate experience level, medical history positive for hypertension treated with medication, made series of drift dives with buddy, on second dive saw something beneath surface and descended, was found on bottom unconscious.
Cause of Death: Drowning

This 43-year-old male had advanced open-water certification with 35 lifetime dives completed. His medical history was remarkable for hypertension for which he took medication. He and a dive buddy were making a series of drift dives from a boat. After completing the second dive of the day the decedent surfaced and said he saw something so he descended again. The divemaster found the diver unconscious on the bottom. A very cursory autopsy was performed, and the death was ruled a drowning. The report mentions an abnormality found in the heart but what was described is a very common artifact that would not have contributed to the death. Some other divers in the group had complained of "bad air" but no toxicology or gas analysis information is available.
BMI = na

05-76 Certified diver with unknown level and experience, diving with buddy on scooter on first saltwater dive, had buoyancy problem, adjusted weight, had difficulty on swim to shore, sank below surface.
Cause of Death: Drowning

This 40-year-old male was a certified diver with an unknown amount of diving experience. He and a dive buddy were using scooters on the decedent's first lifetime saltwater dive. He had a buoyancy problem and returned to the boat for more weights. After beginning the dive again he felt he was still too buoyant and the two divers began to head back to the boat. The decedent swam ahead of his buddy and called out for help before dropping below the surface. The autopsy report was not made available but the death was officially reporting as a drowning. Air embolism cannot be entirely excluded.
BMI = na

05-77 Certified diver with unknown experience level, multiple medical problems, on medications, made uneventful dive with buddy, surfaced before buddy, in distress and lost consciousness, low on air.
Cause of Death: Drowning

This 48-year-old male was a certified diver with an unknown amount of diving experience. He had been diagnosed with multiple medical problems for which he took medications, including hypertension, attention deficit disorder, fatigue on exertion, and an abnormal electrocardiogram. The diver and a buddy were completing a dive from a boat and made it to the safety stop without event. The decedent surfaced ahead of his buddy and thrashed about on the surface before losing consciousness. The medical examiner ruled the death a drowning but conceded that a cardiac event may have contributed. The autopsy revealed cardiomegaly and evidence of prior cardiac ischemia. An examination of the decedent's tank showed that he was low on air.
BMI = 27.9 $kg \cdot m^{-2}$

05-82 Certified diver in refresher class, under instruction with buddy performing skills, panicked and instructor brought to surface, lost consciousness.
Cause of Death: Drowning

This 43-year-old female was a certified diver but enrolled in a requalification class. She and a buddy were under instruction, performing buoyancy control drills when she panicked and began to flail in the water. The buddy could not get her to the surface but the instructor

succeeded. By then she had lost consciousness and resuscitation efforts were unsuccessful. If an autopsy was performed, the report was not made available but the investigation indicated that the cause of death was determined to be drowning.
BMI = na

05-05 Inexperienced certified diver, poor swimmer, diving with buddy on shore dive in poor visibility, aborted dive and began swim to shore, separated and the victim was found later unconscious on the bottom, weight belt in place.
Cause of Death: Drowning due to Scuba Diving

This 51-year-old male was a certified but inexperienced diver, with fewer than 10 lifetime dives. The diver was reported to be a poor swimmer and prone to panic. Approximately 20 yards from shore the diver and his buddy decided to abort the dive due to poor visibility. They planned to swim the length of the pier. At that point the divers separated and the decedent, found unconscious on the bottom 1.5 h later during a search. His weight belt was still in place. An autopsy was not performed and the death was ruled a drowning.
BMI = na

05-09 Very experienced dive instructor, on wreck dive with group, multiple medical conditions including hypertension and liver disease, separated from others and surfaced alone, unconscious at surface.
Cause of Death: Drowning due to Scuba Diving

This 60-year-old male was a very experienced dive instructor making a wreck dive to 120 fsw (37 msw) with three other divers. His medical history was extensive and included hypertension for which he took medication, as well as cirrhosis of the liver and possibly a malignancy that involved the liver. The diver handed his camera off to another diver and headed for the surface. He was unconscious at the surface and could not be resuscitated. The death was ruled a drowning that was contributed to by an upper gastrointestinal tract hemorrhage due to cirrhosis of the liver.
BMI = 33.4 $kg \cdot m^{-2}$

05-17 Inexperienced diver, unknown if certified, solo diving with topside support, struggled at surface and found in six feet water.
Cause of Death: Drowning due to Scuba Diving

This 53-year-old male was "new to diving" and it is uncertain if he possessed formal certification. Minimal information is available on his diving related death but it was reported that he was solo diving with support topside on a boat. A lifeguard saw the diver struggling on the surface and a bystander swam out to render assistance. The body was recovered in approximately six feet of water. An autopsy was performed, and the death was ruled a drowning.
BMI = na

05-19 Certified diver with unknown experience, obese with hypertension and moderate coronary disease, made solo dive and found unconscious on bottom, toxicology showed alcohol intoxication
Cause of Death: Drowning due to Scuba Diving

This 45-year-old male was a certified diver with an unknown amount of experience. His health problems included obesity and hypertension. The diver was making a solo dive from a boat and was found unconscious at 68 fsw (21 msw) by other divers. The diver did not drop his weights but may have attempted to ditch his gear, according to the investigative report. The autopsy disclosed moderate coronary artery disease, and enlarged heart, and changes

consistent with drowning. Toxicology revealed a blood ethanol concentration of 122 $mg \cdot dL^{-1}$ (6.8 $mmol \cdot L^{-1}$) (80 $mg \cdot dL^{-1}$ [4.4 $mmol \cdot L^{-1}$] is the standard concentration resulting in driving-under-the-influence charges). The deceased complained about his regulator a few weeks earlier, but the equipment checked out okay. The death was ruled a drowning.
BMI = 32.5 $kg \cdot m^{-2}$

05-26 Experienced diver with medical history of hypertension and high cholesterol, completed dive for game collection, returned to water with mask and weight belt on to retrieve a dive buoy, caught in strong current and body was recovered after two days.
Cause of Death: Drowning due to Scuba Diving

This 49-year-old male was an experienced, certified diver on a lobster hunt with a buddy. The diver had a medical history that included hypertension and an elevated cholesterol level. The diver completed the dive and returned to the boat. He took off all of his gear except for a mask and weight belt before returning to the water to retrieve a dive buoy. At that point the diver got caught up in the strong current and drifted away from the boat. The body was recovered two days later and the autopsy findings were consistent with drowning.
BMI = na

05-38 Experienced dive instructor with neurological disease, made shore-entry dive with buddy, struggled on surface after dive in strong current, unable to use arms because of disease, aspirated water and lost consciousness.
Cause of Death: Drowning due to Scuba Diving

This 51-year-old male was a very experienced dive instructor who had been diagnosed with amyotrophic lateral sclerosis, a progressive, debilitating, neurological disease. The decedent made a shore-entry dive to 50 fsw (15 msw) with a buddy but struggled on the surface in a strong current after ascending from the dive. His neurological disease essentially prevented him from using his arms. The buddy tried to render assistance but the decedent lost consciousness after aspirating water. The autopsy findings were consistent with drowning.
BMI = 24.8 $kg \cdot m^{-2}$

05-41 Advanced open-water certified diver, no dives in last year, made dive with buddy from boat in strong current and poor visibility, new wetsuit, buddy had equipment problems and victim tried to help, struggled and drifted away, body recovered 10 days later.
Cause of Death: Drowning due to Scuba Diving

This 42-year-old female had been a certified diver for seven years and had attained advanced open-water certification. She had not made any dives in the previous year. The diver and a buddy entered the water from a boat to make a dive. The current was strong and visibility was poor. The decedent was wearing a new wetsuit for the first time and told her buddy that it was not comfortable. Almost immediately after entering the water the decedent's buddy had mask, fins, and buoyancy compensator problems. The decedent rendered aid but the buddy lost a fin. The decedent went after the fin, struggled in the current, and drifted away from her buddy. The buddy saw the regulator drop from the decedent's mouth. The body was recovered 10 days later, miles away from where the diver was last seen alive. The medical examiner ruled the case a drowning.
BMI = 25.9 $kg \cdot m^{-2}$

05-49 Certified, advanced level diver, made dive on a wreck in strong current, problem with mask, surfaced, struggled, and lost consciousness.
Cause of Death: Drowning due to Scuba Diving

This 53-year-old female had been a certified diver for four or five years with approximately 40 lifetime dives. She was making a wreck dive from a boat in a strong current. The decedent developed problems with her mask during descent at 10-15 fsw (3-5 msw). She surfaced and struggled on the surface. The divemaster rendered assistance and inflated her buoyancy compensator. The decedent lost consciousness in the process and resuscitation efforts were unsuccessful. The autopsy disclosed changes associated with drowning and pleural adhesions. There was no anatomic evidence of pulmonary barotrauma.
BMI = 24.1 $kg \cdot m^{-2}$

05-86 Diver with unknown certification and minimal diving experience, first dive in several years, made dive with buddy in poor visibility, separated, surfaced and descended separately, body recovered, weight belt unbuckled but still on, BC removed.
Cause of Death: Drowning due to Scuba Diving

There is much information missing regarding the death of this male diver, including his age and certification status. It appears that he had minimal experience and this was his first dive in several years. He and a buddy made a dive in a quarry and descended while 30-40 ft (9-12 m) apart. In the murky water they had no visual contact below the surface. According to witnesses, the divers surfaced independently and went back down. The buddy surfaced a second time but the decedent did not. His body was recovered by rescue divers. The decedent's weight belt was unbuckled but still on and his buoyancy compensator had been removed. An evaluation of the equipment revealed that the regulator was attached 180 degrees from the standard configuration. The death was reported out as a drowning.
BMI = na

05-57 Certified diver with unknown experience, did solo dive to collect scallops, two others in boat, after a while they did not see bubbles and pulled diver into boat, limited information.
Cause of Death: Drowning due to Scuba Diving

There is little information available on the death of this 47-year-old male. It is uncertain if he was a certified diver and his experience level is completely unknown. Apparently the diver entered the water alone while two other individuals waited topside in the boat. The diver planned on collecting scallops. When the individuals in the boat stopped seeing bubbles, they pulled him back up to the surface and tried to revive him. The autopsy report was not made available. The cause of death was drowning; however, complications from the person’s health history cannot be completely excluded.
BMI = na

05-89 Diver with basic certification and unknown experience, diving with group to shallow depth, surfaced complaining that he had swallowed water, lost consciousness.
Cause of Death: Drowning due to Scuba Diving

This 42-year-old male held an open-water certification for 15 years. It is not known how often he has gone diving in those 15 years. He was diving from a boat with three others and apparently submerged to a depth of approximately nine feet (three meters) before surfacing. The decedent returned to the surface and complained that he had swallowed some water before losing consciousness. Resuscitation efforts were unsuccessful. The autopsy disclosed some changes associated with drowning and nothing anatomically that would correlate with

air embolism. The death was reported out as an accidental drowning. The possibility of an air embolism, particularly with the history given, cannot be excluded.
BMI = na

05-01 Experienced diver, made series of solo river dives for personal task with no topside support, found two days later, tangled in rope, all equipment still in place.
Cause of Death: Drowning due to Entanglement (rope)

This 28-year-old male was a very experienced diver making a series of dives in a river to retrieve an anchor. After a very short, shallow first dive the deceased entered the water for a second dive. He was diving alone and without any topside support. The diver was found two days later, entangled in rope and with all of his equipment on. He had a knife sheath but the knife was not recovered. According to the dive computer, there was little or no air consumed during the second dive. The death was ruled an accidental drowning, but the complete autopsy report was not made available.
BMI = 31.0 $kg{\cdot}m^{-2}$

05-66 Experienced dive instructor, medical history positive for hypertension, heart disease and prostate cancer, diving with group, surfaced for more weight, became entangled in line, removed BC, struggled and found unconscious.
Cause of Death: Drowning due to Entanglement (rope)

This 69-year-old male was a very experienced dive instructor. His medical problems included hypertension, coronary artery disease, and prostate cancer. The decedent entered the ocean with a large group off a cruise ship. After entering the water the decedent felt he needed more weight and returned to the boat. He became entangled in the mooring line and slipped out of his buoyancy compensator. The decedent struggled at this point because his weights remained in place but he was not wearing a buoyancy compensator. He was found unconscious at 90 fsw (27 msw). An autopsy was performed and it disclosed cardiomegaly. The coroner certified the death as natural and due to congestive heart failure. Her logic was that the decedent had pleural effusions at autopsy and foamy fluid in the airway was absent. Unfortunately the circumstances almost dictate that this be certified as a drowning and pleural effusions are a common finding in drowning deaths. The diver began the dive with 12 lb (5.5 kg) of weight and ended up wearing 31 lb (14 kg) of weight by the time he ran into trouble.
BMI = na

05-35 Diver with minimal experience and unknown if certified, solo dive to attach chain to buoy, using inadequate and poorly maintained equipment, several dives but did not surface after last descent, found on bottom.
Cause of Death: Drowning due to Entanglement (weeds)

This 30-year-old male had minimal diving experience and it is unclear if he was a certified diver. He entered the water alone to attach a chain to a buoy. The diver did not wear fins, his equipment was out of inspection standards and in poor repair, and the power inflator of his buoyancy compensator was not connected. The dive was from a boat and to a depth of 18 ft (5.5 msw), with another person staying back in the boat. The diver surfaced at least once and maybe multiple times. When he did not come up at an expected time the person in the boat jumped in to find him but was unsuccessful. A rescue diver pulled the decedent from the bottom but resuscitation efforts were unsuccessful. The autopsy disclosed changes associated with drowning and gastroesophageal reflux disease as well as obesity. No evidence of air embolism was noted, though that does not completely exclude the possibility of pulmonary barotrauma. The death was ruled a drowning.
BMI = na

05-45 Inexperienced newly certified diver, made solo dive in strong current for lobster, inadequate equipment, became entangled in lines.
Cause of Death: Drowning due to Entrapment (line)

This 42-year-old male was a newly certified diver, having received his C-card six weeks earlier. He made a solo dive in a strong current to look for lobsters. The decedent did not use a buoyancy compensator and became entangled in lines attached to lobster pots. The report had conflicting information about whether the diver dropped his weights. There was still 2000 psi (138 bar) of air left in his tank. The autopsy report was not made available but the death was ruled a drowning.
BMI = na

05-46 Certified one year, but experienced rescue diver, made deep dive with buddy in poor visibility to break his own depth record, both became disoriented and separated, found five days later.
Cause of Death: Drowning due to Nitrogen Narcosis due to Scuba Diving

This 18-year-old male had been certified one year and had attained rescue certification, with approximately 75 lifetime dives. He and a buddy planned a dive to 230 fsw (70 msw) on air using twin tanks in murky water. The decedent was attempting to surpass his previous personal depth record of 200 fsw (61 msw). The buddy reported that they were both disoriented from nitrogen narcosis at 160 fsw (49 msw) and at that depth he lost sight of the decedent. The buddy ascended and completed 20 minutes of decompression time. When the decedent did not surface a search was launched. The body was recovered five days later. The cause of death was drowning secondary to nitrogen narcosis.
BMI = na

05-83 Diver with unknown certification and experience level, medical history of alcohol abuse, hypertension and depression, on multiple medications, drank alcohol and did solo dive, returned to boat in distress, found by rescue divers.
Cause of Death: Drowning due to Ethanol Intoxication (acute)

The certification status and diving experience of this 54-year-old male is unknown. From the investigation it appears that he was either recently certified or still a student. He had a medical history significant for alcohol abuse, hypertension, and depression, for which he took multiple medications. The diver and his buddy reportedly had "a couple of drinks" prior to going diving. The diver entered the water alone from the boat. His buddy decided not to dive. The diver returned to the boat after approximately 30 minutes in distress, attempted to get back into the boat on his own but fell back into the water. His buddy tried to bring him up but was not in scuba gear and was unsuccessful. Rescue divers eventually brought the decedent to shore. The autopsy disclosed changes associated with drowning, cirrhosis of the liver, and a blood ethanol concentration of 138 $mg \cdot dL^{-1}$ (7.7 $mmol \cdot L^{-1}$). The medical examiner called the death a drowning due to cardiac arrest but it was really a drowning due to scuba diving while acutely intoxicated with ethanol.
BMI = 29.3 $kg \cdot m^{-2}$

B.7 Proximate Cause: Unspecified or Body not Recovered

05-02 Diver with unknown experience and certification, made a dive with a guide and group, had difficulty breathing at depth, brought to surface where he collapsed.
Cause of Death: Unspecified Cause of Death

There is very little information available on the circumstances surrounding the death of this 63-year-old male. His certification status and experience level are not known. The diver apparently made a 20-minute dive to 53 fsw (16 msw) with a guide and other divers. According to the investigation, the diver had difficulty breathing while at depth and was assisted to the surface where he collapsed. This was very likely a cardiac-related death but there are no other details available.
BMI = na

05-16 Experienced dive instructor testing rebreather unit in pool, found unconscious at the bottom of the pool in four feet water, unknown cause of death.
Cause of Death: Unspecified Cause of Death

This 38-year-old male was a very experienced dive instructor who was testing out a rebreather rig in a swimming pool. He was found unconscious, at the bottom in approximately four feet (1.2 m) of water by a fellow instructor. Resuscitation efforts were unsuccessful. The investigation revealed a possible equipment problem but the autopsy report was not made available and the exact cause of death is not known.
BMI = 21.7 $kg{\cdot}m^{-2}$

05-87 Diver with unknown certification or experience, made shore entry dive, possible cardiac event, limited information
Cause of Death: Unspecified Cause of Death

There is very little information available on the death of this 46-year-old male. He made a shore entry dive and physicians who attempted to resuscitate him speculated that he may have suffered a cardiac event. There is no official report on the cause of death, diving experience, or certification status.
BMI = na

5-24 Student in open-water certification course, on ocean dive, limited information available.
Cause of Death: Unspecified Cause of Death

There was no information made available on the death of this 59-year-old male who was a student in an initial open-water certification course. It is known that the dive fatality occurred in the ocean but no other details were made available.
BMI = na

05-07 Very experienced advanced open-water diver, with medical history of hypertension, spearfishing with two buddies in strong current, using nitrox, surfaced and became separated, weight belt found 4 days later but victim never found.
Cause of Death: Unknown Case of Death, Body not Recovered

This 49-year-old male was a very experienced diver with advanced open-water certification. The diver's medical problems included hypertension. He and two other divers were spearfishing at approximately 120 fsw (37 msw) in a strong current and using nitrox. All of the divers surfaced away from the boat and became separated. One diver was picked up by the

boat immediately, another was rescued eight hours later, and the weight belt of the deceased third diver was found four days later. The body was never recovered.
BMI = na

05-15 Experienced diver and dive shop owner, diving with group, was low on air and began ascent, separated, body never recovered.
Cause of Death: Unknown Cause of Death, Body not Recovered

This 53-year-old male was a dive shop owner and very experienced diver. He and three other divers went down initially to 105 fsw (32 msw) and then through a swim-through at 130 fsw (40 msw). One buddy and the decedent noted that they were low on air and ascended while the other two divers stayed below. The decedent did not surface and his body was never recovered. Insufficient air and nitrogen narcosis likely contributed to this death, but without recovery of the body an exact cause of death cannot be determined.
BMI = 26.2 $kg \cdot m^{-2}$

05-18 Experienced diver made dive with buddy and group, diving on nitrox, spearfishing around wreck, separated, body never recovered.
Cause of Death: Unknown Cause of Death, Body not Recovered

This 34-year-old male was an experienced, certified diver making a nitrox dive from a boat with a buddy. The divers were part of a large group and were spearfishing around a wreck. The decedent separated from his buddy at 90 fsw (27 msw) and was never seen again. A body was not recovered.
BMI = na

05-40 Advanced open-water diver with intermediate level experience, history of trouble equalizing ears, several medical conditions including diabetes, obesity and smoking, on medication, diving with group but went off solo, on third drysuit dive on nitrox, body never recovered.
Cause of Death: Death, Unspecified Cause (Body not Recovered)

This 52-year-old male received his initial open-water certification three years earlier. He had advanced open-water certification, but had only made 35 lifetime dives. The diver's medical history included increased serum lipids, diabetes mellitus treated with oral medication, hypertension treated with medication, obesity, and cigarette smoking. He went on a dive with a large group but was essentially solo diving. The diver was making his third lifetime dive in a drysuit and planned to descend to 115 fsw (35 msw), deeper than he had ever been previously. He also had a history of having trouble equalizing the pressure in his ears. The dive was made using 28% nitrox. The decedent was seen at 110 fsw (34 msw) but was not seen again. A body was never recovered.
BMI = 26.9 $kg \cdot m^{-2}$

05-42 Unknown certification level and experience, diving with group, lost consciousness early in dive, possibly ran low on air, also possible stroke or air embolism.
Cause of Death: Death, Unknown Cause

There is little information available about the death of this male that was in his 50s. There were three divers in a group making a dive to 60 fsw (18 msw). The decedent lost consciousness 10 minutes into the dive. The report mentioned that the diver may have run low on air but also stated that it was possible he had a cerebrovascular accident (stroke) or even an air embolism. The latter is much less likely if the diver lost consciousness at depth without an ascent.
BMI = na

05-59 Recently certified, inexperienced diver, diving with group from boat, surfaced after 15 min bottom time and on surface swim to boat became distressed, lost consciousness, pulled into boat by buddy.
Cause of Death: Unknown Cause

This 50-year-old male was a recently certified diver with a minimal amount of diving experience. There is little information available about this death. The diver was diving from a boat with a group and went to 80 fsw (24 msw). He surfaced after 15 minutes of bottom time and was in obvious distress during the surface swim back to the boat. The diver was unconscious by the time his buddy pulled him to the boat and resuscitation efforts were unsuccessful. The autopsy report and any details about the cause of death were not released. The history is good for an air embolism as well as a cardiac event.
BMI = na

05-64 Diver certified but unknown experience, made dive with a buddy to a wreck, surfaced and lost consciousness, had made uneventful dive the day before, limited information.
Cause of Death: Unknown Cause

There is little available information about the death of this 58-year-old male who was a certified diver. He had completed an uneventful dive the day before. According to the available information, the decedent surfaced with a buddy from a wreck and rapidly lost consciousness. An autopsy was performed but the report was not made available. This was most likely an air embolism, but without the autopsy information the person's health history cannot be excluded.
BMI = na

05-65 Diver with unknown certification level and experience, diving with group in ocean, reported to have had heart attack, limited information.
Cause of Death: Unknown Cause

There is little available information about the death of this 54-year-old male. His dive certification status and level of experience are not known. He died while diving in the ocean with a group of 10 divers. One report stated that he had a "heart attack" but an autopsy report was not provided.
BMI = na

05-54 Experienced dive instructor made dive instructing four divers from boat, all divers disappeared, never recovered.
Cause of Death: Unknown Cause (Body not Recovered)

This 30-year-old male was an experienced dive instructor leading a group of four other divers from a boat. There was another group of divers diving from the same boat. The latter group completed the dive and returned to the boat. None of the decedent's group returned and no bodies were ever recovered. A multiday search yielded only a single buoyancy compensator. This case is described as a single fatality in the tally since the other four victims were non-American/non-Canadian nationals for which little information was available.
BMI = na

05-62 Unknown certification and experience, diver made first dive in cold water and poor visibility, panicked and removed her mask, lost consciousness, buddy went to surface for help, body never found.
Cause of Death: Unknown Cause (Body not Recovered)

There is little information available about the death of this 33-year-old female. Her certification status and amount of diving experience are not known. This was apparently the first dive for her in cold water and poor visibility. She reportedly panicked at 50 fsw (15 msw), lost her mask and regulator and then lost consciousness. Her buddy surfaced for help but when they went back down to assist the stricken diver, they could not locate her. The body was never recovered.
BMI = na

05-63 No details on this case.
Cause of Death: Unknown Cause (Body not Recovered)

There are no details regarding the diving related death of this 39-year-old male.
BMI = na

05-68 Experienced diver, made dive on rebreather using trimix, with buddy, had difficulty at depth, possible seizure, omitted decompression, buddy had problems at surface and could not hold victim, buddy treated for decompression sickness, victim never found.
Cause of Death: Unknown Cause (Body not Recovered)

This 43-year-old male was a very experienced, certified diver. He and a buddy were making a dive with rebreather rigs in rough seas. He had made two similar dives the day before without any difficulty. They were using trimix and the max depth was 186 fsw (57 msw). The decedent's rebreather had recently been serviced. The divers had a bottom time of 20 minutes but the ascent was eventful for some difficulty at 120 fsw (37 msw). The decedent may have used enriched air at that depth and had a seizure. The buddy assisted him to the surface; they had omitted approximately 50 minutes of decompression time. As the boat captain and the buddy tried to help the decedent into the boat, the dive buddy developed severe DCS symptoms and they lost their grip on the decedent. The decedent's body was never recovered but his rebreather apparatus was found four days later. It was not in a condition that was amenable to testing.
BMI = 22.5 $kg \cdot m^{-2}$

B.8 Proximate Cause: Other

05-14 Diver training on rebreather apparatus, separated from instructor who found him unconscious, died two days later.
Cause of Death: Hypoxic Encephalopathy due to Near Drowning due to Cardiac Dysrhythmia

This 33-year-old male was performing a training dive using a rebreather apparatus. The instructor lost sight of the diver and then found him unconscious. The diver was resuscitated and transferred to a medical treatment facility where he died two days later. The autopsy report was not released but the medical examiner found focally severe coronary artery disease. The diver was most likely incapacitated by a cardiac event and then suffered a near-drowning episode.
BMI - na

05-48 Experienced diver participating in advanced open-water class, on fourth dive of day, uneventful night dive, found unconscious at depth, treated at hospital and died next day.
Cause of Death: Hypoxic Encephalopathy due to Near Drowning due to scuba diving

This 50-year-old male had been a certified diver for five years who was under instruction taking part in a night dive during an advanced open-water training class. It was the fourth dive of a long day of training. According to the investigative report, the dive was uneventful and the diver and his buddy ascended to 17 ft (5 m) together. The two did not surface together and the instructor brought the diver to the surface. He had been unconscious at depth. The stricken diver was taken to a local hospital where he was treated for a day before being declared dead. The death was due to hypoxic encephalopathy from a near drowning incident. A precipitating medical event or possibly entanglement in weeds may have contributed to the mishap.
BMI = na

APPENDIX C. BREATH-HOLD INCIDENT CASE REPORTS

C.1 Hypoxia of Ascent

05-01 Fatal

This 38-year-old male was spearfishing with a partner. The water depth was approximately 65 fsw (20 msw) where the victim made his dive. He surfaced, signaled to his partner, then fell unconscious within five seconds and began to sink. His partner brought him to the surface from a depth of approximately six feet (1.8 m) and towed him to shore. Cardiopulmonary resuscitation was provided on shore with no success. Subsequent autopsy found no external injuries. The immediate cause of death was determined to be drowning. The events were consistent with hypoxia of ascent.
BMI - 30.7 $kg{\cdot}m^{-2}$

05-04 Fatal

This 34-year-old male was an avid freediver who entered the water from a dive liveaboard with the intention of practicing to extend his breath-hold time. He was alone. He was recovered unresponsive at the surface approximately 15 minutes later. No additional information was available. The surface location was consistent with hypoxia of ascent for a properly weighted breath-hold diver (neutral at approximately 15 ft [4.6 m]).

05-13 Fatal

This 37-year-old male was freediving with another individual while a third person remained in a tender dinghy. While underwater, the divers were not in sight of one another. A boat passing overhead caused the second diver to delay surfacing. When he did surface, the person in the dinghy described seeing the victim surface and then quickly submerge again. The body was recovered the next day from the bottom at 65 fsw (20 msw). It was speculated that the victim may have also delayed his ascent because of the boat traffic. No further information was available. The brief surfacing and rapid submersion was consistent with hypoxia of ascent.

05-18 Fatal

This 18-year-old male was spearfishing approximately 1,500 ft (450 m) from shore with two others. He was seen to become limp at a depth of 10 fsw (3 msw) while surfacing from a dive to approximately 70 fsw (21 msw). He was immediately brought to the surface and taken onto shore. Attempts at resuscitation were unsuccessful. An autopsy was performed. The immediate cause of death was determined to be asphyxia due to drowning as a consequence of a freediving accident. The events were consistent with hypoxia of ascent.
BMI - 24.6 $kg{\cdot}m^{-2}$

C.2 Possible Blackout or Hypoxia of Ascent (Unwitnessed)

05-06 Fatal

This 42-year-old male, experienced freediver went snorkeling alone in 48°F (9°C) water. He was physically fit with no known current health issues but a history of childhood asthma, hiatal hernia and gastric reflux. He failed to return; his body was found on the bottom at 13 fsw (4 msw) the next day. An autopsy was performed. Cause of death was determined to be drowning, due to two possible causes: it could have been secondary to an asthma attack provoked by cold water and saltwater inhalation; or it may have been a result of hypoxia of ascent. The explanation of possible hypoxic blackout is favored since the victim had no recent history of asthma attacks.
BMI - 23.9 $kg{\cdot}m^{-2}$

05-09 Fatal

This 20-year-old male was freediving alone in a freshwater spring cave. He was a competitive swimmer and university junior. The events were unwitnessed. His absence was reported by his girlfriend who was unaware that he left their campsite in the early morning. The body was found underwater. No further information was available.

05-10 Fatal

This 24-year-old male was an experienced freediver. He was a physically fit, competitive swimmer who worked as a lifeguard. After spending the day fishing at a lake, he called home in the late afternoon to indicate that he would be late so he could practice freediving. The events were unwitnessed. The diver was reported missing in the early hours of the next morning. The body was found by a dive team in the afternoon. No further information was available.

05-11 Fatal

This 31-year-old male was collecting abalone from a kayak along a rugged coastline. A friend left the site to call for help when he failed to surface. The friend returned to the site and found the victim on the bottom, pulling him to the surface by the time lifeguards paddled out. Attempts at resuscitation were unsuccessful. No further information was available.

05-16 Fatal

This 26-year-old male was spearfishing from a boat. He was a healthy, experienced freediver. His partner, who was on the boat, noticed that he was underwater longer than expected. Looking over the side, he saw the victim slumped over on the bottom at approximately 50 fsw (15 msw). He dived down to recover the victim. Attempts at resuscitation were unsuccessful. An autopsy determined the immediate cause of death to be drowning. No further information was available.
BMI - 24.4 $kg{\cdot}m^{-2}$

C.3 Boat Interaction

05-02 Non-Fatal

This 56-year-old male was snorkeling near shore when he was struck by a speedboat towing a wakeboarder. The propeller severed one of his arms just below the shoulder. The arm could not be saved. The wakeboard activity was unusually close to shore. Criminal charges were filed against the boat pilot.

05-12 Fatal

This 26-year-old male and a partner were snorkeling from an ocean beach 15 minutes before sunset. They had a float and dive flag with them. The victim was struck by a passing boat while on the surface. The boat did not stop. No further information was available.

C.4 Pre-Existing Health Issue

05-08 Fatal

This 44-year-old male told a friend that he intended to go freediving near an urban beach area early the next morning even if he did not find a partner. The events of the day were unwitnessed. The body was found by a swimmer late morning approximately 500 ft (150 m) from a seawall on the bottom at 40 fsw (13 msw). A wetsuit and a 17-lb. (7.7-kg) weight belt were in place. The victim had a history of seizure disorder and stroke. An autopsy was performed. The immediate cause of death was determined to be asphyxia due to or as a consequence of drowning. Seizures and cerebral infarction were listed as contributing causes or other significant conditions.
BMI - 27.3 $kg{\cdot}m^{-2}$

05-14 Fatal

This 59-year-old male was snorkeling with a crew member from the tourist dive boat he was on when he suffered what was suspected to be a heart attack. He was pulled from the water onto the dive boat. Attempts at resuscitation were unsuccessful. No further information was available.

C.5 Animal Interaction

05-03 Fatal

This 22-year-old male was spearfishing with a friend in late afternoon, within 1,000 ft (300 m) of shore. A great white shark made multiple runs at the victim, ultimately seizing him and carrying him underwater. The victim's partner shot at the shark but could not stop the attack. The victim's body was not recovered.

05-15 Fatal

This 37-year-old male was snorkeling near shore off a coastal beach with another male. The two were separated and the victim was reported missing when he did not return to the beach. His mutilated body was found the next day, approximately one mile (1.6 km) from the dive site. A crocodile attack was suspected. An autopsy report was not made available.

C.6 Entanglement

05-07 Fatal

This 46-year-old male and a partner were spearfishing separately from kayaks paddled out from shore. His partner noticed he was missing and found him underwater after 15-30 minutes had elapsed. The victim was on the bottom at approximately 30 fsw (9 msw) with his weight belt and fishing net tangled on a rock. An autopsy was performed. There was no evidence of trauma or foul play. The immediate cause of death was determined to be asphyxia due to drowning as a consequence of a freediving accident, likely entanglement. BMI - 27.1 $kg{\cdot}m^{-2}$

C.7 Insufficient Information - No Categorization

05-05 Fatal

This 59-year-old male was engaged in solo shore diving for abalone. He was pulled from the water by a bystander after his wife, who remained on shore, expressed concern over his floating motionless at the surface. Efforts to resuscitate him were unsuccessful. No further information was available.

05-17 Fatal

This 68-year-old male was snorkeling from a tourist craft with two family members. He was reportedly in good health and exercised daily but had no experience in snorkeling. Water conditions included unexpected swells, current and wind. The group was separated immediately upon entry when a second member of the group who was not wearing fins was carried away and the second went to assist. Neither partners nor boat crew saw the victim disappear. His body was not found.

APPENDIX D. PROJECT DIVE EXPLORATION DATA COLLECTION

DAN Interns Collecting PDE Data

Intern	Center	Dives Collected
2006		
Kristin Lyons	Ocean Frontiers, Grand Cayman	2.959
Juliana Belolloti	Atlantis Divers, Fernando De Noronha, Brazil	934
Catherine Sincich	Institute of Nautical Archaeology, Bodrum, Turkey	854
Mairead Conneely	Scapa Flow, Scotland	765
Lucas Keenan	University of California, Santa Cruz	547
Brett Anderson	Aquatic Safari & Diver's Emporium, Wilmington, NC	390
Eric Little	Utila Lodge, Bay Island, Honduras	275
Andrea Krzystan	South Florida dive shops	109
2005		
Robert Conway	Ocean Frontiers, Grand Cayman	1,222
Aaron Mishkin	Cozumel, Mexico	1,130
Jessica Begyn	Sunset House, Grand Cayman	1,079
Matt Horton	Global Underwater Explorers, High Springs, FL	921
Lisa Zuckerwise	Aquatic Safaris, Wilmington, NC	338
Steve Hardy	Nautilus Explorer, Canada / Silent World, WA	191

Independent FRCs - Top collectors (over 100 dives submitted)

Peter Berende
Patrick Murphy
David Grenda
Robert Eichholtz, Jr.
Brian Basura
Dave Valaika

APPENDIX E. PUBLICATIONS

2005

Refereed Articles (primary literature)

Moon RE. Bubbles in the brain: what to do for arterial gas embolism? Crit Care Med. 2005; 33:909-910.

West BJ, Griffin LA, Frederick HJ, Moon RE. The independently fractal nature of respiration and heart rate during exercise under normobaric and hyperbaric conditions. Respir Physiol Neurobiol. 2005; 145:219-233.

Vann RD, Pollock NW, Pieper CF, Murdoch DR, Muza SR, Natoli MJ, Wang LY. Statistical models of acute mountain sickness. High Alt Med Biol. 2005; 6(1):32:42.

Book Chapters

Pollock NW. Human physical stresses at normal and abnormal cabin pressures. In: Handbook of Environmental Chemistry, Volume 4, Part H of Series on Air Pollution: Air Quality in Airplane Cabins and Similar Enclosed Spaces. Heidelberg, Germany: Springer-Verlag; 2005: 87-109.

Edited Proceedings

Mitchell SJ, Doolette DJ, Wachholz CJ, Vann RD, eds. Management of Mild or Marginal Decompression Illness in Remote Locations: Workshop Proceedings. Proceedings of the May 24-25, 2004 Workshop. Durham, NC: UHMS/Divers Alert Network; 2005: 240 pages pp.

Pollock NW, Uguccioni DM, Dear GdeL, eds. Diabetes and recreational diving: guidelines for the future. Proceedings of the Undersea Hyperbaric Medical Society/Divers Alert Network 2005 June 19 Workshop. Proceedings of the Workshop. Durham, NC: Divers Alert Network; 2005: 136 pp.

Proceedings Articles

Freiberger JJ, Denoble PJ. Is there evidence for harm from delays to recompression treatment in mild cases of DCI? In: Mitchell SJ, Doolette DJ, Wachholz CJ, Vann RD, eds. Management of Mild or Marginal Decompression Illness in Remote Locations. Kensington, MD: Undersea Hyperbaric Medical Society; 2005: p. 70-89.

Moon RE, Dear G de L, Nord D. Diagnosing decompression illness in remote locations. In: Mitchell SJ, Doolette DJ, Wachholz CJ, Vann RD, eds. Management of Mild or Marginal Decompression Illness in Remote Locations. Kensington, MD: Undersea Hyperbaric Medical Society; 2005: p. 22-29.

Pollock NW, Uguccioni DM, Dear G de L. 2005 diabetes and recreational diving workshop: executive summary. In: Pollock NW, Uguccioni DM, Dear G de L, eds. Diabetes and recreational diving: guidelines for the future. Proceedings of the Undersea Hyperbaric Medical Society/Divers Alert Network 2005 June 19 Workshop. Durham, NC: Divers Alert Network, 2005: p. 5-9.

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APPENDIX F. GLOSSARY

Acetaminophen
Tylenol, paracetamol, N-acetyl-p-aminophenol, APAP. A drug that is used as an alternative to aspirin to relieve mild pain and to reduce fever.

Antihistamine
Drug that may be part of some 'over-the-counter' (OTC) medicines for allergies and colds. Some antihistamines cause drowsiness. See Over-the-Counter.

Ambiguous DCS
A case where the diagnosis of DCS is not certain; for example, a case with sufficient decompression exposure but minimal, atypical symptoms or symptoms of short duration that spontaneously resolve.

Arterial Gas Embolism (AGE)
Air in the arterial circulation. In divers this may be caused by a sudden reduction in ambient pressure, such as a rapid ascent without exhalation that causes over-pressurization of the lung and pulmonary barotrauma. The most common target organ is the brain, and the usual signs and symptoms include the rapid (<15 min) onset of stroke-like symptoms after reaching the surface.

International Association for the Development of Apnea (AIDA)
Established in 1992 to manage and oversee the recognition of records, organize competitions and develop standards for freediving education.

Atmosphere (atm)
Measure of atmospheric pressure indexed to the normal conditions at sea level. Normal sea level pressure is 1.0 atm, 1.0 bar, 14.685 pounds per square inch, or 0.01 kilopascals of pressure.

Barotrauma (BT)
A condition caused by a change in ambient pressure in a gas-filled space due to the effects of Boyle's law (see definition below). When gas is trapped in a closed space within the body, the gas will be compressed if the depth increases and will expand if the depth decreases. Barotrauma injuries of descent include ear squeeze, tympanic membrane rupture or sinus squeeze. Injuries of ascent include pulmonary barotrauma, which can result in air embolism, pneumothorax or pneumomediastinum.

Body Mass Index (BMI)
BMI is measure of body weight:height proportionality used to predict body composition. It is computed by dividing body weight in kilograms by the squared height in meters. BMI is often used as a convenient surrogate for actual body composition measures. Body composition categorization by BMI (in $kg{\cdot}m^{-2}$): <18.5 = underweight; 18.5 to <25.0 = normal; 25.0 to <30.0 = overweight; 30.0 to <35.0 = grade 1 obesity; 35.0 to <40.0 = grade 2 obesity; and ≥40.0 = morbid obesity.

Bounce Dive
Any dive where the diver returns to the surface with little or no decompression. This is opposed to a saturation dive, where decompression can require many days, depending on the depth.

Boyle's Law
Under conditions of constant temperature and quantity, there is an inverse relationship between the volume and pressure for an ideal gas. Volume increases as pressure decreases and vice versa.

Buoyancy Compensator (BC)
Device used to regulate buoyancy during diving activity. Necessary given the buoyant changes associated with gas compression and expansion.

Carbon Monoxide (CO)
Carbon monoxide binds to hemoglobin 200-250 times more effectively than oxygen, effectively reducing the oxygen carrying capacity of the blood.

Cause of Death (COD)
The medically determined reason for death. This is often distinct from the factors leading to the situation in which death occurred.

Cerebrovascular
Pertaining to the blood vessels of the brain.

Chokes
Pulmonary decompression sickness. Respiratory distress after a dive characterized by sore throat, shortness of breath, and / or the production of pink, frothy sputum. The cause of chokes is poorly understood but may result from low-pressure pulmonary edema that caused by large quantities of bubbles in the venous circulation that damage the cells of the blood vessel wall leading to pulmonary capillary leakage, circulatory blockage and respiratory dysfunction due to impaired gas exchange.

Clonus
A form of movement marked by rapid succession of contractions and relaxations of a muscle.

Coronary Artery Disease
A disease with many causes resulting in the thickening, hardening and narrowing of the medium to large-sized arteries of the heart.

DARF (Diving Accident Report Form)
A form used by DAN from 1987 through 1997 to collect information about injured divers treated in recompression chambers.

Decompression Dive
A dive that requires decompression stops during ascent; limits vary with the dive tables or computer model used.

Decompression Illness (DCI)
The broad term that encompasses both DCS and AGE. DCI is commonly used to describe any disease caused by a reduction in ambient pressure. It is used because the signs and symptoms of DCS and AGE can be similar and because recompression is the treatment for both.

Decompression Sickness (DCS)
A disease caused when the total gas tension dissolved in a diver's tissue exceeds ambient hydrostatic pressure and gas bubble formation occurs. The symptoms may include itching, rash, joint pain, muscle aches or sensory changes such as numbness and tingling. More serious symptoms include muscle weakness, paralysis or disorders of higher cerebral function, including memory and personality changes. Death can occur from DCS, although very rarely in modern times. See also Type I DCS and Type II DCS.

Depth-Time Profile — See Dive Profile

Diabetes
A disease characterized by improper production or improper use of insulin in the body. Most common form is Type II (non-insulin-dependent diabetes mellitus; NRDM), largely controllable by diet and exercise. Less common is Type I (insulin-requiring diabetes mellitus; IRDM), controlled with insulin therapy.

DIRF (Diving Injury Report Form)
A form used by DAN from 1998 through 2004 to collect information about injured divers treated in recompression chambers.

Dive Computer
Personal electronic devices that continually measure time and pressure during the dive, calculate remaining dive time, monitor ascent rate and provide instructions for decompression. Dive computers may employ any one of a number of mathematical models to compute decompression status. Some dive computers are integrated with breathing gear and may measure the pressure in gas dive cylinders.

Dive Log
The dive log is a document maintained by divers in which relevant information about dives is recorded. The amount of information depends on personal interest of divers. See Dive Log-7 for the computerized dive log information of interest for PDE.

Dive Log-7 (DL-7)
A standard computer format for recording information about divers, their dive profiles and medical outcomes.

Dive Profile
A set of depth-time-gas points describing the dive. The number of points depends on the minimal recording interval of dive recorder and can vary from one second to one minute. For use in PDE, the recording interval should be five seconds or less.

Dive Recorder
An electronic device that records depth and time during the dive. The recorder does not calculate saturation of the body with inert gas and does not provide any instruction for decompression. Some recorders are designed as "black boxes," with no visible display, while others have a display to indicate current depth and time of dive.

Dive Safety Lab (DSL)
A project similar to Project Dive Exploration developed and conducted by DAN Europe, with shared goals and methodology.

Dive Series
As applied to PDE, all the dives between a period of 48 hours without diving and 48 hours without diving or flying.

Diving Accident Report Form – See DARF

Diving Injury Report Form – See DIRF

EAN (Enriched-Air Nitrox)
A nitrogen / oxygen breathing gas mixture containing more than 21% oxygen, usually made by mixing air and oxygen. Also known as nitrox and oxygen-enriched air.

Emergency Medical Services (EMS)
System responsible for providing pre-hospital or out-of-hospital care by paramedics, emergency personnel, emergency medical technicians, and medical first aid responders.

FAD (Flying After Diving)
For this report, all flights within 48 hours after diving are considered "flying after diving." Flying after diving involves exposure of divers to a secondary decompression. The cabin altitude of pressurized commercial airliners must be maintained at 8,000 ft (2,438 m) or less by law. However, most aircraft are only pressurized to around 6,000 ft (1,800 m), approximately 80% of the atmospheric pressure at sea level. In the first few hours after a dive, a diver may still have enough excess nitrogen dissolved in his body to allow the secondary decompression stress from flying to cause decompression sickness. Unpressurized aircraft may reach altitudes in excess of 8,000 ft. Divers may also be exposed to reduced atmospheric pressure by mountain travel.

First Aid Oxygen – See Surface Oxygen Treatment

Field Research Coordinator (FRC)
A trained volunteer who helps DAN collect data for PDE.

Feet of Freshwater (ffw)
A unit of pressure synonymous with depth in freshwater. Thirty-four feet of freshwater is equal to approximately one atmosphere, 1 bar, 14.685 pounds per square inch, or 0.01 kilopascals of pressure. The differences in density of seawater and freshwater result in small pressure differences at the same depth.

Feet of Seawater (fsw)
A unit of pressure synonymous with depth in salt water. Thirty-three feet of seawater is equal to approximately one atmosphere, 1 bar, 14.685 pounds per square inch, or 0.01 kilopascals of pressure. The differences in density of seawater and freshwater result in small pressure differences at the same depth. The fsw term is traditionally used by Navy and was adopted by the dive industry. For metric conversions, the term is meters of seawater (msw). 1 fsw = 0.30479999 msw.

Fisher Exact Test
A non-parametric statistical test like Chi Square except that it calculates an exact p value; useful if the marginal is very uneven or if the value in a single cell is very small value. Exact p values tend to be more conservative than most approximate estimates, such as Chi Square or t-test.

Freediving
Breath-hold diving conducted while wearing a mask and some form of fin or fins. Freedivers generally dive to depth and train to increase their range. Freediving is typically conducted in open-water settings. See also Breath-Hold Diving and Snorkeling.

Hart-Kindwall Oxygen Recompression Treatment Table
A 2:30 h:min recompression protocol used to treat decompression sickness. Oxygen is breathed throughout. The protocol employs a maximum pressure equivalent to a depth of 60 fsw (18 msw).

Decompression travel is at 1 ft·min^{-1} (2 ft·min^{-1} if all symptoms were mild and cleared within the first 10 min of reaching the 60 fsw).

Heliox – See Mixed Gas

Health Insurance Portability and Accountability Act (HIPAA)
U.S. Federal legislation designed to protect the privacy and interests of individuals and their families. DAN collects dive injury and fatality information in compliance with HIPAA.

Hypertension
High blood pressure. A medical condition associated with the development of heart disease and stroke.

Hyperventilation
Voluntary ventilation of the lungs in excess of metabolic need (achieved by increasing depth of breaths and/or rate of breathing). Often used to lower carbon dioxide content of the bloodstream and increase breath-hold time. Excessive hyperventilation will increase the risk of loss of consciousness due to hypoxia.

Hypoxia
Condition of lower-than-normal oxygen partial pressure in the blood. Also see Hypoxia of Ascent.

Hypoxia of Ascent
Unconsciousness resulting from hypoxia compounded by surfacing at the end of a breath-hold dive. The reduction in pressure associated with returning to the surface causes the oxygen partial pressure to fall faster than through metabolism of the gas alone. Commonly called shallow water blackout in North America, but not desired since this name was previously used in the UK to describe a different problem. See also Hyperventilation, Hypoxia, and Hypoxic Loss of Consciousness.

Hypoxic Loss of Consciousness (HLOC)
Loss of consciousness resulting from an acute state of hypoxia.

International Association for the Development of Apnea (AIDA)
AIDA is the Worldwide Federation for breath-hold diving, established in 1992. The association manages and oversees the recognition of records, organizes competitions, and works to promote standards for freediving education.

Kruskal-Wallis
A nonparametric statistic used to compare three or more samples. The null hypothesis is that the groups have comparable distributions; the alternative hypothesis is that at least two of the samples differ (with respect to median). It is analogous to the F-test used in analysis of variance (parametric). While analysis of variance tests depend on the assumption of normal distribution, the Kruskal-Wallis test is not so restricted.

Lung Barotrauma – See Pulmonary Barotrauma

Mean
The arithmetic average calculated by taking the sum of a group of measurements and dividing by the number of measurements. See Median.

Median
The middle value in a range of numbers. Half the numbers are higher than the middle value and half are lower. The mean and median will be extremely similar if the group of numbers is normally distributed. See Mean.

Mediastinal Emphysema (Pneumomediastinum)
Air that surrounds the heart (not within the heart or blood vessels). This is usually the result of pulmonary barotrauma.

Mixed Gas
Any breathing gas made by mixing oxygen with other gases. Mixed gas usually consists of oxygen plus nitrogen and / or helium. Heliox refers to helium and oxygen mixtures, nitrox to nitrogen and oxygen mixtures. Trimix refers to mixtures containing helium, nitrogen, and oxygen.

Meters of Seawater (msw)
1.0 msw = 3.28084 fsw. See Feet of Seawater (fsw).

Multiday Diving
Dives spread out over a period longer than 24 hours but where the surface interval between successive dives is less than 24 hours.

Multilevel Dive
A dive where the diver spends time at several different depths before beginning his or her final ascent to the surface. Usually associated with dive computers that allow a diver to ascend gradually from maximum depth while tracking the decompression status.

Myocardial Infarction
Heart attack. Death of some of the cells of the heart from lack of adequate blood supply resulting from constriction or obstruction of the coronary arteries.

Nitrogen Narcosis
Euphoric and anesthetic effect of breathing nitrogen at greater than sea level pressure. All gases except helium have an anesthetic effect when their partial pressure is increased. Because nitrogen is the principal component of air, its anesthetic effect is the most pronounced in divers at depth and may cause serious impairment of mental abilities. Nitrogen narcosis is first noticed when breathing air at depths of 60-100 fsw (18-30 m of seawater), depending on diver susceptibility.

Nitrox – See EAN and Mixed Gas

No-Decompression Dive or No-Stop Dive
A dive where direct ascent to the surface at 30-60 fsw (9-18 m of seawater) per minute is allowed at any time during the dive without a decompression stop.

Normal Distribution
A group of numbers is normally distributed when the majority are clustered in the middle of the range with progressively fewer moving out to both extremes. The frequency plot of a normal distribution appears as the classic bell-shaped curve.

Obesity – See BMI (Body Mass Index)

Over-the-Counter (OTC)
Medications/Drugs purchased legally without a prescription.

Oxygen-Enriched Air – See EAN

Oxygen Toxicity
Syndrome caused by breathing oxygen at greater than sea level pressure. Primarily affects the central nervous system (CNS) and lungs. CNS oxygen toxicity may come on immediately and be manifested by seizures, twitching, nausea and visual or auditory disturbances. It may occur in a highly unpredictable manner at partial pressures greater than 1.4 to 1.6 atm in an exercising diver. Pulmonary oxygen toxicity can take much longer to develop (hours) but may occur at lower partial pressures of oxygen (>0.50 atm). Pulmonary oxygen toxicity is caused by inflammation of the lung tissue, resulting in shortness of breath, cough and a reduced exercise capacity.

Protected Health Information (PHI)
Information that could disclose the identity of a research subject, patient or decedent according to the Health Insurance Portability and Accountability Act (HIPAA). DAN does not disclose PHI to any party other than employees, representatives and agents of DAN who have a need to know.

Perceived Severity Index (PSI)
A measure of the severity of decompression injury.

Paresthesia
Numbness or tingling of the skin; a common symptom of DCS in recreational divers.

Pneumomediastinum – See Mediastinal Emphysema

Pneumothorax
A collection of gas in the pleural space (the space surrounding the lungs) which results in collapse of the lung on the affected side.

Pulmonary Barotrauma
Damage to lungs from expanding gas. See Barotrauma

Pulmonary Emphysema
A medical condition commonly caused by smoking that leads to abnormal distension of the lungs resulting from the destruction of its supporting and elastic internal structure.

Pulmonary Overexpansion
Abnormal distension of the lungs. In divers, pulmonary overexpansion usually results from the effects of Boyle’s law. It can cause rupture of alveoli and penetration of gas into various surrounding spaces, causing mediastinal emphysema, pneumothorax or arterial gas embolism.

Rapid Ascent
An ascent rate fast enough to put a diver at increased risk of decompression illness (DCI), usually at rates in excess of 60 fsw (18 msw) per minute.

Recompression Treatment
Treatment involving a return to pressure. Typically completed in a recompression chamber but, in some cases, may involve an in-water return to pressure. Well-established, standard treatment tables exist for recompression chamber therapy. See United States Navy Treatment Tables 6 and 5 (USN TT6 and TT5) and Hart-Kindwall.

Repetitive Dive
For the purposes of DAN’s injury reporting, a repetitive dive is any dive occurring within 24 hours of a previous dive. The previous dive affects the decompression requirements of the repetitive

dive. Some decompression computers carry over information from previous dives for 24 hours or longer, depending on the decompression model used.

Representative Sample
A group selected from a population for testing that reasonably represents the characteristics of the population.

Residual Symptoms
Symptoms remaining at the conclusion of treatment. May respond to additional treatments, be refractory to further treatment but eventually resolve spontaneously, or permanently.

Resolution of Symptoms
Symptoms resolving (disappearing) after appearance. Resolution may be spontaneous or in response to treatment.

Rhomberg (Sharpened)
The Sharpened Rhomberg test is intended to detect ataxia, commonly used for diver assessment. The subject stands erect on a firm, level surface with feet aligned in a tandem (heel-to-toe) position. The arms are then folded across the chest. Once stable, the subject is instructed to close his or her eyes and to maintain the position for 60 seconds. The measured score is the time in seconds the position is held. The end is marked by opening of the eyes or movement of the hands or feet to maintain balance.

Safety Stop
A halt in the planned ascent to the surface (usually for 3-5 minutes at 10-20 fsw [3-6 msw]) intended to reduce risk of decompression injury. A safety stop is not an obligatory decompression stop required by tables or a dive computer.

Scuba Epidemiological Reporting Form (SERF)
A new injury recording system for DAN that replaces the DIRF. It emphasizes collection of recorded dive profiles.

Shallow-Water Blackout
Out-of-favor name. See Hypoxia of Ascent

Surface Interval Time (SIT)
Time spent on surface between sequential dives.

Snorkeling
Swimming with mask, snorkel and fins. Snorkelers may remain at the surface or conduct breath-hold dives. See also Breath-Hold Diving and Freediving.

Square Dive
A dive in which the descent is made to a given depth and where the diver remains for the entire dive before ascending to the surface.

Standard Deviation (SD)
A measure of the variability within a group of numbers reported with discussion of means. Approximately 68% of the values will be within one SD of the mean (half above the mean and half below), approximately 95% within two SD, and approximately 99% within three SD. Outlier values, deviants from the norm, are conservatively identified as those more than two SD from the mean.

Subcutaneous Air (Subcutaneous Emphysema)
Air under the skin after pulmonary barotrauma. The most frequent location is around the neck and above the collarbones where the gas may migrate after pulmonary overexpansion.

Surface Oxygen Treatment (SOT)
Oxygen delivered at the surface with a therapeutic intent. Gas may flow from the supply system in a continuous mode or through a demand valve upon inspiration of the conscious, spontaneously breathing injured person. The breathing circuit may be open (dumping exhaled gas) or closed (reusing exhaled gas after it is scrubbed of carbon dioxide). The delivery interface may be some form of simple non-breathing facemask, a partial rebreathing facemask or a nasal cannula. The fraction of oxygen delivered to the injured person and the oxygen flow rate required will vary dramatically depending on system configuration and use.

Thrombocythemia
A blood disorder of excess cell proliferation. It is characterized by the production of too many platelets in the bone marrow.

Trimix – See Mixed Gas

Type I DCS (DCS I, Musculoskeletal DCS)
Decompression sickness where the symptoms are felt to be non-neurological in origin such as itching, rash, joint or muscle pain.

Type II DCS (DCS II, Neurological or Cardiopulmonary DCS)
Decompression sickness where there is any symptom referable to the nervous or cardiovascular system.

Type III DCS (DCS III)
A more serious type of DCS that is sometimes seen after long deep dives with a rapid ascent. Type III DCS is thought to be caused by the occurrence of arterial gas embolization after a dive where a large quantity of inert gas has been absorbed by the tissues. Presumably the arterial bubbles continue to take up inert gas and grow, causing a deteriorating clinical picture that becomes rapidly worse.

United States Navy Treatment Table 5 (USN TT5)
A 2:15 h:min oxygen with air breaks recompression protocol used to treat decompression sickness. The protocol employs a maximum pressure equivalent to a depth of 60 fsw (18 msw). Extensions can increase the duration at 30 fsw (9 msw).

United States Navy Treatment Table 6 (USN TT6)
A 4:45 h:min oxygen with air breaks recompression protocol commonly used to treat decompression sickness. The protocol employs a maximum pressure equivalent to a depth of 60 fsw (18 msw). Extensions can increase the duration at either 60 fsw or 30 fsw (9 msw).

Upper Respiratory Infection (URI)
The most frequently reported acute health problem from the DAN sample of injured divers.

Waist-to-Hip Ratio (WHR)
The waist-to-hip ratio is used to assess for disproportionate accumulation of tissue in the abdominal region, such accumulation being associated with increased health risk. WHR is computed by dividing the circumferences of the waist at the narrowest point by the circumference of the hips at the widest point. Optimal scores are ≤0.8 for men and ≤0.7 for women.