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Diving Deaths Down Under

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Combined diving fatality data starting in 1972 (N=351) are reviewed from Project Stickybeak and DAN Asia-Pacific. Equipment problems, breathing-gas management, rough water, anxiety and exertion were common triggers to fatal dive accidents in this series. The predominant (44 percent) disabling injury was asphyxia from the inhalation of water. The high incidence of cerebral air gas embolism (CAGE) and pulmonary barotrauma (PBT) as disabling injuries could be reduced by better monitoring of breathing gas, careful selection of the suitability of dive sites to reduce diver stress and careful attention to training and practice in ascent technique. The increasing incidence of cardiac-related disabling injuries could be reduced by better education of divers and doctors about the inherent, and potentially substantial, cardiac stressors associated with diving.

Introduction

The publication of diving fatality reporting began in Australia in 1972 with the introduction of Project Stickybeak by Dr. Douglas Walker, a general practitioner with an interest in dive medicine. Since then, Project Stickybeak reports have been regularly published in the *Journal of the South Pacific Underwater Medicine Society* (SPUMS), now as *Diving and Hyperbaric Medicine*, a joint journal of SPUMS and the European Underwater and Baromedical Society.

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In 2005, DAN Asia-Pacific (DAN AP) began incorporating all of the Project Stickybeak data into a DAN dive fatality database, along with the relatively scant data on dive-related deaths throughout other parts of the Asia-Pacific region. DAN Asia-Pacific has since launched its Dive Fatality Data Collection and Reporting Project, which incorporates Project Stickybeak. The first detailed joint reports were based on diving accidents in Australia in 2003 (Walker et al. 2009) and 2004 (Walker and Lippmann 2009). In addition, DAN Asia-Pacific regularly publishes summaries of regional diving fatalities in its Asia-Pacific editions of *Alert Diver*.

DAN Asia-Pacific has also published a series of combined reports on Australian diving deaths from 1972-1993, 1994-1998 and 1999-2002, which were previously published as individual annual reports in the SPUMS journal (Walker 1998, 2002, 2009). These combined reports include basic analyses of the data for the relevant periods.

Diving Fatality Data

Figure 1 shows a comparison of the provisional 2009 fatality numbers for the Asia-Pacific region. We believe that the numbers for Australia, New Zealand and Singapore are reasonably accurate. However, we have little confidence in the accuracy of the data from other countries and suspect that there would have been substantially more deaths in some of these places. It is difficult to collect good data for a variety of reasons, including remoteness, poor communication and, in some places, certain cultural issues. In addition, in some places there is a real reluctance to provide information due to the perception that news of a diving death(s) there could affect dive tourism to those areas. We have tried to gain the support of the

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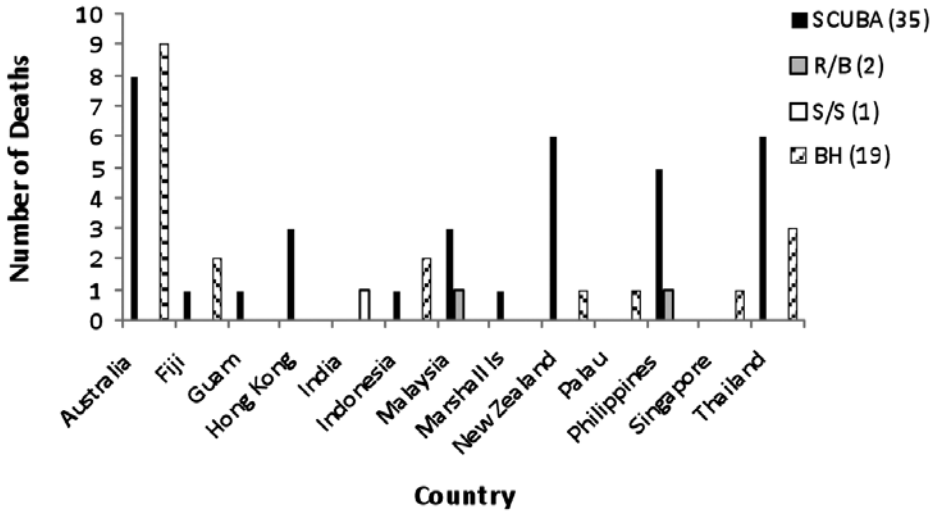
international diver training agencies in our data-gathering efforts by notifying us when they hear of a death, but unfortunately this has been largely in vain.

In Australia, DAN Asia-Pacific has gained access to information on diving-related deaths recorded in the National Coronial Information System (NCIS) and was required to obtain various ethics approvals to do so. We also sought and obtained ethics approval to access information from various state coronial offices, something that is becoming increasingly difficult in this age of privacy protection. Not surprisingly, these approvals come with certain restrictions on how the data is used.

Figure 1: 2009 (provisional) Asia-Pacific dive-related deaths



Our first stage of data collection occurs as soon as we hear about a dive accident. At this time we try to obtain at least some basic information about what occurred so we can open a file. Sometimes we are able to speak to witnesses and at times are required to provide some counseling to rescuers, buddies or family. Once the investigation has progressed to completion through the coronial system, we seek access to coroners' report, police reports, witness statements, medical records and autopsy reports, where available. The existence and depth of these reports can vary greatly, depending on a variety of factors.

In Australia, the knowledge of the various pathologists of the special requirements for autopsies of diving accident victims is improving, largely as a result of the better dissemination of relevant information (Anon. 2008). However, CT scans, if conducted, are often delayed by more than eight hours and are therefore less useful in trying to differentiate gas from an embolism versus that from postmortem decompression and decomposition. In many other countries in the Asia-Pacific region, pathologists are generally unaware of the special autopsy requirements, and death is routinely given as drowning, with the occasional cardiac cause and, rarely, arterial gas embolism.

From 1972 to 2005, we have records of 351 deaths in divers who were breathing compressed gas underwater. These cases included 288 scuba divers (including five using rebreathers), 62 divers using surface supply and one with unknown breathing apparatus.

Figure 2 shows the distribution of these deaths over the years. One can see from Figure 2 that there appears to have been an increase in these fatalities since the earlier years of reporting, although the pattern is rather erratic.

"In many other countries in the Asia-Pacific region, pathologists are generally unaware of the special autopsy requirements, and death is routinely given as drowning, with the occasional cardiac cause and, rarely, arterial gas embolism."

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Figure 2: Compressed gas deaths, 1972-2005

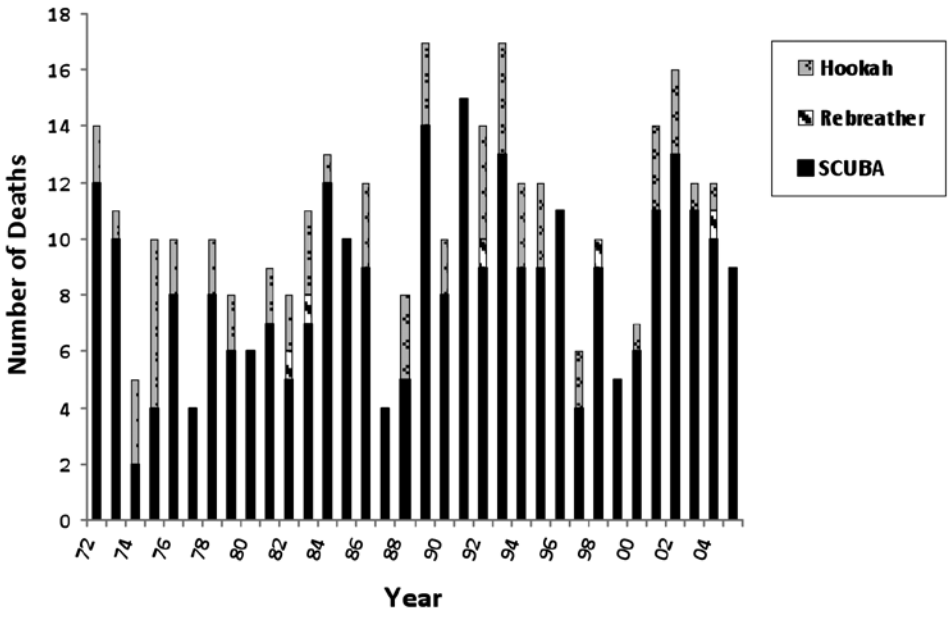

Table 1 (Lippmann 2008) shows the average annual fatality rate for various decades, or parts thereof, from which we have data. Although there has been an increase in the annual average of compressed-gas deaths over the decades, this was not significant ($p = 0.12$).

"Data from Australian government sport participation surveys from 2005 and 2006 indicate that at that time an estimated 80,000 Australian residents went scuba diving regularly and participated in almost 1 million annual dives."

Diving Activity in Australia

There are approximately 50,000 new scuba divers trained in Australia annually, a number that appears to have remained relatively stable for the past 20 years (Esguerra et al. 1989; Wilks 1993).

Table 1: Average fatalities per year per period, 1972-2006

Years	All Modes	Scuba
1972-79	12.6	6.8
1980-89	12.8	7.9
1990-99	18.4	9.2
2000-6	23	9.1

Data from Australian government sport participation surveys from 2005 and 2006 indicate that at that time an estimated 80,000 Australian residents went scuba diving regularly and participated in almost 1 million annual dives (Australian Sports Commission 2005, 2006). In addition to this, in 2006-2007 an estimated 200,000 foreign visitors went scuba diving in Queensland (mostly on the Great Barrier Reef), conducting an estimated 1.2 million dives (Queensland Government 2007). Although the participation data needs to be interpreted with caution due to the small sample sizes, some are consistent with earlier surveys and provide the best available denominators to date.

Using the above data and the Australian fatality statistics from the DAN Asia-Pacific database, various estimates of the fatality rate for scuba diving can be calculated, as shown in Table 2.

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Table 2: Scuba fatality rate in Australia, 2002-2006 (Lippmann 2008, 2009)

Australian residents	Overseas visitors
0.7 / 100,000 dives (95% CI = 0.3, 1.5)	0.4 /100,000 dives (95% CI = 0.1, 1.2)
8.5 /100,000 divers (95% CI = 4.2, 17.5)	1.5 /100,000 divers (95% CI = 0.5, 4.3)

Sequential Analysis

A sequential analysis was conducted of all compressed-gas diving fatalities that occurred between 1972 and 2005 as recorded in the DAN Asia-Pacific database. The 351 cases involved 283 on scuba, 62 on surface-supplied breathing apparatus (SSBA), five on rebreather and one unknown. Each incident was examined to determine the trigger, disabling agent, disabling injury and cause of death, as described previously (Denoble et al. 2008).

Triggers

The triggers identified were classified as related to equipment, gas supply, rough water, anxiety/stress, exertion, other and unknown. A breakdown within some of these categories is shown in Table 3. The incidence of the various groups of triggers is shown in Table 4. There was a fairly even distribution of accidents thought to be triggered by equipment, gas supply and rough water, while anxiety and exertion were thought to play an important role in a substantial number of events. It is not surprising that the mean age was higher with exertion-related triggers. It is interesting to note the increased representation of females with the anxiety-related triggers.

"There was a fairly even distribution of accidents thought to be triggered by equipment, gas supply and rough water, while anxiety and exertion were thought to play an important role in a substantial number of events."

Table 3: Triggers

Equipment-related	Gas supply-related
BCD (e.g. sticky inflator)	Out of gas
Hose entanglement	Inappropriate gas
Broken fin/mask strap	Gas contamination
Drysuit blowup	Gas supply interruption
Weight belt detachment	
Tank slippage	
Rough water	**Other**
Surface conditions	Hit by boat
Current	Silting
Surge	Spearfishing / fish collecting
Suction	Vomiting
	Water in snorkel
	Suicidal intentions

Figure 3 shows the occurrence of the various trigger groups over the entire period and individually for three decades to try to highlight any apparent trends. Over the last decade there appears to have been a reduction in equipment-related triggers. If this is so, one could suggest that it may be due in part from improvements in equipment and/or better understanding and/or maintenance of equipment. There was an apparent rise in gas-supply-related and anxiety/stress-related triggers in the last decade shown.

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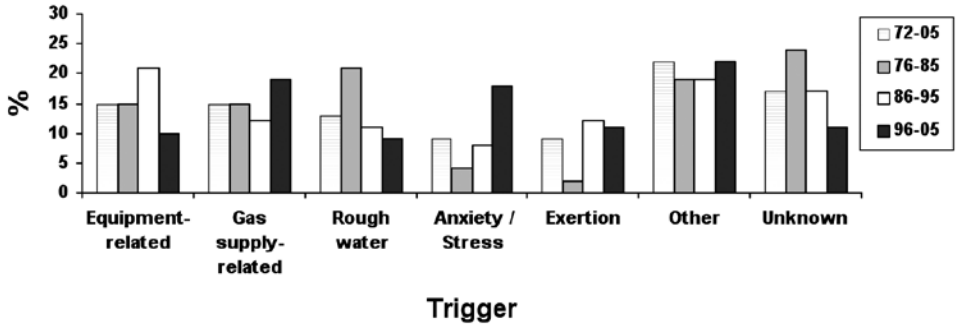
Table 4: Relative occurrence (%) of triggers (n = 351)

Trigger	Occurrence %	Male	Female	Mean Age
Equipment-related	15	92	8	33
Gas supply-related	15	82	18	35
Rough water	13	80	20	36
Anxiety / stress	9	62	38	38
Exertion	9	91	9	47
Other	22	87	13	33
Unknown	17	90	10	36

Figure 3: Comparison (percent) of triggers over various periods



"Problems with gas supply were thought to have been the disabling agent in almost one-quarter of incidents and ascent issues in almost 20 percent."

Disabling Agents

The disabling agents identified were classified as gas-supply-related, cardiovascular disease, ascent-related, buoyancy-related and other, as shown in Table 5. The incidence of the various groups of disabling agents is shown in Table 6. Problems with gas supply were thought to have been the disabling agent in almost one-quarter of incidents and ascent issues in almost 20 percent. Of note, cardiovascular disease was believed to be the disabling agent in 14 percent of cases. Older divers and males were highly represented with cardiovascular disease (CVD) and other medical conditions.

Table 5: Disabling agents

Gas supply-related	**Cardiovascular disease**	**Ascent-related**
Out of gas	Older recruits to diving	Rapid ascent
Inappropriate gas	Aging divers	Breath-holding on ascent
Gas contamination	Unfit divers	Gas sharing on ascent
Gas supply interruption		
Buoyancy-related	**Other**	**Other** (cont)
Lack/loss of buoyancy on surface	Blow to head	Crocodile attack
Inadequate buoyancy control underwater (- or +)	Propeller	Inadequate decompression
	Vomiting underwater	Laryngospasm
	Hypothermia	Narcosis / CO_2

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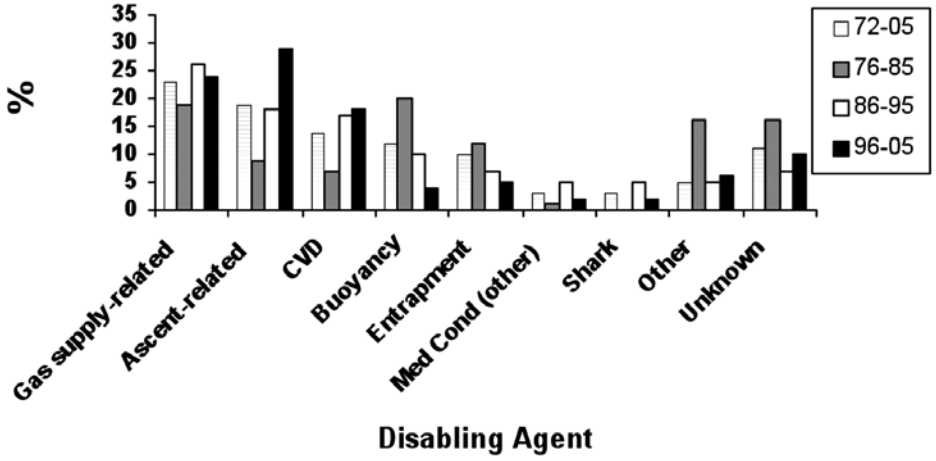
Table 6: Relative occurrence (percent) of disabling agents (n = 351)

Disabling Agent	Occurrence %	Male	Female	Mean Age
Gas supply-related	23	85	15	33
Ascent-related	19	80	20	36
CVD	14	92	8	50
Buoyancy	11	75	25	31
Entrapment	9	88	12	30
Other medical condition	3	100	0	44
Shark	3	90	10	30
Other	5	87	13	34
Unknown	11	84	16	36

Figure 4 shows the occurrence of the various groups of disabling agents over the entire period and individually for three decades. There was a consistent rise in ascent-related disabling agents over the decades reported and a consistent fall in buoyancy-related problems. It is interesting to note the apparent rise in cardio-vascular disease as a disabling agent from the initial decade of reporting. This apparent increase could be due to the participation of older divers and/or better reporting of the accidents.

Figure 4: Comparison (percent) of disabling agents over various periods



"There was a consistent rise in ascent-related disabling agents over the decades reported and a consistent fall in buoyancy-related problems."

Disabling Injuries

The disabling injuries identified were:

- Asphyxia
- Cerebral arterial gas embolism/pulmonary barotrauma (CAGE / PBT)
- Cardiac
- Trauma
- Decompression sickness (DCS)
- Other: stroke, gastrointestinal hemorrhage, head injury

The incidence of the various groups of disabling injuries is shown in Table 7. The predominant disabling injury (44 percent) was asphyxia from the inhalation of water while diving, which is unsurprising given the nature of the activity. CAGE/PBT was thought to have contributed to almost one-quarter of the deaths, and

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there was thought to be cardiac involvement in 16 percent of cases over the 33 years studied.

Table 7: Relative occurrence (percent) of disabling injuries (n = 351)

Disabling Injury	Occurrence %	Male	Female	Mean Age
Asphyxia	44	82	18	31
CAGE / PBT	22	84	16	36
Cardiac	16	91	9	48
Trauma	4	93	7	31
DCS	1	100	0	35
Other	2	100	0	47
Unknown	11	80	20	34

Figure 5 shows the occurrence of the various disabling injuries over the entire period and individually for three decades. There has been a steady decrease in asphyxia as a disabling injury. This has been accompanied by an increase in the number of divers who were thought to have suffered from CAGE/PBT or cardiac-related disabling injuries. The trends are unsurprising as, with the emerging greater awareness of the factors involved in diving deaths, pathologists and researchers are more inclined to look for factors other than drowning to explain the accident scenario.

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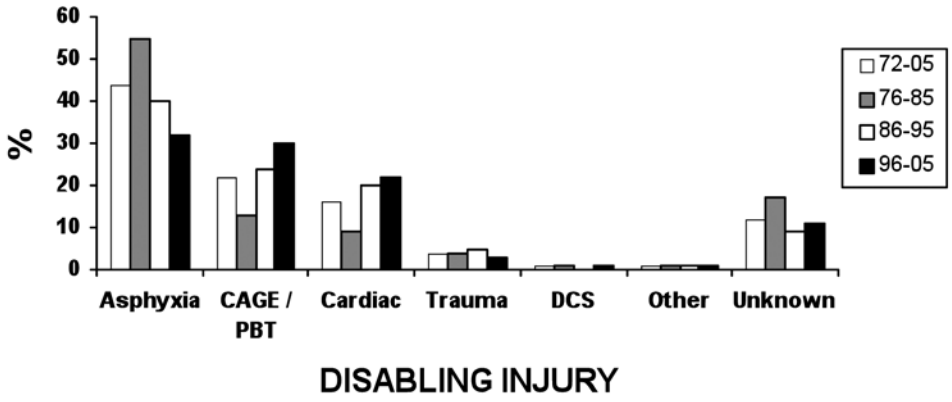
Figure 5: Comparison (percent) of disabling injuries over various periods



Cause of Death

The causes of deaths identified were:

- Drowning
- CAGE/PBT
- Cardiac
- DCS
- Trauma
- Other

The incidence of the various causes of deaths is shown in Table 8. The predominant cause of death was listed as drowning, which was reported to have occurred in half of the cases. This was followed by CAGE/PBT (19 percent) and cardiac-related causes (14 percent). Comparing Tables 7 and 8, it is apparent that there are differences in the relative frequency of certain disabling injuries and causes of death. It is thought that disabling injury is likely to be a better indicator for

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the assessment of diving accidents. Some of the deaths reported to have occurred from drowning are likely to have arisen from cardiac events or CAGE/PBT, which caused the divers to become unconscious and drown.

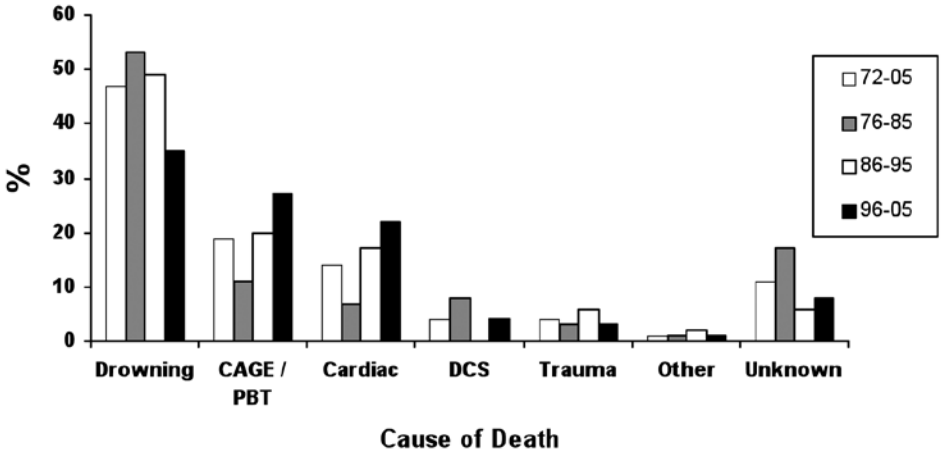
Table 8: Relative occurrence (percent) of various causes of death

Cause of Death	Occurrence %
Drowning	50
CAGE / PBT	19
Cardiac	14
Trauma	4
DCS	1
Other	1
Unknown	11

Cardiac Causes of Diving Fatalities

As seen from Figure 6, there was been a steady increase in cardiac-related diving deaths over the three decades studied, from 7 percent in the first decade to 22 percent in the last. In 2003, 44 percent (4/9) of deaths were thought to have been cardiac-related; 31 percent (4/13) in 2004; and 20 percent (2/10) in 2005; giving an average of 34 percent over these final three years of the last decade reviewed.

Figure 6: Comparison (percent) of causes of death over various periods



"Some of the deaths reported to have occurred from drowning are likely to have arisen from cardiac events or CAGE/PBT, which caused the divers to become unconscious and drown."

Other Trends

A variety of other information was identified from the fatality reports, including the experience of the victims, weights management, BCD management, the remaining gas found in their supply, dive purpose, buddy situation, the depth at which the accident occurred, and the gender and age of the victim.

Experience

Unfortunately, the fatality reports from which these data were taken did not use an objective measure to record the experience of the victim. Instead, the statement of their level of experience was based on statements by the buddy or family (Walker, pers. comm.) This makes the determination of experience highly subjective and difficult to compare, except for those who had no experience. Seventeen percent of victims in this study died on their first dive, either under instruction, alone or with a friend (Table 9).

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Table 9: Reported diving experience

Experience	Occurrence %
Experienced	44
Inexperienced	37
None	16
Unknown	3

Weights Management

Almost three-quarters of the victims were found with the weights in place as shown in Table 10. This highlights an ongoing problem of divers being reluctant, or unable, to ditch their weights when they get into trouble. It is likely that, on many occasions, by the time divers recognize the need to ditch their weights, they are too incapacitated to do so.

Table 10: Weights management (percent)

Weights	Occurrence %
On	73
Off	10
Buddy ditched	5
Tangled	1
None	1
Not applicable	1
Not stated	1

"Although ditching one's weights is not appropriate in certain circumstances, if a diver is in danger of losing consciousness underwater it is important that they gain positive buoyancy so that they rise to the surface and can be found more easily."

Although ditching one's weights is not appropriate in certain circumstances, if a diver is in danger of losing consciousness underwater it is important that they gain positive buoyancy so that they rise to the surface and can be found more easily. One way to achieve this is to ditch weights. Dive training courses should devote more training time to this important factor to imbed the skill, and divers need to remain cognizant of the importance of gaining positive buoyancy in an emergency.

BCD Management

As can be seen in Table 11, over the entire reporting period almost one-third of the divers who died were not wearing a BCD, although this figure dropped to 10 percent over the final decade as BCDs became standard fare. However, it is interesting to note that 36 percent of the victims failed to inflate their BCD. This figure rose over the last two decades and is probably a function of the increased wearing of BCDs.

Table 11: BCD management (percent)

BCD	Occurrence %
Not inflated	36
Not worn	32
Inflated	9
Part inflated	6
Faulty	4
Buddy inflated	3
Not applicable	1
Not stated	9

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Inflating the BCD is an important first step for a diver in trouble to gain some positive buoyancy, although this is obviously impossible underwater if the gas supply is depleted.

Remaining Breathing Gas

Table 12 indicates that a third of the victims had sufficient remaining gas to make a safe ascent. Fifteen percent were low on gas, and one-quarter had depleted their gas supply. Some of these events were a result of entrapment, narcosis, equipment failure, poor planning and others from inattention and/or inexperience. Many of these situations could have been avoided by adequate equipment maintenance, better dive planning, especially with regard to gas management, and better attention to gas monitoring.

Table 12: Remaining gas (percent)

Remaining Gas	Occurrence %
Adequate	33
None	25
Low	15
Not stated	10
Not applicable	17

Purpose of Dive

Most of the divers (56 percent) were diving for recreation. A disturbing 8 percent of victims died during dive training (Table 13).

Table 13: Purpose of the dive (percent)

Dive purpose	Occurrence %
Recreation	54
Collect seafood	16
Work	13
Training	8
Cave	4
Resort	2
Military	1
Other	2

Buddy Status

Although diving with a buddy does not guarantee that assistance will be at hand, the presence of a buddy will usually increase the likelihood of help when required and reduce the time to rescue and first aid management. This is important to reduce mortality and morbidity. Sixty-five percent of the victims were alone at the time of their accident, while an additional 17 percent separated from their buddy during the accident (Table 14).

Table 14: Buddy status (percent)

Buddy Status	Occurrence %
Separated before	49
With buddy	18
Separated during	17
Solo	16

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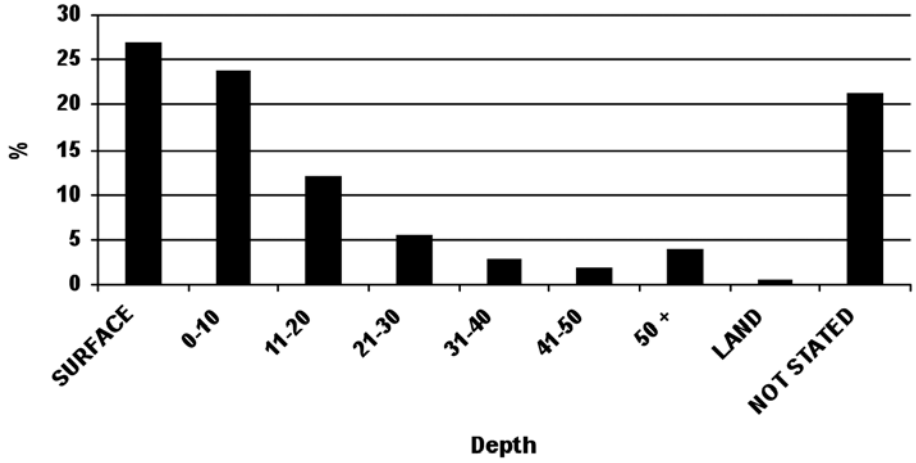
Depth

From Figure 7 one can see that more than half of the victims appear to have gotten into trouble within the first 10 meters, 27 percent of them at the surface.

Figure 7: Depth of accident (percent)



Gender

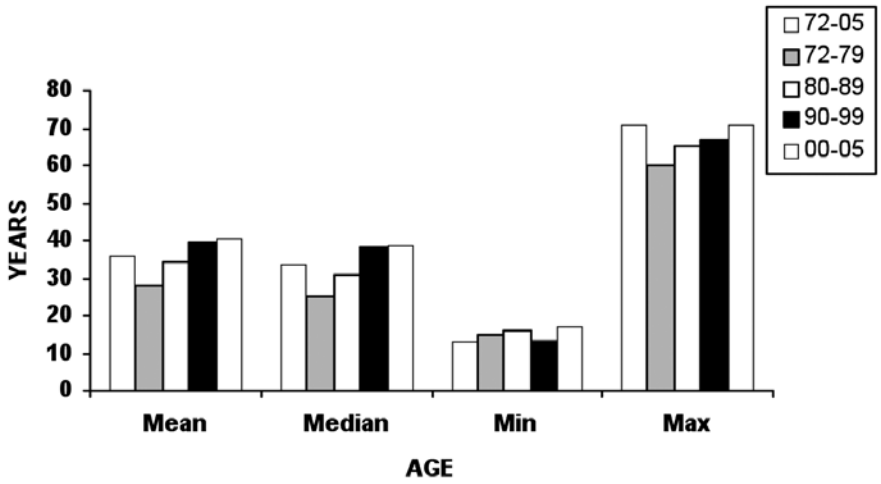
Over the entire reporting period 88 percent of the victims were males and 12 percent females. However, over the three decades studied, the percentage of female victims increased from 6 percent to 19 percent, reflecting a greater participation of females in the activity. PADI certification data for 2002-2008 indicate that females comprise an average of 33 percent of certifications during that period.

"Over the three decades studied, the percentage of female victims increased from 6 percent to 19 percent, reflecting a greater participation of females in the activity."

Age

The mean age of victims over the entire period was 35.8 years (median 34). The mean age for the decades, or parts thereof, steadily increased from 27.9 to 40.6 years (median 25-39) (Figure 8).

Figure 8: Age (percent)



Conclusion: Lessons Learned

Equipment problems, breathing-gas management, rough water, anxiety and exertion were common triggers to fatal dive accidents in this series. Adequate equipment maintenance, better breathing-gas planning and monitoring, thorough consideration of the suitability of the diving conditions and increased education,

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training and/or preparation of divers should help to reduce the frequency of these precipitants to serious diving accidents.

The predominant disabling injury was asphyxia from the inhalation of water, which appears to have occurred in 44 percent of cases. It is almost inevitable that most serious dive accidents will evolve to asphyxia due to the nature of the activity. However, the incidence can be reduced by ensuring that divers' aquatic skills are well-honed and increasing the appreciation of, training in and practice of attaining positive buoyancy by inflating one's BCD and/or ditching weights when appropriate.

The high incidence of CAGE/PBT as a disabling injury could be reduced by better monitoring of the breathing gas, careful selection of the suitability of dive sites to reduce diver stress and careful attention to training and practice in ascent technique.

Finally, the increasing incidence of cardiac-related disabling injuries could be reduced by better education of divers and doctors about the inherent, and potentially substantial, cardiac stressors associated with diving. This education, combined with appropriate diver health reporting and monitoring strategies, could reduce the incidence of diving fatalities from adverse health factors.

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Discussion

KEN KURTIS: I have a clarification request. On your depth slide, is that where they ended up or where they started?

JOHN LIPPMANN: That is the depth at which the accident was thought to occur. They got into trouble on the surface, they got into trouble within the first 10 meters.

DR. RICHARD SADLER: Regarding your talk and cardiac deaths or for all of the speakers for that matter, there is a lot of reasons for cardiac death, ischemic disease. Having reviewed some deaths, I have been disappointed with the quality of the autopsy reports because it does not specifically address these issues. How confident are you or is any of the presenters over the quality of our cardiac death categorization? Do we really know what is going on and why that occurs?

LIPPMANN: In Australia in the last few years we have gained confidence. There is a document that pathologists are using when they are performing the autopsies, and there is a better advisory system, and there is a better feedback system. And it is being queried. So they are getting better at autopsy and at writing the report. But then again, we have a fairly experienced pathologist, as DAN America does, reviewing all the autopsies and looking at the history of the dive, looking at the history of the person, the medical history, looking at the autopsy report and reviewing everything. In our reports in the last three years since we have taken it over we are making the determination of disabling injury, cause of death, not necessarily completely relying on what the coroner at the time said, using the tools that they provided. So it is getting better in Australia and certainly probably getting better here. So we are getting more confidence in that. Out of, for instance, Thailand we have no confidence. It is often just drowning or a heart attack.

SADLER: Just to answer that for the States, I would echo that. I have veto power on the database, so I will tweak some cases when they come in if they do not make sense. Unlike Australia, the United States has a much higher number and less control over the input of the data. While I am reasonably confident and know most of the medical examiners in places like San Diego and Los Angeles, cases that come in from smaller jurisdictions or certainly the cases from the Caribbean are abysmal. An autopsy sent in from a Caribbean country may mean that a general surgeon opened up the body, felt the organs for palpable coronary calcifications and said it was a cardiac death, and the heart was never weighed even or examined. So there is a lot of room for error. And in some cases, if there is not enough information there, I will have to just say that we cannot conclude the cause of death in a case.