

World as it is

Recreational and technical rebreather fatalities and diving safety status

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Abstract

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Introduction: The Divers Alert Network (DAN) aims to provide safety information for all types of diving. Assessing the number of active closed-circuit rebreather (CCR) divers is difficult, as pertinent information is often not available. This review aims to give an overview of global use and safety of CCR diving equipment from 2013–2022.

Methods: Data were combined and assessed from various DAN internal and public sources on CCR diver demographics, fatalities, and CCR sales.

Results: Over the past 10 years, the number of certified CCR divers has increased from an estimated 2,000 in 2013, to 3,000 in 2022. There has been an increase in growth in CCR sales over a five-year period from 2018, with around 25,000 to 35,000 units on the market today; rebreather divers are a growing community. There were 241 confirmed CCR fatalities from 2013–2022, mean 24 (SD 6) per year. Most fatal accidents involved dives made between 40–80 m (130–260 ft) depth. Cause of death is difficult to establish due to lack of detail and dive-specific training for the medical examiner. The estimated death rate is 1.8–3.8 deaths per 100,000 CCR dives although these values are derived from limited data.

Conclusions: Not enough information is made available to address CCR accident analysis effectively, perhaps stemming from family reticence to discuss the incident, fear of litigation, and/or lack of diving knowledge reducing the useful information. DAN continues to collect CCR data, but increased collaboration between training bodies, equipment providers, and comprehensive reporting of incidents is needed to reveal the true picture.

Introduction

This review gives an overview of the global use and safety of closed-circuit rebreather (CCR) diving equipment. The topics covered include CCR diver demographics, a review of fatalities since the 2012 Rebreather Forum Three (RF3)³ that includes data from January 2013 through to the end of December 2022, and a description of the state of the CCR market. It also draws on collated survey information from the caustic cocktail survey¹ ($n = 413$) for data on gender, age, years of experience. The challenges of incident and accident investigation are discussed, then leading on to the future of rebreather safety.

Diver demographics

Data sourced from the caustic cocktail survey¹ show that the reported age of rebreather divers was mean 46 (standard deviation [SD] 10) years, with 95% of participants being

male, while the Divers Alert Network (DAN) hotline reported that 84% of callers were male and their median age was 42 (2012–2022 data). The length of time that a CCR diver had been certified was median six (interquartile range [IQR] 3, 12) years, with 40% being certified for less than five years, and 10% for more than 20 years.¹ The median self-reported dive experience was 200 (IQR 100, 500) CCR dives, with 300 (IQR 120, 750) hours clocked on CCR equipment.¹ The certification time and experience for Rebreather Forum 4 participants was almost twice as high, which is not surprising given the specialisation of the audience.

CCR DIVERS CONTACTING DAN

Divers contact DAN to ask for information on diving with a CCR and to log accident cases, which entail emergencies. Figure 1 details the types of calls (emergency or information) from rebreather divers made to DAN from January 2013 through to the end of December 2022.

Figure 1

Closed circuit rebreather divers contacting the Divers Alert Network (*n* = 325 emergency cases, *n* = 281 information requests)

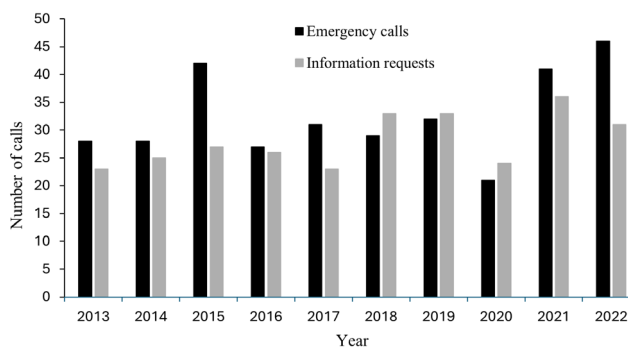


Figure 2

Distribution of emergency calls and information inquiries by age and sex where disclosed for calls made between January 2013 through December 2022 (*n* = 319)

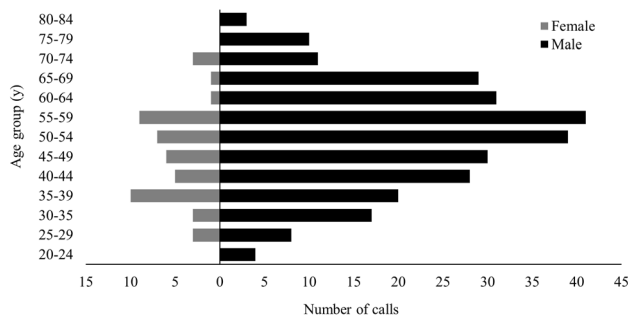


Table 1

Differential diagnoses of closed-circuit rebreather-related emergency calls to the Divers Alert Network taken from a sample November 2021 through March 2023 (*n* = 47); DCS – decompression sickness

Differential diagnoses (<i>n</i> = 47)	Cases <i>n</i> (%)
Type 1 DCS	13 (28)
Type 2 DCS	9 (19)
Anxiety	8 (17)
Middle ear barotrauma	4 (9)
Trauma	4 (9)
Sinus barotrauma	2 (4)
Infectious disease	2 (4)
Dental barotrauma	1 (2)
Mask barotrauma	1 (2)
Suit barotrauma	1 (2)
Loss of consciousness	1 (2)
Neurological	1 (2)

It was found that little had changed since RF3 with regards to the sex and age distribution of CCR divers contacting DAN. The majority of the 319 phone calls and email inquiries for which sex and age was reported were made by men, with only 48 female inquirers (Figure 2). The age distribution of the callers was centred around those 50–59 years of age.

The differential diagnoses obtained from the emergencies are often of greater interest (Table 1). Decompression sickness (DCS) involving pain (Type I DCS) comprised ~27% of the cases reported, while more severe neurological DCS (Type II DCS) made up ~19% of cases. Anxiety caused by the worry of DCS and later diagnosed as such (rather than the originally attributed DCS) accounted for around 17% of cases (Table 1). Barotrauma of varying types formed several differential diagnoses, the frequency of CCR-derived barotrauma being relatively comparable with other forms of diving. Trauma, loss of consciousness, and neurological

complications made up the rest of the categories reported (Table 1).

Fatality review: what data are available?

Although it might be expected otherwise, there is a paucity of fatality data available making meaningful interpretation difficult. Most of the available data is collected from insurance claims and the emergency calls received by DAN America and DAN Europe. DAN conducts a fatality surveillance project, scanning media and news outlets for possible fatalities, then following up the primary information to collect further data from medical reports, investigation reports, and witness statements, when available. Equipment experts who examine rebreathers used in accidents may also forward information. Internet databases are useful to compare with the DAN fatality database to check for any cases that might have been missed. Finally, individuals who have expertise in CCR, for example, manufacturers, training agencies, diving physicians, and pathologists occasionally call with information that they feel would be useful to share. Once all these data were collated and merged, duplicates were identified and removed. Verification of the incident followed. Once the database was consolidated a final tally was obtained; from 2013–2022 there were 241 verified CCR fatality records captured.

Limitations to collecting and verifying the data include a hesitancy to share information by family or friends, language barriers, legal restrictions (for example, in Australia case data is released only five-years post-accident), the time and effort needed for follow-up, data reliability, incomplete information, third-hand information, and conflicting information, all of which weaken any analysis.

CCR fatality 25-year review

A report on CCR fatalities for the period of 1998–2010 showed a peak at around 26 fatalities per year in 2005, having risen from five to ten fatalities per year from 1998–2004.² Figure 3 displays these data plus additional numbers

Figure 3

Closed circuit rebreather fatality 25-year review 1998–2022; counts per year (solid line) with 5-year rolling average trend line (dashed line)

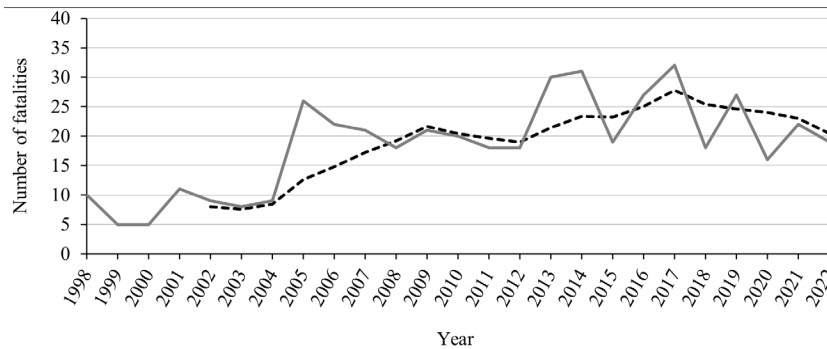


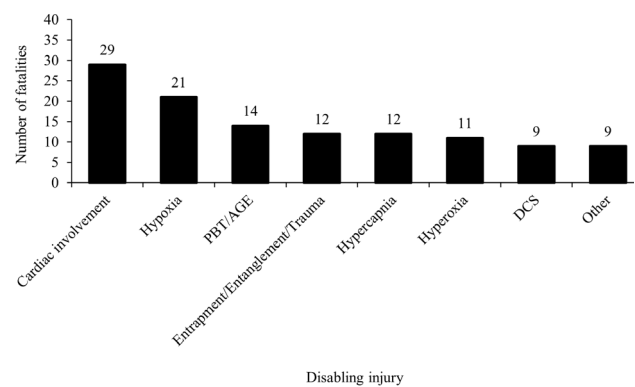
Table 2

Age and sex of deceased rebreather divers (*n* = 193; 20% of ages unknown); *y* – years

Age group (y) (<i>n</i> = 241)	Male <i>n</i> (%)	Female <i>n</i> (%)
18–29	5 (2)	1 (0.4)
30–39	22 (9)	5 (2)
40–49	57 (24)	1 (0.4)
50–59	67 (28)	3 (1)
60+	32 (13)	0
Unknown	56 (23)	2 (0.8)

Figure 4

Disabling injuries that contributed to fatalities (*n* = 117, 52% unknown); note that cardiac involvement, hypoxia, hypercapnia, and hyperoxia all contributed considerably and remain issues that should be addressed. AGE – arterial gas embolism; DCS – decompression sickness; PBT – pulmonary barotrauma



through to 2022, showing that in the years 2013–2017, an even larger spike in the number of CCR fatalities was seen, rising to around 35 cases per year at its zenith. In the years 2018–2022, the number of fatalities varied enormously but did not dip below 20 per year. A 5-year rolling average trend line reveals that in 2022, the typical number of fatalities was still around 25–30 deaths per year.

On further examination of the data from the last 10 years, it was possible to derive 241 confirmed CCR fatalities (12 female, 229 male) with a trend towards fewer deaths in the second half of those 10 years. This count excludes military and commercial accidents.

WHAT IS KNOWN ABOUT THESE FATAL ACCIDENTS?

As previously noted, the majority of CCR divers who had fatal accidents were between 40–59 years of age, and only 12 of the 241 (5%) confirmed cases were women (Table 2).

Fatalities are reviewed at DAN using an adaptation of the method used by Vann et al,⁴ classifying each fatality in respect of possible predisposing factors, trigger events, disabling/harmful agents, nature and mechanism of the

disabling injury, and cause of death (COD). Frequently in diving-related incidents, the COD is difficult to establish and is most often ruled a drowning in the medical examiner reports submitted to DAN.

For the analysis of the current dataset, we established the disabling injury that most likely contributed to the chain of events of the fatal outcome/drowning. Of the 241 confirmed cases, 124 fatal accidents had insufficient information to draw any conclusions, classified as unknown. Cardiac incidents or questionable cardiac health of the diver were involved in 29 of these cases and provided the largest category in the 117 deaths where data analysis was possible. Given the distribution in age of the fatalities, with most occurring in the over 40 age groups and the risk of cardiac-related illness increasing with age, this finding was not surprising. Hypoxia was likely responsible for 21 deaths and the remaining confirmed causes are illustrated in Figure 4. The category ‘other’ included less than three occurrences of suicide, gas contamination, venomous marine life encounters, or poor gas management.

Table 3

Diving depth at which the problem that led to the fatal outcome first occurred ($n = 208$; 17% unknown dive depth)

Depth (m)	Fatalities (n)
< 20	32
20–39	31
40–59	46
60–79	40
80–99	19
100–119	23
120–200	13
> 200	4

A primary concern related to CCR diving relates to the depth of the dives made given that rebreathers may allow divers to go deeper for longer. Table 3 illustrates the depths in which the issue that led to the fatality most likely occurred, showing that most cases are situated in the relatively deep 40–80 m (130–260 ft) range. There is a fairly even spread at depths shallower than this, some of which have occurred during entry-level CCR training, as well as the occasional exceptionally deep dives greater than 200 m (656 ft), for example, exploratory dives or record attempts.

CCR industry statistics: how big is the industry and is it growing?

We were able to gather information from eight CCR training agencies on how many certifications are issued each year over 10 years (Figure 5). Certifications are classified as basic, intermediate, and advanced (60 m plus) qualifications. Although the number of certificates for the advanced group remains similar across the 10-year period, a trend towards an increase in the numbers qualified for the basic and intermediate qualifications can be seen. Overall, over 5,000 certificates were awarded in the last year that were related to rebreather diving. However, it is unlikely that this allows us to determine how many CCR divers are actively diving, as people can start to dive CCR on either basic or intermediate certification, and many divers will have more than one certification, resulting in duplication within the total number of divers.

With regards to duplication, in a quick poll of the participants of RF4 it seemed that it may be fair to assume that each CCR diver has at least two certifications, which would suggest that around 50% of the total could be deducted and this is also illustrated in Figure 5. Overall, these ranges provide an educated estimate, which suggests that post-2020, there was an increase in training certifications awarded.

Drawing on these data, we could start to address the question of how large the CCR industry is, which might help to assess

the growth of the CCR community worldwide. The training survey suggested a minimum growth of 1,400–2,800 new CCR divers per year over the past 10 years. We included 22 manufacturers of rebreather equipment to ask how many units they sold per year (estimated or calculated), and how many sales they made per year since RF3 in 2012.

Twenty manufacturers agreed to share data anonymously (two opted for a data use agreement before supplying this information), and from this, it was estimated that around 23,000 units had been sold in total over the past ten years. The data provided were very limited since 36% of the manufacturers provided an estimate of their sales only. Of the remainder, 55% provided actual sales numbers, and 9% did not provide data.

The growth of the rebreather market is illustrated in Figure 6. Overall, there has been an increase in growth of the market over a five-year period starting in 2018. Although we cannot be sure what has driven this, potential explanations include a rise in the choice of CCR units coming to market from a range of manufacturers, or the high price of helium making recirculation of gas more attractive. It is noteworthy that the increase in CCR diving certifications shown in Figure 5 is reflective of the expansion of the rebreather manufacturing market (Figure 6). Overall, CCR diving is a flourishing market and there is a growing community of these divers across the world. However, we cannot account for how many divers own multiple units, how many divers buy units second-hand, or how many sell units when they leave the sport.

Safety status

DAN data suggest that there are around 180–220 diving fatalities per year that are attributed to scuba diving. Of these, 10–15% ($n = 20–25$ per year) are thought to be rebreather divers. The number of deaths is likely underreported for both CCR and open circuit.

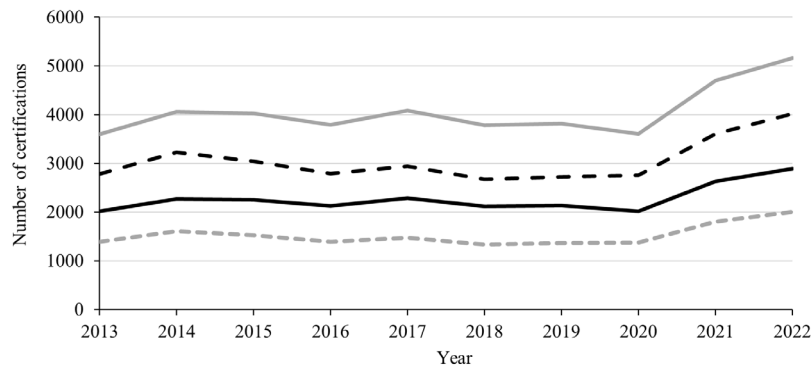
CCR DEATH RATES

We have previously published an estimate of the demographics of CCR divers, the number of dives conducted, and the hours spent underwater by rebreather divers.¹ From these data, a rough estimate of death rates can be made. If the estimate of 20,000 active CCR divers is used alongside 20–25 deaths per year, then the CCR death rate would be 1.8–3.8 deaths per 100,000 dives or 1.2–2.5 deaths per 100,000 h of CCR dive time. In previous presentations on the topic, this estimated rate reached 4–5 deaths per 100,000.

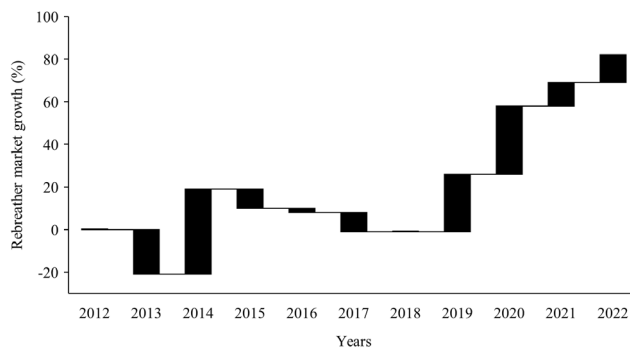
There is no doubt that to strengthen these data accident and incident surveillance needs to be improved in the future, which will be aided by the industry (training agencies, CCR manufacturers, and computer manufacturers) continuing, or in some cases starting to provide anonymised data to

Figure 5

Training survey 2013–2022 showing total and corrected certifications issued each year; grey solid line represents all certifications including basic, intermediate, and advanced; black dashed line represents basic and intermediate certifications; black solid line represents total certifications minus ~44% duplicates; grey dashed line represents basic and intermediate certifications minus 50% (see text for explanation)

**Figure 6**

Growth of the rebreather market (%) since 2012 derived from submitted sales data from CCR manufacturers



produce a common denominator to report against the fatality numbers. Incident reporting would be encouraged by a safe space for individuals to report their close calls to experts without any peer judgment. Country-specific information needs to be streamlined and standardised to facilitate easier collation of data.

DAN continues to produce its annual diving report, which monitors diving incidents and fatalities, and relies in part on people accessing the DAN website and filing a report on the diving incident reporting system (<https://dan.org/safety-prevention/incident-reporting>). Data quality and usefulness can be improved by better reporting. Thus, divers and their families should be encouraged to provide information as soon as possible after an incident to help them provide accurate information, and follow-up should be made. Continuing medical education efforts could help to aid clinicians in identifying not only the obvious COD of drowning in a watery environment, but also to look for triggers and existing medical conditions that may have pre-empted the drowning. Expert handling of the diving equipment following an accident is also necessary to extract the maximum amount of information available. This could include returning units to the manufacturer or knowledgeable independent third parties for examination. In

the US, DAN tries to work with law enforcement with some success in areas where diving is common, although in the states and counties where diving accidents are infrequent, the information is often not passed on or reported in detail. Again, education is key. Another important link is being able to provide people who have training to talk to family members and witnesses, which aids in collection of pertinent information.

Conclusions

In summary, it should be made clear that not enough information is made available to address accident analysis in full. This lack of detail may stem from family/friends not wanting to talk about the accident, other priorities, fear of litigation, and/or lack of diving knowledge or familiarity with the subject matter reducing the amount of useful information that can be provided.

Although attempts are made to collect as much data as possible on global provision and use of CCRs, increased collaboration between the providers of equipment and training, and education of those involved in reporting on incidents and accidents, will help to allow collection of the best quality data. This is key to improving our knowledge and in turn to disseminate potentially life-saving information to the CCR community.

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