

# Mortality rate during professionally guided scuba diving experiences for uncertified divers, 1992–2019

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## Key words

Diving deaths; Diving industry; Epidemiology; PADI; Recreational diving; Risk; Training

## Abstract

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**Introduction:** The aim of this study was to re-examine the mortality rate among participants in the Professional Association of Diving Instructors' (PADI)'s Discover Scuba Diving (DSD) programme.

**Methods:** Fatalities reported to PADI as having occurred during DSD scuba dives were counted for each year between 1992 and 2019. DSD participant registrations were also counted for each year. The data were conveniently divided into two equal 14-year periods, 1992–2005 ('early') and 2006–2019 ('late'). To smooth out the year-to-year variation in raw rates, Monte Carlo simulations were performed on the mean rate per 100,000 participants per year during each period.

**Results:** There were a total of 7,118,731 DSD participant registrations and 79 fatalities during the study period. The estimated overall mean mortality rate in the early period was 2.55 per 100,000 DSD registrations whereas the estimated rate of 0.87 per 100,000 DSD registrations was significantly lower in the late period ( $P < 0.0001$ ).

**Conclusions:** PADI's contemporary Discover Scuba Diving introductory scuba experiences, at 0.87 fatalities per 100,000 participants, have a calculated mortality rate that is less than half that calculated for 1992–2008. The late period's rate improvement appears due either to significant under-registration in the early period, or to significant safety-performance improvement in the late period or, more likely, some combination of the two.

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## Introduction

Introductory scuba diving programmes allow individuals who are not certified divers to experience scuba diving under the direct supervision of a professional instructor, and are among recreational scuba diving's most frequent scuba programs worldwide. The Professional Association of Diving Instructors (PADI)'s Discover Scuba Diving (DSD) program is likely the most popular such program by a large margin.<sup>1</sup> PADI requires their professional members to use prescribed DSD program participant materials and requires participant registration to allow quality management follow-up by PADI. Every participant with an e-mail address receives a course evaluation questionnaire, PADI's standard quality-management instrument. This process also gives PADI a unique data set: the number of participants in its formal introductory scuba program.

Although there have been incremental revisions over time, which is typical of scuba programs, the DSD introductory program was launched in largely its current format in 1992.<sup>1</sup> Before approximately 2002, instructors would photocopy participant registration forms and, after completion of

the diving experience, these forms needed enveloping, addressing and stamping, then mailing in to the local PADI regional office for PADI to then mail out a course evaluation questionnaire.<sup>2</sup>

The early 2000's were a time of significant changes in the recreational scuba industry. A new medical assessment form, widely adopted by recreational diving instructors globally, was launched in 2000 to assess whether would-be divers should undertake further assessment by a physician before being taken into the water. Internet use became widely adopted and was used to advertise the DSD program online increasingly frequently, as more and more travellers planned holidays using the internet. Very large dive centres commenced using the program in a number of diving hotspots, for example in Cairns, Australia and the Caribbean.

Based on anecdotal reports that not all DSD participants were registered, in 2001 and 2002 PADI engaged an independent market research company to conduct an online survey of PADI members, to estimate the 'true' number of DSD experiences being conducted each year.<sup>3</sup> Both individual DSD instructors and dive centres responded. Almost half

(47%) of surveyed dive centres that conducted DSD in 2002 also reported not registering any DSD participants. Moreover, just 21% of dive centres reported registering all their 2002 DSD participants.<sup>3</sup> The study suggested that the number of registered DSD participants underestimated the true number of DSD divers.

At about the same time, PADI required instructors to use a new, full-colour, glossy participant registration form. It had a tear-off card for the customers and was pre-addressed to return participant registrations to PADI. This method was followed by the introduction of an online registration system, making the process even more convenient and efficient. The annual number of DSD registrations doubled in two years, then doubled again, going from almost 200,000 registered DSD participants in 2002/03 to nearly 800,000 in 2007/08. This level of introductory scuba participation had never before been documented.

At the 2010 Divers Alert Network Recreational Diving Fatalities Workshop the President/CEO of PADI presented a seminal diver mortality study, which showed the raw number of fatalities per 100,000 participants for a range of diver training programmes, 1989–2008.<sup>1</sup> Of high interest was the DSD mortality rate, since this program is typically taken by participants who have not previously been certified as trained recreational divers. The programme is designed to enable a complete novice to try scuba for the first time in the open water, always directly supervised by a PADI Instructor.<sup>2</sup>

Although it was made clear that, while the fatality counts were likely accurate (because all, or nearly all, fatalities were likely known and counted), the numbers of DSD participants' figures were suspected to have been artificially-low due to a proportion of participants not having had their participant registration forms submitted to PADI (even though participant registration was contractually required of members).<sup>1,3</sup> Factors affecting participant registration may have included the cost of hiring staff to envelope and address photocopied forms, especially in areas where there was an intense dive season.<sup>3</sup> Because DSD registrations were suspected to have been lower than actual participation, the published DSD mortality rate per 100,000 participants was considered artificially high in the 2010 paper.

The aim of this study was to re-examine the mortality rate among DSD participants using today's much larger (and likely more accurate) annual denominators, and to compare

the current mortality rate with that of an earlier period. The null hypothesis is that the calculated mortality rate per 100,000 DSD participants per year has not significantly changed.

## Methods

Ethics approval was granted by the Human Research Ethics Committee of Curtin University, approval HRE2020-0444 dated 11 August 2020. Fatalities reported to PADI as having occurred during DSD scuba dives, which are contractually required to be reported to PADI by its members, were counted for each year between 1992 and 2019. DSD participant registrations were also counted for each year. The data, stored in Excel and analysed using SAS ver 9.4 (SAS, Cary, NC), were conveniently divided into two equal 14-year periods, 1992–2005 ('early') and 2006–2019 ('late'). Individual raw mortality rates per 100,000 registrations were calculated for each year. Potential linear trends in increasing or decreasing raw rates were tested for significance in each period by univariate regression. To smooth out the year-to-year variation in raw rates, Monte Carlo simulations were performed on the mean rate per 100,000 participants per year during each period, with 10,000 iterations and resampling. The resultant 10,000 14-year mean mortality rates were normally distributed for each period, in accordance with Central Limit Theorem. Standard deviations around the estimated means for each period were too disparate to pool the variance (Table 1); therefore, a Student's *t*-test with un-pooled (Satterthwaite) variances was used to assess the magnitude of the difference in estimated mean mortality rate during each period (early versus late).<sup>4</sup> Significance was accepted at  $P < 0.05$ .

## Results

There were a total of 7,118,731 DSD participant registrations and 79 fatalities during the study period. There was no linear trend in increasing or decreasing raw rate per 100,000 registrations associated with calendar year during either the early period ( $t = -1.45$ ,  $P = 0.17$ ) or the late period ( $t = 1.06$ ,  $P = 0.30$ ). The results of the Monte Carlo simulation are presented in Table 1. The distributions of the estimated means ( $n = 10,000$  per period) are shown in Figure 1. The estimated mean mortality rate per 100,000 DSD registrations was significantly lower ( $t = 341$ ,  $P < 0.0001$ ) in the later period.

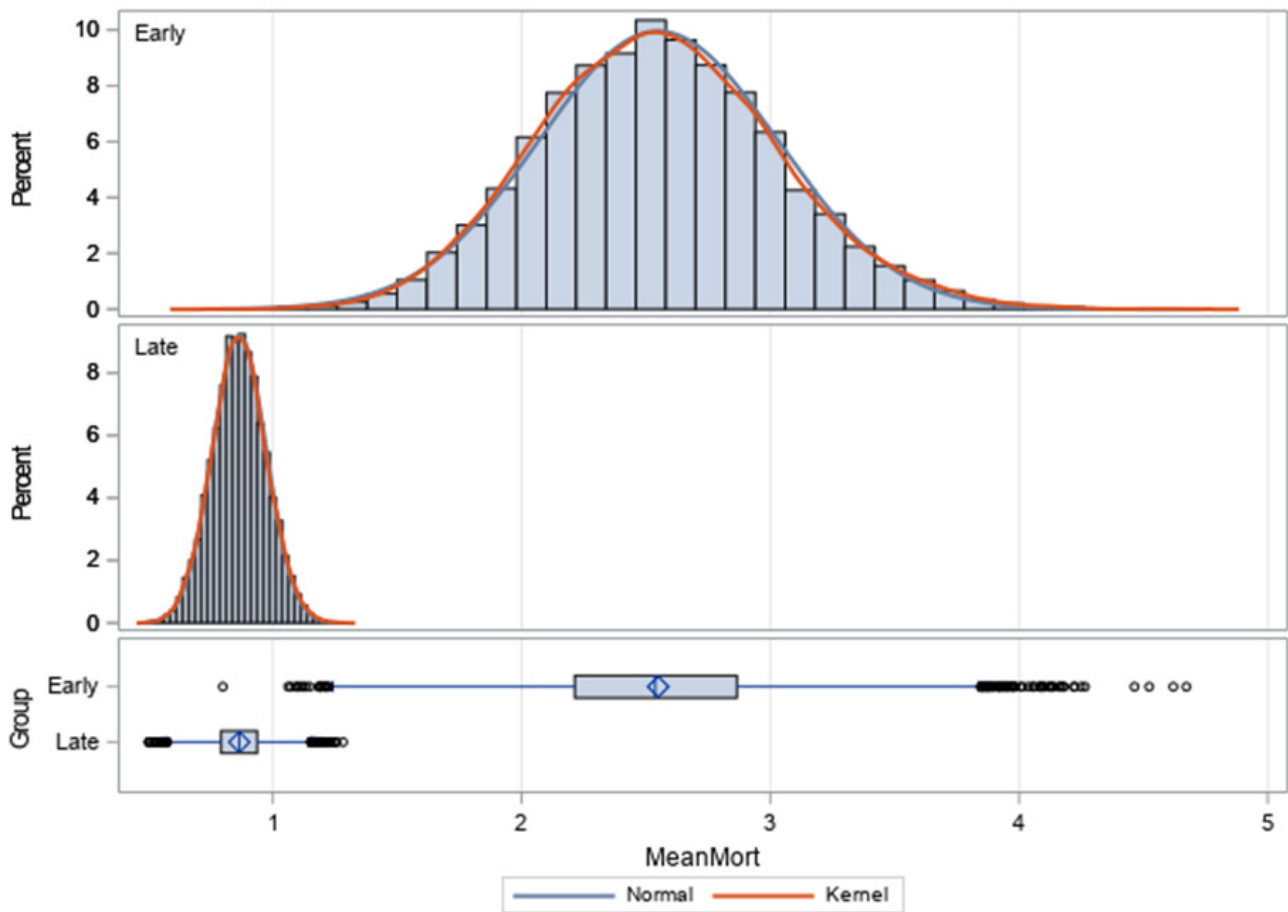
**Table 1**

Descriptive characteristics of the raw and estimated mean mortality rates per group (early or late) generated by Monte Carlo simulation

Group	Registrations	Fatalities	Raw rate per 100,000	Estimated mean (SD)	Estimated 95% CI	Estimated means ( <i>n</i> )
Early	1,355,987	28	2.06	2.55 (0.48)	2.54, 2.56	10,000
Late	5,762,744	51	0.88	0.87 (0.11)	0.86, 0.87	10,000

**Figure 1**

Histogram with box-and-whisker plots for 10,000 estimated mean mortality per 100,000 participants, by group (early or late)



**Discussion**

The annual mean number of fatalities per 100,000 DSD participants during a recent 14-year period was significantly lower than in the 2010 analysis.<sup>1</sup> Presently, calculated overall mortality during DSD experiences is less than half that described just a decade ago, both in raw numbers and in the Monte Carlo simulation. We infer that this is likely in part due to increased accuracy of participant registration numbers, and that prior mortality rate estimates were artificially high due to relatively less-consistent participant registration. However, additional measures aimed at reducing participant risk during the conduct of DSDs were added over the years, including the evolution of required training materials, a reduction in the instructor-to-participant supervision ratio, increased quality-management control made possible through increased registrations, and increased DSD-instructor training during PADI Instructor Development Courses, any or all of which may have contributed to the reduction as well, but by what scale remains unquantifiable. Whether the significantly lower rate in the later period is due to greater DSD registration compliance, or improved

safety, or some combination of both, we posit the mortality rate of 0.87 per 100,000 participants reported herein for the latter period represents the most accurate estimate to date.

While a variety of methods have been utilised to estimate mortality rates in recreational scuba diving, using them for making direct comparisons between locations, types of diving or diving groups is problematic. This is due to a lack of commonality and consistency of research methodologies, missing data, different levels of diver experience and/or training and, typically, differences in important influences upon diver behaviour, such as the presence of professional supervision, dive site selection, the total number of dives involved, etc. Furthermore, the DSD programme is a single dive experience, making comparisons with groups undertaking a series of multiple dives, or comparisons with annual mortality rates, invalid. That being said, comparisons between studies using similar dive-count methodologies may provide some indications of comparative risk. Unfortunately, studies with reliable denominators are rare and mortality rates based on retrospectively recalled survey estimates differ substantially from rates calculated using actual dive counts, such as in the present study.

In 2000/01 in British Columbia, dive cylinder air fills were counted and mortality over 14 months was estimated at 2.05 per 100,000 dives.<sup>5</sup>

A similar method was employed at a US Military base at Okinawa 1989–95, where there were few (if any) opportunities to obtain air-fills elsewhere, generating an estimated mortality rate of 1.3 deaths per 100,000 dives.<sup>6</sup>

In 1993/94 a count was made of scuba cylinder air-fills in Victoria, Australia,<sup>7</sup> where mortality was estimated at 2.5 per 100,000 dives.<sup>8</sup>

Scuba cylinder air-fills were also counted in Japan, at popular dive sites where access to diving was limited to registered diving companies. Mortality was calculated in 2000 at 1.75 per 100,000 dives, (with 95% confidence interval 1.06, 2.44).<sup>9</sup>

Direct comparisons of scuba diving's mortality rate with that of other activities are difficult. In the various annual mortality rate comparisons that have been made, scuba diving consistently has a low mortality compared with many other types of adventure recreation,<sup>10</sup> especially considering the potential risks. It should be noted that rigorous training and implementation standards are used to address and manage the risks and severity of incidents inherent in scuba and any underwater excursion. While any death is viewed as one too many, DSD discloses this risk in an informed consent process, and its standards manage the risk with the aim of making morbidity as low as possible.

A relatively recent separate analysis identified that, among certified divers being supervised by a PADI diving professional in North America and the Caribbean, such as when diving from commercial dive operator boats, 57% ( $n = 70$ ) of the 122 recreational diver fatalities had a medical cause of death, as opposed to other causes directly associated with diving *per sé*, such as running out of air.<sup>11</sup> In the present study, however, while medical causes have been reported in some DSD fatalities the proportion of all DSD fatalities that were attributed to medical causes could not be reliably determined as the fatalities were distributed globally and in many cases medical examiner reports and/or autopsies were not included in the reports filed with PADI.

Never before have diving fatalities with an exposure denominator of > 7,000,000 introductory scuba experiences over 28 years been reported. Nonetheless, the limitations of this study include that the number of participants who are not registered remains unknown, but if this bias is in fact considerable, (as suspected), and its scale were known, then it would lower the estimated mortality rate even further. Especially given today's online interconnectedness, we consider the likelihood of there being a substantial discrepancy between the number of annual fatalities and

the number reported to PADI to be slim, at best. Another limitation is that these data and conclusions apply only to the PADI DSD introductory scuba experience. Other training organisations have their own such programmes, but do not use the same instructional system and therefore, may have differing mortality rates. That said, because PADI has an estimated 70% global market share in recreational diving, the DSD numbers likely represent two thirds to three quarters of global introductory scuba experiences.

## Conclusions

PADI's DSD introductory scuba experience presently, at 0.87 fatalities per 100,000 participants, has a calculated mortality rate per 100,000 participants that is less than half that calculated in 2008 for the 1992–2008 period. The more recent period's rate improvement may be due either to significant under-registration in the early period, or to significant safety-performance improvement in the later period or, possibly, some combination of the two. Regardless, the data suggest the DSD mortality rate compares favourably with mortality in recreational scuba diving overall.

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#### Conflicts of interest and funding

Within the previous three years PB was employed by Divers Alert Network in North Carolina, which provides insurance to scuba diving instructors, and both AH and KS are currently employed by the Professional Association of Diving Instructors. All authors

have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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