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

by

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1 **Mortality rate during professionally guided scuba diving experiences for uncertified**

2 **divers, 1992-2019**

3 Abstract

4 Background: The aim of this study is to re-examine the mortality rate among Professional

5 Association of Diving Instructors' (PADI)'s Discover Scuba Diving (DSD) program. A

6 secondary aim was to investigate if the proportion of fatalities that were assessed as caused

7 by medical issues, as opposed to causes directly related to diving, has declined.

8 Methods: Fatalities reported to PADI as having occurred during DSD scuba dives were

9 counted for each year between 1992-2019. DSD participant registrations were also counted

10 for each year. The data were conveniently divided into two equal 14-year periods, 1992-2005

11 ("early") and 2006-2019 ("late"). To smooth out the year-to-year variation in raw rates,

12 Monte Carlo simulations were performed on the mean rate per 100,000 participants per year

13 during each period.

14 Results: There were a total of 7,118,731 DSD participant registrations and 79 fatalities during

15 the study period. The estimated overall mean mortality rate in the early period was 2.55 per

16 100,000 DSD registrations whereas the estimated rate of 0.87 per 100,000 DSD registrations

17 was significantly lower in the latter period ($P < 0.0001$).

18 Conclusions: PADI's Discover Scuba Diving introductory scuba experiences today, at 0.87

19 fatalities per 100,000 participants, have a calculated mortality rate per 100,000 participants

20 that is less than half that calculated for 1992-2008. The latter period's rate improvement

21 appears due either to significant under-registration in the early period, or to significant safety-

22 performance improvement in the latter period or, more likely, some combination of the two.

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Introduction

Introductory scuba diving programs 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.[1] 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.[1] 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 (CEQ).[2]

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.[3] 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.[3] The study suggested that the number of registered DSD participants underestimated the true number of DSD divers.

58   At about the same time, PADI required instructors to use a new, full-colour, glossy

59   participant registration form. It had a tear-off card for the customers and was pre-addressed to

60   return participant registrations to PADI. This method was followed by the introduction of an

61   online registration system, making the process even more convenient and efficient. The

62   annual number of DSD registrations doubled in two years, then doubled again, going from

63   almost 200,000 registered DSD participants in 2002/03 to nearly 800,000 in 2007/08. This

64   level of introductory scuba participation had never before been documented.

65   At the 2010 Divers Alert Network Fatality Conference the President/CEO of PADI, Dr. Drew

66   Richardson, presented a seminal diver mortality study, which showed the raw number of

67   fatalities per 100,000 participants for a range of diver training programs, 1989-2008.[1] This

68   was the first time that such information had been shared by a global recreational diver

69   training organization. Of high interest was the DSD mortality rate, since this program is

70   typically taken by participants who have not previously been certified as trained recreational

71   divers. The program is designed to enable a complete novice to try scuba for the first time in

72   the open water, always directly supervised by a PADI Instructor.[2]

73   Although it was made clear that, while the fatality counts were likely accurate, (because all,

74   or nearly all, fatalities were likely known and counted), the numbers of DSD participants'

75   figures were suspected to have been artificially-low due to a proportion of participants not

76   having had their participant registration forms submitted to PADI, (even though participant

77   registration was contractually required of members).[1,3] Factors affecting participant

78   registration may have included the cost of hiring staff to envelope and address photocopied

79   forms, especially in areas where there was an intense "dive season."[3] Because DSD

80   registrations were suspected to have been lower than actual participation, the published DSD

81   mortality rate per 100,000 participants was considered artificially high in the 2010 paper.

82   The aim of this study is to re-examine the mortality rate among DSD participants using

83   today's much larger (and likely more accurate) annual denominators, and to compare the

84   current mortality rate with that of an earlier period. The null hypothesis is that the calculated

85   mortality rate per 100,000 DSD participants per year has not significantly changed.

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87   **Methods**

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88 Ethics approval was granted by the Human Research Ethics Committee of Curtin University,

89 approval HRE2020-0444 dated 11th August 2020. Fatalities reported to PADI as having

90 occurred during DSD scuba dives, which are contractually required to be reported to PADI

91 by its members, were counted for each year between 1992-2019. DSD participant

92 registrations were also counted for each year. The data, stored in Excel and analysed using

93 SAS (Cary, NC) ver 9.4, were conveniently divided into two equal 14-year periods, 1992-

94 2005 ("early") and 2006-2019 ("late"). Individual raw mortality rates per 100,000

95 registrations were calculated for each year. Potential linear trends in increasing or decreasing

96 raw rates were tested for significance in each period by univariate regression. To smooth out

97 the year-to-year variation in raw rates, Monte Carlo simulations were performed on the mean

98 rate per 100,000 participants per year during each period, with 10,000 iterations and

99 resampling. The resultant 10,000 14-year mean mortality rates were normally distributed for

100 each period, in accordance with Central Limit Theorem. Standard deviations around the

101 estimated means for each period were too disparate to pool the variance (Table 1), therefore a

102 Student's T-test with un-pooled (Satterthwaite) variances was used to assess the magnitude of

103 the difference in estimated mean mortality rate during each period (early vs. late).[4]

104 Significance was accepted at $P < 0.05$.

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106 **Results**

107 There were a total of 7,118,731 DSD participant registrations and 79 fatalities during the

108 study period.

109 There was no linear trend in increasing or decreasing raw rate per 100,000 registrations

110 associated with calendar year during either the early period (t = -1.45, $P = 0.17$) or the late

111 period (t = 1.06, $P = 0.30$). The results of the Monte Carlo simulation are presented in Table

112 1. The distributions of the estimated means ($n = 10,000$ per period) are shown in Figure 1.

113 The estimated mean mortality rate per 100,000 DSD registrations was significantly lower (t =

114 341, $P < 0.0001$) in the latter period.

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116   **Table 1:** Descriptive characteristics of the raw and estimated mean mortality rates per group

117   (early or late) generated by Monte Carlo simulation

Group	Registrations	Fatalities	Raw Rate per 100,000	Estimated mean (SD)	Estimated 95% CI	Estimated means (n)
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

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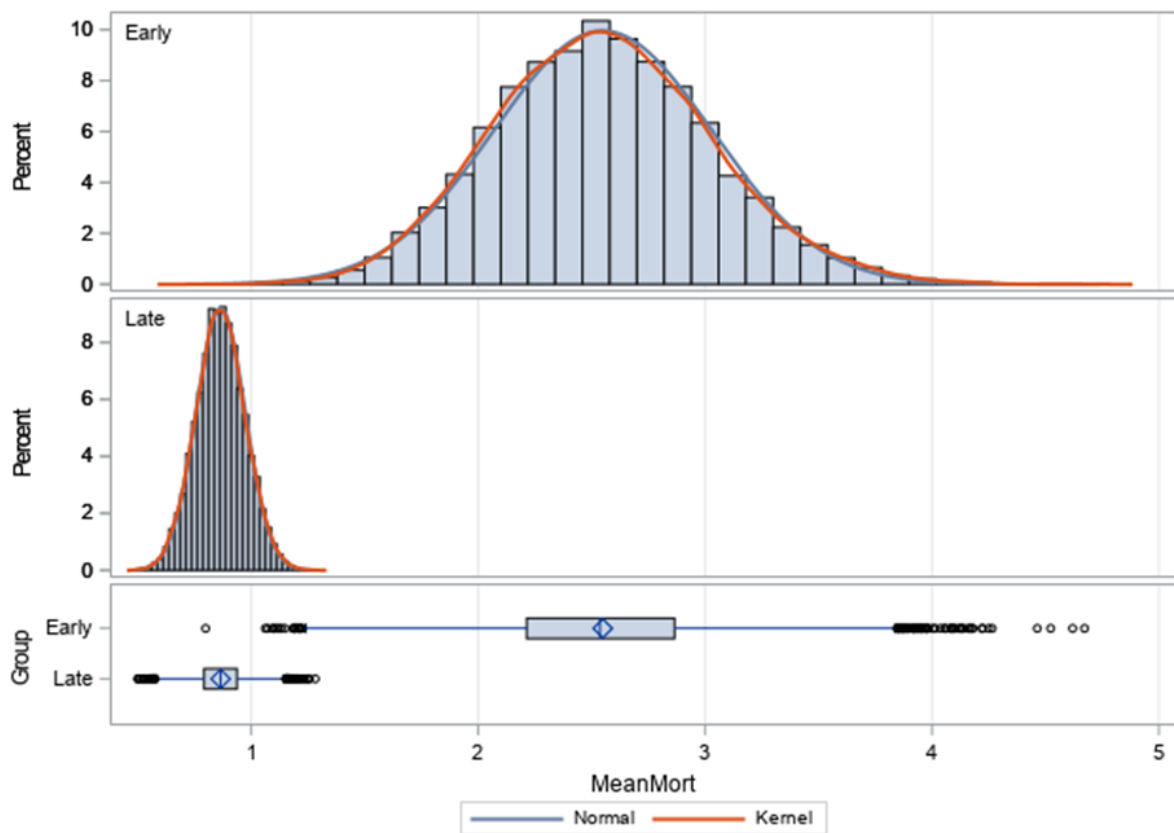
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120   **Figure 1:** Histogram with box-and-whisker plots for 10,000 estimated mean mortality per

121   100,000 participants, by group (early or late)

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Discussion

124   The primary aim of this study was achieved, and we have identified that the annual mean

125   number of fatalities per 100,000 DSD participants during a recent 14-year period was

126   significantly lower than in the 2010 analysis.[1] Today, calculated overall mortality during

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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 utilized 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 program 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.[5]
- 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.[6]

158 • In 1993/94 a count was made of scuba cylinder air-fills in Victoria, Australia,[7] where
159   mortality was estimated at 2.5 per 100,000 dives.[8]
160 • Scuba cylinder air-fills were also counted in Japan, at popular dive sites where access
161   to diving was limited to registered diving companies. Mortality was calculated in
162   2000 at 1.75 per 100,000 dives, (with 95% confidence interval 1.06, 2.44).[9]

163 Although direct comparisons are similarly difficult comparing scuba diving's mortality rate
164 with that of other activities, in the various annual mortality rate comparisons that have been
165 made scuba diving consistently has a low mortality compared with many other types of
166 adventure recreation,[10] especially considering the potential risks. It should be noted that
167 rigorous training and implementation standards are used to address and manage the risks and
168 severity of incidents inherent to scuba and any underwater excursion. While any death is
169 viewed as too many, DSD discloses this risk in an informed consent, and its standards
170 manage the risk with the aim of making morbidity as low as possible.

171 A relatively-recent separate analysis identified that, among certified divers being supervised
172 by a PADI diving professional in North America and the Caribbean, such as when diving
173 from commercial dive operator boats, 57% ($n = 70$) of the 122 recreational diver fatalities had
174 a medical cause of death, as opposed to other causes directly associated with diving *per sé,*
175 such as running out of air.[11] In the present study, however, the proportion of fatalities that
176 were attributed to medical causes could not be determined, as the fatalities were distributed
177 globally and in many cases medical examiner reports and/or autopsies were not included in
178 the reports filed with PADI.

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180 Never before have diving fatalities with an exposure denominator of > 7,000,000
181 introductory scuba experiences over 28 years been reported. Nonetheless, the limitations of
182 this study include that the number of participants who are not registered remains unknown,
183 but if this bias is in fact considerable, (as suspected), and its scale were known, then it would
184 lower the estimated mortality rate even further. Especially given today's online
185 interconnectedness, we consider the likelihood of there being a substantial discrepancy
186 between the number of annual fatalities and the number reported to PADI to be slim, at best.
187 Another limitation is that these data and conclusions apply only to the PADI DSD
188 introductory scuba experience. Other training organizations have their own such programs,
189 but do not use the same instructional system and therefore, may have differing mortality

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rates. That said, because PADI has an ==estimated== 70% global market share in recreational diving, the DSD numbers likely represent 2/3rds to 3/4ths of global introductory scuba experiences.

Conclusions:

PADI's Discover Scuba Diving introductory scuba experience today, 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 latter 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, overall the data suggest the DSD mortality rate compares favourably with mortality in recreational scuba diving in general.

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241   **Conflicts of Interest**

242   None declared. Full disclosure: Within the previous three years PB was employed by Divers
243   Alert Network in North Carolina, which insure scuba diving instructors, and both AH and KS
244   are currently employed by the Professional Association of Diving Instructors. All authors
245   have declared that there are no other relationships or activities that could appear to have
246   influenced the submitted work.

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