# Diver Health Survey score and probability of decompression sickness among occupational dive guides and instructors

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**Abstract**

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**Introduction:** This study attempted to correlate self-reported post-dive Diver Health Survey (DHS) scores with computed daily probability of decompression sickness (pDCS) values as a measure of decompression stress in occupational divers in the recreational diving industry.

**Methods:** Divers completed the DHS form and their dive profiles were recorded electronically. The pDCS for each dive was calculated using the LE1 probabilistic model. Data were analysed using a mixed effects model.

**Results:** DHS score was not significantly associated with pDCS. Mean DHS score on non-diving days was 1.6 and increased by 0.8 for each dive made during any day. Mean number of daily dives was 1.9 and mean DHS score on diving days was 3.1.

**Conclusion:** Utility of the DHS for monitoring daily decompression stress among occupational divers working in the recreational diving industry in New Zealand remains unproven.

**Key words**

Occupational diving, occupational health, health surveillance, diving at work, decompression sickness, models

## Introduction

Decompression schedules for diving have progressively evolved from those developed by Haldane in the early 1900s, all with the common goal of avoiding decompression sickness (DCS).[1] DCS is a multisystem condition that can be protean in its manifestations. Both clinicians treating divers and researchers testing decompression procedures have historically utilised a binary classification system – DCS vs no-DCS. However, it is also accepted that the physiological processes responsible for the clinical manifestations of DCS are active to a greater or lesser degree after all but the most trivial exposures to pressure. Where to draw the line for diagnosis of DCS depends on a number of factors but, irrespective of the exact definition used, DCS remains a rare event. This very low incidence of clinical DCS presents a challenge to researchers in that a prohibitively large number of trials need to be conducted before a decompression model can be statistically shown to be effective at preventing such a rare event.

Weathersby et al. pointed out the advantages of applying maximum likelihood techniques to binary outcomes from diving decompressions and proposed fitting a risk model to profiles of depth-time-breathing gas with known DCS outcomes.[2] For a given dive profile, such 'trained' models can predict the probability of DCS (pDCS). How accurate the prediction is depends to a large extent on how well the dive being assessed matches the original data set.[3] Use of binary outcome data (DCS/no-DCS) can limit the complexity of the models that can be fitted because of the low incidence of DCS within most diving data sets.[4] Statistically based decompression models have been fitted to Doppler venous bubble scores and to binary DCS/no-DCS results with the inclusion of 'marginal' cases to increase model degrees of freedom.[5,6] Regardless, many dives must be monitored to detect enough DCS cases to allow fitting of complex decompression models.

### THE DIVER HEALTH SURVEY

An alternative approach to detecting DCS in the field is to utilise self-reported health status measured in the form of a questionnaire. Doolette suggested this approach commenting that, if diving health outcome could be reliably measured in the field, results could be matched to electronic depth-time profiles and could provide an alternative source of data for decompression model calibration.[4] The Diver Health Survey (DHS) was subsequently developed to measure self-reported diver health status following decompression. The DHS tool consists of a single-sided A4 post-dive questionnaire with nine explicit items covering five general concepts indicative of health status, (physical functioning, role limitation, general health perception, bodily pain, and vitality), six common symptoms of DCS, (pain, paraesthesia, weakness, vitality, rash, and balance/dizziness), and time of onset of symptoms relative to diving activity. A response to each of the nine explicit items is chosen from four check boxes with semantic anchors representing scores of 0 through 3; the lower the score, the more normal is the health status. The DHS has been described in detail elsewhere.[7] Psychometric testing of this survey tool suggested that it was a statistically valid measure of decompression-related health outcome and that it also appeared sufficiently reliable for collection of grouped data for decompression model calibration.[7] Advantages of the DHS were that it removed the need to diagnose DCS in the field (replacing binomial DCS/no-DCS with 30-point interval data, significantly increasing model degrees of freedom), it was brief (nine questions + one free response) and it was self-administered.[7]

The DHS was used initially on tuna farm divers in South Australia to review their diving practices and the impact of multi-day diving on reported post-dive health status.[8,9] It has also been used to measure perceived post-decompression health status in hyperbaric chamber attendants following standard medical hyperbaric exposures, health status following dry chamber dives on nitrox, on a cave diving expedition and on a small group of technical divers.[10–13] The work on tuna farm divers comprises the only published data correlating occupational diver health scores with computed probability of DCS. The DHS is described as a valid instrument for field assessment of DCS with significant correlation of DHS scores and concurrent medical diagnosis.[7] The aim of this study was to assess if the DHS correlated with computed daily pDCS values as a measure of decompression stress in occupational divers in the recreational diving industry.

## Methods

Thirty-one occupational divers working in Tutukaka, New Zealand were invited to participate and 25 (81%) agreed. Participants were supplied with an information sheet describing the study's aims, the data to be collected and the ultimate destination of the data. Participants then gave signed consent. The research protocol was approved by the University of Auckland Human Research Ethics Committee. Participants completed the DHS form both on diving and non-diving days. None reported previous DCS. DHS scores were calculated and stored in an Excel spreadsheet matched to each diver's individual identifier (ID). Also recorded were the consecutive number of days each diver had participated (DAY), total daily dive duration in minutes (DUR), daily maximum depth reached in metres' sea water (MSW) and the number of dives per day (NUM). All dives were made breathing air.

Depth-time dive profile data were recorded by Sensus Ultra loggers (Reefnet inc, Mississauga, Canada) or personal dive computers (Suunto Oy, Finland; ScubaPro Uwatec, USA; and DeltaP Technology, UK). The Sensus Ultra loggers had a pressure resolution to 1 mbar, with an accuracy of +/-30 mbar, equivalent to 30 cms change in depth whilst immersed in sea water. Variation in depth resolution between personal dive computers was not measured. Depth-time profiles were downloaded from each depth-time recorder directly to a laptop PC using each unit's proprietary interface and software. Data were exported from each manufacturer's proprietary software in comma-delimited ASCII format, before being transferred into a purpose-built spreadsheet via an import routine programmed in Visual Basic for Applications (Microsoft Excel 2002, Microsoft Corp, Redmond, WA, USA).

Repetitive dives (defined as a surface interval of less than 18 h) were combined into a single depth-time profile linked with the DHS score from the end of that day. Dive profile data were analysed by Dr David Doolette to compute pDCS for each 'diving day' employing the LE1 probabilistic model calibrated to military air diving using the methods described by Thalmann and co-workers in 1997.[6] The resultant column of daily pDCS values completed the dataset.

Six of the 25 participants were lost to follow-up when they left the area at the end of the summer diving season without returning their data collection booklets or dive data recorder. A seventh experienced a dive computer malfunction which rendered its data unusable, leaving 18 participants for analysis.

ANALYSIS

Data were analysed using SAS (ver. 9.2, Cary, NC). Strengths of association with the dependent variable DHS were evaluated using a linear mixed effects model. Mixed effects models are particularly suited to the analysis of repeated measures data involving randomly selected subjects exhibiting inter-subject variability.[14,15] Variance components and parameters were estimated using maximum likelihood. The full model before later variable selection was:

$$HS_{ij} = ß_{0i} + e_i + ß_1 pDCS_{ij} + ß_2 DUR_{ij} + ß_3 MSW_{ij} + ß_4 NUM_{ij} + e_i$$

where $ß_0$ = the intercept of the regression which is dependent upon the diver (subscript i) and e = random error, which was associated with the diver (subscript i) and the day on which data were collected (subscript j). Homoscedasticity for individual residual variance was tested for using a likelihood ratio test. In search of the most parsimonious model, independent variables were manually removed from the full model one at a time and the increasingly simplified models fitted to the data. Models were evaluated using Akaike Information Criteria (AIC), which bypasses the need to specify a level of significance a priori to model building unlike backwards elimination; smaller AIC indicates better fit.[15] Differences in fit between models pre- and post-variable removal follow a chi-square distribution and were tested for significance ($P < 0.01$) using a likelihood ratio test with degrees of freedom equal to the number of explanatory variables removed.[16]

## Results

Eleven of the 18 divers were male. Mean diving experience was 11.5 years with a median of 1,200 lifetime dives. Participant characteristics are presented in Table 1; subjects

**Table 1**
**New Zealand occupational dive guide and instructor demographic characteristics (*n* = 18)**

| Characteristic | Median | Range |
|---|---|---|
| Age (years) | 30 | 23–39 |
| Body mass index (kg $m^{-2}$) | 24 | 21.9–33.5 |
| Diving experience (years) | 11.5 | 6–26 |
| Number of lifetime dives | 1,200 | 340–5,000 |

**Table 2**
**Diving data, showing medians (range) for individual Diver Health Survey (DHS) scores, depths, dive durations, numbers of daily dives and computed pDCS (LE1) values and means (SD) for grouped data; msw – metres' seawater depth; DCS – decompression sickness**

| Diver | Number of days | DHS score | Depth (msw) | Duration (min) | Daily dives | Probability of DCS | |
|---|---|---|---|---|---|---|---|
| A | 54 | 3 (1–8) | 18 (2–39) | 73 (10–149) | 2 (1–4) | 0.008 | (0.000–0.020) |
| B | 20 | 0 (0-2) | 18 (11–31) | 80 (12–104) | 2 (1–2) | 010 | (0.003–0.023) |
| C | 52 | 2 (0–8) | 31 (9–44) | 61 (20–147) | 2 (1–4) | 0.013 | (0.003–0.044) |
| D | 12 | 0 (0–5) | 18 (10–37) | 63 (34–105) | 2 (1–2) | 0.057 | (0.008–0.159) |
| E | 31 | 2 (1–9) | 18 (10–32) | 86 (40–133) | 2 (1–3) | 0.009 | (0.003–0.120) |
| F | 17 | 5 (3–7) | 20 (10–37) | 98 (40–114) | 2 (1–4) | 0.011 | (0.002–0.034) |
| G | 11 | 5 (2–8) | 19 (12–33) | 75 (39–100) | 2 (1–2) | 0.007 | (0.005–0.014) |
| H | 15 | 2 (1–5) | 20 (11–32) | 90 (36–114) | 2 (1–2) | 0.012 | (0.002–0.022) |
| I | 11 | 4 (3–6) | 11 (8–28) | 81 (57–140) | 2 (2–5) | 0.007 | (0.000–0.013) |
| J | 17 | 3 (1–5) | 17 (4–29) | 99 (28–131) | 2 (1–3) | 0.009 | (0.000–0.026) |
| K | 4 | 7 (7–10) | 10 (7–23) | 101 (57–150) | 2 (2–3) | 0.009 | (0.005–0.040) |
| L | 7 | 5 (4–7) | 18 (6–29) | 88 (50–153) | 2 (1–2) | 0.008 | (0.002–0.044) |
| M | 25 | 2 (1–4) | 21 (15–31) | 85 (35–155) | 2 (1–3) | 0.010 | (0.002–0.023) |
| N | 8 | 2 (0–6) | 18 (7–30) | 51 (24–74) | 2 (2–3) | 0.009 | (0.003–0.019) |
| P | 28 | 3 (2–7) | 17 (11–39) | 91 (34–135) | 2 (1–3) | 0.006 | (0.003–0.015) |
| Q | 5 | 1 (0–7) | 15 (10–25) | 114 (54–125) | 2 (1–3) | 0.007 | (0.003–0.014) |
| R | 21 | 3 (0–5) | 21 (12–29) | 57 (40–135) | 2 (1–3) | 0.008 | (0.003–0.012) |
| S | 21 | 4 (2–6) | 19 (3–37) | 61 (18–103) | 1 (1–3) | 0.008 | (0.000–0.023) |
| **Sub-total** | | | | | | | |
| **Single dives** | 93 | 2.4 (1.5) | 22.2 (9.0) | 45.5 (16.8) | 1.0 (1.0) | 0.011 | (0.019) |
| **Repetitive dives** | 266 | 3.3 (2.1) | 20.0 (7.1) | 88.5 (24.1) | 2.2 (0.5) | 0.014 | (0.016) |
| **Overall** | 359 | 3.1 (2.0) | 20.5 (7.7) | 77.3 (29.3) | 1.9 (0.7) | 0.013 | (0.017) |

were primarily young, fit, experienced divers.

The mean delay between surfacing from the last dive of each day and completing the DHS was 6.0 hours (SD 1.3). As shown in Table 2, the mean DHS overall during diving days ($n$ = 359) was 3.1 (SD 2.0). Mean DHS during non-diving days ($n$ = 395) was 1.6 (SD 1.7).

Divers' individual residuals were sufficiently different to reject the assumption of homoscedasticity, (chi-square = 24.9, df = 1, $P$ < 0.01), therefore, the effect of repeated measures (ID) was retained within each model tested. Though these are not shown in Tables 3 or 4, the range of intercepts for ID in model 1 of Table 3 was -2.5 to +3.1.

Removal of DUR did not significantly improve the full model ($P$ = 0.16) nor did the removal of pDCS ($P$ = 0.16). By model 3, the AIC was the lowest value of any model but the parameter estimate of MSW was so small as to affect DHS by a score of -1 for every increase of 50 msw maximum depth. Model 3 was significantly worse for the removal of either NUM (model 4, $P$ < 0.01) or MSW (model 5, $P$ < 0.01). In keeping with the aim of the study model, model 6 was also tested and found to be significantly worse than model 3 ($P$ < 0.01), as was the null model comprising only the intercept and random error (model 7, $P$ < 0.01).

Taking into account Table 3, the delay in minutes between surfacing from the last dive of each day and completing the DHS (SUR2DHS) was added to the model and the AIC process repeated for data recorded during diving days only ($n$ = 359). The fitting of the model including SUR2DHS is presented in Table 4.

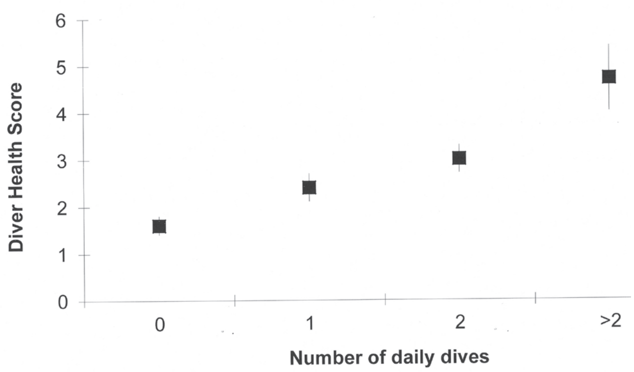
Fitting all data ($n$ = 754) in Table 3, the lowest AIC was calculated for model 3, in which the size of the effect of MSW was negligible, and where the addition of pDCS did not result in a significantly improved fit (model 3 vs 2, $P$ = 0.16). Likewise, for the diving data alone ($n$ = 359) the removal of pDCS from the model with the lowest AIC (model 3) did not result in a significantly worse fit (model 5 vs 3, $P$ = 0.17). The fit of model 3 was not significantly worsened for the removal of SUR2DHS and pDCS (model 8, AIC 1265 vs 1261, $P$ = 0.15), but it was significantly worse for the removal of NUM (model 6, AIC 1300 vs. 1261, $P$ < 0.001), suggesting that, among occupational divers in the recreational industry, DHS is most closely linked to the daily number of dives. An intercept of 0.8 (model 3) suggests an increase in DHS of 0.8 for each additional dive made during any day, as can be seen in Figure 1.

**Table 3**
**Model improvement through variable removal and fitting to all data (*n* = 754)**

| Model | Variables | Parameter Estimate | (SE) | AIC | LL | Likelihood ratio Test | chi square | (df) | *P* value |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Intercept | 3.10 | (0.214) | 2595.2 | -1257 | | | | |
| | pDCS | 0.14 | (3.934) | | | | | | |
| | DUR | <0.01 | (0.003) | | | | | | |
| | MSW | -0.02 | (0.008) | | | | | | |
| | NUM | 0.72 | (0.117) | | | | | | |
| 2 | Intercept | 3.10 | (0.214) | 2593.2 | -1257 | 2 vs 1 | 2 | (1) | 0.157 |
| | pDCS | 0.14 | (3.923) | | | | | | |
| | MSW | -0.02 | (0.007) | | | | | | |
| | NUM | 0.72 | (0.075) | | | | | | |
| 3 | Intercept | 3.10 | (0.214) | 2591.2 | -1257 | 3 vs 1 | 4 | (2) | 0.135 |
| | MSW | -0.02 | (0.007) | | | 3 vs 2 | 2 | (1) | 0.157 |
| | NUM | 0.72 | (0.075) | | | | | | |
| 4 | Intercept | 3.30 | (0.286) | 2661.4 | -1293 | 1 vs 4 | 66.2 | (3) | < 0.01 |
| | MSW | -0.03 | (0.005) | | | 3 vs 4 | 70.2 | (1) | < 0.01 |
| 5 | Intercept | 2.95 | (0.223) | 2598.1 | -1261 | 1 vs 5 | 2.9 | (3) | 0.407 |
| | NUM | 0.55 | (0.053) | | | 3 vs 5 | 6.9 | (1) | <0.01 |
| 6 | Intercept | 3.68 | (0.256) | 2673.9 | -1299 | 1 vs 6 | 78.7 | (3) | < 0.01 |
| | pDCS | 11.18 | (3.242) | | | 3 vs 6 | 90.8 | (1) | < 0.01 |
| 7 | Intercept | 3.79 | (0.251) | 2682.0 | -1304 | 1 vs 7 | 86.8 | (4) | < 0.01 |

pDCS – probability of decompression sickness; DUR – dive duration (minutes); MSW – maximum depth in metres of sea water; NUM – number of daily dives; AIC – Akaike Information Criteria; LL – log likelihood; df – degrees of freedom

**Figure 1**
**Diver Health Score by daily number of dives**




## Discussion

This review of the diving practices of occupational dive guides and instructors suggests they manage their decompression risk conservatively. There were no reported incidences of DCS among the study participants and their DHS scores were typically within the asymptomatic range. However, DHS scores did not correlate highly with computed pDCS values.

As with the Doolette study of tuna divers, the random effect of diver ID had a significant effect upon the model AIC.[9] Given the generalised nature of the health status indicators used in the DHS, the capture of some non-diving-related symptoms is expected. While this reduces the specificity of the survey at the level of the individual diver, it maintains sensitivity for the non-specific, generalised symptoms of DCS, which is needed when collecting group data. Internal consistency testing of the DHS has previously demonstrated the survey items measure aspects of the same attribute (established by concurrent validity testing for symptoms of DCS).[7] In this study, the intercept for ID ranged from -2.5 to +3.1 (range 5.6), similar to the variance among tuna divers of 0.1 to 4.7 (range 4.6).[8]

The mean pDCS recorded in this study during 359 diving days was 0.013, which was higher than recorded during 383 occupational tuna diving days (pDCS = 0.005).[9] Of the 359 diver-days in this study, 293 (82%) exceeded a pDCS of 0.005. The LE1 model used to compute pDCS in this study may not be a good predictor of DCS in occupational dive guides and instructors. A mean pDCS of 0.013 over 359 diving days equates to 4.67 predicted incidents. There were no reported cases of DCS and only two diving days with DHS > 8, which has been associated previously with clinical DCS.[7] The dataset used to calibrate the LE1 model contained only 8% repetitive air dives; whereas this study recorded 266/359 (74%) repetitive air dives and this may also have affected the pDCS. The LE1 model has previously under-estimated pDCS for repetitive air dives.[6]

**Table 4**
**Model improvement through variable removal and fitting to data on diving days only ($n$ = 359)**

| Model | Variables | Parameter Estimate | (SE) | AIC | LL | Likelihood ratio Test | chi square (df) | *P* value |
|---|---|---|---|---|---|---|---|---|
| 1 | Intercept | 2.01 | (0.480) | 1263.8 | -590 | | | |
| | SUR2DHS | 0.00 | (0.001) | | | | | |
| | pDCS | 19.48 | (7.589) | | | | | |
| | DUR | 0.00 | (0.003) | | | | | |
| | MSW | -0.01 | (0.010) | | | | | |
| | NUM | 0.71 | (0.126) | | | | | |
| 2 | Intercept | 2.02 | (0.478) | 1261.9 | -631 | 1 v 2 | 1.9 (1) | 0.168 |
| | SUR2DHS | 0.00 | (0.001) | | | | | |
| | pDCS | 20.22 | (7.389) | | | | | |
| | MSW | -0.01 | (0.010) | | | | | |
| | NUM | 0.73 | (0.107) | | | | | |
| 3 | Intercept | 1.80 | (0.445) | 1261.3 | -591 | 3 v 1 | 2.5 (2) | 0.287 |
| | SUR2DHS | 0.00 | (0.001) | | | | | |
| | pDCS | 15.42 | (6.208) | | | | | |
| | NUM | 0.77 | (0.104) | | | | | |
| 4 | Intercept | 2.53 | (0.258) | 1262.8 | -592 | 4 v 1 | 1.0 (3) | 0.801 |
| | pDCS | 16.44 | (6.240) | | | 4 v 3 | 1.5 (1) | 0.221 |
| | NUM | 0.72 | (0.102) | | | | | |
| 5 | Intercept | 1.83 | (0.442) | 1263.2 | -593 | 5 v 1 | 0.6 (3) | 0.896 |
| | SUR2DHS | 0.00 | (0.001) | | | 5 v 3 | 1.9 (1) | 0.168 |
| | NUM | 0.81 | (0.102) | | | | | |
| 6 | Intercept | 3.40 | (0.426) | 1300.2 | -611 | 1 v 6 | 36.4 (3) | < 0.01 |
| | SUR2DHS | 0.00 | (0.001) | | | 3 v 6 | 38.9 (1) | < 0.01 |
| | pDCS | 33.71 | (6.613) | | | | | |
| 7 | Intercept | 3.45 | (0.271) | 1298.2 | -611 | 1 v 7 | 34.4 (4) | < 0.01 |
| | pDCS | 33.65 | (6.586) | | | | | |
| 8 | Intercept | 2.62 | (0.252) | 1265.1 | -595 | 8 v 1 | 1.3 (4) | 0.861 |
| | NUM | 0.76 | (0.101) | | | 8 v 3 | 3.8 (2) | 0.150 |
| 9 | Intercept | 3.72 | (0.414) | 1308.6 | -616 | 1 v 9 | 44.8 (4) | < 0.01 |
| | SUR2DHS | 0.00 | (0.001) | | | | | |
| 10 | Intercept | 3.76 | (0.256) | 1306.6 | -616 | 1 v 10 | 42.8 (5) | < 0.01 |

pDCS – probability of decompression sickness; DUR – dive duration (minutes); MSW – maximum depth in metres of sea water; NUM – number of daily dives; SUR2DHS – delay between surfacing from last dive and completing the DHS; AIC – Akaike Information Criteria; LL – log likelihood; df – degrees of freedom

The mean depth of non-repetitive dives of 22 msw and mean dive time of 45 minutes approaches the no-stop limit of the DCEIM tables, which has a pDCS ≥ 0.0156.[9] One daily dive schedule did exceed that no-stop limit (pDCS = 0.159) resulting in an unremarkable health outcome (DHS score 1). Overall, this study found a mean depth of 20 msw, mean total daily duration underwater of 77 min, spread over 1.9 dives per day (Table 2). This contrasts with occupational tuna divers who recorded a mean depth of 17 msw, a mean dive time of 23 min and a mean of 1.4 dives per day.[8] Though the divers in this study recorded greater mean depth, total bottom time and daily number of dives than occupational tuna divers, these parameters may not adequately portray overall decompression stress because of potential differences in dive profiles, for example multi-level vs square-wave. That the DHS was insensitive among New Zealand recreational dive guides and instructors, yet useful as a measure of decompression stress among Australian tuna farm divers, may be (at least in part) due to these differences in diving profiles. Caution is, therefore, advised before generalising these findings to other occupational recreational diving populations.

It is also possible these results may have been influenced by a degree of response bias. The South Australian tuna farm divers studied by Doolette were predominantly company employees with attendant benefits under Australian employment law,[9] whereas the recreational divers surveyed in this study were predominantly employed on short-term casual contracts in New Zealand. Though data were collected from the recreational group independently of their employers, the lack of sick leave provisions for many individuals may have influenced reporting of post-dive symptoms, as previously found in other occupational diver groups.[17] Better correlation may be achieved by comparing DHS scores to pDCS computed using a predictive model developed using repetitive, multi-level air diving data.

The divers in this study were a relatively young, fit group with a relatively high number of annual dives. This suggests the possibilities of, firstly, selection bias whereby less fit dive professionals may drop out of the industry or move elsewhere leaving behind only the most suited and, secondly, the potential for an acclimatisation to these elevated levels of diving stress resulting in lower reported DHS score.

The potential advantages of the DHS as a tool for self-assessment of post-dive health status both logistically in terms of data collection and statistically when modelling the results are substantial. The acquisition of field data to complement laboratory dives used in the development of decompression models remains an important goal, though how well the DHS correlates with pDCS among other diving cohorts remains to be seen.

## Conclusion

The DHS score was most strongly associated with the daily number of dives, increasing by 0.8 for each additional dive made in a day, but did not correlate highly with pDCS values calculated using the LE1 model. Reasons for this may be that the LE1 model is a poor predictor of decompression stress in this population of divers, the DHS tool may be too insensitive to detect variation in decompression stress or sub-clinical DCS in this group, or the DHS may not be a good outcome measure in this population. Utility of the DHS for measuring daily decompression stress among occupational divers working in the recreational diving industry in New Zealand remains unproven.

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