The rate of decompression sickness in scientific diving at the Australian Institute of Marine Science (Townsville) 1996 to 2001

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Key words
Decompression sickness, diving tables, science diving, safety, epidemiology

Abstract

(Carter A, Muller R, Thompson A. The rate of decompression sickness in scientific diving at the Australian Institute of Marine Science (Townsville) 1996 to 2001. *SPUMS J*. 2005; 35: 125-30.)
Objectives: To detail the rate of decompression sickness (DCS) in and describe the pattern of scientific diving according to the Canadian Defence and Civil Institute of Environmental Medicine (DCIEM) decompression tables, and project the impact of the AS/NZS Scientific Diving Standard (AS/NZS 2299.2:2002) on dive profiles at the Australian Institute of Marine Science (AIMS), Townsville.
Methods: Data have been collected for all scientific diving conducted at AIMS according to the DCIEM tables from October 1996 to December 2001. Details of location, date, time in and out, bottom time, effective bottom time (bottom time calculated according to residual nitrogen from previous dives), maximum depth, repetitive group and factor, and surface interval were recorded via the dive work sheets.
Results: The data from 14,944 dives were analysed. The total bottom time for all dives was 13,033 hours. No cases of DCS were reported in this period for a DCS rate of zero (exact binomial 95% confidence interval 0 to 30) cases per 100,000 dive hours. More than half (58.0%; n = 8,669) of all dives were conducted more than two hours' travel time from a recompression chamber. Two thirds of dives were conducted at the rate of two (35.8%; n = 5,352) or three (31.4%; n = 4,698) dives per diver per day. The median depth of dives was 10 metres' sea water with a median effective bottom time of 1:00 hr (interquartile range 0:40–1:21 hours). One quarter (25.1%; n = 3,241) of dives would have exceeded the maximum repetitive group limits if they were conducted according to AS/NZS 2299.2:2002.
Conclusions: The results of this analysis demonstrate that the rate of DCS in multi-day scientific diving conducted according to the DCIEM tables is low, regardless of maximum dive depth and travel time from recompression chamber support. The observed DCS rates at AIMS provide evidence that the repetitive group limits of AS/NZS 2299.2:2002 are restrictive for the purposes of scientific diving and require modification.

Introduction

The Australian Institute of Marine Science (AIMS) is located near Townsville and was established by the Commonwealth Government in 1972 to generate knowledge for the sustainable use of the marine environment through scientific research. Accordingly, scientific diving is a core component of the field operations. Diving activity is predominantly focussed in the warm waters of northern Queensland and Western Australia, often in remote locations. Routine tasks performed by scientific divers at AIMS include equipment deployment and recovery, filming transects of reef, and sample collection. Dives are commonly conducted in fixed locations as monitoring changes to the Great Barrier Reef is a core component of the activities of AIMS.

Pressure change is the main occupational health and safety hazard for underwater divers.[1,2] Excess nitrogen absorbed under pressure at depth can form gas bubbles during the decreasing pressures of an ascent and lead to decompression sickness (DCS). The symptoms of Type I DCS are skin rashes, lymphoedema and joint pain, while Type II DCS is characterised by respiratory, neurological, auditory-vestibular, circulatory shock or barotrauma symptoms. The dive-profile parameters of depth, bottom time and ascent rate are the best understood and most readily modifiable risk factors for DCS. While increasing age, obesity, fatigue, dehydration and decreasing maximal oxygen uptake have been identified as risk factors for DCS they are less well understood and modifiable than the dive-profile parameters.[3,4] The incidence of DCS is minimised by the use of decompression schedules that provide time limits for dives according to the maximum depth of the dive. Scientific diving at AIMS is conducted according to the Canadian Defence and Civil Institute of Environmental Medicine (DCIEM) decompression tables.

Standards Australia and New Zealand replaced the previous standard governing scientific diving, the Occupational Diving Standard (AS 2299-1992),[5] with a sector-specific Scientific Diving Standard (AS/NZS 2299.2:2002)[6] in 2002 following considerable deliberation. The major difference between these standards is the modification of the DCIEM decompression tables that restrict the dive bottom time and repetitive group according to proximity to a recompression chamber. It is anticipated that the new, more conservative, time limits will increase resource use in scientific diving as most field operations are conducted at least two hours from recompression chamber support.

Very few collections of robust epidemiological data of the rates and patterns of DCS are available in the scientific literature. The rate of DCS in scientific diving is estimated to be 1 per 100,000 dives. This is, however, an arbitrary estimate based on expert opinion only and is unsubstantiated by epidemiological data.[7] The routinely collected, detailed data of AIMS scientific diving operations represent a rich source of information for a historically poorly researched area of occupational health. The aims of this analysis are to detail the rate of scientific diving injury and diving profiles from 1996 to 2001, and to project the likely impact of the AS/NZS Scientific Diving Standard on dive profiles at AIMS. The results of this analysis can be used as a baseline for comparison to subsequent analyses of data of the DCS rate and diving profiles at AIMS following the implementation of the new AS/NZS standard.

Methods

AIMS routinely documents data of all scientific diving as part of its diving safety procedures. The James Cook University Occupational Health Research Group has analysed data of all dives from October 1996 to December 2001.

A dive plan for all proposed dives was submitted to the AIMS Dive Officer in electronic form prior to departure of each dive trip. Divers completed a dive work sheet following every dive. Details of location, date, time in and out, actual and effective bottom time, maximum depth, repetitive group and factor, and surface interval were recorded on the work sheet. The Dive Supervisor appointed for the trip verified that the data entered on the work sheets for each diver were correct. The Dive Officer verified that the work sheets for all participating divers were correct at the completion of each trip. The completed work sheets were stored in hard copy at AIMS by the Dive Officer.

All scientific divers employed by AIMS in the observation period satisfied the qualifications required by AS 2299-1992. Dives conducted under the jurisdiction of AIMS must not exceed an absolute depth of 30 metres' sea water (msw). Visiting divers not employed by AIMS had as a minimum the equivalent of a Confédération Mondiale des Activités Subaquatiques (CMAS) two star diver accreditation.[8] These divers did not exceed a maximum depth of 15 msw unless prior approval was obtained from the AIMS Dive Officer.

All dives during the observation period were conducted according to the AIMS diving procedures.[9,10] The AIMS procedures are based on AS 2299-1992 and allow diving to the no-decompression limits of the DCIEM Air Diving Tables and Procedures. The repetitive group and repetitive factors in this analysis were calculated according to the DCIEM tables. Dives conducted according to these tables and procedures were described as square profiles, where a single ascent and constant depth were assumed. Bottom time was defined as the total elapsed time from the diver commencing the initial descent from the surface to the diver commencing the final ascent. DCS was defined as a confirmed diagnosis of the clinical manifestations by a medical practitioner.

Data from the work sheets were used to calculate the following variables for each dive:

- bottom time
- effective bottom time (bottom time calculated according to residual nitrogen from previous dives)
- repetitive group (classified according to the residual nitrogen in a diver's body immediately on surfacing from a dive)
- surface interval (the time from when a diver surfaces from a dive to the commencement of the descent for a subsequent dive)
- repetitive factor (a factor determined by the repetitive group and the surface interval from a previous dive that modifies the planned bottom time for a subsequent dive)

Travel times by helicopter from recompression chamber support were estimated for each trip in accordance with Clauses 3.4 and 3.13.3 of AS/NZS 2299.2:2002 and are displayed in Figure 1.

The maximum repetitive group limits from the DCIEM tables and according to recompression chamber support in AS/NZS 2299.2:2002 are displayed in Table 1. The criteria for determining the repetitive group limits according to recompression support for dives deeper than 12 msw in Table 3.2 of AS/NZS 2299.2:2002 were applied to dives to depths of less than 12 msw to obtain the modified limits displayed in Figure 3. That is, for dives less than two hours from recompression support, the DCIEM no-decompression

Figure 1
Travel time by helicopter from recompression chamber support

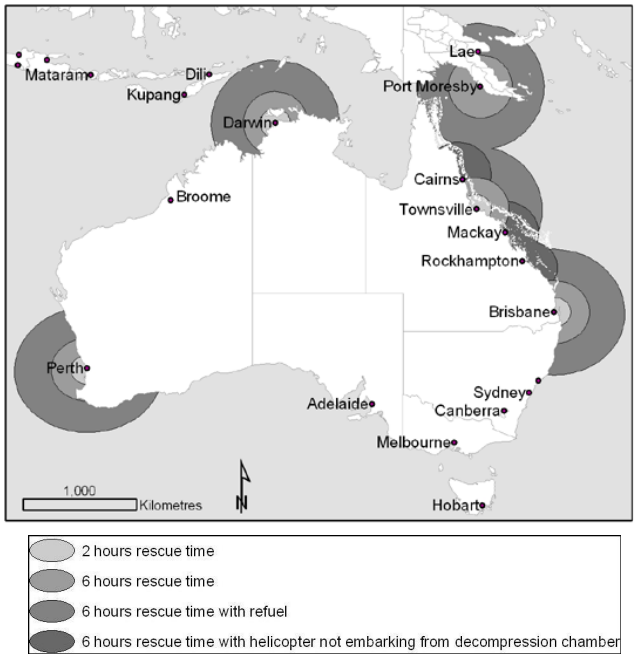


Table 1
Limits for repetitive dives from the DCIEM tables and Table 3.2 in AS/NZS 2299.2:2002 according to depth of dive and level of recompression chamber support

Maximum depth (m)	Maximum repetitive group DCIEM table	AS/NZS 2299.2:2002 Chamber < 2 hrs	Chamber 2 – 6 hrs	Chamber > 6 hrs
3	M	No limit	G (H)	G
6	M	G (J)	G (H)	G
9	M	H	G	F
12	J	H	E	D
12 – 15	G	G	F	E
15 – 18	F	F	E	D
18 – 21	E	E	D	C
21 – 24	E	E	D	C
24 – 27	D	D	C	B
27 – 30	D	D	C	B

limit was used; for dives two to six hours and more than six hours from recompression support, one and two repetitive groups fewer than the DCIEM no-decompression limits were used respectively.

The data were analysed using SPSS for Windows™ statistical software (Version 10, Chicago, USA).

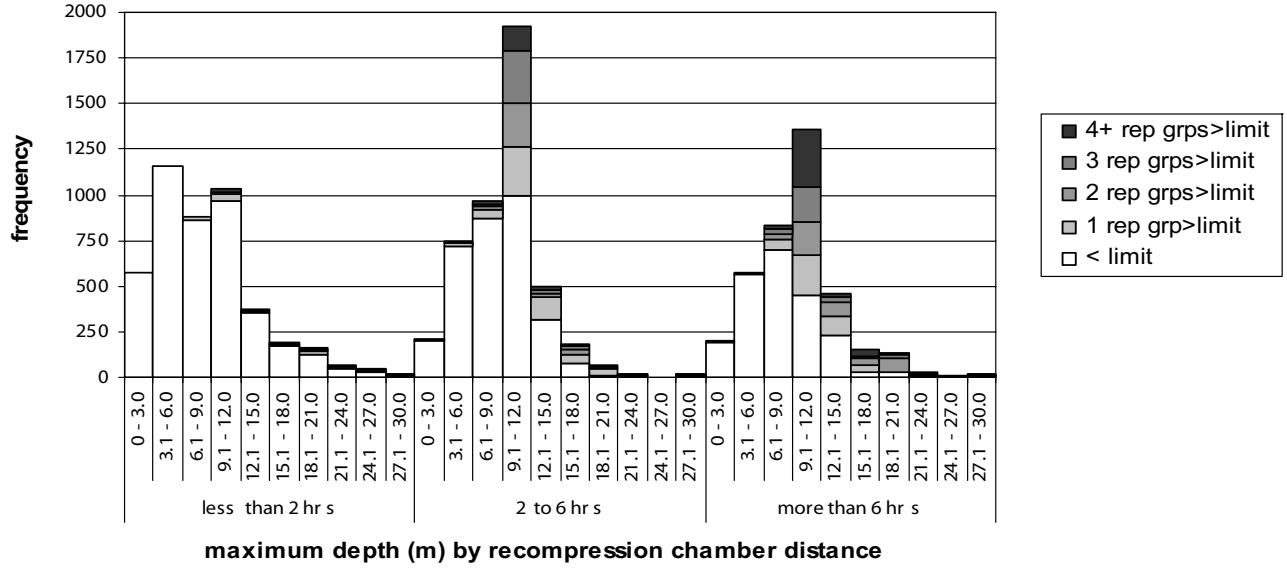
Results

The data from 14,944 dives between October 1996 and December 2001 are detailed in Table 2. The total bottom time for all dives was 13,303 hours. No cases of DCS were reported in this period. The observed DCS rates are zero per 100,000 dives (exact binomial 95% confidence interval 0 to 20) and per 100,000 dive hours (exact binomial 95% confidence interval 0 to 30).

Four hundred dive trips were undertaken by 272 identified divers. The number of dives per diver during the observation period ranged from 1 to 541 dives with a median of 20 (interquartile range 10 to 53). Dives at the rate of one per diver per day accounted for 17.0% (n = 2,546) of all dives. Two thirds of dives were conducted at the rate of two (35.8%; n = 5,352) or three (31.4%; n = 4,698) dives per diver per day. The maximum number of dives per day was eight, all of which were to a maximum depth of 3 msw.

Almost two thirds of all dives were conducted at locations more than two hours (two to six hours, 31.8%, n = 4,751; more than six hours, 26.2%, n = 3,918) in travel time from a recompression chamber. The median maximum depth was 10 msw. The median bottom time was 0:51 hours (interquartile range 0:35 to 1:06 hours). One quarter (25.3%) of dives generated a repetitive group of A to C, while half

Figure 2
Compliance of AIMS scientific dives from 1996 to 2001 with repetitive group limits set by Table 3.2 of AS/NZS 2299.2:2002



(50.4%; n = 7,529) generated a repetitive group of D to F. The surface interval was 18 hours or more for one third (32.7%; n = 4,881) of the dives; for the dives with a surface interval of less than 18 hours, the median interval was 2:37 hours (interquartile range 0:46 to 6:31 hours). Dives were predominantly conducted within no-decompression limits (95.6%; n = 14,282).

Data relating to the proximity of recompression chamber support and effective bottom time are available for 12,915 (86.4%) of the dives conducted. One quarter (25.1%; n = 3,241) of these dives would exceed the maximum permissible repetitive group for dives if the limits according to recompression chamber support introduced in the AS/NZS Scientific Diving Standard in 2002 (AS/NZS 2299.2:2002, Table 3.2) were applied (Figure 2). Dives within two hours of a recompression chamber would be conducted predominantly (95.6%; n = 4,290) within the modified repetitive group limits, while almost one third (31.2%; n = 1,447) of dives between two and six hours and almost half (42.1%; n = 1,595) more than six hours from chamber support would exceed the limits.

Almost half (43.4%; n = 2,933) of all dives to deeper than 9 msw, compared to 5.0% (n = 308) of dives to 9 msw or less, would exceed the repetitive group limits of AS/NZS 2299.2:2002. More than two thirds (68.1%; n = 2,207) of all dives to deeper than 12 msw would exceed the repetitive group limits of AS/NZS 2299.2:2002. Of these, 20.5% (n = 666), 15.5% (n = 502) and 16.5% (n = 535) would be within one, two and three repetitive groups of the limits respectively. More than half (58.6%; n = 1,899) of dives that would exceed the limits would be of the depth category 9 to 12 msw; 28.5% (n = 924) and 28.2% (n = 915) would be two to six hours and more than six hours' travel time respectively from a recompression chamber.

Almost 10% (9.5%, n = 1,225) of dives would exceed the repetitive group limits in Table 3.2 of AS/NZS 2299.2:2002 if the criteria for maximum repetitive group for dives of 12 msw or deeper (as described in the Methods section) were applied consistently to dives at all depths (Figure 3). More than 10% (less than two hours, 3.0%, n = 136; two to six hours, 9.4%, n = 435) of dives within six hours of a recompression chamber, and 17.3% (n = 654) of dives at more than six hours, would exceed the limits. Less than one third (31.9%; n = 1,034) of all dives that would exceed the limits are to depths less than 12 msw.

Discussion

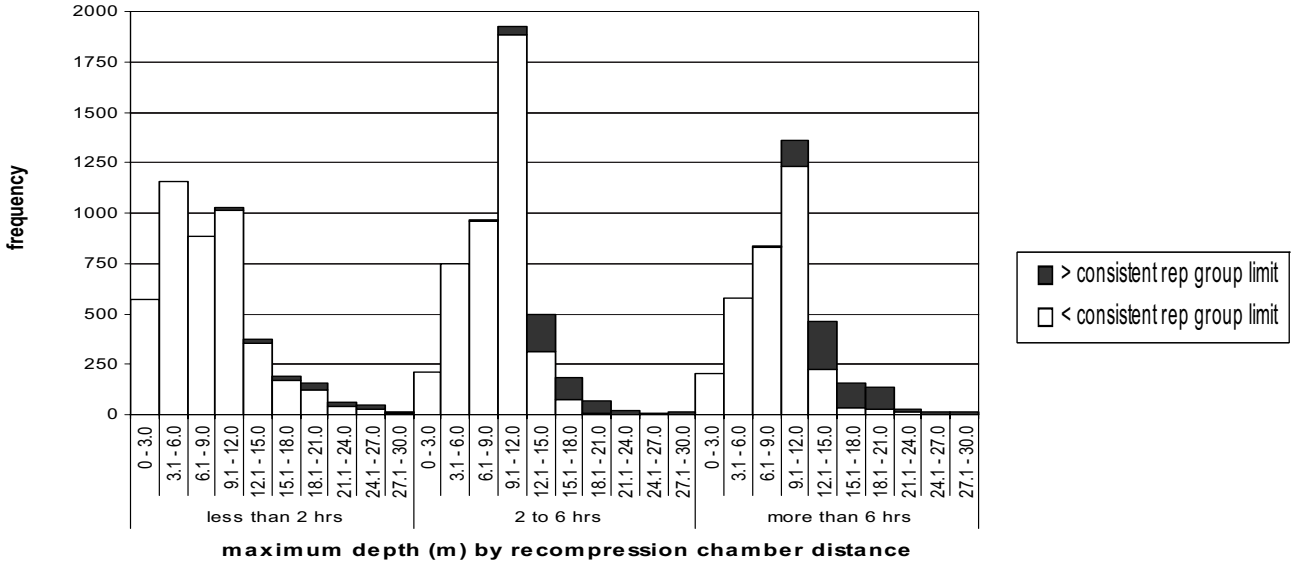
No cases of DCS were reported from the 14,944 dives conducted by AIMS divers during the five-year study period (exact binomial 95%, confidence interval 0 to 20). Scientific diving conducted by AIMS is characterised by multi-day diving (83.0%). Approximately two thirds of all dives were repetitive dives. The dive profiles were typically of depths of approximately 10 msw with effective bottom times of about one hour. More than half (58%) of the dives were in locations more than two hours' travel time from a recompression chamber. The results of this analysis demonstrate that the risk of DCS during multi-day scientific diving conducted according to the DCIEM tables is low.

The low rate of DCS observed in this analysis refers to diagnosed cases where a medical practitioner confirmed the clinical physical manifestations of the condition. However, DCS is a syndrome characterised by a variety of

Table 2
Univariate description (IQR – interquartile range)

Variable	Summary	Result
Year	1996	4.90%
	1997	22.30%
	1998	19.40%
	1999	17.80%
	2000	16.00%
	2001	19.60%
Travel time from chamber support	< 2 hours	30.10%
	2 to 6 hours	31.80%
	> 6 hours	26.20%
	Unspecified	11.90%
Dives per diver per day	1	17.00%
	2	35.80%
	3	31.40%
	4	10.70%
	5 or more	5.00%
Maximum depth	Median	10.0 metres (IQR 6.0 – 12.0)
Bottom time	Total	13,303:08 hours
	Median	0:51 hours (IQR 0:35 – 1:06)
Effective bottom time	Total	15,846:37 hours
	Median	1:00 hours (IQR 0:40 – 1:23)
Repetitive group	A	5.70%
	B	8.60%
	C	11.00%
	D	20.10%
	E	17.00%
	F	13.30%
	G	10.00%
	H	7.20%
	I to P	4.90%
	Unspecified	2.20%
Repetitive factor	Median	1.1 (IQR 1.0 – 1.4)
Surface interval	18 hours or more	32.70%
	< 18 hours	65.20%
	Median	2:37 hours (IQR 0:46 – 6:31)
Decompression stop required	Yes	2.30%
	No	95.60%
	Not known	2.10%

Figure 3
Categorisation of AIMS scientific dives from 1996 to 2001 by consistent application of repetitive group limits for dives of deeper than 12 metres from Table 3.2 of AS/NZS 2299.2:2002 to dives at all depths



symptoms, each with a spectrum of intensities of effect. It is therefore possible that the observed rate may not account for DCS in cases where divers perceived their symptoms to be insufficiently intense to seek any clinical intervention. While tools are available for divers to self-evaluate the presence and the accompanying intensity of the symptoms of DCS,[11,12] they were not used in this study.

The maximum repetitive group limits in Table 3.2 of the AS/NZS Scientific Diving Standard (AS/NZS 2299.2:2002) will impact significantly on diving and resource use at AIMS, as 25% of the dive profiles in this analysis would require a reduced maximum depth or bottom time to comply with the limits (Figure 2). The proportion of dives that would require a reduced maximum depth or bottom time increases with increasing travel time from recompression chamber support. More than one third of dives in this analysis at locations further than two hours (two to six hours, 31%; more than six hours, 42%) from recompression support would exceed the limits, while almost half (43%) of all dives to deeper than 9 msw, compared with 5% of dives to less than 9 msw, would exceed the limits.

Consequently, the time available both to perform routine tasks and to access the biodiversity at depth is likely to be restricted in remote locations. The restrictions to the maximum allowable bottom times and repetitive groups in AS/NZS 2299.2:2002 are intended to minimise the risk of permanent injury resulting from the delay in onset of treatment of DCS. However, the observed DCS rate at AIMS provides evidence that scientific diving conducted according to the DCIEM tables is low risk, and that the repetitive group limits in Table 3.2 of AS/NZS 2299.2:2002 are unnecessarily conservative and likely to be restrictive for the purposes of scientific diving.

There are inconsistencies in the repetitive group limits in Table 3.2 of AS/NZS 2299.2:2002 that will impact on the dive profiles typically used by AIMS divers. For dives more than two hours' travel from a recompression chamber, the repetitive group limits for scientific dives to less than 12 msw have been set at least three repetitive groups below the DCIEM no-decompression limits. This is in contrast to the limit for dives deeper than 12 msw being set to one (two to six hours' travel time) and two (more than six hours) repetitive groups below the no-decompression limits. In addition, the progression of repetitive group limits with dive depth for dives more than two hours' travel time from a recompression chamber is haphazard. The repetitive group limits for dives between two and six hours' travel from a chamber to depths of 6, 9, 12, 15 and 18 msw are G, G, E, F and E respectively. Similarly, for dives more than six hours from a chamber, the repetitive group limits for the corresponding depths are G, F, D, E and D.

These inconsistencies in the repetitive group limits, rather than the dive profiles used by scientific divers at AIMS, are the major contributing factor to the 25% of all dives that would exceed the maximum repetitive group limits of AS/NZS 2299.2:2002. More than half (53%) of all dives that would exceed the limits were to less than 12 msw and within three repetitive groups of the limits. There is no reference to data in AS/NZS 2299.2:2002 relating the specified maximum repetitive groups to DCS risk equivalence to support the selection of the limits for the depth categories. The limits are the result of modifications, according to expert consensus, to the no-decompression limits of the DCIEM tables that are considered a reliable and valid estimate of DCS risk for dives at all depths. The inconsistencies in maximum repetitive group limits in Table 3.2 of AS/NZS 2299.2:2002 compared to the DCIEM dive

tables indicate that the risk of DCS is not consistently controlled for dives at depths of less than 12 msw and more than two hours from recompression chamber support.

The distinguishing feature of contemporary risk management processes is the iteration between analysis, deliberation and decision.[13] Addressing the inconsistencies identified in the repetitive group limits of AS/NZS 2299.2:2002 will not only contribute to this process, but also serve to reduce the impact of the limits on the dive profiles typically used by AIMS divers. A plausible modification to Table 3.2 of AS/NZS 2299.2:2002 is to apply the criteria determining the repetitive group limits for dives at deeper than 12 msw (as detailed in the Methods section) to dives at all depths. This modification resolves the identified inconsistencies in determining the limits, while still allowing a conservative safety margin in addition to that already incorporated in the DCIEM tables. The proportion of dives that would require a reduced maximum depth or bottom time would be more than halved to 10% (Figure 3).

Conclusions

The pattern of scientific diving conducted by AIMS is characterised by multi-day diving. The results of this analysis demonstrate that the rate of DCS in multi-day diving conducted at AIMS according to the DCIEM decompression tables is low. While it is anticipated that the repetitive group limits of AS/NZS 2299.2:2002 will restrict the underwater scientific research conducted by AIMS, further research is needed to fully evaluate their impact on dive safety, activity and resource utilisation.

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Erratum

The book review by Glen Hawkins recently published in this journal (*SPUMS J*. 2005; 35: 111-2.) mistakenly indicated that he was based in Adelaide. Dr Hawkins is in fact Hyperbaric Fellow in the Department of Diving and Hyperbaric Medicine at Prince of Wales Hospital, Sydney. The Editor apologises for this error.