

# Risk factors for running low on gas in recreational divers in Western Australia

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## Key words

Low air, risk factors, recreational diving, scuba diving, epidemiology, research

## Abstract

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**Introduction:** The aim of this study was to investigate risk factors associated with running low on gas among certified recreational divers.

**Methods:** Dive and diver information were collected from divers joining organised recreational dives in Western Australia and depth/time loggers were attached to each diver. Case dives ending with < 50 bar in the cylinder were compared with control dives made at the same dive site and time by divers with  $\geq 50$  bar remaining. A conditional logistic regression model identified factors significantly associated with running low on gas.

**Results:** In total, 1,032 dive profiles were collected. Case dives ( $n = 183$ ) returning with < 50 bar were compared with 510 control dives ending with  $\geq 50$  bar. Perceived workload was associated with rate of consumption of gas. Factors associated with a dive ending low on gas included: younger age; males; lower number of lifetime dives; a longer period since last dive; deeper maximum depth and breathing at a heavier rate. Eleven per cent of case divers, compared with 1% of control dives, reported surprise at the low remaining level of gas.

**Conclusions:** Dive organisers are recommended to select dive sites based on the recent experience of the group and to encourage divers to monitor their remaining gas frequently, relative to the depth of the site. Divers are reminded that, if they perceive a strenuous workload, they should pay even closer attention to monitoring their gas reserves. That 89% of low-on-gas dives were reported to be no surprise to the divers making them warrants further investigation.

## Introduction

Running low on gas has been implicated in diving morbidity and mortality.<sup>1,2</sup> An analysis of 859 reported diving incidents in Australia found that 168 (19.5%) involved an out-of-gas problem, 57 (35%) of which resulted in diver harm.<sup>3</sup> A survey completed by 515 Western Australian divers in 2000 found that 19% divers reported running low on gas.<sup>4</sup> A 2005 survey of Western Australian recreational divers reported running out of gas and making for the surface among 7% of respondents, sharing gas with a buddy among 9% and making an emergency ascent among 9%.<sup>5</sup>

To reduce the likelihood of running out of gas, the Western Australian Code of Practice for Recreational Divers specifies “Certified divers should be briefed on:... the need to regularly monitor gas levels in gas cylinders and note minimum gas content requirements for a safe return to the surface”.<sup>6</sup> Dive leaders in Western Australia (WA) commonly set the minimum reserve in the cylinder with which to return at 50 bar, as many submersible pressure gauges (SPG) have the lowest 50 bar colour coded, usually red (Figure 1).

Excepting cases where entrapment is implicated, information on the reasons why divers run low on gas is limited. A Delphi survey of diving experts suggested the most likely reasons for recreational divers to run out of gas were, in order:

- failing to monitor the gauge;
- inexperience;
- overexertion/strong current;

- inadequate training;
- poor dive planning;
- panic/anxiety/stress;
- diving deeper than usual.<sup>7</sup>

A recent cross-sectional analysis of 52,582 open-circuit scuba dives made by 5,046 adult recreational divers found that divers who reported running out of gas ( $n = 86$ ) were more likely to be older and to be female.<sup>8</sup> Controlling for age and sex, and comparing the 86 out-of-gas dives to 1,207 normal dives made by the same group of divers, the study found that out-of-gas dives were more likely to have been deeper, shorter, made from a live-aboard or day boat and to

**Figure 1**  
Submersible pressure gauge with lowest 50 bar coloured coded (usually red)



have involved a higher perceived workload.<sup>8</sup>

By controlling for the factors of depth, length and type of dive, the aim of this study was to further investigate other dive- and diver-related factors associated with finishing a dive low on gas among certified recreational divers. As perceived workload has been found to be significantly associated with the likelihood of reporting running out of air, we also hypothesized that a higher perceived workload would manifest as higher rates of air consumption.<sup>8</sup>

## Methods

Adult, certified divers attending organised recreational group dives were recruited as previously described.<sup>9</sup> Briefly, dive businesses and dive clubs in WA were invited to participate. A researcher (PB) then met organised groups of recreational divers at popular dive sites around the coast of WA. The study was approved by the Human Research Ethics Committee of the University of Western Australia.

Dive and diver information were collected using a modified Divers Alert Network (DAN) Project Dive Exploration (PDE) survey questionnaire and Sensus Ultra data loggers (ReefNet, Ontario) were attached to each diver. Data collected included sex, age, weight, dive experience, certification level and problems experienced during the dive. Self-reported starting and returning gas pressures and stamped cylinder volumes were recorded on the dive record. Consumed gas volume was calculated by multiplying cylinder volume by the difference between starting and ending cylinder pressures, expressed as surface-equivalent air consumption (SAC, L min<sup>-1</sup> kg body weight<sup>-1</sup>).

## ANALYSIS

Mean depth was calculated by dividing the total of recorded depths from each dive by the number of samples recorded between the time the diver left the surface (depth >1 metres' sea water, msw) and the time of returning to the surface (depth = 0 msw). This included divers swimming back to the boat underwater, but excluded time spent at the surface. For example, when taking a bearing back to the boat near the end of a dive, it is assumed that divers at the surface would have temporarily discontinued using scuba and breathed air from the atmosphere. SAC was calculated by dividing the gas volume used by the number of minutes spent underwater and by the mean ambient pressure in bar at the mean depth (excluding time at the surface, as described above). Trends in decreasing gas pressures and increasing depth were tested for significance using a general linear model.

To control for environmental conditions, dives in which a diver exited with < 50 bar in the cylinder were classed as 'case' dives, and dives made at the same dive site and at the same time by another diver that ended with ≥ 50 bar remaining were classed as 'control' dives. The data were

imported into SAS version 9.2 (Cary, North Carolina) and the distribution of variables tested for normality. Bivariate analyses were conducted for each factor. Four variables with cell counts of less than five were excluded from further analysis. These were regulator malfunction (two cases), reported panic (four cases), reported severe workload (one case), and losing the weight system (one case). Twelve remaining factors were fitted to a conditional logistic regression model, which was achieved by numbering each organised dive consecutively and stratifying the regression by dive number. Non-significant associations ( $P > 0.05$ ) were removed by backwards elimination.

## Results

A description of the participants and range of diving conditions has been reported previously.<sup>9</sup> A total of 1,032 dives were recorded, of which 339 were made by groups where no diver returned with < 50 bar remaining. Case dives returning with < 50 bar ( $n = 183$ ) were compared with 510 simultaneous control dives ending with ≥ 50 bar.

Dives made by females ( $n = 199$ , 29%) tended to be longer than those by males (55 versus vs. 49 mins,  $P < 0.01$ ), although they reached similar maximum depths (mean 19.8 msw for females vs. 20.3 msw for males,  $P = 0.36$ ). When divided by reported body weight, there was no difference between the sexes in mean SAC rates (males 0.22 vs. females 0.23 L min<sup>-1</sup> kg<sup>-1</sup>,  $P = 0.70$ ). Females ascended 10% slower than males (10.7 vs. 11.8 m min<sup>-1</sup>,  $P < 0.01$ ), used smaller dive cylinders than males (11.5 vs. 11.9 L,  $P < 0.01$ ) but returned with more gas remaining than males (80.0 vs. 68.8 bar,  $P < 0.01$ ).

There were three methods of supervision employed by divemasters leading recreational dive groups: dives made from live-aboard vessels were supervised from the deck; dives made from the shore or a day boat were either supervised from the surface or personally guided in the water. The method of supervision had no effect on the likelihood of running low on gas ( $P = 0.63$ ).

## RUNNING LOW ON GAS

Case dives ( $n = 183$ ) ended with a mean of 36.3 bar of gas remaining and control dives ( $n = 510$ ) ended with twice as much, a mean of 75.9 bar remaining. Table 1 presents univariate comparisons between case and control dives. SAC was associated with running low on gas ( $P < 0.01$ , Table 1) and with perceived workload ( $P < 0.01$ , Table 2).

Divers reported keeping watch on their remaining gas pressure more often during the last half of the dive for case dives than for control dives (95% vs 91%,  $P = 0.09$ ). Case divers were also more likely to report being surprised at the end of the dive by their remaining gas pressure (11% vs 1%,  $P < 0.01$ ).

**Table 1**  
**Univariate associations with case dives (< 50 bar) and control dives (≥ 50 bar)**  
 \* Each risk factor modelled as a continuous variable per units indicated in parentheses

Risk factor	Cases	Controls	Univariate OR	(95% CI)	P-value
<b>Younger age*</b> (mean) (per 10 years)	39.0	41.8	1.37	1.07 to 1.74	<0.01
<b>Male/female ratio</b>	83:17	67:33	3.30	1.99 to 5.49	<0.01
<b>Fewer dives last 5 yrs*</b> (median; per 100 dives)	100 (range 0–1,500)	150 (range 5–1,500)	1.22	1.11 to 1.35	<0.01
<b>Time since last dive*</b> (wks; per year)	10.4	3.4	1.23	0.95 to 1.51	<0.01
<b>Deeper average depth*</b> (per 5 msw)	12.2	11.3	1.81	1.11 to 2.93	<0.01
<b>Higher SAC*</b> (L min <sup>-1</sup> kg <sup>-1</sup> )	0.25	0.21	1.07	1.04 to 1.10	<0.01
<b>Smaller cylinder*</b> (L)	11.5	11.7	1.45	1.11 to 1.91	<0.01
<b>Surprised by low gas pressure (%)</b>	11.0	1.0	10.42	3.58 to 30.30	<0.01
<b>Low vs high certification (%)</b>	73:17	58:35	2.35	1.46 to 3.76	<0.01
<b>Fewer years of diving*</b> (median)	6.0 (range 0–35)	10.0 (range 0–39)	1.60	1.27 to 2.02	<0.01
<b>Fewer dives with BCD*</b> (median; per 10 dives)	67.5 (range 0–1,100)	100.0 (range 0–1,100)	1.02	1.01 to 1.03	<0.01
<b>Buoyancy problem (%)</b>	8.0	3.0	2.33	0.99 to 5.52	<0.01

**LIVE-ABOARD DIVERS**

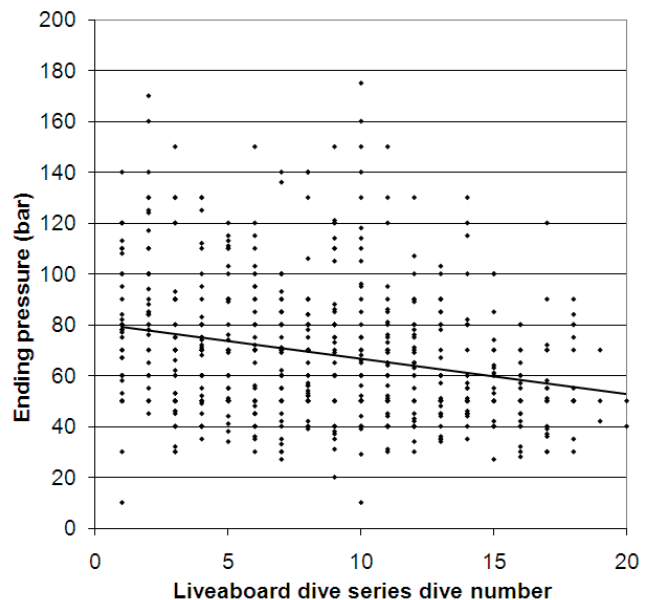
Among live-aboard dives (*n* = 656/1,032 dives by 44 divers), the median number of dives in each dive series was 15 (range 10–20). Returning gas pressures by dive number in live-aboard dive series are shown in Figure 2. The trend line indicates that returning pressures fell on average, over the course of each trip, and this trend was significant (*P* < 0.01). Maximum depth also increased significantly over the dive series (*P* < 0.01) as shown in Figure 3.

Mean maximum depth during dives one to three was 17.8 msw. By dives 17–20, after six days of diving, mean maximum depth was 25.3 msw. Maximum depths reached by divers who had dived within the previous 12 weeks and by divers who had not are shown separately in Figure 4. Divers who had dived more recently (*n* = 449) increased their maximum depth over the dive series whereas divers who had not dived during the previous 12 weeks did not (*n* = 207).

**MULTIVARIATE ANALYSIS**

Twenty-six dives (4%) were not considered because of missing data, leaving 667 dives for multivariate analysis. Variables significantly associated with dives ending with < 50 bar are shown in Table 3. The four most significant risk factors for running low on gas were dives made by younger

**Figure 2**  
**Decreasing remaining air over 656 dives in 44 dive series**  
*(P* < 0.01)



divers, being male, deeper average depth, and reporting surprise at how low the remaining gas pressure was at the end of the dive. However this last factor had a broad confidence interval, suggesting an imprecise estimate.

**Table 2**  
Surface-equivalent air consumption (SAC) by perceived workload (L.min<sup>-1</sup>.kg<sup>-1</sup>) in the low-on-gas subset (n = 677)

	Perceived workload		
	Resting/light	Moderate	Severe
SAC	0.22 (0.07)	0.24 (0.08)	0.28 (0.06)

**Discussion**

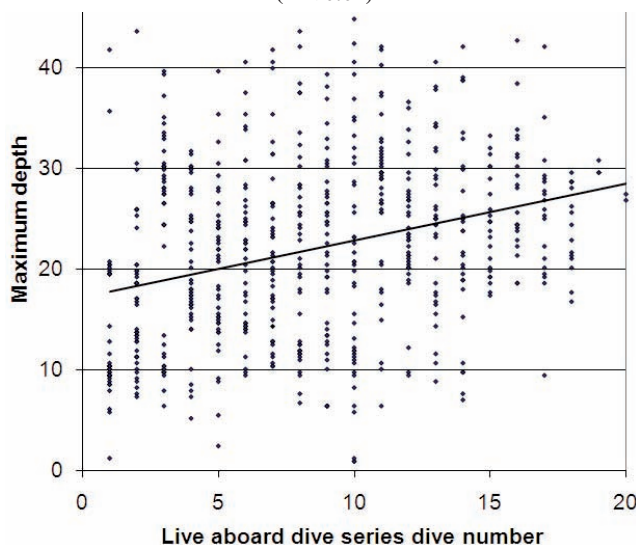
Whilst a recent study found that dives running out of gas were associated with older females, this study found that dives ending with < 50 bar were more commonly made by younger males.<sup>8</sup> There are a number of plausible explanations for this disparity. The two studies were conducted in different geographic locations using different methods and this may have had an impact on their findings.

That divers returning low on gas were surprised by their remaining pressures supports the consensus of diving experts who suggested the most likely cause of running out of gas was failure to monitor the gauge.<sup>7</sup> The experts suggested the second most likely reason might be inexperience and, in this study, case dives were made by divers with 50% fewer dives during the previous five years (100 vs. 150), a longer period since previously diving (10.4 vs. 3.4 weeks) and lower median years of diving overall (6.0 vs. 10.0 y). An increasing SAC rate was significantly associated with increasing perceived workload in the low-on-gas case-control subset. A higher SAC rate was also significantly associated with case dives, thus supporting the expert opinion that overexertion is a likely cause of running out of gas.

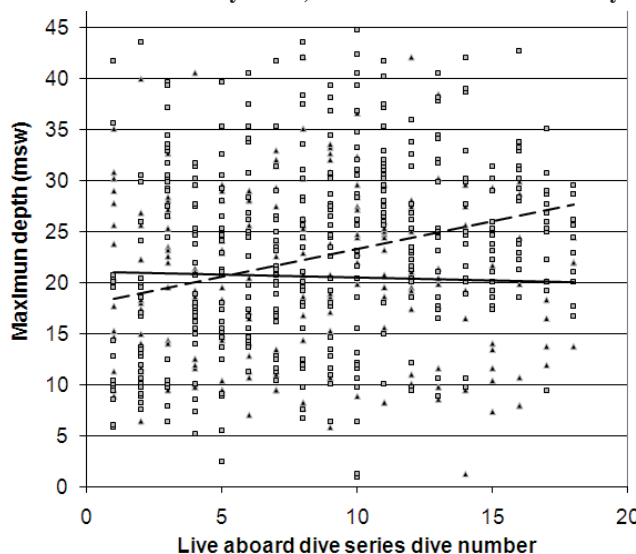
Failure to discuss a returning gas pressure during the pre-dive plan was not included in the final model as there was little difference between case dives and control dives (71% vs. 74%). However, there is more to dive planning than simply agreeing a turn-around pressure. In this study, panic was not common enough to determine if it was significantly associated with running low on gas, but diving deeper than usual was found to be significant. Of the top seven reasons suggested why divers run out of gas, this study suggests the predictive tally of the expert panel to be four significant associations, one further association significant at the univariate level only, and two as yet unproven.<sup>7</sup> It should be acknowledged, however, that the expert panel considered running out of gas whereas this study investigated running low on gas. How non-participants may have differed to participants could not be investigated, nor was how self-organised dives might differ from professionally organised dives. Caution is needed in generalising these findings beyond the population sampled.

Another limitation of this study was the large proportion of dives made from live-aboard dive platforms, suggesting a sampling bias. However, there was no significant difference between live-aboard and day-trip divers in age, sex, height,

**Figure 3**  
Increasing maximum depth over 656 dives in 44 dive series (P < 0.01)



**Figure 4**  
Maximum depth over dive series by recent experience status; dotted line – recently dived; solid line – not dived recently



weight, dive certification level, years of diving, number of dives, dive computer use or likelihood of being a ‘case’. Furthermore, dive platform was controlled for by the study design. That divers on live-aboard vessels returned with decreasing gas pressures over the duration of their dive series was an unexpected finding, as was the fact that maximum depths concurrently increased among divers with more recent diving experience. If this pattern of increasing depth and decreasing gas reserves is observed on other live-aboard dive vessels then dive organisers should consider this likely trend when selecting each day’s dive sites and in reiterating the need for divers to monitor their gas.

While 95% of divers running low on gas stated that they

**Table 3**  
**Multivariate risk factors for running low on gas**

Risk factor	Adjusted OR	95% CI	P
Male vs. female	13.51	6.41 to 28.57	<0.01
Deeper average depth* (per 5 msw)	3.46	1.85 to 6.48	<0.01
Younger age* (per 10 years)	2.02	1.47 to 2.77	<0.01
Surprised by low remaining gas	21.74	5.00 to 90.91	<0.01
Time since last dive* (per year)	1.51	1.11 to 2.06	<0.01
Fewer dives last 5 yrs* (per 100 dives)	1.22	1.00 to 1.49	0.01
Higher SAC* (per L min <sup>-1</sup> kg <sup>-1</sup> )	1.14	1.09 to 1.19	<0.01
Warmth (warm vs. cold)	4.25	1.28 to 14.13	0.02
Cylinder volume* (per L)	1.01	1.03 to 1.90	0.03

\* Variables modelled as per units indicated in parentheses

had kept a close eye on their remaining gas during the last half of the dive, 11% of them reported being surprised by how low their gas was at the end of the dive. Due to the limitations of this study it is difficult to interpret this finding. Did the 11% who were surprised not actually monitor their gauge, or were they surprised at how rapidly their reserve was depleted, and/or did the 89% who did not report being surprised consciously return with < 50 bar?

### Conclusions

Dive organisers are recommended to select sites based on the recent experience of the group and to encourage divers to monitor their remaining gas frequently, relative to the depth of the site. This may be especially important over the course of live-aboard dive trips, when some divers appear to increase their maximum depth as the trip progresses. Perceived workload is correlated with SAC rate, and divers should be reminded that, if they feel as though they are working harder, it is likely they are consuming their gas faster than if they were drifting along relaxed. In that circumstance, even closer than normal attention should be paid to the SPG. Lastly, divers are reminded to heed the advice of dive organisers and to turn their dives before the SPG needle enters the red zone.

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