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Historical diving profiles for pearl oyster divers in Western Australia

H. M. A. Lulofs and N. R. Sumner

Department of Fisheries
Government of Western Australia

Fish for the future

Fisheries Research Division
WA Marine Research Laboratories
PO Box 20 NORTH BEACH
Western Australia 6920

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Enquiries
Department of Fisheries
3rd floor SGIO Atrium
168-170 St George's Terrace
PERTH WA 6000
Telephone (08) 9482 7333
Facsimile (08) 9482 7389
Website: http://www.wa.gov.au/westfish/res

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Fisheries research in Western Australia
The Fisheries Research Division of the Department of Fisheries is based at the Western Australian Marine Research Laboratories, P.O. Box 20, North Beach (Perth), Western Australia, 6920. The Marine Research Laboratories serve as the centre for fisheries research in the State of Western Australia.

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Contents

Historical diving profiles for pearl oyster divers in Western Australia

H. M. A. Lulofs and N. R. Sumner
Western Australian Marine Research Laboratories
PO Box 20, North Beach WA 6920

Abstract

The annual value of the pearl oyster fishery off the north coast of Western Australia is in the vicinity of 153 million dollars. Most pearl oyster fishing occurs in the Broome area. This area is managed on a quota system with a total allowable catch of 512,000 shells in 1996, during which 511,716 shells were taken. This required 12,775 hours of dive time at a catch rate of 40 shell per hour.

Drift diving practices in the Western Australian pearling industry over the last eighteen years are described and related to the number of medical incidents. The study provides a better understanding of diving schedules used by industry and related concerns for diver safety.

Historical drift diving data obtained from the Fisheries Department log books (1978 to 1990) and the Pearl Producers Association's drift diving database (1991 to 1994) is analysed. The variation in dive practices over time is detailed. The incidence of medical disorders such as decompression sickness is too low (five or less cases per year) to apply statistical techniques; instead a descriptive approach is adopted.

Up to 36,561 dives and 24,127 hours of dive time in depths of up to 35 metres were performed each year with the greatest number of dives occurring in 1990. An increase in the number of deeper dives was observed for the years 1988 to 1993 after several years of dives predominantly below 14 metres.

Since the introduction of the Pearl Diving Industry Code of Practice in 1991, mean dive times and the total daily dive time increased and the mean interval between dives decreased for all depths. For all years approximately eight dives per day were performed, however, since 1991 there is less variation in the number of dives per day. Oxygen is now widely used during decompression stops on every second dive and the last dive for the day.

While the overall rate of non-compliance with the Code of Practice for bottom times is seven percent, there is reason for concern at certain depths, particularly 14.1-16.9 and 27.1-29 m, where the rate of non-compliance is much higher. Compliance with the ascent rates has improved over the last four years with the level of non-compliance in 1994 falling between one and two percent. Non-compliance with the total daily bottom times is negligible. The overall rate of non-compliance with the minimum surface intervals is 7.9 percent. All dives complied with the maximum number of dives allowed for the depth. There has been a reduction in the number of dive related medical incidents over the period 1991 to 1994.

1.0 Introduction

Pearl oysters (*Pinctada maxima*) are collected in waters off the Western Australian coast from Cape Leveque to Exmouth, although the majority are collected off Eighty Mile Beach south of Broome (Bowen, 1991). The annual value of the pearling fishery off the north coast of Western Australia is in the vicinity of 153 million dollars (Anon, 1996). This area is managed on a quota system with a total allowable catch of 512,000 shells in 1996 during which 511,716 shells were taken (Anon, 1996). This required 12,775 hours of dive time at a catch rate of 40 shell per hour (Anon, 1996). The pearl oysters are hand collected by up to three or more divers using surface supplied breathing apparatus (SSBA) in water up to 35 m in depth. The boats move over the pearling ground as divers below are towed from extended booms under the control of a chief diver (Malone *et al.*, 1988).

The first records of pearling in Western Australia were made in 1850 involving the hand gathering and dredging of shells from sandy flats at Shark Bay. The gradual depletion of the shallow water pearl stocks caused pearling to progress northward to Roebuck Bay and by 1910, Broome had become the centre of the Western Australian Pearling Industry (Malone *et al.*, 1988). The operations also moved into deeper waters (20-40 m) with the use of luggers as sailing vessels and hand pumps to supply individual helmet divers with air (Taylor, 1985). By the 1930s all vessels were motorised with mechanised air pumps allowing two divers to collect shells. The advent of World War II brought about the virtual cessation of all pearling. By the end of the 1970s, catches were 200-300 tonnes annually from around 12 boats compared with some 2,000 tonnes from over 300 vessels in earlier years (Malone *et al.,* 1988).

In 1978, pearl diving log books were introduced by the Fisheries Department to record information for stock assessment purposes. The log books were also used to record data on diving profiles. Initially, each pearling company used its own diving schedules. It was only in the late 1980s that all the companies, under the umbrella of the Pearl Producers Association, agreed to dive to the same profile. In August 1989, the Pearl Diver's Safety Committee was formed to develop sound diving practices for the pearling industry and in 1991, a Code of Practice was adopted. The Code of Practice included safe diving procedures and dive profiles for rotational and non rotational dives (refer Appendix A). In January 1991, diver log books were introduced by the Pearl Producers Association, to facilitate the collation of diving details into a computerised database. In 1995, the rotational diving profiles were revised with changes made to bottom times, maximum daily bottom times and oxygen decompression regimes. In addition, a maximum limit of 8 to 10 dives per day, depending on the dive depth, was introduced.

The subject of this study is drift diving practices in the Western Australian pearling industry over seventeen years (1978 to 1994). Historical diving practices are described and related to the number of medical incidents to increase knowledge and understanding of diving schedules used by industry and related concerns for diver safety.

2.0 Methods

2.1 Database

Data on drift diving used for analysis were extracted from the Fisheries Department log books for 1978 to 1990. The information recorded for 1978 to 1981 included vessel, date, trip number, diver's name, grid reference, wind direction, dive number, dive start and finish times, total dive time, diver identification as well as the number and weight of culture and mother of pearl (MOP) shells collected per dive. The information recorded for years 1982 to 1989 also included the dive depth and the size range of shells for culture. Information for years 1991 to 1994 was extracted from Pearl Producers Association diver log books via the drift diving database established in 1992. Additional data supplied from Pearl Producers Association log books included neap tides, surface arrival and departure time, bottom departure time, time spent decompressing on air or oxygen, depth when decompressing and surface interval between dives. Log books from 19 vessels were used in this study.

2.2 Analysis of historical dive profiles

The historical data were analysed in two ways; variation of dive practices throughout time and variation over different dive depths. A year by year comparison was made between total number of dives, total dive time and mean number of dives per day. Dive practices were compared over different diving depths and years. The comparisons include mean individual and mean total daily dive time, mean interval between dives, mean ascent time and rates, mean individual and mean total daily oxygen time, and mean individual and mean total daily bottom time. The variation in diving related medical incidents for the years 1991 to 1994 was also investigated.

2.3 Calculation of dive statistics

Total number of dives for 1978 to 1994 by depth

For the earlier years (1978-1981) often the depth data was either not available or incomplete. When this occurred, and the grid location was known, the depth was estimated from charts. However, it was not possible to estimate the depth for some dives in 1980 due to an incorrect grid reference. Since it was not possible to estimate depths from charts to the accuracy required, data for years 1978 to 1981 were omitted from most types of analyses requiring depth data. A further 12.7% of dives were omitted from analyses for years 1982 to 1989 for the same reason.

Mean individual and mean total daily dive time per diver for 1978 to 1994

Dive time was calculated as the time elapsed between the diver departing and returning to the surface. Dive time was used instead of bottom time (the time elapsed between surface departure and the beginning of the ascent) because the time the ascent commenced was not recorded prior to 1990. Mean individual dive time refers to the mean amount of time a diver spends on an individual dive. The mean total daily dive time refers to the total time spent diving for an individual diver for all dives performed on one day.

Total dive time for 1979 to 1994

The total amount of time spent diving by all divers within each year was calculated. Data from 1978 were incomplete as not all vessels were logging their dives. Data from this year were omitted from any analysis involving total dive times.

Mean number of dives per diver per day for 1978 to 1994

Mean number of dives calculated for individual divers per day for each year between 1978 to 1994. Calculated as the total number of dives divided by the number of days dived.

Mean surface interval between dives for 1978 to 1994

Surface interval was calculated as the time elapsed between a diver surfacing from the previous dive to when the diver departed from the surface to commence the next dive. Intervals were only calculated for consecutive dives completed on the same day.

Mean ascent time and mean ascent rates for dives from 1991 to 1994

Data on ascent times were only recorded after 1991. Ascent time was calculated as the time elapsed between the start of the ascent and the time that the diver surfaced. Ascent rate was calculated from the maximum depth recorded for that dive divided by the ascent times. Only dives that did not include a decompression stop were included in this analysis.

Mean individual and mean total daily oxygen time for 1991 to 1994

Mean individual oxygen time refers to the time an individual diver spends decompressing on oxygen for a particular dive. Total daily oxygen time refers to the combined amount of time a diver spends decompressing on oxygen for all dives during the day. The frequency of decompressions using oxygen by dive number was also analysed.

Mean individual and mean total daily bottom time for 1991 to 1994

Bottom time was calculated as the time elapsed between the surface departure time and the start of the final ascent. Mean individual bottom time refers to the mean amount of bottom time a diver spends on one dive. Total daily bottom time refers to the total bottom time for an individual diver for all dives performed on a particular day.

3.0 Results

3.1 Total number of dives for 1978 to 1994 by depth

The total number of dives varied considerably during the years 1978 to 1994 (Figure 1). The data for 1978 were incomplete since not all vessels were keeping logs during this year. Where no depth data was available, depths were estimated from charts for grid locations supplied. The total number of dives during 1978 to 1994 was 388,948. A total of 66.2% of these dives were less than 14 m, 26.2% were between 14 and 21 m, 2.2% were between 22 and 28 m and 4.8% exceeded 29 m. The maximum number of dives per year (36,561) occurred in 1990. In all years except 1988 and 1991, the greatest proportion of dives were less than 14 m. In years 1986 and 1987, no dives were deeper than 21 m, and in 1994, no dives were greater than 23 m. There was an increase in deeper diving in the years 1988 to 1993 after several years (1984 to 1987) of dives predominantly less than 14 m.

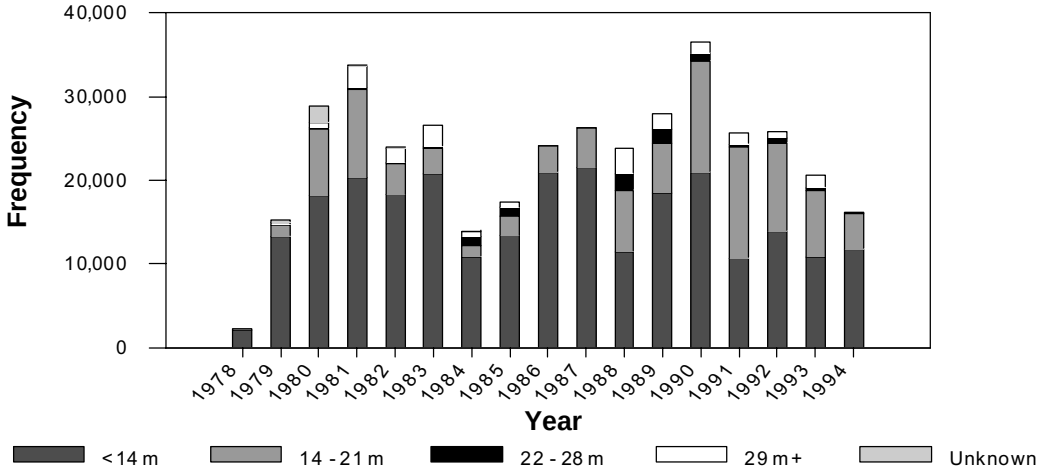

Figure 1. Total number of dives for years 1978 to 1994 by depth categories with estimated depths (the data for 1978 is incomplete).

3.2 Mean individual dive time for 1978 to 1994 by depth

Analysis of mean dive time revealed two distinct groups; 1978 to 1990 and 1991 to 1994 (only representative years are shown for clarity - Figure 2). These groups correspond to the two data sets used. However, since the data sets appear to be consistent in the way dives were recorded, any change in diving practices is more likely due to the introduction of the Pearl Producers Association Code of Practice in 1991. The mean daily dive time was higher for dives performed during 1991 to 1994 (52 min; std dev. = 14.5), and the dive times remained relatively constant over the depth range. The mean dive time for dives less than 21 m was 52 min (std dev. = 12) and for dives of 21 m or more was 50 min (std dev. = 9.4). Dives performed during 1978 to 1990, were shorter and showed a greater difference in mean dive times between dives of less than 21 m (42 min; std dev. = 13.4) and 21 m or more (34 min; std dev. = 8.3). The standard deviations for dives in the 28.9-33+ m class were slightly lower for years 1978 to 1990.

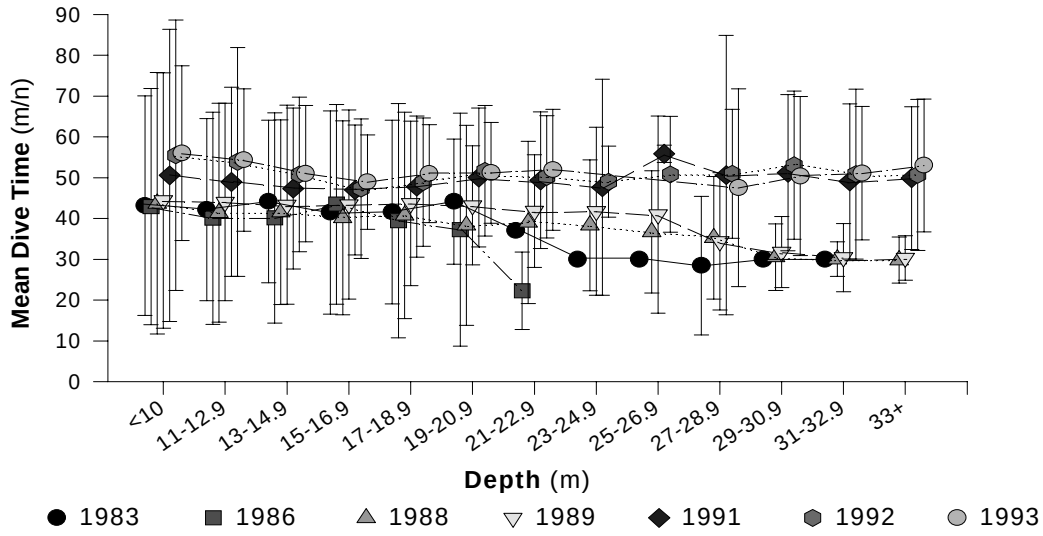

Figure 2. Mean individual dive time for years 1983, 1986, 1988, 1989, 1991, 1992 and 1993 by depth (+/- 2 std dev.).

3.3 Mean total daily dive time for 1982 to 1994 by depth

Two groups of total daily dive times were revealed; dives between 1978 to 1990 and 1991 to 1994 (only representative years are shown for clarity - Figure 3). A total of 99% of all total daily dive times were less than or equal to 545 min. The mean total daily dive time decreased markedly when the dive depth was 21 m or more. The mean total daily dive time for years 1978 to 1990, for depths less than 21 m and 21 m or deeper, was 318 min (std dev. = 123.3) and 143 min (std dev. = 49.8) respectively. The mean total daily dive time for years 1991 to 1994, for depths less than 21 m and 21 m or deeper, was 420 min (std dev. = 98.7) and 310 min (std dev. = 109.8) respectively. The standard deviation for dives greater than or equal to 23 m was smaller for all years.

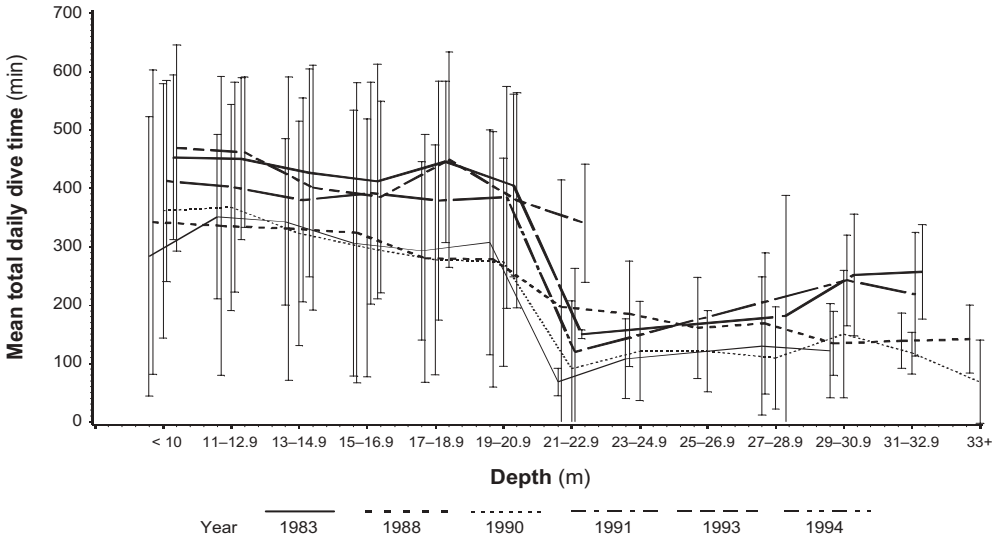

Figure 3. Total daily dive time by depth category for years 1983, 1988 and 1990 to 1994 (+/-2 std dev.).

3.4 Total dive time for 1979 to 1994

Analysis of total dive times showed that the greatest amounts of time spent diving were in 1990 (1,447,614 min) and 1980 (1,446,040 min) (Figure 4). Data for 1978 were omitted since not all vessels were logging their dives during this year.

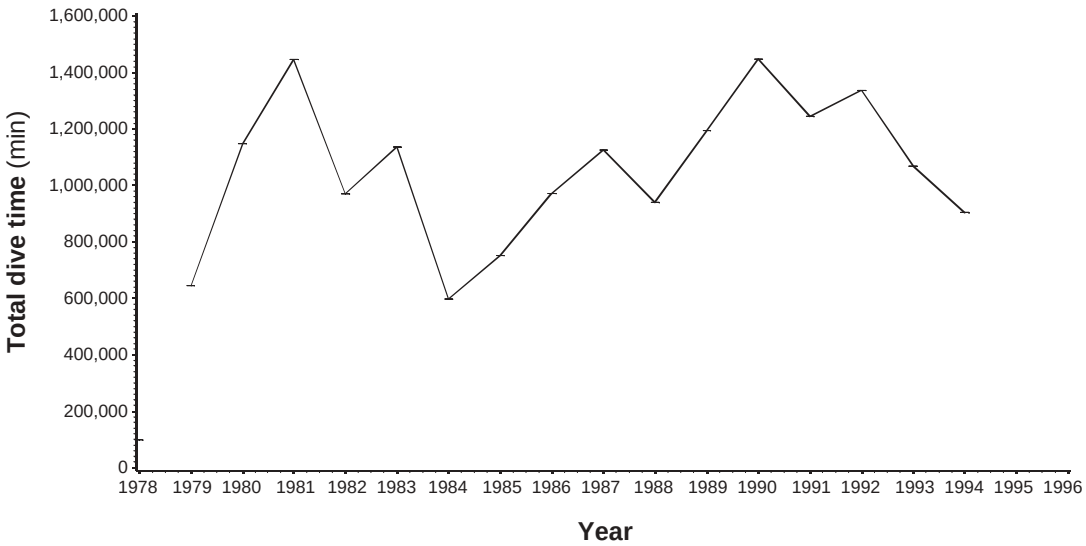

Figure 4. Total dive time for years 1979 to 1994.

3.5 Mean number of dives per day for 1978 to 1994

The mean number of dives per diver per day remained fairly constant over the years 1978 to 1994 (Figure 5). The mean number of dives per diver per day, for all years, was 7.7. The highest mean number of dives per diver per day was nine, this occurred in 1980. Ten or less dives were performed daily by a diver 87.4% of the time. The standard deviations were smaller for years 1991 to 1994. The data were skewed to the left.

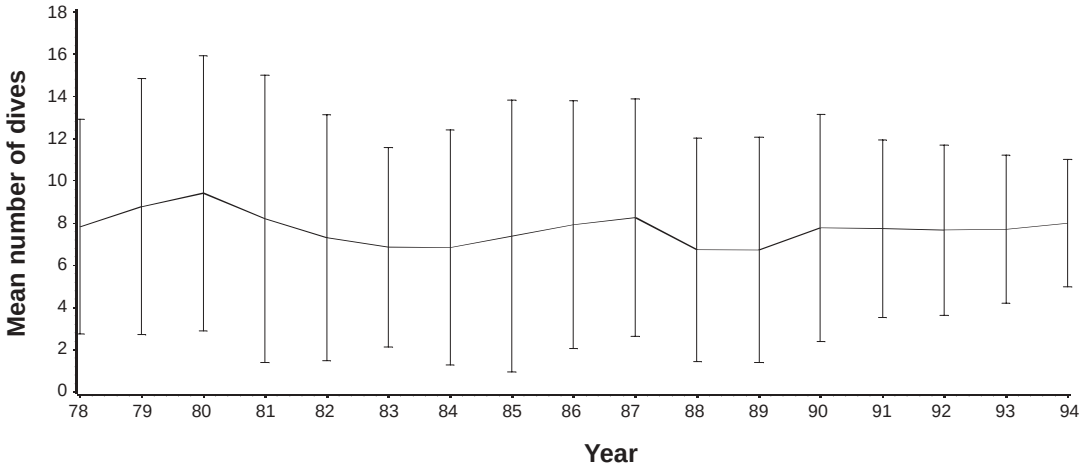

Figure 5. Mean number of dives per diver per day for years 1978 to 1994 (+/-2 std dev.).

3.6 Mean surface interval between dives for 1982 to 1994 by depth

Analysis of surface intervals between dives revealed two distinct groups; dives performed during 1982 to 1990 and 1991 to 1994 (only representative years are shown for clarity - Figure 6). The most frequent surface interval was 70 min. The mean interval at depths less than 23 m, was 84 min (std dev. = 82) for dives between 1982 and 1990, and 57 min (std dev. = 112.5) for dives between 1991 and 1994. The mean interval between dives at depths greater than or equal to 23 m, was 136 min (std dev. = 85.1) for dives between 1982 and 1990, and 71 min (std dev. = 52.3) for dives between 1991 and 1994.

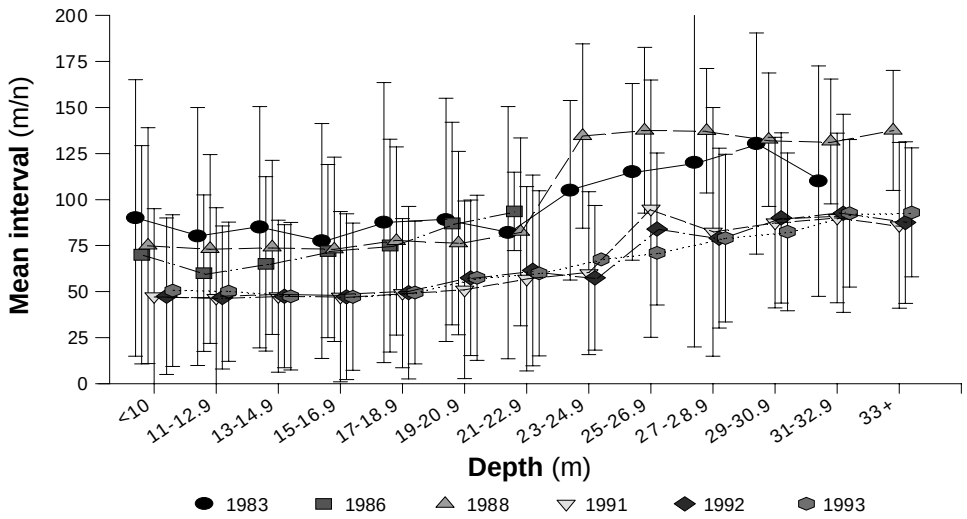

Figure 6. Mean surface interval between dives for years 1983, 1986, 1998 and 1991to 1993 by depth category (+/-2 std dev.).

3.7 Mean ascent time and ascent rate for 1991 to 1994 by depth

The time taken to ascend at the end of a dive was longer for deeper dives (Figure 7). The analysis excluded 35,111 dives which involved decompression stops. The mean ascent time for dives less than 25 m was 8 min (std dev. = 8.02) and for dives 25 m or deeper, 24 min (std dev. = 9.6). The most common ascent time was 5 min and 99% of the ascent times were less than or equal to 35 min. The variability in ascent times was less for dives less than 25 m. The mean ascent rate decreased slightly from 2.86 m/min (std dev. = 1.38) in 1991, to 1.84 m/min (std dev. = 0.93) in 1993, then increased slightly to 2.01 m/min (std dev. = 1.18) in 1994 (Table 1). The mean ascent rate, over all years, for dives greater than or equal to 23 m was 1.5 m/min (std dev. = 1.4) and 2.4 m/min (std dev. = 1.3) for dives less than 23 m.

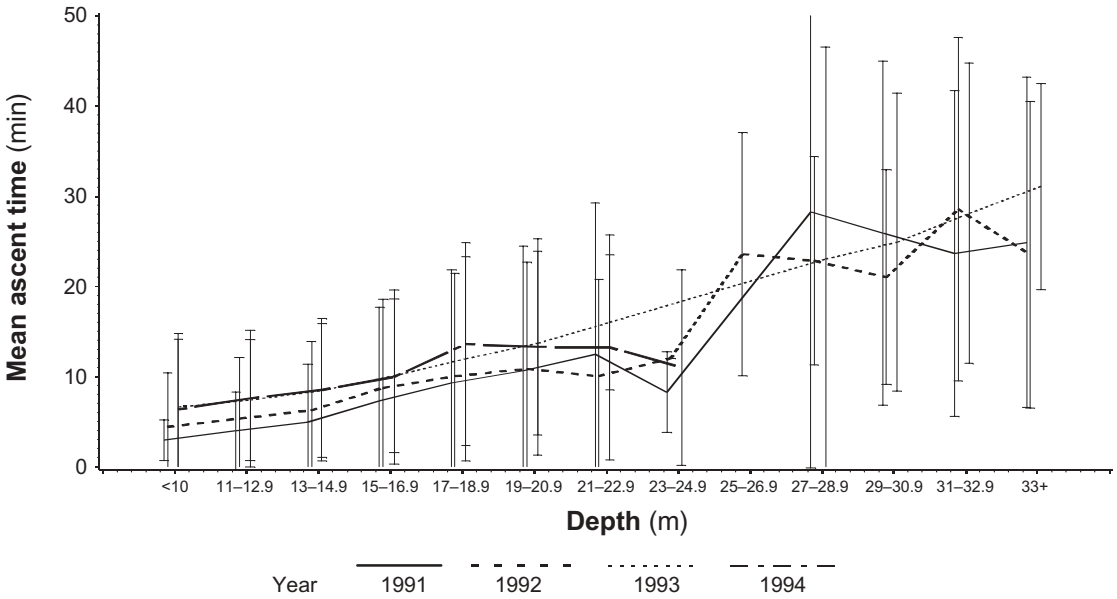

Figure 7. Mean ascent time for dives for years 1991 to 1994 by depth category (+/-2 std dev.).

Table 1. Mean ascent rates for years 1991 to 1994.

Year	No. of dives (excluding those with decompression stops)	Mean ascent rate (m/min)	Std Dev
1991	11,847	2.86	1.38
1992	12,163	2.50	1.13
1993	9,736	1.84	0.93
1994	7,904	2.01	1.18

3.8 Mean individual oxygen time for 1991 to 1994 by depth

The 1991-1994 dive profiles in the Pearl Diving Industry Code of Practice should be consulted for more detail on the use of oxygen for decompression (Appendix A). The oxygen use on the final dive was extracted from the data for each day and displayed separately from the other dives (Figures 8 and 9). The mean oxygen time was higher for the last dive of the day (Figure 8). The mean oxygen time for the last dive of the day was 26 min for dives of 25 m or deeper (std dev. = 6) and 11 min (std dev. = 4) for dives less than 25m. The mean oxygen time for the 5th dive of the day for dives of 25m or deeper was

20 min (std dev. = 2.5) and 8 min (std dev. = 3.05) for dives less than 25 m. The mean oxygen time for dives 1 to 4 was 9 min (std dev. = 3.78) for dives of 25 m or deeper and 6 min (std dev. = 2.01) for dives less than 25 m. The mean oxygen time for dives 6 to 9 was 23 min (std dev. = 3.27) for dives of 25 m or deeper and 7 min (std dev. = 2.7) for dives less than 25 m. The shortest time spent on oxygen per diver per dive was 3 min and the longest time was 35 min. The most frequent amount of time spent on oxygen per dive was 5 min and 75% of the time less than 11 min was spent on oxygen. The most common decompression depths were 9 m (73.8%) and 6 m (25.6%). Oxygen was used on 35,111 (49%) of dives most commonly on the 2nd, 4th, 6th, and 8th dive of the day (Figure 9).

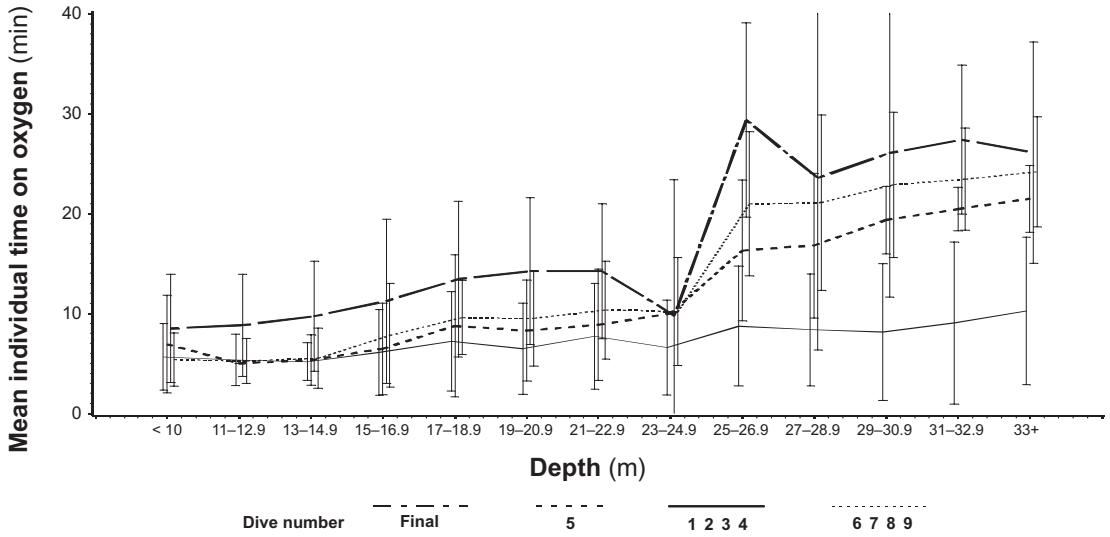

Figure 8. Mean individual oxygen time by dive number for years 1991 to 1994 by depth category (+/-2 std dev.).

Since the mean individual oxygen time was similar for the years 1991-1994 the data were pooled and analysed by dive number. The oxygen time for the final dive of the day was shown to be longer which was expected due to the 1991 Code of Practice specifying a decompression stop on the final dive of the day (Figure 9). The oxygen time increased for deeper dives as more decompression time was specified in the Code of Practice (Figure 8).

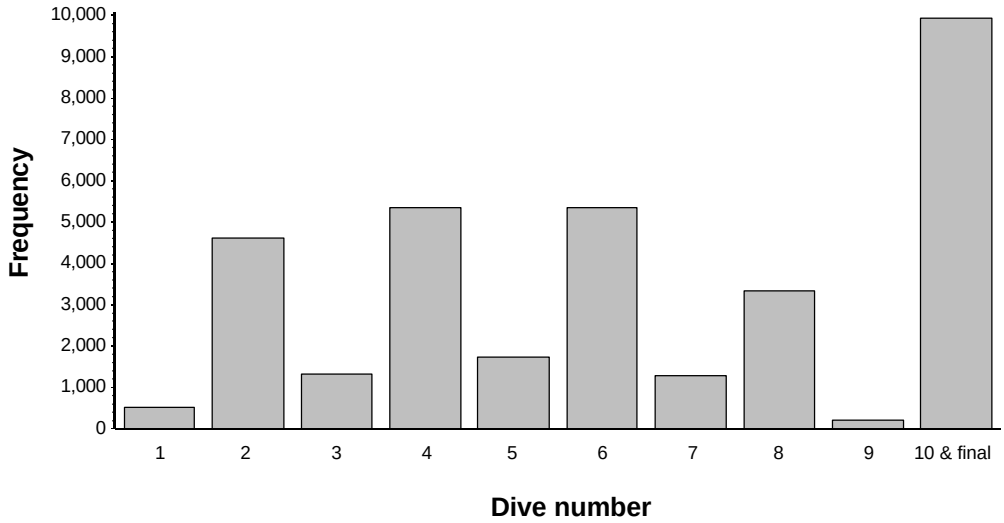

Figure 9. Frequency of oxygen use on dives during a day for years 1991 to 1994.

The oxygen time was higher for the 5th dive due to the Code of Practice specifying a decompression stop on this dive. However, the frequency of oxygen use on the 5th dive was low. The oxygen time for dives 6 to 9 was high. However, the frequency of oxygen use was high on dives 6 and 8 but low on dives 7 and 9. The mean oxygen time for dives 1 to 4 was lower than for the other dives.

3.9 Mean total oxygen time per day for 1991 to 1994 by depth

The total amount of time spent decompressing on oxygen per diver per day varied from 5 to 120 min. The most common amount of time was 15 min (Figure 10). The mean total daily time spent on oxygen for divers diving 25 m or more was 80 min (std dev. = 22.1) and 26 min (std dev. = 16.3) for dives of less than 25 m.

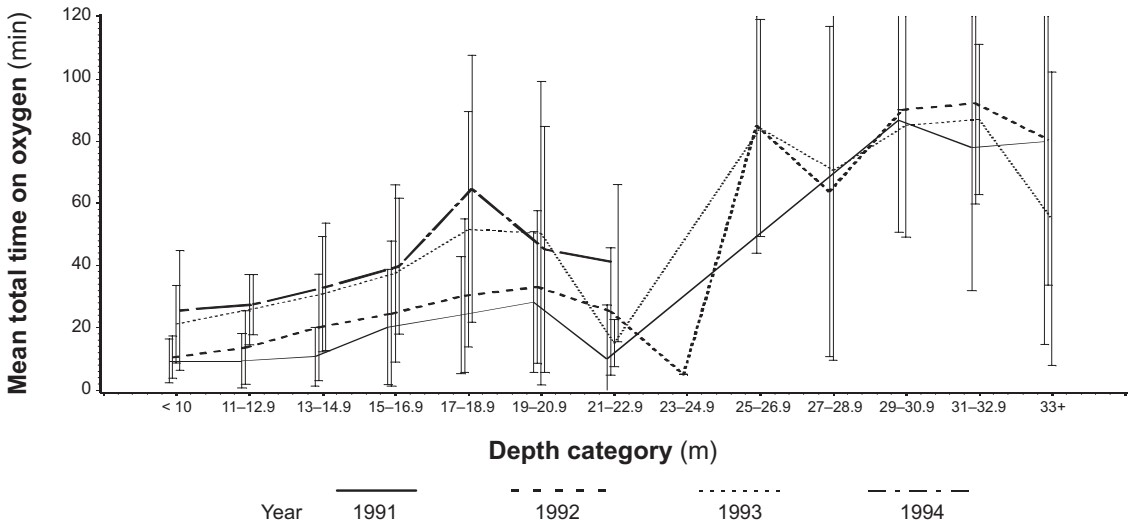

Figure 10. Total oxygen time per day per diver for years 1991 to 1994 by depth category (+/-2 std dev.).

3.10 Mean individual bottom time for 1991 to 1994 by depth

The mean individual bottom time decreased as the diving depth increased for all years between 1991 to 1994 (Figure 11). The most frequent bottom time was 40 min. Ninety-five percent of the bottom time was less than 61 min. The mean bottom time was 27 min (std dev. = 5.5) for dives 25 m or deeper and 45 min (std dev. = 12.3) for dives less than 25 m.

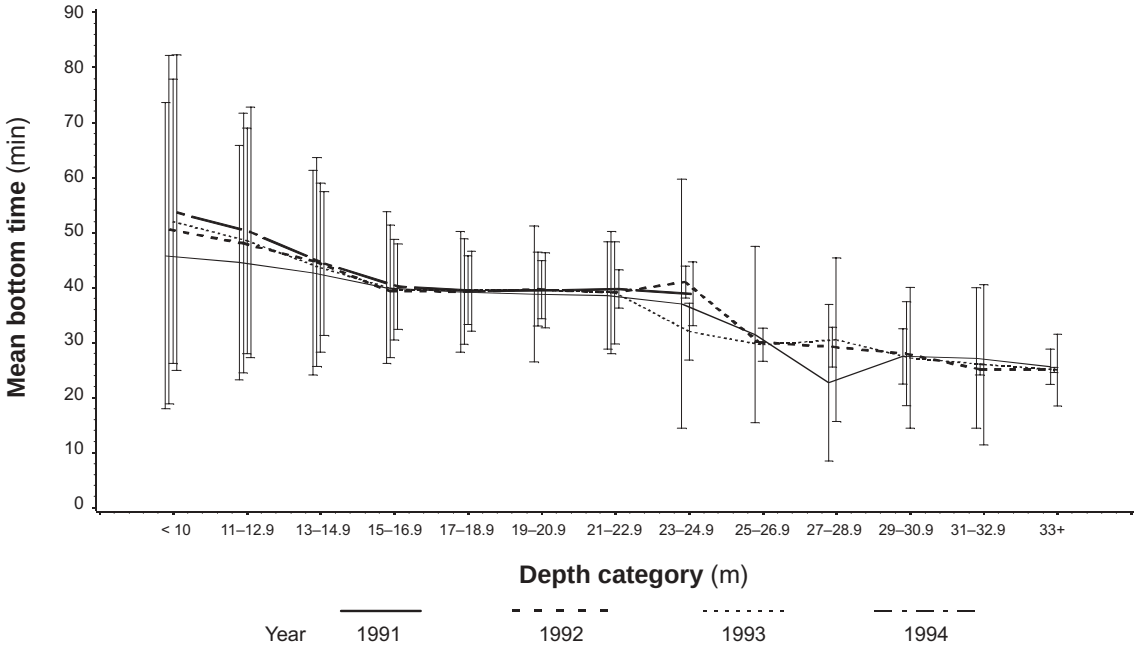

Figure 11. Mean individual bottom time for years 1991 to 1994 by depth category (+/-2 std dev.).

3.11 Mean total daily bottom time for 1991 to 1994 by depth

The total daily bottom time decreased markedly at depths greater than 20.9 m (Figure 12). The mean total daily bottom time for dives less than 21 m was 360 min (std dev. =92), and 126 min (std dev. = 44) for dives 21 m or more. The most frequent total bottom time was 360 min. Ninety-nine percent of all total daily bottom times were less than or equal to 501 min.

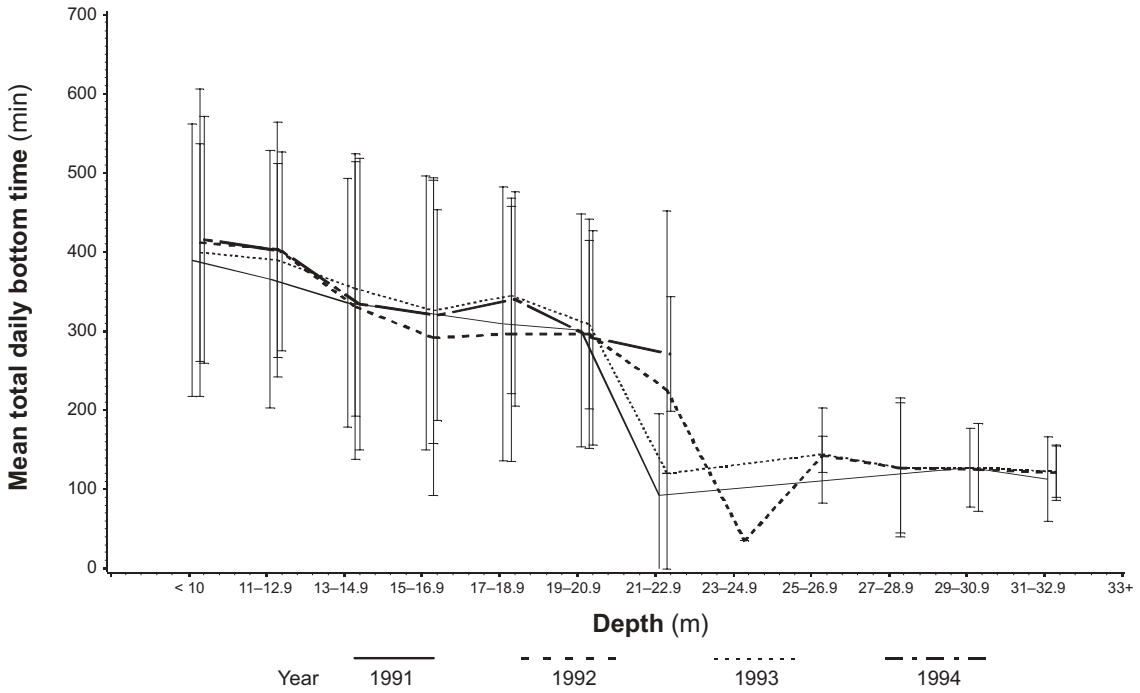

Figure 12. Mean total daily bottom time for years 1991 to 1994 by depth category (+/-2 std dev.).

3.12 Compliance with Pearl Producers Association Code of Practice 1991-1994

The diving regimes for dives completed in 1991 to 1994 were compared to the dive schedules as set out in the Code of Practice 1991-1994 (Appendix 1).

Dive Depth

Eleven dives (0.04%) performed in 1991 exceeded the 35 m maximum diving depth limit by 1 m. In 1992 and 1993 the deepest dives were to 35 m. In 1994 the deepest dives were to 23 m.

Bottom time

The number of dives performed exceeding the maximum allowable bottom time, decreased significantly over the years 1991 to 1994 (Table 2). The highest non-compliance rate is in the depth category 27.1-29 m (45.45%). The non-compliance rate for 14.1-16.9 m (23.64%) is also high. The data for 1995 were incomplete and no data were available for later years.

Table 2. Number of rotational and non rotational dives not complying (NC) with the maximum allowable bottom time (BT) for individual dives for years 1991 to 1995 (1995 incomplete).

Depth category (m)	Maximum BT (min)	1991	1992	1993	1994	1995	Total NC by depth	Total number of dives	%NC
0-11	90[a]	6	106	18	54	153	337	32,393	1.04
11.1-12	60	81	208	30	42	0	361	9,970	3.62
12.1-13	60	36	157	12	18	0	223	8,392	2.66
13.1-14	45	264	195	108	66	6	639	4,642	13.77
14.1-16.9	40	918	703	318	226	60	2,225	9,413	23.64
17-18.9	40	595	261	84	24	6	970	11,427	8.49
19-20.9	40	552	201	66	42	0	861	9,870	8.72
21-22.9	40[b]	185	44	42	12	0	283	2,862	9.89
23-25	40[b]	7	6	0	0	0	13	191	6.81
25.1-27	35	3	3	0	0	0	6	320	1.88
27.1-29	25	12	69	154	0	0	235	517	45.45
29.1-31	25	146	4	26	0	0	176	1,023	17.20
31.1-33	25	100	55	60	0	0	215	2,167	9.92
33.1-35	25	6	19	12	0	0	37	270	13.70
Total NC by year		**2,911**	**2,031**	**930**	**484**	**225**	**6,581**	**93,457**	**7.04**
Tot. dives by year [c]		**20291**	**20352**	**16905**	**12682**	**1,559**			
% NC		**14.35**	**9.98**	**5.5**	**3.82**	**14.43**			

a Maximum allowable bottom time for an individual dive in 1995 for dive depth 0-11 m was 60 min
b Maximum allowable bottom time for an individual dive in 1995 for dive depth 21-25 m was 35 min
c Total dives includes only those dives where a bottom time was recorded.

Ascent rates

The ascent rates for dives without a decompression stop were investigated. Non-compliance for ascent rates decreased from 197 (18.38%) in 1991 to 3 (0.63%) in 1994 for dives to 21 m or deeper (Table 3). Non-compliance for dives less than 21 m decreased from 702 (6.52%) in 1991 to 116 (1.56%) in 1994.

Table 3. Number of dives not complying (NC) with maximum ascent rate for years 1991 to 1994.

Year	NC >=21m >3m/min	Total dives >=21m[a]	% NC >=21m >3m/min	NC <21m >5m/min	Total dives <21m[a]	%NC <21m >5m/min
1991	197	1072	18.38	702	10775	6.52
1992	73	1501	4.86	237	11662	2.03
1993	12	728	1.65	10	9008	0.11
1994	3	474	0.63	116	7430	1.56

a Excludes dives which included a decompression stop.

Total daily bottom time

In 1991, two divers exceeded the maximum total daily bottom time allowed of 360 min, in the depth range 17-18.9 m, by 25 min.

Surface interval

The number of dives which did not comply with the minimum surface interval required, decreased significantly over the years 1991 to 1995 (Table 4). The highest non-compliance was in the 14.1-16.9 m depth category with 1,046 (12.84%) dives performed with less than the minimum surface interval required between dives.

Table 4. Number of non rotational dives not complying (NC) with the minimum acceptable surface interval (SI).

Depth category (m)	Minimum SI (min)[a]	1991	1992	1993	1994	1995	Total NC by depth	Total number of dives	%NC
0-11	15	305	338	42	245	6	936	28,142	3.33
11.1-12	20	277	373	128	226	42	1,046	8,653	12.09
12.1-13	20	270	250	86	134	36	776	7,317	10.61
13.1-14	20	179	172	66	52	18	487	4,152	11.73
14.1-16.9	20	361	383	192	86	24	1,046	8,144	12.84
17-18.9	20	234	387	190	54	31	896	10,001	8.96
19-20.9	20	320	233	148	54	0	755	8,771	8.61
21-22.9	20	96	37	22	60	0	215	2,599	8.27
Total NC		2,042	2,173	874	911	157	6,157	77,779	7.92
Total dives[b]		15356	14936	11675	9481	1559			
%NC		13.3	14.55	7.49	9.6	10.07			

a Refer to 1991-1995 dive profiles in the Code of Practice (Appendix 1).
b Total dives includes only those dives where a surface interval was recorded and were less than 23 m depth

Number of dives

All dives complied with the maximum daily total number of dives allowed for each depth category over the years 1991 and 1995.

3.13 Diving related medical incidents

All diving related medical incidents have decreased over the time period 1991 to 1994 (Figure 13). Incidents of decompression sickness decreased from five in 1991, to three by 1994 (Figure 14). Only two incidents of lung barotrauma were reported in 1992. Ear or sinus problems decreased from 16 in 1991 to six in 1994. Salt water aspiration decreased from 18 in 1991 to six in 1994. The number of bailouts decreased slightly from three to one from 1991 to 1994. These trends may be due, at least in part, to the decrease in the number of dives over the same period (Figure 1).

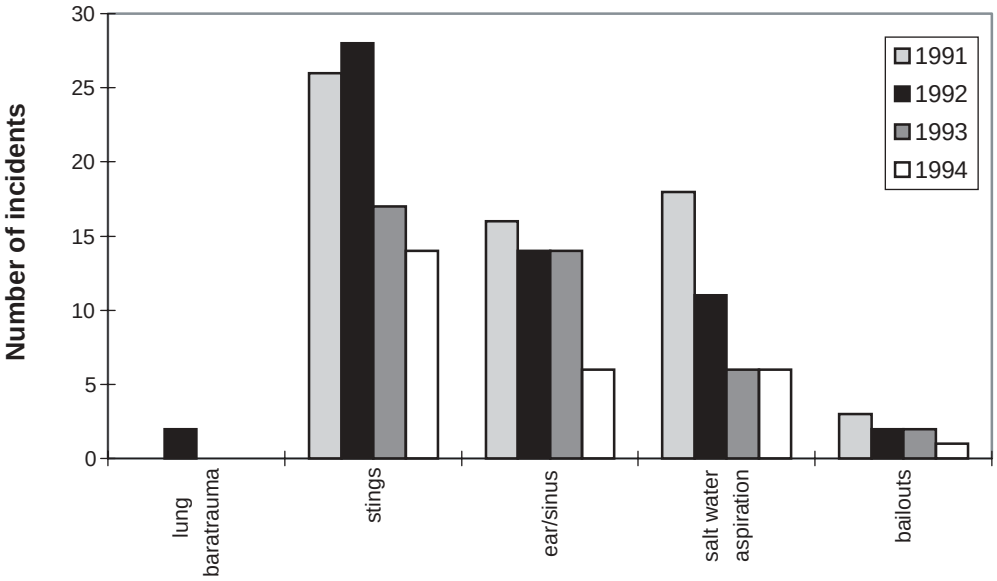

Figure 13. Diving related medical incidents for years 1991 to 1994 (Anon, 1994).

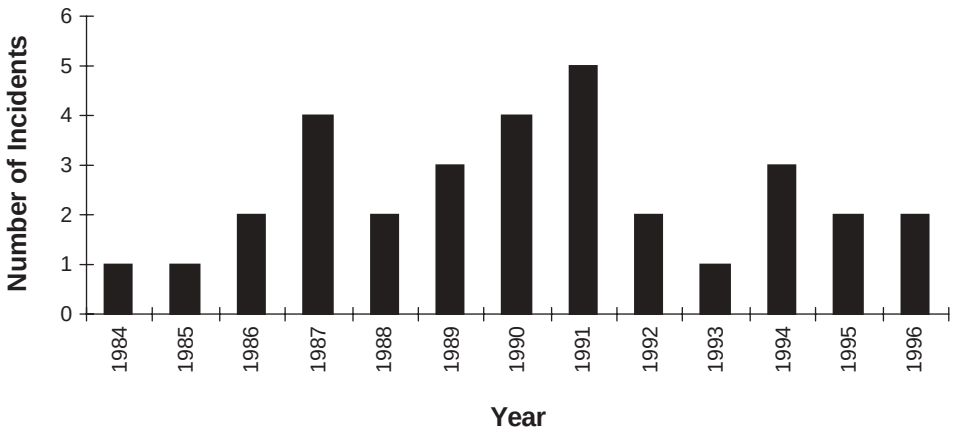

Figure 14. Decompression Incidents presenting to Broome District Hospital (does not include recreational divers and Research project cases) (Anon, 1994).

4.0 Discussion

4.1 Historical dive profiles

Similar dive practices were used from 1978 to 1990. From 1991 the mean dive time and total daily dive time increased and the interval between dives decreased for all depths. The dive practices for 1991-1994 were also similar. These groups correspond to the two data sets used, however, since the data sets appear to be consistent, any change in diving practices is more likely due to the introduction of the Pearl Producers Association Code of Practice in 1991. There are no data on the use of oxygen for decompression prior to 1991 although anecdotal evidence indicates that it has become more prevalent in recent years.

For all years the dive schedules used were related to the depth dived. There is a noticeable difference in the mean dive times, mean total daily dive time and mean interval between dives for depths less than 21 m and 21 m or deeper. The mean individual and total daily bottom times decrease for deeper dives which is consistent with the Code of Practice specifying less bottom time for deeper dives. The surface interval between dives increased for dives of 21 m or more due the greater time required to release nitrogen from the blood stream before recommencing the next dive. Longer ascent times for deeper dives reflect the time taken to ascend from a deeper depth at a slower rate. Divers were ascending more slowly from deeper depths to allow more time for nitrogen to be liberated from their tissues.

Prior to 1991 dive times decreased for deeper dives. This was either due to decreased bottom times (bottom time was not recorded for these years) or shorter decompression times (also not recorded) or both. However, there is a high level of variability in the diving practices which is of concern. The variability in the dive times from 1991 onwards is less, particularly for deeper dives.

The number of dives per day remained the same for all years. The standard deviation for dives after 1990 was slightly smaller possibly due to the limit on the maximum number of dives per day limit imposed by the 1991 Code of Practice. Most of the time (87.4%) 10 or less dives were performed daily by a diver. Observation showed that the data were left skewed.

It is likely that the depths dived during the year reflect the abundance of shell suitable for culture and MOP shell (in the earlier years). The reduction in number of dives in deeper water in the mid to late 1980s (Figure 1) may be due to the increased emphasis on culture shell found in shallower water rather than MOP shell which are found in deeper water. In the early years the focus on MOP, particularly for providing cash flow for newly established companies, largely dictated which areas were fished. In 1984, the taking of shell for MOP was prohibited south of Broome on the grounds that they were the breeding stock which could provide a source of recruitment of shell to waters closer inshore (Malone *et al.*, 1988).

Fishing in the early to mid 1980s was concentrated in the shallower waters to 20 m off Eighty Mile Beach, as the pearl fishers focussed their efforts on the smaller shells suitable for culture found in the shallower water (Malone *et al.*, 1988). In 1984, most operators reported difficulty in collecting enough shell to fulfil their quota (Malone *et al*., 1988). In 1986, 95% of the total catch was from the Eighty Mile Beach region. By 1987, the shallow waters off Eighty Mile Beach no longer contained sufficient oysters of a suitable size for

culture shell, resulting in a move to deeper waters again in late 1980s and early 1990s (Joll, 1994). The ability to dive in deeper waters has increased with the implementation of safer diving schedules and use of oxygen for decompression.

The total dive time per year inversely reflects the catch per unit effort of shells collected, the higher the number of shells collected per hour the lower the total dive time for that year. The lowest number of shell collected per hour dived (19.6) and the highest number of dives occurred in 1990 (Figure 15). In more recent times the catch per unit effort increased to levels similar to when fishing for MOP in the late 1970s and early 1980s. This may be due to a combination of an increased level of recruitment to the fishable stock and increases in vessel efficiency from the introduction of Global Positioning Systems for navigation (Anon, 1996).

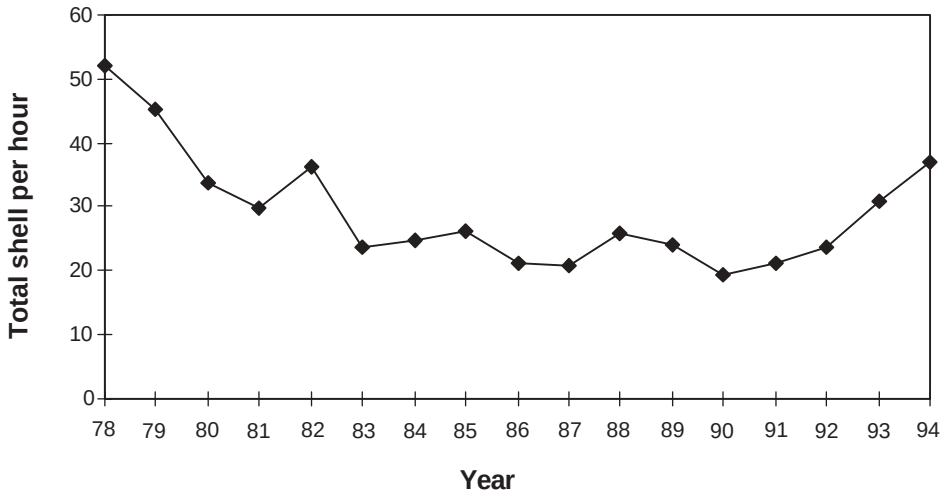

Figure 15. Historical changes in catch per unit effort in Culture and MOP shells in the Broome area (Zones 2 &3) (Reproduced from State of the Fisheries Report 1995-1996).

Oxygen was used on dives of less than 13 m which is not specified in the Code of Practice. Oxygen need only have been used on dives of less than 13m if deeper dives were done during the rest of the day, and the decompression schedule for the deepest dive of the day was used. For this reason, a decompression stop may have been required on dives of less than 13m. The highest number of dives in the period 1991 to 1994 was in the depth ranges less than 14 m and less than 21m. Therefore, only a small percentage of dives other than the 5th and last dive of the day need have used oxygen.

The mean total time spent on oxygen per day per diver was higher for deeper dives which was expected due to the Code of Practice specifying a longer oxygen time for dives in deeper water to increase the amount of time allowed for nitrogen to be liberated from the tissues.

4.2 Compliance with dive schedules

The Pearl Producers Association profiles are different from the standard decompression tables since they allow repetitive dives (up to 10 per day, depending on depths), multi-day diving (usually 8 consecutive days during neap tides) and diving from shallow water to deep water, which are all recognised as risk factors in causing Decompression Illness. However, Wong (1994) found that the Pearl Divers Profiles in the years 1991-1994 appeared to be safe. The safety of the profiles could be due to the slow rate of ascent, oxygen decompression, suitable depth of decompression and suitable surface interval (Wong, 1994).

Many divers appear to be doing additional decompression stops to that required by the Code of Practice. Many of the divers were doing decompression stops every second dive. Decompressing on oxygen assists in the elimination of inert gas. Up to 1994, Suunto Dive computers, which record at 3 min intervals, were used to record the dives, however, this was inadequate for the purpose of recording the ascent rate. In September 1994 a number of Citizen Hyper Aqualand watches were acquired which record depth-time profiles every 5 seconds (Wong, 1994).

The non compliance of surface intervals between dives still needs to be improved to allow adequate time to reduce residual nitrogen levels to acceptable limits. Furthermore, this needs to be combined with the correct sequence of dives from deeper to shallow dives during the day.

4.3 Medical incidents

The low occurrence of decompression sickness could be due to a number of factors such as the slow ascent rate of 3 m/min as opposed to the other rates of ascent of 9-18 m/min. Non-compliance with the ascent rates in 1994 was between 1 and 2 percent. Almost all of the time (99%), the ascent rate was less than or equal to 6 m/min, while 99.9% of the time the rate of ascent was less than 13 m/min. On two occasions the ascent rate was 29 m/min from 29 m. In 1994 when no dives deeper than 23 m were performed there was no occurrence of decompression sickness.

5.0 Conclusion

The low level of medical incidents suggests the dive schedules used are appropriate, however there still may be room for improvement in the schedules at certain depths. Although compliance with the Code of Practice is generally good, there is reason for concern at certain depths where the rate of non-compliance, particularly with respect to bottom time, may not be acceptable. The reasons for non-compliance should be investigated.

Since the introduction of the Pearl Diving Industry Code of Practice in 1991, mean dive times and the total daily dive time have increased and the mean interval between dives has decreased for all depths. For all years approximately eight dives per day were performed, however, since 1991 there is less variation in the number of dives per day. Oxygen is now widely used for decompressing on every second dive and the last dive for the day.

It is essential that the collection and analysis of data on both dive practices and medical incidents should be an ongoing commitment. This will provide valuable information for monitoring dive practices, assessing the level of compliance with, and refining of, the Pearl Producers Association Code of Practice.

6.0 Acknowledgments

David Appleby provided data for years 1991 to 1994 from the Pearl Producers Association's drift diving data base. Nancy Ripepi entered data from the Fisheries Department log books. Various staff in the Mollusc Section of the Western Australian Marine Research Laboratories provided valuable advice during the life of the project. Nick Caputi and Chris Chubb reviewed the draft manuscript and provided many useful comments. This work forms part of a broader study on the safety of pearl diving and as such was partly funded by the Fisheries Research Development Corporation.

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8.0 Appendix

Pearl Diving Industry Code of Practice

Maximum Limit Dive Profile

NO ROTATION

DEPTH (Maximum)	BOTTOM TIME (Maximum)	ASCENT RATE	SURFACE INTERVAL	No. of DIVES OR MAX BOTTOM TIME	DECOMPRESSION
0-11	90 mins	3 metre/min	Min 15 mins Min Accumulated Surface Intervals 135 mins	Max bottom time for the day 500 mins	Not required
11-13	60 mins	3 metre/min	Min 20 mins	Limit of 500 mins	10 mins on Air at 5 metres at end of day. Then 3 min per metre to surface ascending on air
13-14	45 mins	3 metre/min	20 mins	Limit of 400 mins	10 mins on O_2 at 9 metres at end of day. Then 3 metre/minute ascending on O_2.
15-17	40 mins	3 metre/min	20 mins	Limit of 400 mins	10 mins on O_2 at 9 metres at end of day. Then 2 mins / metre ascending on O_2 at end of day
17-19	40 mins	3 metre/min	20 mins	Limit of 400 mins	5 mins on O_2 at 9 metres after the 5th drift. 15 mins on O_2 at 9 metres at end of day. Then 2 mins / metre ascending on O_2 at end of day.
19 - 21	40 mins	3 metre/min	20 mins	Limit of 360 mins	5 mins on O_2 at 9 metres after the 5th drift (then ascending at 3 metres/min on O_2). 15 mins on O_2 at 9 metres at end of day Then ascending on O_2 at 2 mins / metre.
21 - 23	45 mins	3 metre/min	20 mins	Limit of 360 mins	10 mins on O_2 at 9 metres after the 5th drift then ascending at 3 metre / min on O_2. 20 min on O_2 at 9 metres after the last drift ascending on O_2 at 3 minutes / metre.

ROTATING SYSTEM 4 IN 2 OUT

DEPTH (Maximum)	BOTTOM TIME (Maximum)	ASCENT RATE	SURFACE INTERVAL	No. of DIVES OR MAX BOTTOM TIME	DECOMPRESSION
19 - 21	40 mins	3 metre/min	20 mins Surface/Interval 90 mins S/I Rotating Sequence	8	10 mins on O_2 at 9 metres then ascending with O_2 at 3 metres/ minute after the last dive.
21 – 23	40 mins	3 metre/min	20 mins 90 mins Rotating Sequence	8	15 mins on O_2 at 9 metres then ascending with O_2 at 3 metres/ minute after the last dive.

ROTATING 2 TEAM ROTATING SYSTEM

DEPTH (Maximum)	BOTTOM TIME (Maximum)	ASCENT RATE	SURFACE INTERVAL	No. of DIVES OR MAX BOTTOM TIME	DECOMPRESSION
23 – 25	40 mins	5 metre/min to 21 metre then 3 metre/ min to stage point at 9 metres	After D1 = 60 mins D2 = 70 mins D3 = 80 mins D4 = 90 mins	5 per team	D1 = air ascent to surface at 3 metre/min D2 = 5 min on O_2 D3 = 10 min on O_2 D4 = 15 min on O_2 D5 = 20 min on O_2 (D2 – D5 then ascent on O_2 at 3 metre/min).
25 – 27	35 mins	5 metre/min to 21 metre/min to 9 metre	After D1 = 60 mins D2 = 70 mins D3 = 80 mins D4 = 90 mins	5 per team	D1 = 5 mins on O_2 D2 = 10 min on O_2 D3 = 15 min on O_2 D4 = 20 min on O_2 D5 = 25 min on O_2 (D2 – D5 then ascending at a rate of 3 metre/minute on O_2).
27 – 29	30 mins	5 metre/min to 21 metre 3 metre/min to 9 metre	After D1 = 60 mins D2 = 70 mins D3 = 80 mins D4 = 90 mins	5 max per team	D1 = 5 mins on O_2 D2 = 10 min on O_2 D3 = 15 min on O_2 D4 = 20 min on O_2 D5 = 25 min on O_2 (D2 – D5 then O_2 ascending to surface at 3 metre/minute).
29 – 31	25 mins	5 metre/min to 21 metre 3 metre/min to 9 metre	D1 = 70 mins D2 = 80 mins D3 = 90 mins D4 = 100 mins	5 max per team	D1 = 5 mins on O_2 D2 = 10 min on O_2 D3 = 15 min on O_2 D4 = 20 min on O_2 D5 = 25 min on O_2 (D2 – D5 then ascending to surface on O_2 at 3 metre/minute).
31 – 33	25 mins	5 metre/min to 21 metre 3 metre/min to 9 metre	D1 = 70 mins D2 = 80 mins D3 = 90 mins D4 = 100 mins	5 max per team	D1 = 5 mins on O_2 D2 = 10 min on O_2 D3 = 15 min on O_2 D4 = 20 min on O_2 D5 = 25 min on O_2 (D1 – D5 then ascending to surface on O_2 at 3 metre/minute).
33 – 35	25 mins	5 metre/min to 21 metre 3 metre/min to 9 metre	D1 = 80 mins D2 = 90 mins D3 = 100 mins	4 max per team	D1 = 10 mins on O_2 D2 = 15 min on O_2 D3 = 20 min on O_2 D4 = 25 min on O_2 (D1 – D4 then ascending to surface on O_2 at 3 metre/minute).

NOTE:

This dive profile is the maximum recommended times with an ascent rate of 3 metres/min from 21 metres. (Below 21 metres ascending at 5 metres/min). The profile is to be used when conditions are ideal and if necessary the profile associated with the next 2m interval when conditions are less then ideal (for example, when considering the fitness of the diver; weather conditions; visibility; prevalence of stingers and the experience of crew).

Three zones have been marked as:

(1) Deeper than 23m
(2) 15m to 23m
(3) 0 to 15m

If you propose to move from a shallower to a deeper zone you should do the full decompression stop for that day before moving to the deeper zone. Once you have moved to another zone, then you should observe the full decompression stop at the end of the day for whatever zone you have moved into.

If you move from a deeper to a shallower zone, at the end of the day decompression would be that of the deeper zone.

Skippers must allow for transducer position on ship's hull when determining depth.

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