sea Biomed Res 1985; 12(3): 269-289
35 Donald KW. Oxygen bends. *J Appl Physiol* 1955; 7: 639-644
36 Gorman DF, Edwards CW and Parsons DW. Neurologic Sequelae of DCS: A clinical report. Underwater and Hyperbaric Physiol IX. 1987; UHMS: 993-998
37 McIver NKI. Treatment of compressed air decompression accidents. *J R Soc Med* 1989; 82(2): 74-79
38 Douglas JDM and Robinson C. Heliox treatment for spinal DCS following air dives. *Undersea Biomed Res* 1988; 15: 315-319
39 *USN Diving manual* 1989. Washington DC: US government printing office, Section 8: 29-39

Dr Geoffrey S Gordon, BHB, MB, ChB, FFARACS, is an anaesthetist at the Townsville General Hospital, Townsville, Queensland 4810, Australia.

HIGH RISK DIVING
TASMANIA'S AQUACULTURE INDUSTRY

David Smart and Peter McCartney

Despite its cool climate and waters Tasmania has a large population of commercial and sports divers working in, and enjoying the waters of its 3,200 km coast line. Of a total population of 446,500 (1986 figures)[1], over one percent are active divers (Table 1).

Diving accidents in Tasmania requiring hospital admission or recompression therapy occur on average fifteen to twenty times per year. These patients are treated at the Royal Hobart Hospital (RHH) Recompression Chamber by staff of the Hyperbaric Unit, which is linked to the Department and Anaesthesia. There has been little change in the number of accidents over the years 1985 to 1988. The 1985-1988 population treated at RHH consisted mostly of abalone divers and a small number of recreational divers. In 1988 the first of a new population of divers presented for treatment. These divers were employed in the aquaculture industry. From April 1988 to October 1989, eighteen divers from all sources were admitted to hospital for diving related illness and twelve were treated in the recompression chamber. Sixteen of the eighteen divers had been using hookah apparatus and nine divers were employed in the aquaculture industry.

This industry is now a major export earner for the state of Tasmania and by October 1989 according to the Department of Sea Fisheries more than 270 people were employed at 35 separate ventures. At the time of writing approximately 40-50 were divers. During 1990 further growth is expected in the industry to over 400 employees. From its humble beginnings in 1986 the industry now produces Atlantic Salmon of world export quality. The salmon are "farmed" from smolt (50 g size) to adult size in floating circular pens approximately 20 m in diameter (Plate 1, page 151) supporting a cylindrical net approximately 8 m deep. Feed is released automatically at regular intervals to the fish. There can be as many as 5,000 fish per pen. Larger operations manage 40 pens or more. Surrounding the inner pens is a coarser mesh perimeter net (Plate 2, page 151) of up to 250 m by 500 m to prevent predators such as seals attacking the salmon. Divers in the industry are required to maintain these nets and pens and to remove diseased or dead fish from the pens. They are also required to inspect and maintain mooring lines. In some leases the perimeter nets and mooring lines extend to depths of 40 m. Divers contribute significantly to the quality of the salmon when it is finally ready for marketing.

TABLE 1

DIVERS IN TASMANIA

Registered by the Department of Sea Fisheries	
Non Commercial Diving Licence	3100
Commercial Abalone Licence	125
Commercial Diving Licence (including police divers)	229
Unregistered divers (estimates)	
Unlicenced Amateur Divers	3000
Sea Urchin and Periwinkle Divers	400
Aquaculture divers	50

This paper examines the diving practices of the industry, based on information gained from divers treated at RHH, in the hope of reducing the number of diving accidents in the future. One of the authors (DS) was privileged to visit one of the larger fish farm leases at Tassal, Dover, and witnessed its impressive operation at first hand.

Information gained

Nine aquaculture divers were treated at RHH. The majority (5) were aged between 21 and 30. Two were between 31 and 40. There was one in the 10-20 group and one aged between 41 and 50. Eight were male and one female.

Of concern is that only 2 divers had had appropriate training, i.e. specifically for the industry. Even more disturbing is the fact that 4 of the divers had had no formal training while the other three had only had formal training for using scuba as a recreational diver. Of these one had more than 5 years' diving experience while 2 had less, one of them less than a year's experience.

Presenting syndromes

4 divers presented with decompression sickness. Two had neurological symptoms and two had musculo-skeletal symptoms. Three presented with inhalational pneumonitis (discussed below) and two with barotrauma (also discussed later).

TABLE 2

BACKGROUND OF DIVERS REQUIRING TREATMENT

Age		**Number of Divers**
10-20		1
21-30		5
31-40		2
41-50		1
Sex	8 Male	1 Female

Equipment used:
Hookah surface supply (all divers).

Diving Experience	
No formal training	4
Sport diving training:	
Less than 1 year	1
1 - 5 years	1
More than 5 years	1
Other training specific to the industry	2
Presenting Condition	
Decompression sickness	
Neurological	2
Musculoskeletal	2
Hydrocarbon inhalation	
Pneumonitis	3
Sinus and Aural Barotrauma	2

Discussion

Divers working in the aquaculture industry are employed in a dual capacity to perform diving tasks as well as non-diving "farm hand" tasks. Their daily underwater tasks are to inspect and maintain salmon pens and nets and pick up dead fish from within the pens. They also dive and maintain anchor ropes, moorings and lines and inspect and repair the perimeter nets on a regular basis. Their other tasks are to change all salmon pen nets once a week, also clean and repair them. They have to repair and maintain their diving equipment, feed the salmon, fill the feeders and exchange batteries for the feeders and finally catch salmon for processing.

TABLE 3

RISKY DIVE PRACTICES IDENTIFIED FROM INTERVIEWS WITH PATIENTS

Diver training
Training is inadequate or inappropriate to the industry.

Equipment maintenance/use
No set schedules exist for maintenance of gear.
Untrained personnel allowed to tamper with gear.
Use of non-recommended materials for air filtering.
Salt water in regulators.
Use of non-recommended oil in hookah compressor.
Use of hookah apparatus to excessive depths.
Inappropriate thermal protection.
Limited use of specialised underwater tools.
No method of diver to surface communication.

This system should allow some flexibility. Divers who are unable to dive, for reasons such as an upper respiratory tract infection, or who are on a "rest day" can still contribute to the running of the enterprise and so reduce their risk of diving related illness.

In theory this "multi-skilling" should work well, allowing for rest days from diving and rotating divers in and out of the water according to diver health and decompression table limits.

In practice, based on information supplied by patients treated at RHH, divers are at greater risk of accidents for many reasons (Table 3). The risk to health covers the whole spectrum of diving related illness.

Diver training

This is inadequate or inappropriate to the industry. At present there is no requirement by law in Tasmania that professional divers must receive formal diving training from any authority, although Australian standards for underwater air breathing (AS 2299)2 recommends training specific to the type of equipment or diving apparatus being employed. Insufficient training is highlighted in this study. Only five out of nine divers had received formal diving instruction and only two out of nine had training specific to the industry, which is available through the Maritime College in Launceston. Sport diving basic qualification is better than no training at all, however this is not appropriate to the type of diving performed in the industry. Basic scuba training does not encompass the use of hookah apparatus, deep diving or equipment maintenance and varies considerably between

PLATE 1. Diver entering salmon pen wearing hookah apparatus.

PLATE 2. Salmon pens, work boats and the surrounding perimeter net.

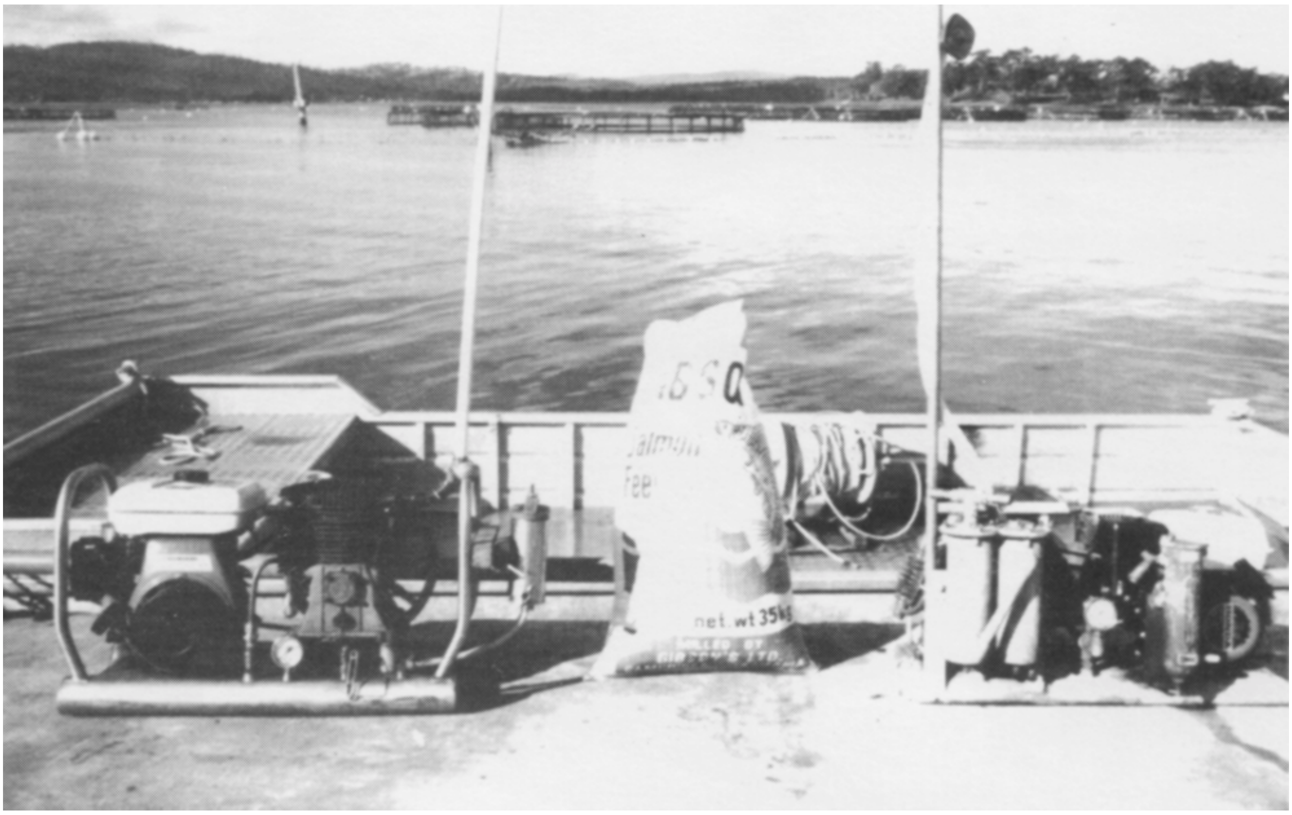

PLATE 3. Hookah apparatus and salmon feed bag with salmon pens in the background.

PLATE 4. Diver exiting from pen.

diving training bodies in the standard of life saving training. Basic scuba training does not cover the use of specialised underwater tools which enable more efficient work practices and reduced bottom times. Adequate training for such a strenuous, high risk occupation is essential.

Without knowledge of tables, basic physics, safety and equipment divers place themselves in potentially life-threatening situations. In addition, lack of training prevents a diver from recognising practices which place he or she at greater risk of accidents. It is known, for example, that barotrauma of the ear has a high incidence in novice divers[3] who are involved in training courses due to inexperience with ear clearing techniques.

Diving equipment and its maintenance

Surface supply (hookah) is almost universally used for air supply to divers in the industry. A petrol motor drives a low pressure compressor feeding a reservoir. The reservoirs of the two available models in Tasmania are 12 litre and 17 litres (Plate 3 page 152). Air is supplied to the diver via a long hose and an upstream second stage. The second stage has a non-return valve to prevent diver injury in the event of a sudden cessation of the air supply. Depth limitations exist because of the inability of the equipment to deliver a sufficient volume of air to the diver at pressures greater than 3 to

4 atmospheres absolute (ATA). Thirty metres (4 ATA) is the maximum safe depth for hookah apparatus.

Hookah is a very safe system provided the equipment is well maintained and the air intake is positioned upwind and well above the exhaust. It is essential to use the correct filters and appropriate oil in the compressor. There must be no kinks in the air supply hose and the demand valve (or regulator) must be functioning properly. The depth restrictions of the equipment need to be strictly observed. Three divers reported using the hookah apparatus to depths greater than 30 metres for inspection and maintenance of perimeter nets surrounding the fish farm. This practice places them at significantly increased risk of inadequate air supply due to depth, the hazards of nitrogen narcosis as well as the higher risk of DCS of deeper diving. Surface attendants are essential with hookah diving. The compressor must never stop while the diver is underwater as the pressure reservoir can usually only supply a few breaths. For safety a backup diver should be available.

Divers in the study population reported that no diver-to-surface communications were used on the farms. Communication systems provide for additional diver safety, especially during deeper dives. However the cost of the equipment necessary (commercial diver full facemasks or helmets and microphones) is much higher than the usually cheap regulators normally used with hookah systems.

Written standards and protocols for equipment handling and maintenance need to be present and used in the industry so that high standards of safety can be practiced on all farms where diving occurs. Lack of protocols for equipment maintenance was demonstrated when three divers presented to Royal Hobart Hospital after breathing contaminated air. They presented after they had been using tea towels as output filters instead of the recommended charcoal filter.

These divers had also changed the oil in the compressor when the air tasted "oily". They demonstrated their lack of knowledge of the equipment they were using by replacing the original oil in the compressor with vegetable oil purchased from a supermarket. After breathing air contaminated with this oil their symptoms ranged from dyspnoea, chest tightness and cough to haemoptysis and headache. None had significant carboxyhaemoglobin levels and chest x-rays were all normal. All had reduced arterial oxygen saturations and mild impairment of ventilatory function which returned to normal after 24 hours breathing humidified oxygen.

These divers were diagnosed as suffering a mild form of hydrocarbon pneumonitis from which they were fortunate to make a full recovery. Inhalation of sufficient amounts of hydrocarbons can cause fatalities.[4,5] The effects of inhaled hydrocarbons are compounded at depth (under pressure). Using vegetable oil has the added risk of carbon monoxide poisoning from partial combustion of oil in the compressor.

If protocols for service and maintenance of equipment (including adequate filters) had been formulated and followed and the divers properly educated about use of their equipment, this dangerous situation could have been prevented.

Hookah equipment is used on fish farms for up to 8 hours every day and is subject to corrosion from salt water. Several divers reported inhaling salt water from the equipment they were using. This is a sign of a (poorly maintained) leaking expiratory valve. Salt water damage to equipment should be minimised by specific maintenance and handling schedules.

Two divers reported using 5 mm thickness wetsuits all year round. For short dives, very hardy divers may tolerate the Tasmanian winter (water temperature 12°C) in a 5 mm wetsuit but for professional diving this degree of thermal protection is inadequate and has accompanying risks of cold stress. There is theoretically an increased risk of decompression sickness. Hypothermia poses many risks to the diver and should be prevented with appropriate thermal protection and shorter diver profiles.[3,6]

Another area which needs to be considered in the industry is maximizing diver efficiency while underwater. Tools designed specifically for underwater use are available and should be evaluated for use in the aquaculture industry. Every minute saved in bottom time reduces the risk to the diver.

Diving practices and profiles

We found a number of areas where divers are at risk of serious accident. In general there was no logging of dive duration nor of entry or exit times. No depth gauges were used. There was no correlation of dive times with accepted dive tables. As a result many divers exceeded the table time limits. There was no schedule for safe ascent rates. Some divers were performing deeper dives after shallow dives. Many divers did multiple bounce dives to depths of up to 15 metres. No divers used "safety" decompression stops. Many divers were performing unnecessary strenuous exits (vaulting the fence) during diving. As well many were performing strenuous exercise after diving. In one case further bounce diving after an emergency ascent produced decompression sickness.

The nature of the diving is unique and places the diver at greater risk of barotrauma and decompression sickness even if accepted protocols are followed. In their daily inspection of the fish pens, divers may be called upon to perform bounce dives to a depth of 10 m 20-40 times over a four to five hour period. Multiple ascents during dives (bounce diving) places a diver at higher risk of decompression sickness (DCS) and barotrauma. Prolonged shallow saturation dives have been shown to produce a high incidence of DCS.[7]

Multiple ascents and rapid ascents are now accepted as major risk factors for DCS, independent of exceeding table limits.[3,8,9] During these dives the pens are inspected for damage and repaired and dead fish removed from the floor of the pen. A risky practice identified by one author's (DS) personal inspection of the pens was throwing rocks into the pen if the floor of the pen did not remain submerged. As a result, the shape of the pen was converted from a cylinder to an inverted cone. The depth of the apex of the cone was measured at 15 m by one of the authors, using a hand held depth gauge. This deepening of some pens to 15 m further increases the risk of DCS.

Divers on the aquaculture farms have a very heavy physical workload. A long swim is required to inspect the pen nets for damage and there may be up to 40 dead fish, weighing 3-4 kg each, to collect from the pen. In addition, extracting oneself from the pen is no easy task requiring strong shoulders and legs and a rapid ascent from 1-2 m to reach the fence and heave oneself across it. Use of a ladder would simplify this task and eliminate extra unnecessary physical work.

After completing their diving the farm hands often are required to perform heavy physical work, such as changing and washing nets. These nets are extremely heavy and may weigh over one tonne when clogged with weed. The lightest work is feeding the salmon (each feed bag weighs 35 kg) and assisting in bringing the catch to shore. Performing heavy physical work after diving adds to the risk of DCS and should be avoided on diving days.

When the divers presented to RHH with medical problems it was impossible to precisely define the profiles they had been diving in the recent past because no records had been kept of dive times nor of entry and exit times, and no diver carried a depth gauge. Logging of dive profiles and following accepted decompression tables is essential for diver safety. Failure to adhere to safe diving practices and tables is the major cause of DCS in recent Australian series.7,10 No safety decompression stops were made by divers requiring treatment at RHH. One diver attempted to relieve his symptoms of DCS by performing another dive to 10 m for half an hour. A very dangerous practice, which compounded the existing problem, especially as one of his symptoms was vertigo.

In three of four cases of DCS the divers had performed a deeper dive (up to 30 m) after their previous shallower dives. All reported that it was not uncommon for divers to inspect mooring lines or the perimeter net (depths up to 40 m) after shallower pen dives were completed. Following shallow dives with deeper dives is a known risk factor for DCS.[3,7,11] The practice of inspecting and repairing moorings and perimeter nets on deeper dives after already completing a morning of shallow pen diving is extremely dangerous. A safer practice would be to perform all the deep dives before the shallower pen diving. It is the authors' opinion that no further diving should be performed on the same day a diver has been working at depths greater than 20 m.

Two of the four divers with DCS had to make emergency ascents due to air supply problems at depths greater than 20 m. One of these divers had complete cessation of air supply due to hookah motor failure and the other experienced inadequate air supply due to mechanical problems which was compounded by panic in a very low visibility environment. The small reservoir available was insufficient to supply adequate air to either diver to enable a controlled ascent. Their symptoms began after these emergency ascents. In neither case was a backup diver immediately available to assist the diver in trouble. Both divers were using hookah at the time and neither carried a backup scuba cylinder. Diving to greater depths to inspect the perimeter nets and moorings associated is with greater hazard because the risk of DCS increases in a non-linear fashion with depth. Without an independent air supply this risk is further compounded when air supply failure necessitates dangerous free ascents.[12]

Some divers dived with viral respiratory tract illnesses. Two divers presented with barotrauma (one with ear, and one with sphenoidal sinus barotrauma). Each had symptoms severe enough to result in referral to RHH by their general practitioner. Fortunately neither diver had other injuries. Respiratory tract illness prevents equalisation in the ears and sinuses and increases risk of barotrauma.[13] Divers in the industry need to be free of any ENT or respiratory illness because the nature of the diving requires frequent equalisation.

Safety and first aid

A number of unsafe practices were identified. Diving took place without a backup diver immediately available on the surface. In most cases there was no first aid or oxygen equipment immediately available. The divers had insufficient knowledge of what dive practices were risky and of the treatment of diving accidents. Some divers dived with upper respiratory tract infections.

Lack of a backup diver immediately available places the diver at risk, especially when performing deep dives around nets with the risks of entanglements, loss of air supply and narcosis. Although a boat hand is always with the diver, divers reported that no first aid or oxygen equipment was in the boats ready for use if accidents occurred. Carrying an independent scuba source on deeper dives could have prevented two divers making free ascents when they experienced air supply difficulties with the hookah apparatus.

All divers reported that there was no protocol documented for initial management of diving accidents. First aid management of diving accidents should be included in a training programme specific to the industry.

Conclusions

At the time of writing this paper there are numerous risks to the diver employed in the aquaculture industry. Many of these risks could be reduced by ensuring adequate diver training specific to the industry, by adhering to accepted diving protocols and decompression tables, by having written schedules for the maintenance and care of equipment and by adequate safety and first aid procedures.

Standards do exist for Underwater Air Breathing Operations (AS2299-1979)[2], and the general principles governing these standards can be applied to the aquaculture industry. To date many of these principles do not appear to have been implemented. There are however a number of deficiencies when applying this set of standards to the unique needs of the industry. These deficiencies need to be addressed when formulating future guidelines for diving practices. Three very important areas which need attention, in the authors' opinion, are training specific to the industry, standards for the use of hookah apparatus and its maintenance, and dive schedules for multiple shallow bounce diving. Consultation with similar industries in other countries (for example Scotland) would assist with this process. It may require a change to the job classifications of farm hands to allow AS2299 to apply to their diving activities. The expense of on-site recompression chambers is probably not justified provided acceptable safety and first aid protocols exist for the management of emergencies.

Now moves, supported by employers and unions, are under way in Tasmania, to review the diving aspects of the aquaculture industry. It is pleasing to note that recent changes implemented at Tassal, Dover, have included the use of contract commercial divers to perform all dives in excess of 18 metres. This lead taken by Tassal constitutes a major advance in diver safety for the industry. It is hoped that in the near future a uniform set of standards will apply to maximize diver safety on all aquaculture leases in Tasmania.

Addendum

During the 6 weeks before submission of this paper (April 1990) a further three divers from the aquaculture industry had been assessed and treated for significant decompression sickness at Royal Hobart Hospital. Only one of these divers had any formal diving experience. One diver had dived every day for three weeks before presenting with DCS.

Acknowledgements

The authors wish to thank sincerely the management and staff of Tassal, Dover, Tasmania for assistance provided in allowing a tour and photography of their impressive facility, for permission to publish the photographs illustrating this paper and for the first hand experience gained by one of the authors (DS) diving there.

We also would like to thank Dr Geraldine MacCarrick, RMO at the Royal Hobart Hospital, for assistance provided in research.

References

1 Australian Bureau of Statistics. *Population Statistics for Tasmanian Census* 1986, Hobart, Australian Government Printing Service, 1986

2 Australian Standard *Underwater Air Breathing Operations*. Standards Association of Australia, AS2299, 1979

3 Edmonds C, Lowry C and Pennefather J. *Diving and subaquatic medicine*. Sydney Diving Medical Centre 1984

4 Perrone H and Passero M A. Hydrocarbon aerosol pneumonitis in an adult. *Arch Intern Med* 1983; 143: 1607-1608

5 Eade N R, Taussig L and Marks M I. Hydrocarbon pneumonitis. *Paediatrics* 1974; 54: 351-357

6 Taylor R F and Yesair D W. Diver hypothermia. *SPUMS J* 1988; 18(2): 66-69

7 Eckenhoff R G, Osbourne S F, Parker J W and Bondi K R. Direct ascent from shallow air saturation exposures. *Undersea Biomed Res* 1986; 13(3): 305-16

8 Gorman D F, Pearce A and Webb R K. Dysbaric illness treated at the Royal Adelaide Hospital 1987. A factorial analysis. *SPUMS J* 1988; 18(3): 95-102

9 Davis J C. Decompression sickness in sport scuba diving. *Physician and Sports Med* 1988; 16: 108-121

10 Orton J. Medical problems of recreational diving. *Aust Fam Phys* 1989; 18(6): 674-685

11 Lippmann J. Lessening the risk of decompression sickness. *SPUMS J* 1988; 18(2): 70-76

12 Walker D. Limbo diving. The dangers of free ascent. *SPUMS J* 1988; 18(4): 133-136

13 Farmer JC. Otolaryngology and diving, Parts I and II in: *Hyperbaric and Undersea Medicine*, Davis J C (Ed) 1981, Medical Seminars Inc., San Antonio, Texas

Dr David Smart, MBBS, Dip DHM, is a Registrar, in the Accident and Emergency Department, Flinders Medical Centre, Bedford Park, South Australia.

Dr Peter McCartney, MBBCh, MMed(Anaesthesia), Dip DHM, is Director, Hyperbaric Unit, Royal Hobart Hospital, Hobart, Tasmania.