Proceedings
American Academy of Underwater Sciences
Diving For Science
2016

Editors
Lisa Lobel
Michael Lombardi

In: Lobel L.K., Lombardi, M.R. eds. Diving for Science 2016.
Proceedings of the American Academy of Underwater Sciences 35th Symposium.

Triple-Redundant Hookah Diving System for Remote Inshore Aquaculture Husbandry and Science that is Cost-Effective, Efficient and Safe

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Abstract

Globally, inshore aquaculture has been expanding rapidly to meet the demand for seafood. In commercial-scale operations diving supports husbandry activities throughout the production cycle or facilitates scientific aquaculture research. To avoid existing user-groups and marine traffic, inshore aquaculture is often sited to remote locations. This poses a challenge to diving activities because the cost and logistics are often proportional to distance traveled. Classical scuba diving, popular for its self-contained nature and perceived convenience, has two major drawbacks in aquaculture; (1) scuba diving is commonly conducted in depths up to 20 m so dive times are limited by the volume of air in cylinders rather than established no-decompression limits, and (2) this creates a need for large numbers of cylinders that must be transported to the site. Hookah diving offers a favorable alternative - the technique is already widely implemented in popular aquaculture regions such as Tasmania, Australia. This study presents a design for an effective two-diver, triple-redundant hookah system that has been optimized with diver safety and work efficiency as priorities. Operation of the system requires three personnel; a dive supervisor, tender and diver. To facilitate a case study, the system was installed at a commercial/research inshore grouper farm in Hong Kong. A cost analysis showed that implementation of the system is cost-effective compared with scuba, the only diving alternative in the region. The addition of hard-wired diver-surface-diver communications substantially improved working efficiency. Hookah diving for remote inshore aquaculture science and husbandry is recommended because it is cost-effective, efficient and safe.

Keywords: Hookah diving, Inshore aquaculture, Aquaculture research, Husbandry

Introduction

Globally inshore/ near-shore/ coastal open-water aquaculture has been expanding rapidly to help meet the demand for seafood, to improve food security or to enhance social and economic sustainability (Karakassis et al., 2000; Pérez et al., 2002). Since the start of commercial open water aquaculture in the 1970s and '80s various forms of diving have been used to support key activities (Smart and McCartney, 1990; Douglas and Milne, 1991). Records of the use of hookah systems in aquaculture are largely unpublished or tied up in gray literature (e.g. Kluger et al., 1994 as cited by Smart et al., 1999; Goodrick et al., 2002) but the technique has been applied effectively to a wide range of husbandry activities that include the collection of broodstock (Windsor et al., 1997), the collection of stock for growout (Wells and Jernakoff, 2006) and for ongoing husbandry activities throughout the production cycle (Smart et al., 1999; Leonardi et al., 2006; Christou et al., 2013). In the 1990s four in seven inshore farms in Tasmania used hookah diving, or a combination of hookah and scuba, for effectively executing farm operations (Smart et al., 1999). Despite the existing applications of hookah diving in aquaculture, scuba diving remains the norm in many regions because of its perceived convenience during training and application.

Inshore aquaculture divers mostly work in depths up to 30 m and their roles include maintaining and repairing of nets, pens and pods; inspecting and servicing anchor ropes, moorings and lines; removing diseased or dead fish; conducting underwater inspections of fish feeding, health and behaviour; inspecting and repairing farm perimeter and predator exclusion nets, assisting in changing of nets, stock crowding and harvest operations; and supervising the deployment of net pens (Smart and McCartney, 1990; Smart et al., 1999). Between regions the tasks of aquaculture divers are relatively standardised; a limited range of working tasks must be carried out among or under floating objects. In Chile divers use hookah systems to collect propagules, seed and harvest the seaweed *Gracileria* (Leonardi et al., 2006). More recently, hookah diving has been used, and recommended, for servicing Aquapods (© InnovaSea Systems); these enclosed subsurface fish cages can be brought to the surface for maintenance so that diving usually occurs in depths up to only 10 m (Christou et al., 2013).

One challenge posed to inshore aquaculture operations is that they are often sited in remote locations to avoid complications with existing user-groups and areas of high marine traffic. Inshore operations generally rely on small service vessels and do not use large ships. Diving activity is often allocated to single or multi-day scuba diving expeditions based on a predetermined list of objectives. This limits the scope for the development of diving as a medium for regular, ongoing husbandry and research. Multi-day scuba operations require large numbers of cylinders that must either be transported on day 1 of the operation, or must be delivered daily. The former is logistically challenging when manpower is limited and the latter is expensive over the long-term. An alternative is to operate an on-site high pressure (HP) scuba cylinder compressor. The capacity for on-site HP compressors is restricted because smaller compressors tend to be inefficient adding a substantial number of man hours to a working day, while larger compressors occupy substantial deck area at a farm site or on the deck of a large support vessel. In diving the maximum allowable dive time is limited by established no decompression limits. However, dive time when scuba diving is often limited by the amount of breathing gas in a cylinder, such as during shallow-water work or when lengthier tasks, requiring decompression, are necessary.

More widespread adoption of hookah diving could overcome these limitations. Replacement cylinders are not necessary as air supply is virtually unlimited and the systems require only a small working footprint. In south Australia and Tasmania, surface-supplied diving has been the industry standard (Smart et al., 1999). Two major criticisms of hookah diving are that there is a lack of redundancy in emergency situations and that the umbilical is stifling during underwater work. The former is addressed in this study by presenting a triple-redundant system. The latter is an assumption mostly made by scientific divers who have not been exposed to surface supplied diving techniques. Commercial divers with surface supplied diving experience find the lightweight nature of hookah systems comfortable and convenient. In addition, the simplicity of adding hard-wired diver-surface-diver communication to the system, linked via cables attached to the umbilical, substantially improves the efficiency and safety with which work can be conducted. Currently many smaller farms rely on the hiring of contract commercial divers to conduct farm maintenance infrequently, but as the industry continues to expand and shift focus to multidisciplinary systems and infrastructure then cost-effective, safe, in-house diving will be essential to maintain industry competitiveness.

Hookah diving could be a functional alternative to scuba in many inshore aquaculture regions. The aim of this white paper was to examine a triple-redundant hookah diving system for remote inshore aquaculture husbandry and science. A literature review was conducted to investigate why such a system is necessary, the technical details behind the system are presented, and a simple cost analysis based on a case study from scientific aquaculture divers in Hong Kong is used to illustrate the efficiency and financial benefits of implementing hookah systems.

Methods

This study was conducted at a commercial-research hybrid fish farm in Hong Kong (22.543894° N, 114.300828° E). The farm formed as part of the Sustainable Ecological Aquaculture project of the City University of Hong Kong, consists of a 300 m^2 fish raft operating under a commercial license to produce 5 tonnes of fish annually. The fish farm was sited in O Pui Tong, a designated fish culture zone approximately 30 km from the central business district, as the crow flies. The commute to the location is lengthy; there are a number of transport combinations by road and sea, the most efficient of which is truck and speed boat, with a total one-way duration of approximately 1.5 hours. All regular logistics and transport were conducted using 4.5 m vessels with single 200 hp outboard engines. In a given diving day, necessary underwater work usually required 8 man hours of diving (e.g. 4 divers × 2 hours). All diving work occurred up to a maximum depth of 14 m, the sea floor, but more than 95% of work was conducted at depths less than 8 m because the maximum depth of fish nets is 6 m. This location was selected for the case study because the farm was previously reliant on scuba diving – cylinders were rented from local dive companies – and the moderately remote location is representative of this type of fish farm throughout the asia-pacific region. Two of the proposed triple-redundant hookah systems were installed at the site.

Development and design of a triple-redundant system

In Spring 2015, the authors assembled two, two-diver hookah systems (4 divers total) for husbandry of the fish raft structure and related undersea research. Each system consisted of the following major system-level components:

1. Control station (Figure 1) and low pressure gasoline powered compressor with oil free piston (Figures 11, 12 and13).
2. Low pressure air supply distribution manifold incorporating an independent regulated high pressure bailout air supply (Figures 2 and 3).
3. Three-gallon stainless steel volume tank (Figures 4 and 5).
4. Communication box with 12vdc battery power.
5. Two 100’ hoses with communications wire.
6. Two Mantis full face masks with OTS communications modules (Figures 6 and 7).
7. Diver bailout block and manifold to permit bailout to a diver-carried bailout cylinder (Figures 8, 9 and 10).

This system was purpose-built for the aquaculture project, however the fundamental system design has evolved from more than 15 years of use during similar very shallow maintenance of yachts and other light inshore working dive tasks, accounting for several thousand hours spent using this type of equipment configuration.

Emphasis has been placed on autonomous operation by an individual diver that may or may not have immediate buddy access. For this reason, triple redundant air supply has been incorporated, where the primary air supply is a low pressure (LP) compressor, the secondary is the diver-carried bailout, and, in an emergency requiring additional time for diver extraction, the third is the HP cylinder topside.

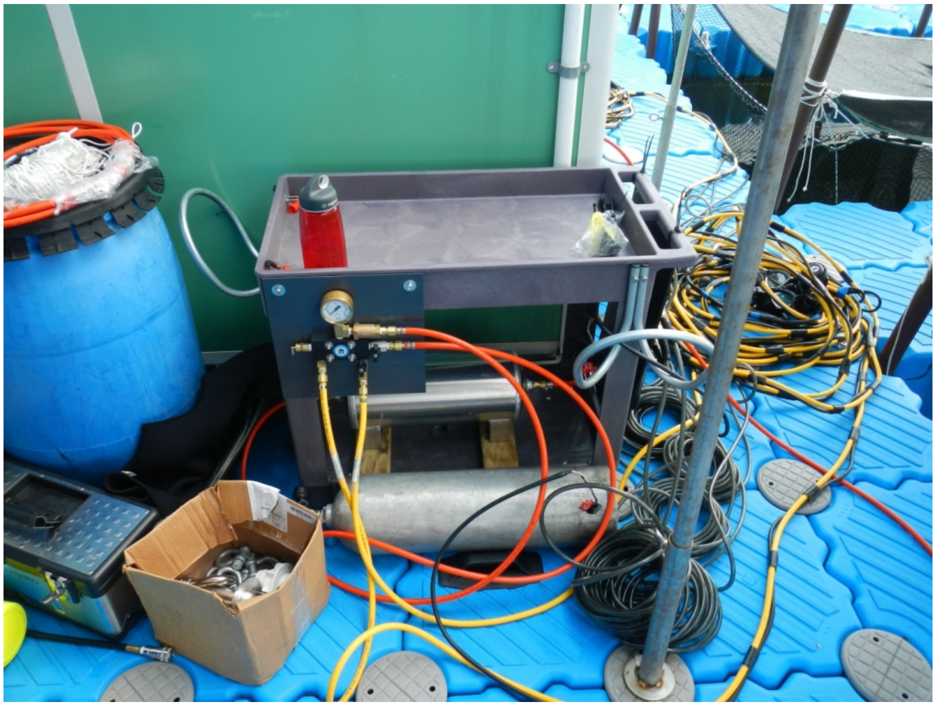

Figure 1. The hookah control station is built into a cart for ease of organization. It is useful to keep hand tools, communications boxes, and spares on the cart for immediate use.

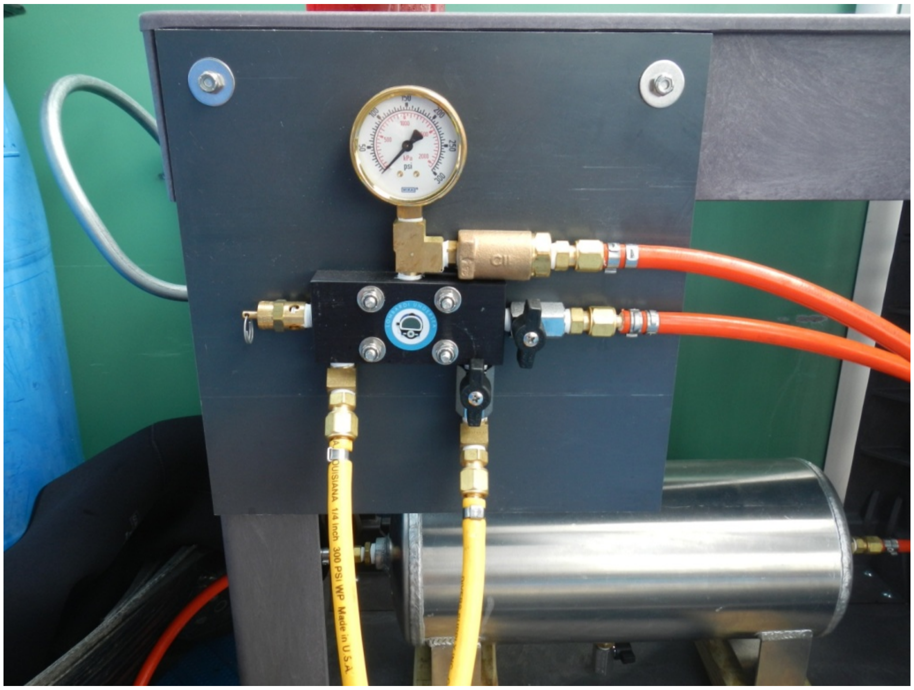

Figure 2. The distribution manifold includes LP air supply in through a check-valve, HP bailout supply in via a quarter turn isolation valve, outlets for 2-divers with diver-2 capable of being isolated for use in 1-diver mode, an over-pressure relief valve, and an operating (intermediate) pressure gauge. The gauge should normally read 120-140 psi, however is frequently adjusted up to 150 psi for 2-diver use.

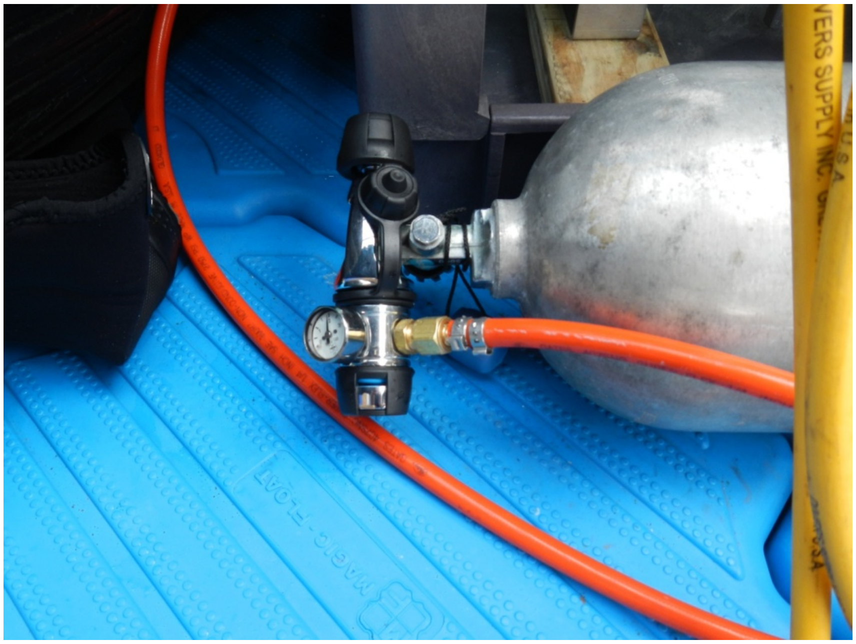

Figure 3. The HP bailout is supplied through a first stage regulator. This includes an HP gauge and its own pressure relief valve. The supply hose is over-engineered to 2250psi however operates at only standard intermediate pressure. This is a failsafe to ensure air supply to the diver in an emergency. This cylinder should be 'on' during the dive, and isolated at the distribution manifold. Note that standard 'oxygen' brass fittings are used throughout the system. These are commonly used in commercial diving operations as they facilitate easy hose repair, and provide for readily available spares on-site.

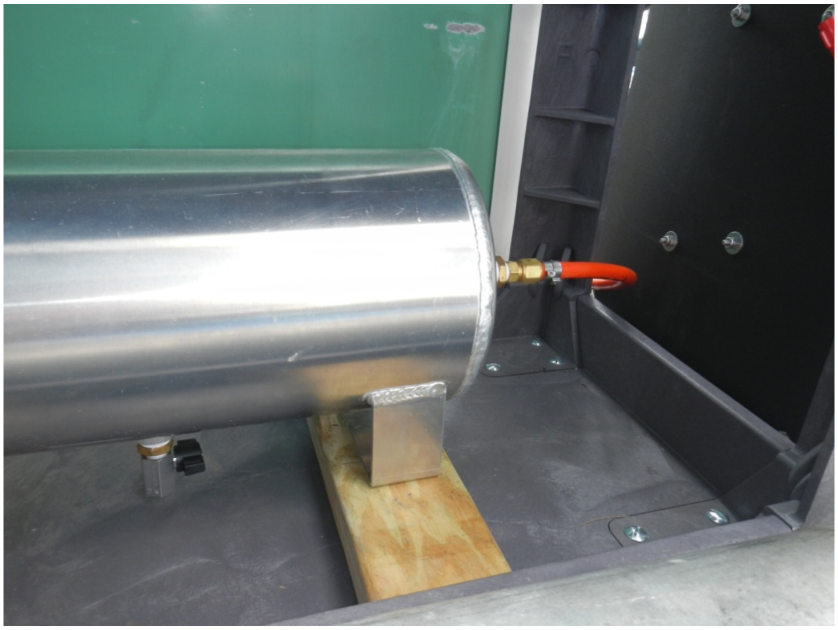

Figure 4. The LP volume tank provides additional volume for the divers to reduce wear on the compressor. It also acts as a moisture trap. Accumulated moisture can be vented from the quarter turn ball valve located at the bottom of the tank. Air from the compressor enters on the right side.

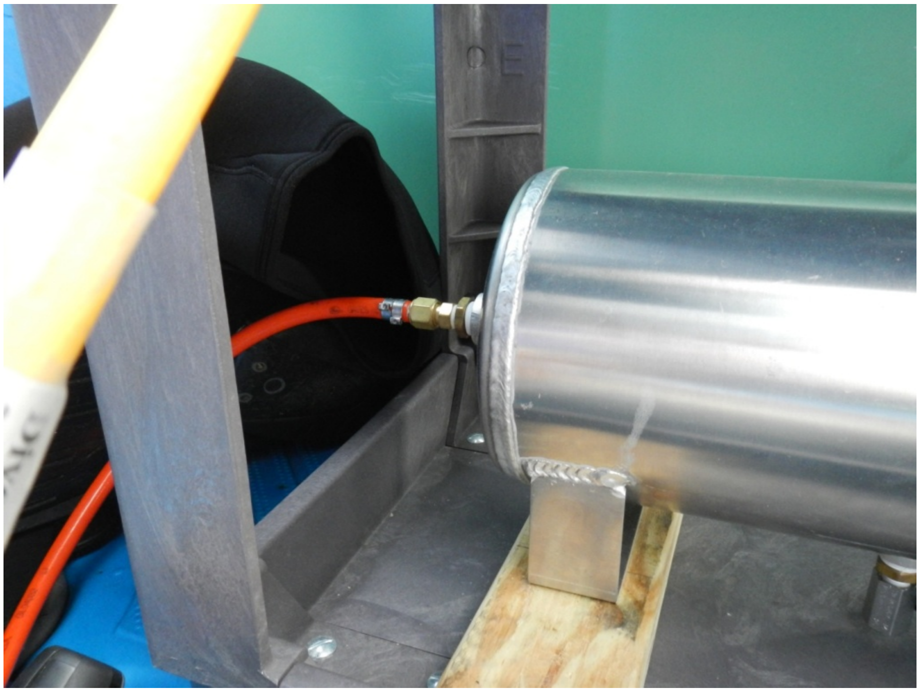

Figure 5**.** Air exits the volume tank on the left side, and runs to the distribution manifold inlet.

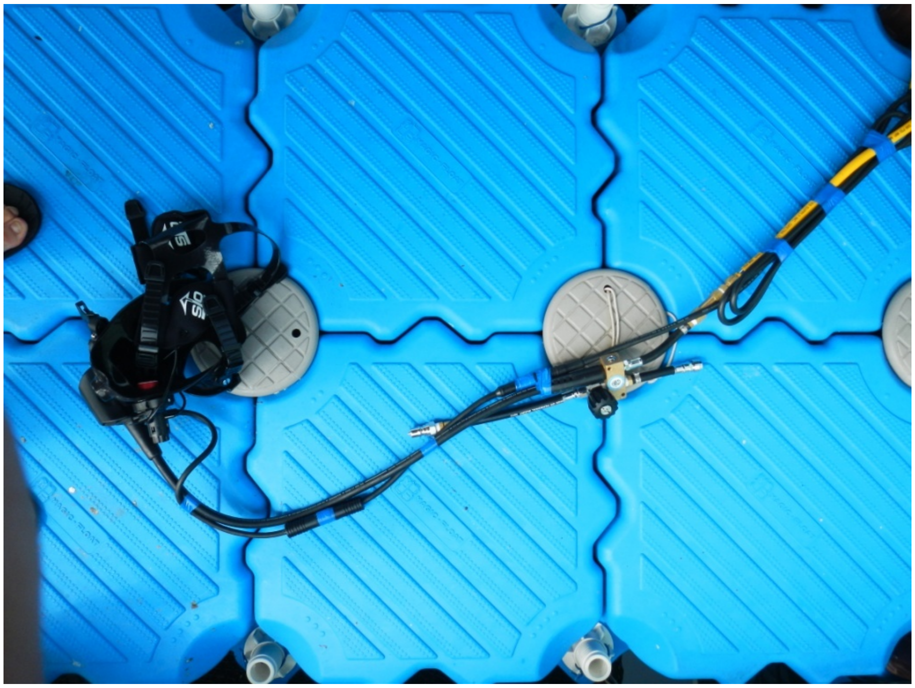

Figure 6**.** At the diver's end, LP air supply is distributed via a small manifold. It is important to streamline hoses and the communications wire. This takes some adjustment over time to meet desired configurations.

Figure 7. The full face mask utilized is the 'Manta' from OTS. It will accept any standard 2nd stage regulator.

Figure 8. The diver-worn bailout cylinder connects to the bailout whip at the manifold block. This is a standard Parker QC fitting used in commercial diving. The isolation valve should be 'off' while diving. If the surface supplied air supply fails, the diver can open this valve and have immediate access to the reserve air on his/her back. The dive should be terminated immediately.

Figure 9**.** The air supply/umbilical attaches to the manifold at a check valve. This prevents the backflow of gas if the umbilical is severed. A short inflator hose fits to the BC inflator at the diver's left chest and positions the manifold block at the left shoulder for immediate access. The LP breathing hose routes around the diver's neck with air supplied over the right shoulder as is standard for scuba equipment.

Figure 10**.** The diver-worn bailout cylinder is worn inverted with the bailout whip coming over the divers left shoulder. The cylinder should be 'on' during the dive, but is only utilized in an emergency. The diver should be able to reach back and actuate this valve unassisted.

Figure 11. The compressor rests in a spill pan to mitigate accidental gas spills. This should always be run in a well ventilated area.

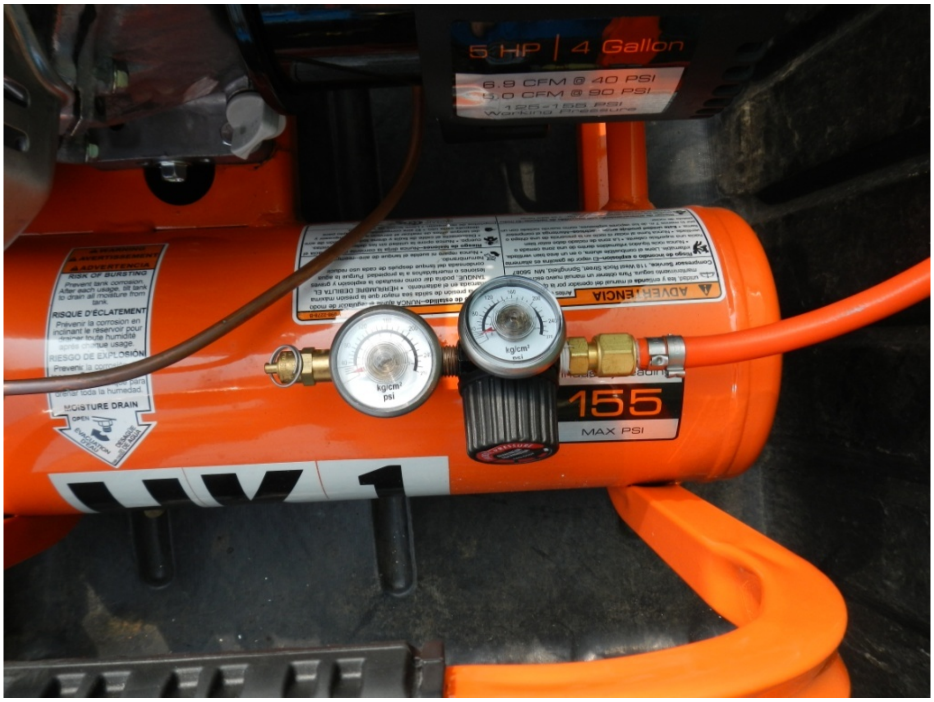

Figure 12. The outlet pressure on the compressor should be adjusted to supply 120-150 psi to the divers.

Figure 13. The air inlet filter should be positioned high and away from any machinery exhaust.

User requirements

Divers should be proficient and competent in scuba diving and understand basic concepts in gas switching and bailout procedures. Topside personnel should be competent persons with experience in diving systems and have an understanding of plumbing and electrical components for diving/marine technology.

The hookah system and bailout system integrates with a standard diver BCD and includes a full face mask with regulator. Standard dive masks and regulators are not needed; however, the hookah system may be used with a standard regulator and half mask, however in this case no communications will be accessible.

Team requirements

The minimum team size for hookah diving is three. This consists of the following:

- *Dive Supervisor* – responsible for all topside operations and safety and maintains regular contact/communications with the divers.
- *Tender* – responsible for tending the diver by handling hoses and raising/lowering supplies and equipment as needed. The tender also aids the diver in suiting up and ingress/egress from the water.
- *Diver* – the diver is responsible for conducting the underwater work efficiently and takes direction from the Dive Supervisor.

An additional diver requires an additional tender. Tenders should be prepared to act as a rescue diver if needed.

Topside responsibilities

The designated dive supervisor is responsible for ensuring the topside systems are functioning properly, and maintains communications with the diver. The supervisor should respond to the needs of the diver by directing the tender or other topside support personnel to respond. Actions may include giving/recovering slack in the umbilical, or lowering or raising tools.

Underwater responsibilities

While utilizing surface supplied systems, the diver is often times diving alone. He/she has bailout systems immediately available and the added security of a hose, which is a direct lifeline back to the point of entry. It is the diver's responsibility to manage the hose to keep it free from entanglement and communicate any issues to the topside dive supervisor.

Should communications be lost, the dive is terminated and the diver should make his/her way back topside. Temporary communications may be re-established by using line signals where:

1 pull – Are you ok? Yes, I'm ok.
2 pulls – Go down or provide slack
3 pulls – Come up or recover slack
4 pulls – Dive is over or recover the diver

Cost and efficiency of the triple-redundant hookah system

A simple cost analysis was conducted to compare the capital expenditure required to establish the triple-redundant hookah system described here with a suitable mid-range HP compressor, the Poseidon PE300-VE (Bauer ©) and associated equipment. As no large ships are used by this aquaculture operation, the 299 kg compressor would require supplementary floatation under the deck of the fish raft to enable placement of the compressor on top. The cost of the supplementary flotation was therefore included in the comparison. An additional cost associated with the compressor is that of the dive cylinders. Under the assumption that 8 dives are conducted a day, the purchase price for 10 20 L cylinders was included.

To quantify the potential for extended dive times when using hookah diving a theoretical dive model was compiled using data for maximum dive times from 12 m to 40 m depths, the most likely working depth range of inshore aquaculture divers. NAUI dive tables were used to construct a curve of recommended maximum no-decompression dive times. A second curve of estimated actual dive time was generated based on a 20 L cylinder filled to a working pressure (WP) of 200 Bar, and a diver average breathing rate of 40 L.min^{-1} (Williams, 2002). The actual dive time curve was constructed using depth-adjusted available gas volume; a 10 m depth increase is equivalent to 1 ATM increase in pressure. For the purposes of conservatism gas volumes required for safety or decompression stops were not included.

Results

Cost and efficiency of the triple-redundant hookah system

The cost of two full hookah systems as described above was US$22,000 (HK$170,600) while the cost of the full HP compressor setup and associated equipment was US$23,420 (HK$181,660) (Table 1). The difference in price to establish these systems is therefore negligible.

Table 1. Capital investment required to implement the (A) Triple redundant hookah system compared to (B) a mid-range scuba cylinder compressor in Hong Kong. Prices are in US Dollars.

	Unit Price	Units	Sub-total
(A) Hookah system			
Complete system (As in methods section)	$11,000.00	2	$22,000
		Total	**$22,000**

	Unit Price	Units	Sub-total
(B) Scuba compressor			
Poseidon PE300-VE (Bauer ©) + 4 × hose connectors	$17,180	1	$19,420
Supplementary flotation	$1,700	1	$1,700
20 L Aluminium cylinders	$230	10	$2300
		Total	**23,420**

Maximum dive time

The curves for maximum table dive time and actual dive time indicate that for the average working diver, diving at depths deeper than approximately 26 m, there is sufficient air in a 20L (0.71 ft^3), 200 bar (2900 psi) cylinder to negate the additional air advantage of the hookah system (Figure 14). At depths shallower than 26 m the hookah system allows for full utilisation of maximum table dive time.

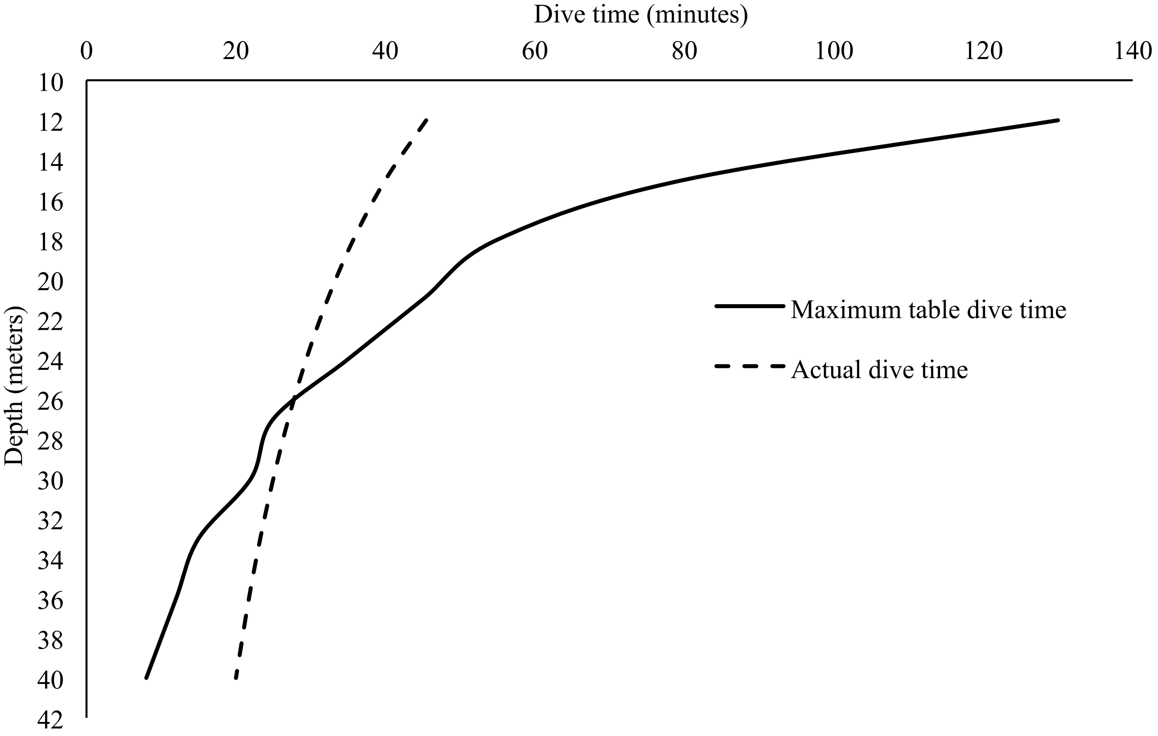

Figure 14**.** Maximum table dive time and actual dive time curves based on NAUI tables and a working diver breathing at a rate of 40L.min^{-1} (Williams, 2002) from a 20L cylinder at 200 bar initial pressure. Available gas volumes were depth-adjusted. Gas volumes required for safety and decompression stops were not included.

Discussion

Inshore aquaculture operations are commonly sited to remote locations. This is a necessary policy measure to avoid existing infrastructure and user-groups but adds to the time and financial cost of operations and limits the potential for ongoing scientific research and development. In Hong Kong, for example, there are 29 designated fish culture zones (FCZs) managed by the Agriculture, Fisheries and Conservation Department. All FCZs are discrete from the central business districts and require access by boat as the final stage to a lengthy commute. The applications of scuba diving for husbandry and science are therefore limited due to logistics like cylinder transport. Hookah diving is one reasonable alternative to scuba diving.

Perceived limitations to hookah diving

There are two primary perceived limitations of hookah diving. The first is that there is a lack of redundancy in traditional hookah systems because they typically only include a primary air supply via a regulated HP supply cylinder, or a single LP compressor. In the event of a failure, a diver-worn bailout is required for safe egress from the dive. Hookah divers do not frequently use this diver-worn bailout, which exposes them to unnecessary risk. This criticism of hookah diving, like other lightweight surface supplied diving modes, is that systems generally offer minimal redundancy and therefore have a poor safety record (Lang and Smith, 2006). Simple measures can be taken to incorporate multiple redundant breathing supplies, which are more commonplace in surface supplied diving operations. The second criticism is that the tether can be perceived as restrictive to divers. Standard hookah practice includes tending the diver with slack in the umbilical. This reduces the effect of the umbilical substantially because the excess umbilical floats at the surface and there is nearly no hindrance to the diver. The umbilical has an added benefit in that it gives a useful point of direct reference to the surface/exit for divers working in low visibility, or overhead environments common in inshore aquaculture situations. Tether management is a skill more commonly ingrained within commercial diver training regimes, and it requires little practice to attain competency. Many commercial divers greatly prefer diving with a tether than without, given the advantages of a virtually unlimited breathing supply and added directional awareness.

Table 2**.** The perceived advantages and limitations of hookah diving systems (Smart and McCartney 1990; Smart et al., 1999; Lang and Smith, 2006; this study).

Advantages	**Limitations**
• Available air volume not restrictive to diving activities. • Tether acts as point of reference in low visibility, overhead environments. • Easily incorporates communications improving working efficiency and safety. • Small working footprint so easily transported and used from boat or fish raft deck. Rapidly deployable. • Flexibility for multiple air sources such as small low pressure compressor or high pressure console fed from scuba cylinders. • Minimal investment, maintenance and operational costs • Can be safely operated with as few as three personnel: diver, line tender, supervisor • A diver can operate alone in the water, unhindered by another diver nearby.	• High risk when practiced without standard operating procedures. • Tether can restrict diver activities if work requires substantial distance travelled. • Tether can pose entanglement hazard if tether management practices are not well rehearsed. • Hookah systems are not well understood, standards of practice are required to educate end-users and policy makers

Cost and efficiency of the triple-redundant system

The cost analysis showed that the capital expenditure of establishing the hookah system compared to a HP compressor system is comparable (Table 1). There are a number of additional advantages to the hookah system that were not quantified in this study. By implementing the hookah systems at the O Pui Tong fish raft it was noted that substantial time advantages were experienced because the hard-wired voice communication system substantially improved the run-time of underwater tasks. The authors estimate that this is as high as 20-30%, and future work could aim to quantify this conclusively. Additional time and energy savings were experienced because divers did not need to end a dive to replace cylinders, nor did cylinders require filling between diving days. Other farms implementing hookah systems have been recorded to dive for up to 8 hours per day (Smart and McCartney, 1990). The near-unlimited air supply from the surface is particularly useful during tasks that increase a divers heart-rate such as the removal of biofouling, or when surface air consumption rates differs greatly between buddy divers. Scuba diving does not present these efficiency advantages.

Safety and the need for SOPs

Hookah systems can provide additional margins of safety to aquaculture and scientific divers when implemented properly with adequate redundancy. Systems with near-unlimited air supply, triple redundancy and communication can help to improve safety substantially. If decompression time is necessary for long-duration tasks at greater depths, the benefits of the additional gas is valuable because longer decompressions are not limited by diver-carried gas volumes. The communication systems are particularly useful when a dive supervisor is overseeing the details of the operation with the availability of a backup diver.

While the tasks that aquaculture divers around the globe must accomplish are relatively standardised, aquaculture diving itself is somewhat unique and can place divers at risk. Standard operating procedures (SOPs) are necessary. In the early days of the industry, individual hookah divers were observed conducting 20 – 40 bounce dives to 10 m, over a four- to five-hour period (Smart and McCartney, 1990). Multiple ascents are well accepted as major risk factors for decompression sickness, despite table limits (Edmonds et al., 1984; Davis, 1988). Prolonged, shallow saturation dives have been shown to produce a high incidence of DCS (Eckenhoff et al., 1986). Additionally, tasks conducted in and amongst fish cages can be challenging to divers, particularly under low visibility conditions. Hookah diving for aquaculture has therefore carried some reputation of being high risk due to early industry incidents. With the implementation, review and development of modern diving systems and protocols the safety and responsible use of these systems has improved substantially (Smart et al., 1999).

Many regions lack aquaculture and research diving SOPs. In Hong Kong for example, SOPs for aquaculture and scientific diving are not yet in place. These diving activities are broadly guided by the Code of Practice: Safety and Health at Work for Industrial Diving (Labour Department of Hong Kong, 1998) and established recreational diving protocols. These broad guidelines should be developed further to include aquaculture and scientific diving activities that hold both work efficiency and diver safety as priorities. Aquaculture-specific training for divers has been shown to greatly reduce incidence rates (Smart et al., 1999). To insure diver safety, it is critical that regional industries adopt SOPs for training and operation and employ only well trained divers. These SOPs should include clear principles on the redundancy required in hookah systems and the dive team structures necessary to achieve particular objectives; most commonly a dive supervisor, line tender, backup diver and an in-water diver.

Conclusions

To enhance the competitiveness of inshore aquaculture operations, and to facilitate ongoing husbandry and research, safe and efficient diving systems are necessary. The triple-redundant hookah diving system presented in this study is cost effective, efficient and safe and therefore presents a promising alternative to scuba diving. The system combines the original advantages of surface-supplied breathing gas with triple redundancy and surface-diver-surface communications that have facilitated effective aquaculture husbandry and scientific research. It is recommended that all regions engaging in these activities develop and abide by SOPs to insure responsible use and diver safety.

Acknowledgements

The authors acknowledge the professional support of the scientific divers that participated in this work. In particular, we thank Mr. Feng ZHANG for coordinating the system installation and diving logistics. This work was supported by Shenzhen Key Laboratory for the Sustainable Use of Marine Biodiversity (ZDSYS20140509155229806).

Literature Cited

Christou, P., R. Savin, B. Costa-Pierce, I. Misztal, C. Bruce, and A. Whitelaw, eds. 2013. *Sustainable Food Production*. New York, NY: Springer.

Davis, J.C. 1988. Decompression sickness in sport scuba diving. *Physician and sports medicine,* 16: 108–121.

Douglas, J.D.M., and A.H. Milne. 1991. Decompression sickness in fish farm workers: a new occupational hazard. *BMJ: British Medical Journal*, 302: 1244-1245.

Eckenhoff, R.G., S.F. Osbourne, J.W. Parker and K.R. Bondi. 1986. Direct ascent from shallow air saturation exposures. *Undersea biomedical research*, 13(3): 305–316.

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

Goodrick, G.B., P.T. Thomas, B.D. Paterson, and A. Smart. 2002. *Southern Bluefin Tuna Aquaculture Sub-program Project 4: Effect of husbandry and handling techniques on the post-harvest quality of farmed southern bluefin tuna.* Queensland, Australia: Fisheries Research and Development Corporation.

Karakassis, I., M. Tsapakis, E. Hatziyanni, K. N. Papadopoulou, and W. Plaiti. 2000. Impact of cage farming of fish on the seabed in three Mediterranean coastal areas. *ICES Journal of Marine Science*, 57:1462–1471.

Labour Department of Hong Kong. 1998. *Code of Practice: Safety and Health at Work for Industrial Diving*. Hong Kong, China: Occupational Safety and Health Branch.

Lang, M.A., and N.E. Smith, eds. 2006. *Proceedings of Advanced Scientific Diving Workshop*: *A Comparison of Surface-Supplied Diving Systems for Scientific Divers*. Washington, DC.: Smithsonian Institution.

Leonardi, P.I., A.B. Miravalles, S. Faugeron, S. Flores, J. Beltran, and J.A. Correa. 2006. Diversit, phenomenology and epidemiology of epiphytism in farmed *Gracilaria chilensis* (Rhodophyta) in northern Chile. *European Journal of Phycology,* 41(2), 247-257.

Pérez, O.M., T.C. Telfer, M.C.M. Beveridge, and L.G. Ross. 2002. Geographical Information Systems (GIS) as a Simple Tool to Aid Modelling of Particulate Waste Distribution at Marine Fish Cage Sites. *Estuarine, Coastal and Shelf Science*, 54(4): 761-768.

Smart, D., and P. McCartney. 1990. High Risk Diving Tasmania's Aquaculture Industry. *South Pacific Underwater Medicine Society Journal*, 20(3): 159-165.

Smart, D., S. Rubidge, P., McCartney, and C. Van Den Broek. 1999. Tasmania's Aquaculture Industry: a Ten-Year Review of Improved Diving Safety. *Papers and Proceedings of the Royal Society of Tasmania*, 133(1): 77-83.

Wells, F.E., and P. Jernakoff. 2006. An Assessment of the Environmental Impact of Wild Harvest Pearl Aquaculture (*Pinctada maxima*) in western Australia. *Journal of Shellfish Research*, 25(1): 141-150.

Williams, P., ed. 2002. *The Diving Supervisor's Manual*. London, England: International Marine Contractor's Association.

Windsor, D. 1997. A Profile of the Queensland Occupational Diving Industry. *South Pacific Underwater Medicine Society Journal*, 27(1): 24-28.