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DIVING IN SUPPORT OF FISHERIES RESEARCH

William C. Phoel*

ABSTRACT

It is ageneralized truth that major scientific opportunities and discoveries are made in conjuction with great technological breakthroughs and advancements. Two such technological advancements are the aquarium and non-breath hold diving. While the invention of the aquarium routinely permitted the viewing of aquatic animals head on for the first time in history, non-breath hold diving permitted not only head on viewing but also observations of the animals in their natural habitat for relatively long periods of time.

Diving has played an important role in fisheries research since Ahstotle when breath-hold divers observed shallow water habitats and their inhabitants for the first time. However these observations were necessarily in shallow water for short periods of time. Diving techniques changed litte until air compressors were developed and divers could receive compressed air from the surface via hoses. Even though the development of surface supplied, full-dress, hard hat diving systems made underwater work safe and efficient, the use of such gear and associated topside support requirements made its use for fisheries research rare. Aquariums provided researchers with the best information regarding the animal's behavior. Not until the advent of high-pressure compressors could diver's cylinders be pressurized with enough air to provide a reasonable amount of bottom time when coupled with the demand regulator. This technological development gave us SCUBA, as we know it today.

Since the 1950s the vast preponderance of dives in support of fisheries research has been accomplished using SCUBA. The reasons for the rapid acceptance of SCUBA was the freedom of movement it afforded the diver and its almost complete lack of required surfes support equipment and the associated expense. From the 1950s through the late 1970s all SCUBA research dives were conducted using air as the brething gas. From about 1970 through the present, undersea laboratories have provided fisheries researchers with greatly extended bottom times for observations and experimentation. In the late 1970s nitrogen-oxygen (NITROX) mixed gas diving techniques increased the researcher's effectiveness to depths of 40m. Building upon NITROX in the 1980s helium was added to the nitrogen and oxygen to produce TRIMIX. TRIMIX permitted the reserches to reach depths of at least 90m using open circuit and closed or semi-closed SCUBA.

The ability to be in situ is an invaluable asset to the fisheries researcher. It permit investigations requiring long bottom times or very deep dives to study fish populations. behavior, and habitat, as well as the observation and documentation of aperiodic and ephemeral events such as hypoxia and associated fishkills.

INTRODUCTION

It is a generahzed truth that major scientific opportunities and discoveries are made in conjunction with great technological breakthroughs and advancement. Among the numerous examples of technological advancements that made research opportunities possibles are the development of the telescopce, microscope, X-rays, magnetic resonance imaging and hyperbaric chambers. The early development of glass for aquarium use and later development of high-pressure compressos are of direct importance to the fishery researcher. Smaller. incremental advances within a m ajor technological breakthrough can increase its efficiency, effectiveness, and safety. Fishery scientists can now avail themselves of several options for conducting observations and experiments in vitro or in situ.

EARLY HISTORY

Xerxes, the Persian ruler and military leader (486-465BC) was among the first to use breath-hold

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* Undersea Research Foundation, Inc.
Toms River, New Jersey, 08753, U.S.A.

divers as underwater combat swimmers during his invasion of Greece around 480BC. The Greek philosopher and natural scientist Aristotle (384-322) recorded the first descriptions of underwater environments based upon the observations of breath-hold divers. More than two thousand years passed without much progress in observing these habitats and their inhabitants because there were no significant technological advances to increase the time the breath-hold diver could spend on the bottom or at the depth to which the diver could descend.

Unitil the 1850s naturalists and artist invariably observed and depicted living fish from a dorsal view. because it was from this orientation that fish, and other submerged aquatic organisms, were observed in nature. Such observations required shallow and clear water in either natural waters or fish pond. Dead specimens could be viewed laterally, ventrally, or eye-to-eye but the viewers would not be able to comprehend the fish in its natural habitat from this perspective. The few eye-to-eye or laterral representatations were drawn with the animal on top of the water or partially submerged at the surface. These were not representations of living fish but of dead fish placed on to the water's surface.

AQUARILUMS IN FISHERY RESEARCH

Prior to the 1850s England and other European nations had an extremely expensive tax on glass. This severely limited the production of aquariums so that most fish observations remained from the dorsal view. During the 1850s these countries drastically reduced or removed the costly tax and the manufacture and marketing of aquaria soared. The great demand for aquaria had begun and professional institutions, well-to-do amateurs, and regular working folk all maintained aquaria. The aquarium rage spanned several decades before declining to a lower, more sustainable level. In aquaria fish could now be observed from eye-to-eye and lateral perspectives. The aquahum was a great advance for fishery research because these new perspectives provided new insights into many fishes' form, function and behavior, e. g. feeding, territoriality, mating and reproduction. Aquaria pemitted the fisheries scientist, and the general public, to observe many aspects as to how fishes conducted their lives. Aquaria also pemitted in vitro experimentation regarding the influences various biotic and abiotic factors had on the species under investigation.

Many fish species were inappropriate for aquaria of that time, e. g.fishes too large, too active, hard to maintain, so these still could not be observed. However the largest shortcoming of observing fish in aquaria was that they were not in their natural environment with all the confounding influences on their lives. The technological advance of aquaria showed us much about fish but similar advances for maintaining a researcher underwater were still decades away. Almost another century would pass before advances in diving technology allowed fisheries scientists to routinely observe fish in their natural habitat.

ADVANCES IN SURFACE SUPPLIED DIVING

The development of low-pressure air compressors allowed Edward Halley to refresh the air in his diving bell for the first time in 1716. This increased the efficiency and safety of the bell for shallow water salvage. In 1837 Augustus Siebe patented and first used his surface supplied diving suit. Siebe's design of a constant flow metal helmet mated to a dry, full-body canvas suit remained baslcally unchanged until the 1970s and is still used today in many areas around the world [1].

Surfase-supplied, hard hat diving gear was designed for underwater construction and salvage. This kind of heavy work requires physical protection and the ability to be heavy in order for the diver to remain stable and apply suitable force. In commercial diving operations, where limited horizontal movement is required, the work is often strenuous, bottom times lengthy, the water may be of dubious quality, and decompressions are commonplace, surface supplied diving is still the safest and most efficient and effective diving technique. These benefits are often under-appreciated by today's noncommercial diving community. Recent advancements in matehals technology, especially those involving synthetic materials such as plastics and fabrics, were adapted to modernize Siebe's helmet and suit designs. These adaptations, along with use of the demand regulator, permitted commercial diving gear to be relatively lighter and more mobile while maintahing its safety and effectiveness. Lightweight, swimmable surface-supplied gear is now available for use when it is more advantageous than the heavier gear.

Sarfase-supplied diving techniquis were and still remain an option for underwater fishery research if the situation has similar considerations to those involved in commercial work. However, because of ites extensive surface support requirements, high associated costs, and lack of mobility relative to SCUBA surface-supplied diving has rarely been used in fisheries research. A typical commercial surface-supplied diving operetion requires a divers umbilical with communications, low pressure comoressor with volume tank, high-pressure compressor and storage cylinders for back-up emergency air, and a vessel large enough to accommodate the equipment. In some cases, e. g. shallow water, remote sites, short bottom times, no decompression stops, it is safe and efficient to use lightweight surface-supplied gear with only an umbilical, communications and high-pressure cylinders. Intemrmediate suppot equipment operetions are also available depending upon the dive site`s environmental conditions and research intended. Since the 1970s the use of lightweight surface supplied diving systems for fisheries and biological research has increased when advantageous in special circumstances.

ADVANCES IN SCUBA RESEARCH DIVING

Although Rouquayrol invented the demand regulator in the 1800s it was not until the technological advance of high-pressure compressors that enough air could be stored in a diver's tank to provide a reasonable bottom time. In the early part of the 20th century Captain Jacques Cousteau improved the design of the demand regulator and combined his design with high-pressure air cylinders. Thus SCUBA diving as we know it today began. SCUBA was quickly accepted into the scientific diving community because of its freedom of movement and almost complete lack of required surface support and associated expense.

During the 1950s and 1960s most SCUBA research dives were conducted in relatively shallow water to observe fishes and other marine organisms in their natural habitat and obtain specimens for laboratory study. The innovation in the 1960s of the variable volume dry suit decreased the diver's heat loss rate and made longer, deeper dives in cold water possible.

SCUBA dives are generally restricted to 40m of seawater breathing air. The U. S. Navy Standard Air Decompression Table permits only a 10-minute bottom time without decompression stops for dives to 40m. Considering that at least two minutes are required for ascent to the surface a maximum of only eight minutes can be spent on the bottom doing research. In 1977 the U. S. National Oceanic and Atmospheric Administration's Diving Program (NOAA/DP) completed studies into the use of mixtures of nitrogen and oxygen to extend the bottom times of its reserch divers without decompression stops[3). The term NITROX was adopted to describe any mixture of nitrogen and oxygen, including air. The concept was to lower the nitrogen partial pressure in the breathing gas mix by increasing the oxygen partial pressure because nitrogen as the inert gas is problematic regarding bubble fomation. Due to the concern for central nervous system (CNS) oxygen toxicity due to the higher partial pressures of oxygen, a depth limit of 40m was detemined for a mix of 68% nitrogen and 32% oxygen (without entering the exceptional exposure oxygen partial pressures). On this mix a diver has a bottom time of 20 minutes at 40m, twice as much as that afforded by breathing air. Increased partial pressures of oxygen at shallower depths pemmit even greater no-decompression stop bottom times. Beside increased bottom time, oxygen enriched NITROX can decrease surface intervals, decrease nitrogen narcosis to some degree, and greatly increase safety regarding decompression sickness when used with air diving tables 3).

In 1978 the NOAA/DP, in collaboration with NOAA's National Marine fisheries Service, made the first operational research dives using NITROX to observe and photo-document herring spawning in the Gulf of Maine, USA. At that time nitrogen and oxygen were mixed into storage flasks before filling diver's SCUBA cyliders with the proper mix. From that simple beginning the method of making oxygen enriched NITROX evolved to adding oxygen to air for compression in non-oil lubricated compressors (to avoid the fire hazard by mixing oil and high-pressure oxygen) to the use of molecular sieves and pressure swing adsorption techniques.

In the late 1980s individual divers rather than govemment, academic, or commercial institutions built upon NITROX by adding helium to the nitrogen-oxygen mixture. The mixture of the three gases became known as TRIMIX. The exact mix is dictated by the depth, anticipated bottom time and decompression requirements. Often varying amounts of helium is added to 32% oxygen NITROX to produce the desired bottom mix. For example, for a dive to 73 m the 32% NITROX is diluted with 50% helium to create a TRIMIX of 50% helium, 35% nitrogen, and 16% oxygen[9]. This mix is a good compromise for that depth to avoid CNS oxygen toxicity, nitrogen narcosis, and lengthy decompression stops. Unlike NITROX, which used basically the same equipment and operational procedures as air SCUBA, TRIMIX equipment and procedures had to be modified and developed. Operationally, the diver will breathe the TRIMIX while working on the bottom until ascending to 30 m. To minimize decompression time the diver will switch to 32% oxygen NITROX at 30 m and breathe this mix to about 6 m when the diver will breathe pure oxygen supplied from the surface. The use of TRIMIX is still seldom used by Government and academic research divers, however individuals and a few private companies are using TRIMIX to document the fish communities and retrive living specimens from depths of 100m.

Because of the complexity and cost of closed and semi-closed rebreather SCUBA systems their use in fisheries research has been uncommon. The few researchers using this technology has reported successful divers to at least 100m. One-atmosphere or "hard" suit technology has created a generation of suits that are more streamhned and mobile than their predecessor systems, e. g. JIM or WASP. Because these suits maintain a pressure of one atmosphere absolute, decompression is no longer a concern and bottom time is detemlined by the life support systems built into the suit. A disadvantage of the one-atmosphere suit for fisheries research is its cost, complexity and suface support requirements. Future advances in closed and semi-closed rebreathers and one-atmospheric suits will allow these systems to be more available to fisheries researchers.

UNDERWATER HABITATS AND LABORATORIES

In 1962-1965 Jacques Cousteau and his team showed that living and working underwater was feasible by spending up to 22 days at depths to 100 m in undersea habitats during his CONSHELF series in the Mediterranean and Red Seas[3]. Undersea habitats and laboratories are normally maintained at the ambient water pressure for the depth at which the habitat is positioned, i. e. the depth of water. Thus the divers are acclimated and maintained at this ambient pressure breathing air or other mixed gas atmospheres within the habitat. This technique is referred to as saturated diving[6]. According to the NOAA Diving Manual (1991) "Saturation diving is the term used to describe the state that occurs when a diver's tissues have absorbed all the nitrogen or other inert gas they can hold at any given depth. Once tissue saturation has occurred, the length of the decompression that will be required at the end of the dive will not increase with additional time spent at that depth." This technique allows greatly increased bottom time for the scientist to accomplish research.

During the 1960s through the 1970s many underwater habitats and laboratories were built and used worldwide. One of the most long-lived and scientifically productive underwater laboratories was the relatively low-tech HYDROLAB, which was used in the Bahamas and off St. Croix, U. S. Virgin Islands. Fisheries researchers used HYDROLAB for decades before its retirement as a museum show piece. The German Underwater Laboratory (UWL) HELGOLAND was more sophisticated and complex laboratory built to support undersea research in the harsh environment of the North Sea and other cold water environments. Unlike HYDROLAB which was moved infrequently, HELGOLAND was moved to a new research site almost every year. Much of its time was spent at various locations in the Baltic Sea. In 1975 it was transported to the Gulf of Maine off Cape Ann, Massachusetts, U. S. to support in situ investigations into fishehries ecology and hydroacoustics. The 1980s saw the UWL HELGOLAND join HYDOROLAB as a museun piece. Japan too developed saturation diving techniquis beginning in 1968 and produced the habitat SEATOPIA[2]. Like the other habitats, SEATOPIA is now relegated to being an exnibit and resides ashore at the Japan Mahne Science and Technology Center (JAMSTEC), Yokosuka, Japan. Operational constraints, in that habitat usage was weather dependent, relatively high support and maintenance costs, and that the large complex laboratories were not very mobile, all combined to hasten the demise of these systems. Kawasaki Heavy Industries, Ltd. and JAMSTEC are collaborating to reverse this trend with their concept design proppsal for a mobile offshore institute and assosiated underwater laboratory [8].

Only one undersea habitat or laboratory exists in the world today. This is the sophisticated AQUARIUS, owned by NOAA and located among coral reefs in the U. S. Florida Keys. Although built in 1986 for use off Catalina Island, California, U. S. it replaced the retired HYDROLAB off St. Croix in 1987 wherer it supported coral reef ecology studies. About 1989 a hurricane heavily damaged the shore facilities which supported AQUARIUS. Although the underwater laboratory was undamaged, the cost of replacing the shore side facihty was such that AQUARIUS was transported back to the United States. It remained on shore in North Carolina undergoing a major refit until 1993 when it was located off Key Largo, Florida where it remains today [1].The high demand by coral reef ecologists and others has caused the AQUARIUS to remain at the same location through to the present, although it has been periodically removed and dry-docked for maintenance and re-certification by the American Bureau of Shipping [6,7].

The modem trend for habitat design may be for small, highly mobile and relatively inexpensive Manned Undersea Instrument Chambers (MUSIC) designed for shallow water use.

Recent advances in low energy consumptive life support systems make the MUSIC design possible. The MUSIC is designed to be towed by a small outboard motor boat, support two aquanauts for two-three days basically independent of resupply from the surface, and support unmanned data collection equipment indefinitely. The Undersea Research Foundation, Inc. has, in the final stages of completion, a MUSIC that will be deployed late this spring the Chesapeake Bay, Virginia, U. S. Named BAYLAB because of its proposed location in Chesapeake Bay it will provite video, audio, and data communication with the shore via bottom cable or two megabyte Ethernet-LAN system, depending upon the site location [10]. Being extremely mobile the MUSIC can be used independently or in association with a larger underwater laboratory to extend the horizontal and/or vertical ranges of data collection.

CONCLUSION

The use of diving for underwater salvage and construction related heavy work has been available since the mid-1800s but aquaria provided more opportunities for firsheries research than diving did at that time. Diving in support of fisheries research came into use a century later with the introduction of modern SCUBA. Observations of fish behavior were among the first underwater research investigations and were shortly followed by population assessments, especially those associated with reefs. In the late 1960s into the 1970s in situ manipulative experiments became routine in fisheries research (e. g. corralling of a species of demersal fish with known abundance and biomass for calibration of hydroacoustics assessment from a saface fisheries research ship). Fragile pelagic species, which did not survive well when removed from the water in nets, could now be studied in situ and recovered without leaving a water environment. Now habitat biogeochemcal variables could be studied [5] and related to the fisheries, e. g. sediment and water-column oxygen depletion rates related to habitat hypolxia and associated fish avoidance and fish kills.

In completing the circle from aquaria to sophisticated diving techniques, these techniques are used today to at least 100m to capture recently described species and retun them alive to the surface for display and study in professional aquaria.

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