

# Gulf and Caribbean Research

---

Volume 27 | Issue 1

---

2016

You Can't Catch a Fish with a Robot

R. Grant Gilmore Jr.

ECOS, [rggilmorej@gmail.com](mailto:rggilmorej@gmail.com)

DOI: 10.18785/gcr.2701.11

To access the supplemental data associated with this article, [CLICK HERE](#).

Follow this and additional works at: <http://aquila.usm.edu/gcr>



Part of the [Evolution Commons](#), and the [Marine Biology Commons](#)

---

## Recommended Citation

Gilmore, R. G. Jr. 2016. You Can't Catch a Fish with a Robot. *Gulf and Caribbean Research* 27 (1): ii-xiv.

Retrieved from <http://aquila.usm.edu/gcr/vol27/iss1/11>

This Ocean Reflections is brought to you for free and open access by The Aquila Digital Community. It has been accepted for inclusion in *Gulf and Caribbean Research* by an authorized editor of The Aquila Digital Community. For more information, please contact [Joshua.Cromwell@usm.edu](mailto:Joshua.Cromwell@usm.edu).

# **GULF AND CARIBBEAN**

**R E S E A R C H**

Volume 27  
2016  
ISSN: 1528-0470



*Published by*

**THE UNIVERSITY OF  
SOUTHERN MISSISSIPPI**

**GULF COAST RESEARCH LABORATORY**

Ocean Springs, Mississippi

## OCEAN REFLECTIONS

### YOU CAN'T CATCH A FISH WITH A ROBOT

R. Grant Gilmore, Jr.

Estuarine, Coastal and Ocean Science, Inc., 5920 First Street SW, Vero Beach, Florida 32968; email: rggilmorej@gmail.com

**ABSTRACT:** In this essay I will relate the challenges associated with deep sea ocean exploration as well as the advantages and disadvantages of today's ocean technologies based on experience with most of these systems. After nearly 5 decades using robotic vehicles (Remotely Operated Vehicles = ROVs and Autonomous Underwater Vehicles = AUVs) and manned submarines for fish research, I thought it would be appropriate to briefly describe a career spent using these technologies as they were developed. Deep sea ichthyologists cannot effectively catch a swimming fish with a robot even 40 years after the development of the first ROV for deep ocean science investigation, nor can most currently-available manned submarines. There is a continuing debate on the advantages of using robotic machines (cheaper, safer) versus manned machines (more expensive, dangerous) for ocean research. Appropriately designed and operated manned submarines can accomplish considerable ocean exploration that robotic vehicles cannot. Robotic vehicles have their own advantages and science missions that manned vehicles cannot accomplish, but there is a loss in capturing mobile specimens for study and recording important behaviors and ecologies that simply cannot be accomplished with robots. I have written this retrospective on deep ocean research capabilities as my profession, ichthyology, and the world, have lost a major technological asset that can easily be brought back once its value is realized.

**KEY WORDS:** Submarine, ROV, AUV, ichthyology, deep ocean, Johnson–Sea–Link

#### INTRODUCTION: THE OCEAN CHALLENGE

Sixty years ago, like many explorers of the past, we did not understand the immensity of the forces that challenged our success in exploring the deep sea. Most problems create valuable and helpful discoveries that aid in making dangerous explorations safer and successful. These discoveries, once understood, often reveal our initial ignorance of the forces that must be conquered, particularly for deep sea exploration. It takes naivety, imagination, fortitude and ingenuity to explore the unknown, particularly when it is a truly life or death endeavor. Often there are decisions to cure problems without truly knowing or understanding the problem. In my personal case it was the physiological impact of the deep sea on human health/survival. With appropriate technological advances, deep ocean machines can keep humans safe while diving to some of the greatest depths on Earth, while allowing unprecedented scientific progress.

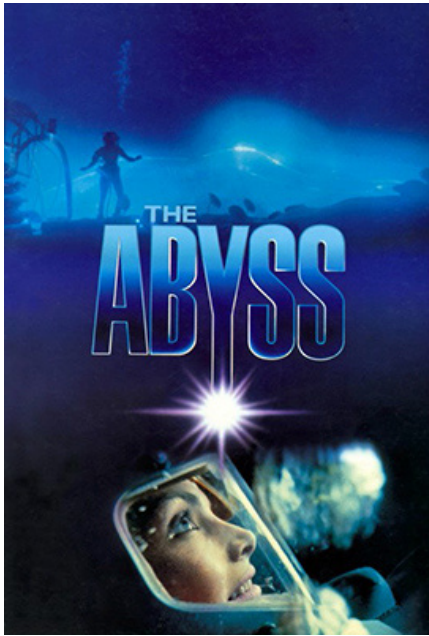
The ocean was romanticized by one of its first routine human inhabitants, the inventor and ocean explorer, Jacques Ives Cousteau (Cousteau 1952; Cousteau and Dugan 1953; Cousteau and Dumas 1962; Cousteau and Schiefelbein 2007). He wrote many articles and books, and was one of the first to use cinema and television to reveal the ocean to the world audience with his global *Calypso* expeditions. Unfortunately, many of the most difficult problems, particularly those involving human physiology in pressure environments, were largely unknown when Cousteau was promoting his early ocean explorations in the 1950s and 60s. However, a contemporary of Cousteau, the ocean pioneer and inventor Edwin Link, was making some of the deepest and prolonged

ocean dives at that time (Link 1958; 1963; 1964; 1973; Link and Littlehales 1965; van Hoek and Link 1993; Marden 1998). Detailed physiological research on humans in pressure chambers was just getting underway during the 1960s (Duke Center for Hyperbaric Medicine and Environmental Physiology, Duke University School of Medicine, [http://www/anesesthesiology.duke.edu/?page\\_id=828766](http://www/anesesthesiology.duke.edu/?page_id=828766); Wicklund 2011). To allow ocean exploration, new developments in materials as well as mechanical, hydraulic and electrical technology were necessary. In many ways, these challenges were considerably more difficult than those engineered for aerospace exploration. For example, humanity's interest in ocean exploration was far less than that for aerial and space exploration simply due to the universal visibility of air and space and the invisibility of the marvelous creatures below the ocean's surface. Out of sight, out of mind! In fact, the Chinese invented the rocket over 900 years ago, while Cousteau and Gagnon invented the first effective 'self-contained underwater breathing apparatus' (SCUBA) regulator in 1943.

People knew the surface of the ocean quite well. When looking out over the ocean from the deck of a ship, you are gazing upon a virtual desert with no visible forests, lush grasslands or animals except for the fortuitous sea bird or flying fish breaking the surface. The ocean's surface looks the same in the South China Sea as does in the Gulf of Mexico, or Caribbean Sea. I have always felt sorry for our predecessors (before 1950) in marine science trying to explore the ocean below the waves before the advent of SCUBA and research submarines. Marine science technology and hyperbaric phys-

biological understanding were literally in the dark ages when compared to space exploration (Kottler 1969; Brubach and Neuman 2003; Finlayson 2009) when I began my career in aquatic science. While large submarines carrying crews of humans have plied the seas for over a century, they had no windows. Tens of thousands of naval sailors swept pass trillions of unstudied, unclassified sea creatures without ever knowing they were there. Military submarines are still passing blindly through this rich ‘living soup’ over 100 years later while tiny manned research submarines are disappearing.

One eternal question that spurred the early ocean explorers during my career was: If living organisms can survive in the deep sea, can humanity survive there too? Additionally, many asked: If seals, dolphins and whales, mammals like us, can live continuously in the sea, why can’t we? The popular movie of the early 1990s, *The Abyss* (Figure 1), presented these very questions. There were many reasons for the inability for humans to enter the sea. Many ocean exploration problems presented greater challenges than those that had to be solved before we could enter outer space, or go to the



**FIGURE 1.** Marquee from the 1990s movie, *The Abyss*, an unexplored physiologically alien environment illustrating the romantic concept of humans living within the deep ocean.

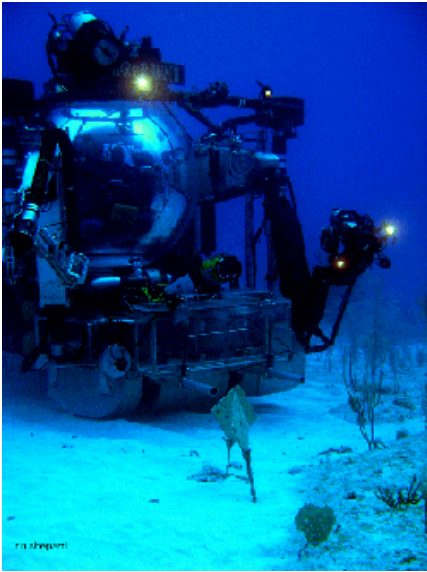
moon. Water is dense, heavy (30 cm of seawater depth = 0.445 psi), and absorbs light to the point that at 1,000 m (~3280 ft) below the surface there is no solar light under the most optimum conditions. It is totally dark beyond that depth except for biological light emanating from bioluminescent organisms. The darkness of the deep sea does not call us as the moon or Mars do since we cannot see it, know it, or understand it. There is one major reason for exploring the deep sea versus the moon and Mars — the sea contains an abundance of living breathing organisms and we are dependent on a living sea for survival.

After World War II (WWII), inventors around the globe created undersea habitats from the Black Sea to the Carib-

bean. Cousteau and Link were among these people who actually put people in undersea habitats for the first time (Stenuit 1964; van Hoek and Link 1993; Marden 1998; Cousteau and Schiefelbein 2007). I was in the generation who thought we could live in the deep sea. Many of my mentors and colleagues in marine science like Bruce Collette, Robert Jones, C. Lavett Smith, James Tyler, John McCosker, Sylvia Earle, and Eugenie Clark also shared the same dream. As a young naive marine scientist I, and my colleagues, agreed to live at 305 m (~1000 ft) depths with our bodies experiencing the pressure equal to about 445 psi (30 x surface atmospheric pressure at sea level) for prolonged periods of time even though it had never been done before. I also agreed to have a deep sea submarine transport me into the depths and ‘burp’ me out to conduct research and return even though it had never been done before. To that end, I agreed to live in an undersea habitat for a week or two and explore the ocean daily to 76 m (250 ft) on air (not helox, but air!).

These experiences were life-changing for me as they were for my colleagues. Most humans have not experienced deep sea organisms except through the public media, television, cell phones, and their computers. What is it like to be surrounded 360° by water with strange creatures that are curious about you? If you could, what would you do while there with these organisms that you could not do by dropping a baited hook and line, or net from the surface, as humans have been doing for millennia? Today there are literally thousands of robots dropped into the sea on a daily basis, although most not for scientific exploration. These robots typically take cameras with them that cable the images to the surface ship’s control room. However, by using robots we are observing through a camera lens, which is not at all like being there within that lively deep remote environment.

What is the advantage in studying the ocean from within an acrylic bubble and making instantaneous decisions with a variety of tools? You are able to maneuver yourself as if you were a fish to make critical collections and observations. Manipulating a robot hundreds or thousands of feet away looking through a camera lens does not allow observation of an organism’s entire environment and what it is doing in 3-dimensional space (i.e., mating, eating, sleeping, chasing, running away). However, while sitting comfortably and quietly in an air conditioned acrylic sphere at 350 m (~1150 ft) in crystal clear tropical waters (Figure 2) you are surrounded by the ocean universe and entertained by thousands of living organisms from minute glowing specks to giant sharks and squid. At the same time you are observing the reaction of the myriad of other creatures surrounding you. I know about the real-time interactions and observations, as I spent over 40 years and hundreds of hours using the undersea robots and staring through camera lenses, start-



**FIGURE 2.** Johnson-Sea-Link manned submarine on bottom in Bahama Islands.

ing with the very first one for scientific investigation, Link's 'Cabled Observation and Rescue Device' (CORD). This was among the first generation of undersea robots (e.g., Figure 3) now known collectively as 'remotely operated vehicles' (ROVs). I also spent thousands of hours in manned submarines starting as one of the first scientists to dive in the acrylic sphere of the *Johnson-Sea-Link-I* (JSL-I) submarine in 1971. The question in my mind during these early years was: "What if you wanted to capture that swimming fish and study its anatomy, physiology, and genetics?" How could a remotely tethered robot 350 m deep do that?



**FIGURE 3.** The author with an early version of one of the most popular ROVs active today, the 'VideoRay.'

### BECOMING A SCIENTIST: PERSONAL EXPERIENCE AND DECISIONS

While growing up around military aircraft and rocket launches I was always fascinated with aeronautics, the emerging space program, and being a pilot. Space and aeronautics were always in the headlines and in my personal experience! However, in parallel with these dreams and in a post-WWII environment of discovery, marine scientists were now able to enter the sea using SCUBA to at least

100 m (~328 ft) and they were making thousands of new discoveries in < 30 m (~98 ft), particularly around reef formations where trawls and dredges pulled by surface vessels were ineffective. It was at this time that Cousteau started his television and book series chronicling his undersea exploration of the world ocean (Cousteau and Schiefelbein 2007). The 1950s and 1960s were exciting years for youngsters interested in science careers. In my home town, Sarasota, Florida, the Cape Haze marine laboratory, founded by Dr. Eugenie Clark, sponsored an annual undersea science lecture series for children (Clark 1969) and across the state the federal space program at Cape Canaveral was open for public tours on weekends. These two fields of interest and study were in many ways similar and exciting. I went to school at the University of Florida to study aeronautical engineering, but I took two biology courses on living creatures as electives which changed my life and career. I transferred to the University of West Florida in Pensacola to study marine biology as an undergraduate and also completed my Master's degree there (see [Biography](#)). I never looked back!

### BE BRAVE AND EXPLORE FOR A JOB IN PERSON: THE LABORATORY THAT WAS NOT YET THERE EVOLVED INTO A MAJOR INSTITUTION FOR OCEAN EXPLORATION

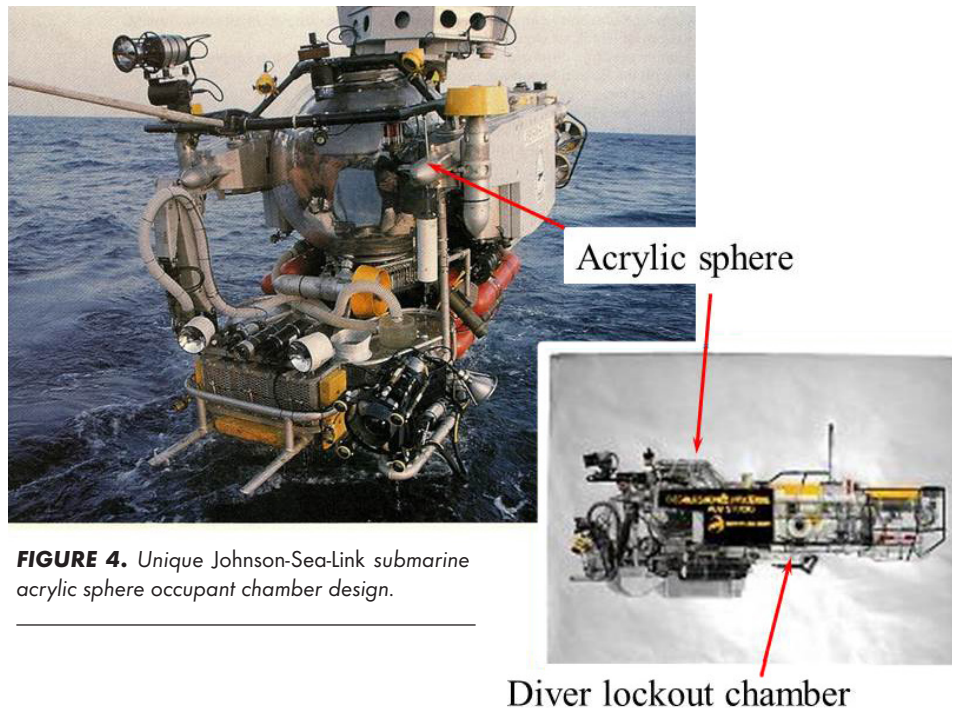
My career started when, while completing my Master's degree, I started looking for a research position at a marine laboratory. After a considerable number of applications were mailed (there was no internet then), it was personal contact with resume in hand that was the key for 4 job opportunities. I actually interviewed at a new marine laboratory that, in fact, was not even built yet! Through a college roommate, I heard about a new marine laboratory under construction in Fort Pierce, Florida and immediately drove to that location to make contacts and hopefully earn an interview. Again personal contacts are critical as I met an inebriated customer at a bar on the waterfront in Fort Pierce who had heard a rumor of a new marine research facility and offered to lead me there. We drove to a dirt road that appeared to lead to nowhere. I drove down the road passing what looked like a ship's bridge rusting in the sand, and after about a mile I came to a rustic metal Butler building. This did not look promising from the exterior but I was surprised when I opened the door, as in front of me was a gleaming aluminum and acrylic submarine. This was the *JSL-I* submarine that had just been completed that year and passed initial sea trials in winter and spring 1971 (Link 1973; van Hoek and Link 1993). It was a revolutionary design with an acrylic sphere for the occupants up front, and an aluminum diver lock out compartment in back (Figure 4). It was owned by the Smithsonian Institution with their logo across the ballast tanks. The sub's metal Butler building was on what appeared to be a channel in the mangroves extending out to a lagoon called the Indian River (see early work in Gilmore

1977a,b; Gilmore et al. 1978).

I met a lady behind a desk (Carolyn Zealand) in the next room and was introduced to Captain Smith, retired Navy, who was supervising the conversion of an old Coast Guard cutter, the *USS Yeaton*, into a research submarine tender (to be called the *R/V Johnson*). Captain Smith and I met in a drafting room and he kindly agreed to interview me and see what I was about. Apparently, I passed my first inspection. He later called Washington, D.C. to speak with Dr. I.E. Wallen of the Smithsonian Institution who met with me on one of his trips to east Florida and eventually gave me a job offer, though there was still no laboratory in which to work. I was then informed that I would be working for a newly established private non-profit entity called the Harbor Branch Foundation.

#### HARBOR BRANCH FOUNDATION FOR INTERDISCIPLINARY OCEAN EXPLORATION AND TECHNOLOGY DEVELOPMENT: THE HISTORY OF MARINE SUBMARINES AT HARBOR BRANCH FOUNDATION

Mr. Seward Johnson, Sr. formed the Harbor Branch Foundation (HBF) in collaboration with Edwin Link for ocean exploration and marine ecological research. We had a credo up on the lab wall for years written by Mr. Johnson that expressed his desire to study everything in the ocean using the *JSL* submarines launched from the decks of the *R/V Johnson* and *R/V Sea Diver*. These ships were augmented with ocean trawling surface vessels, the *R/V Sea Hunter*, *R/V Joie de Vivre* and the *R/V Gosnold*, and by a fleet of small boats for inshore studies. They wanted to begin by classifying all marine organisms from the banks of the Indian River Lagoon to the depths of the ocean on the eastern side of the Bahama platform. They wanted all aquatic disciplines represented and within 7 years had hired chemists, geologists, oceanographers and a diverse array of marine biologists in phycology, phytoplankton, zooplankton, echinoderm biology, malacology, carcinology, polychaete reproduction, benthic ecology, deep sea physiology and comparative ecology (Young et al. 1974). In 1985, marine scientists from the HBF and the Smithsonian Institution joined with Ed Link's group of ocean engineers (first known as the Sea Diver Corporation), and this new endeavor was called the Harbor Branch Oceanographic Institution (HBOI). The first HBF employees (Gilmore, Williams, Putnam, Meek and Gore) had to agree to compress down to depths of 154 m (500 ft) and lock out of the *JSL* submarine to collect ma-



**FIGURE 4.** Unique Johnson-Sea-Link submarine acrylic sphere occupant chamber design.

rine organisms in the deep sea that would be taken back to the laboratory in pressurized containers. I was one of the first HBF science employees (with Doug Putnam and Laverne (Coddy) Williams) to make the first dives in the *JSL-I* submarine, 1971–1972.

We had a laboratory-based steel pressure aquarium for physiological experiments on fish captured at depth by divers from the *JSL* deep sea submarine. To my knowledge this was the only research submarine capable of locking out divers to collect organisms at depths to 183 m (600 ft). Fish captured at depth could then be placed in pressurized transport vessels that were kept at ambient bottom pressure values and brought to the surface. The transport vessel carrying the fish was then mated to the steel pressurized aquarium back in the lab. Dr. Robert Meek conducted successful hyperbaric physiological studies on *Citharichthys* spp. flounders between 1972–73, until the tragic *JSL-I* submarine accident that killed Ed Link's son, Clay and Al Stover in June 1973. Dr. Meek left HBF after this fatal submarine accident and the pressure physiology program at HBF was never reinstated. Thereafter, with the exception of a few brief experiments by Dr. Robert Avent, the unique pressure aquarium was used only for testing and certifying deep sea instruments to be placed on the *JSL* submarines.

Clay Link and Al Stover did not die in vain. Due to the effort of Ed Link and his talented engineers, the following years saw major improvements in equipment and submarine operational procedures. New highly effective personnel created the safest deep sea research submarine operation on the planet. Submarine rescue ROV systems were developed at HBF and carried on the submarine mother ship. Launch and recovery operations were made under strict guidelines

and considerable time and effort was put into training new crews each year. Eventually another *Johnson–Sea–Link* submarine was built (*JSL–II*) as were additional submarine mother vessels. The HBF surface fleet from 1971 to 1990 consisted of the *R/V Sea Diver*, *R/V Johnson*, *R/V Seward Johnson* and the *R/V Edwin Link* carrying the *JSL–I* and *II* submarines and a Perry sub, the *Clelia*, with expeditions from the Mediterranean, to the Great Lakes, along the eastern seaboard from Canada to the Florida Keys, throughout the Caribbean Sea and into the eastern Pacific. Thousands of dives were made safely with hundreds of scientists from institutions around the world.

During the early 1970s, between deep sea field excursions and lock out dives from the *JSL* submarines, there was a series of hyperbaric duration trails using the hyperbaric chambers at the Center for Hyperbaric Medicine and Environmental Physiology, Duke University Medical Center, Durham, NC. All HBF employees were encouraged to participate in 228 m (750 ft) saturation living in the chambers for several days with 2 day excursions to 305 m (1,000 ft) depths. Some HBF employees saturated to 610 m depth pressures (= 2,000 ft seawater; 896 psi). It took several days to decompress from these saturation experiments. Though several scientists, engineers and divers from HBF participated in these dives between 1973 and 1975, enough physiological data were obtained to indicate that saturation at this level was not safe enough for human physiologies. I concurred after monitoring gases and divers in the first saturation dive series in January 1973 at the Duke hyperbaric chamber facility and reading extensively in their hyperbaric medical library.

Although I did not make a saturation chamber dive in that program, 2 years after the tragic 1973 submarine accident the *JSL* submarine saved my life during a NOAA sponsored saturation program. This program included living in the *Hydrolab* habitat and swimming deep excursions to 61 and 76 m (200 and 250 ft) to capture fish on a vertical wall using experimental rebreathers at Lucaya, Grand Bahama Island, Bahama Islands (Wicklund 2011). I lost consciousness at 42.7 m (140 ft) after convulsing from CO<sub>2</sub> poisoning, precipitated by O<sub>2</sub> toxicity, due to the failure of rebreather dissolved oxygen sensors. I was saved by a support diver, Mr. Robert Wicklund, who moved me to an undersea habitat (*Sub–Igloo*) where he gave me CPR (Wicklund 2011). The *JSL* submarine picked me up from there and mated to a decompression chamber below the O1 deck on the *R/V Johnson* which allowed a hyperbaric physician to lock in with me and start treatments for decompression, embolism and salt water consumption. I was eventually transferred to a critical care unit in a stateside hospital, although I nearly expired during the flight from the Bahamas to Miami in a plane that was delayed due to some faulty HBF administrative de-

isions (Wicklund 2011). We learned a lot about rebreathers, scientist capabilities in capturing fish on air to depths of 76 m (250 ft), and duration diving in the *Hydrolab* during these experiences. New species of fish were captured, but at great physical risk to the diving scientists, several suffering from narcosis, or becoming nauseous while working at 76 m (250 ft) depths on air.

## HOW CAN ICHTHYOLOGISTS CAPTURE DEEP SEA FISH USING MACHINES?

The overall objective of the HBF was to pursue aquatic science, and extend the knowledge of estuaries, coasts and the world's ocean. If you are investigating an unexplored ecosystem, the deep sea, and observing creatures never seen before, how can you know who, or what they are without examining them in hand, up close and personal? You cannot determine their reproductive status or stomach contents without examining them. How can you determine their genotype just by photographing them? In 1971 there was a global navy of deep sea “research” submarines but all were designed to observe, not capture, actively swimming marine organisms. Fish were not on the agenda and considered impossible to capture (Terry 1966; Oceanography in Florida 1970; Sweeney 1970; Piccard 1971; Limburg and Sweeney 1973). The exception was the *JSL–I* that was designed from the beginning for capturing fish with lock–out divers.

The logistics of deep sea exploration are challenging. Undersea exploration requires life support systems: air to breath, wastes to expel or modify, and living quarters for rest and work. Undersea vehicles must withstand immense pressure at the deepest location in the ocean, the Marianas Trench. The cold pressurized deep ocean is highly viscous, needing considerable energy and an efficient hydrodynamic design to maneuver within it. You must carry your own power source, reliable state–of–the–art batteries, in order to function. Military submarines use costly and dangerous nuclear energy. The only nuclear powered research submarine other than the Navy's *NR–1*, the *Benjamin Franklin*, was designed and built by a military contractor, Grumman Corporation, and successfully carried out the first long duration ocean exploration to a depth of 610 m (2,000 ft) for 30 days in 1969. Grumman had also built the *Lunar Excursion Module* (LEM) that took Neil Armstrong and Buzz Aldrin to the surface of the moon. They were on the moon when the *Ben Franklin* submerged to drift over 1,400 miles in the Gulf Stream, but no one remembers the *Ben Franklin* feat, only the lunar landing.

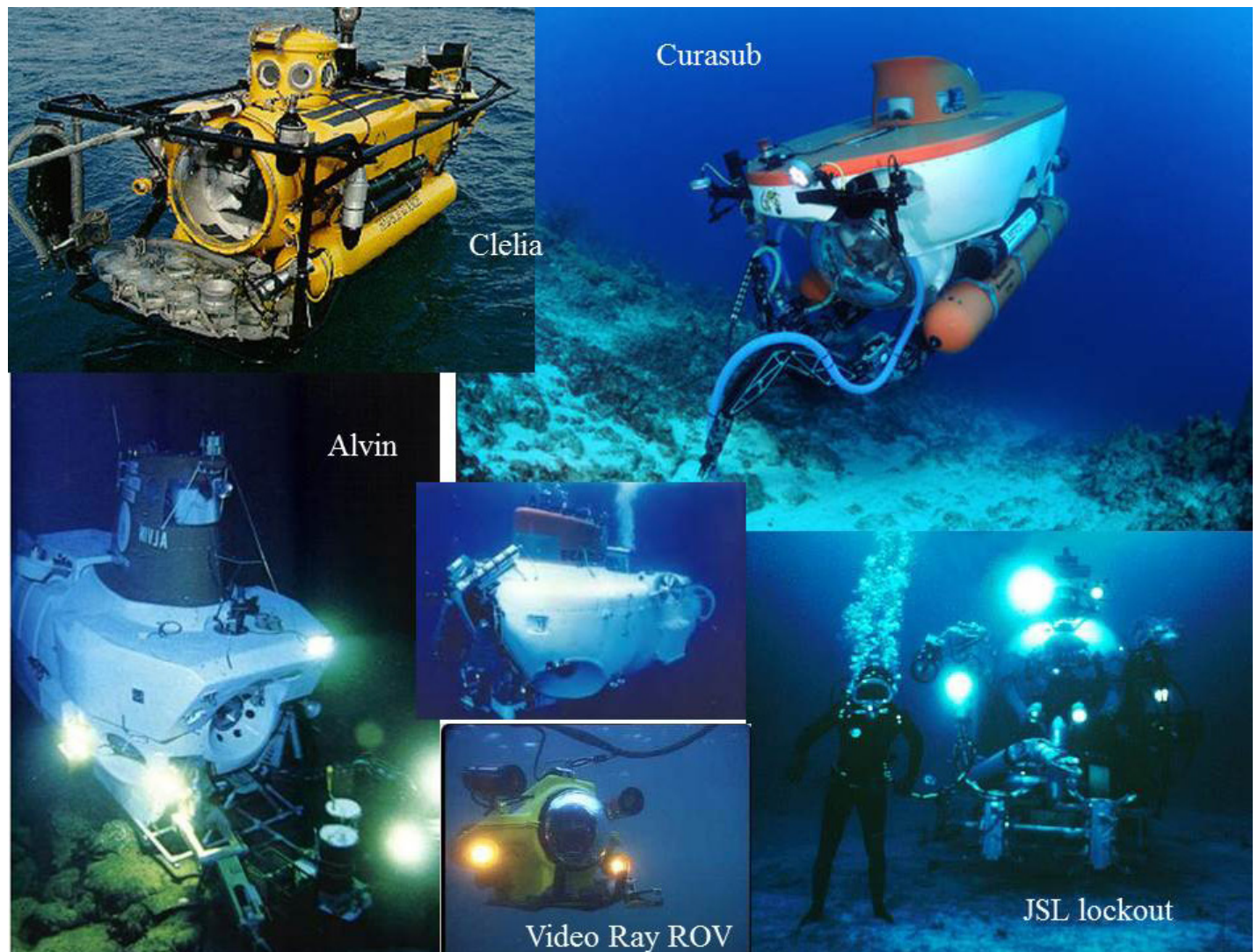
Unfortunately, the *Ben Franklin* was never used again for ocean exploration after its first major mission; the Navy's *NR–1* is also now retired. Unlike the *JSL* research submarine, all the other small research submarines built at the time, the *Perry* subs, *Alvin*, *Aluminaunt*, *Pisces I–IV*, *Deep*

star-2000, *Kuroshio II*, *NR-1*, *Nekton Alpha/Beta*, *Shinkai*, *Stars I & II*, and *Trieste I & II*, were designed to observe the ocean through port holes, or glass hemispheres (Figure 5; Terry 1966; Oceanography in Florida 1970; Sweeney 1970; Piccard 1971; Limburg and Sweeney 1973; Penzias and Goodman 1973; Trillo 1979). Thus, these submarines had limited visibility. Most of them had a single large propeller for forward and backward motion, but not 'all axis' thrusters and maneuverability. Many had mechanical arms for picking up objects like rocks, but not for capturing living mobile creatures. When they were built the greatest concern was with geological resources (such as oil deposits) and military purposes, not biological and ecosystem understanding.

Fortunately, HBF had a unique submarine designed by Ed Link for high visibility with occupants in an acrylic sphere, and high maneuverability with multiple thrusters aligned on several axes (Figure 6A). The requirements of a manned fish capture machine are not too different from that of a manned aircraft used for fighting in aerial combat. So it is

not too ironic that Edwin Link, inventor of the Link Trainer for aircraft pilots, designed and invented a submarine that had many of the capabilities of an aircraft, with emphasis on having high visibility and maneuverability. The rapidity of changing direction in all axes was created by placing stationary propeller thrusters facing in all compass directions both in the bow and along the sides.

From 1976 to 1989, HBF/HBOI engineers and biologists began work on fish capture devices that would eliminate the need for divers to saturate. The *JSL* submarines were being cleared for deeper diving, eventually allowing dives to 914 m (3,000 ft) and we had to develop a variety of fish capture systems. Original HBF biologists Dr. Robert Jones, John Miller, Dr. Marsh Youngbluth and I worked in collaboration with a group of talented HBF engineers, Chris Tietze, Doc Halliday, John Holt, Tony Wilson, Robert Tusting, Mike Camp, and Greg Kennedy to develop such tools. Machinists and vessel/submarine operations personnel, Roger Cooke, Tim Askew, Jeff Prentice, Dom Liberatore, Phil Santos, Jim Sullivan and



**FIGURE 5.** Various deep sea research vehicle designs.



others also helped to develop 7 major fish capture systems in addition to keeping manned submarine operations safe and efficient. These fish capture systems were:

1. *Mechanical arm* – This tool evolved over the years to be very proficient. Lights blinded new species of sharks and chimaeras while the arm captured the fish by grabbing it by the body. The rotenone injection system listed below was mounted on the mechanical arm as was the suction device so that they could be aimed and placed where fish were located (Figures 6B, 7 and 8).

2. *Forward basket* – This tool had a hydraulically operated cover and could be baited or unbaited. Large fish that had been captured with the spear system and hook and line listed below, or with the mechanical arm, could be placed here. This tool was responsible for capturing several rare and new fish species. It was responsible for capturing larger predaceous fishes such as groupers when baited (Figures 6B and 7).

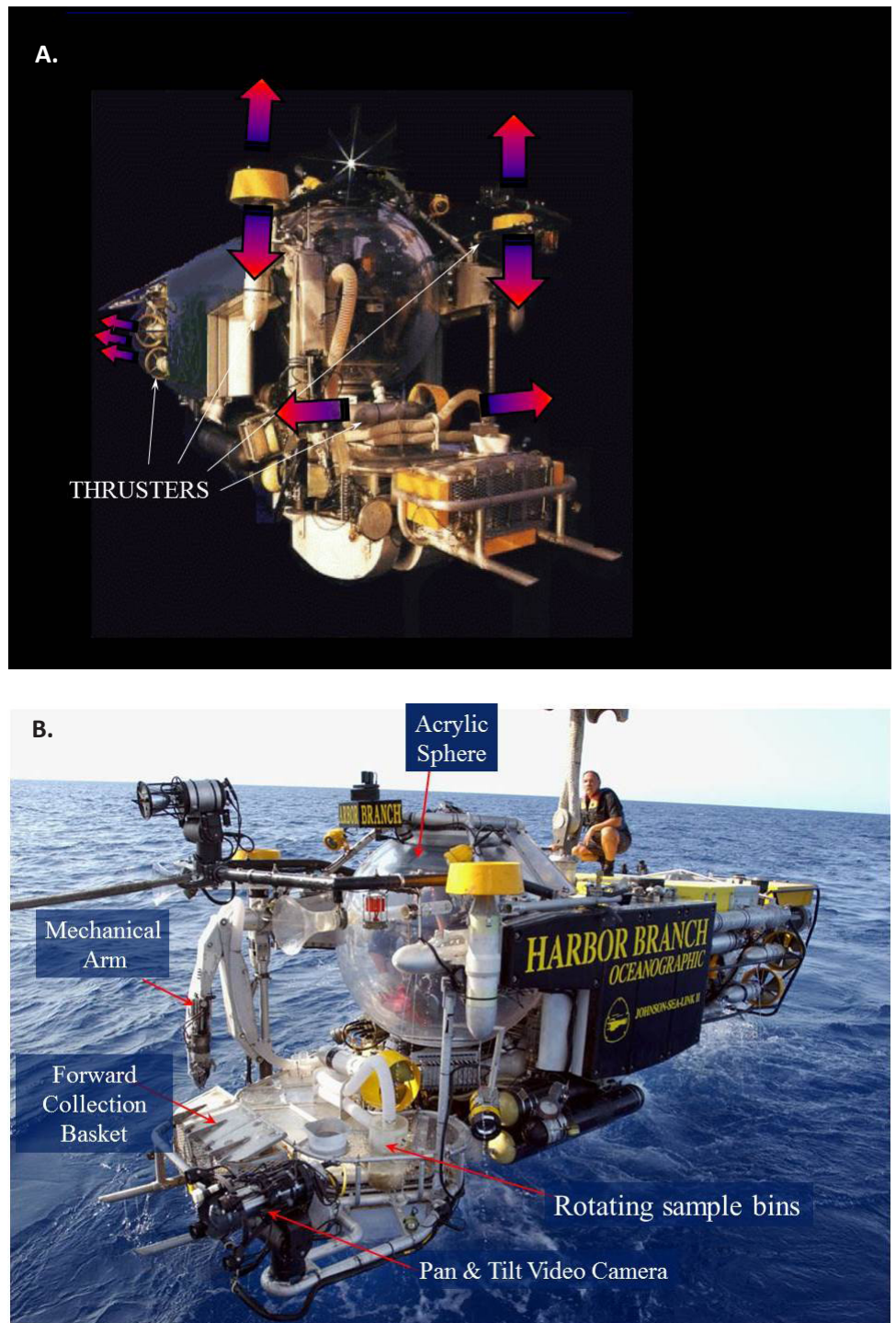
3. *Hydraulic grouper trap* – This large rectangular trap was carried to the bottom and placed up to 10 m from the submarine as it settled on the bottom. It was operated with bait suspended in the center of the trap. Scientists could open and close doors on either end of the trap remotely. Up to 5 species of groupers were captured at one time during its operation at grouper aggregation and spawning sites.

4. *Suction device with rotating bins* – This system was used to suck up fish typically < 30 cm in length. Many new cryptic species were captured with this device. It was also used to suck up fish succumbing to rotenone. The plexiglass bins were numbered and on a rotating platform, so that collections for different depths and locations could be separated and recorded (Figure 6B, 7).

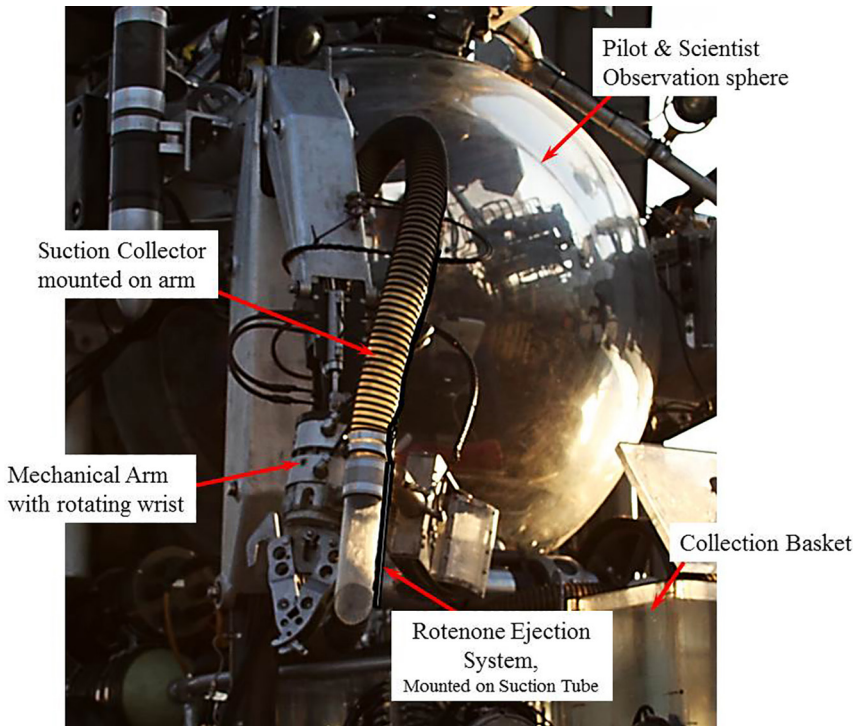
5. *Rotenone injection system* – Laboratory experiments with various rotenone mixtures, solvents, emulsifiers and quality of rotenone determined the mixture that was least toxic to invertebrates, but most effective in capturing fish (Gilmore et al. 1981). This unit ejected a stream of rotenone

from a collapsible 20 liter container tie-wrapped inside the forward basket. Literally hundreds of fish were captured with this system (Figure 7, Gilmore et al. 1981).

6. *Nine shot laser aimed spear/tagging system* – A rotating arborea spear system with hypodermic needle heads was developed that could inject any required agent into the targeted fish, or tag a fish with a streamer tag at depth. The spear was aimed using a laser pointer placed on top of the flat plate positioned above the rotating spears (Figure 8). We



**FIGURE 6.** The Johnson-Sea-Link submarine features that are critical for fish collections. A. Thruster arrangement for maximum maneuverability. B. Sample viewing and collection features.



**FIGURE 7.** Suction collector mounted on mechanical arm along with rotenone injection system on the Johnson-Sea-Link submarine.

were able to successfully spear large fish with this system and place them in the front basket as well as tag several deep sea sharks with streamer tags.

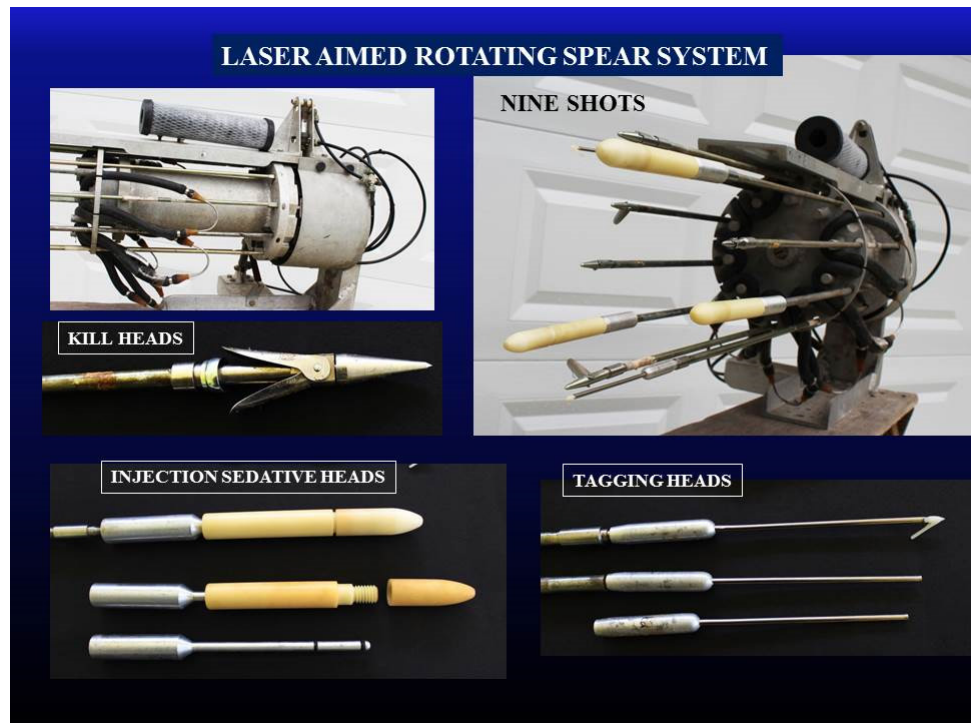
7. *Short line float and baited hook* – This was an invention of the intrepid angler, Dr. John McCosker, California Academy of Sciences, on the 1995 Galapagos Islands expedition. A 1.0 m length of fishing line was tied to a small deep sea float (they do not collapse under pressure) and a 2–3 lb lead weight. A < 30 cm line is suspended between the float and weight with a baited fish hook. A new species of moray eel was captured on one of my submarine dives at 300 m with this system as well as a small scorpionfish, that was then eaten by a larger scorpionfish as it struggled, both being captured simultaneously.

Using all these systems required that the submarine choose a likely location for fish capture. The submarine would either settle at that location, or chase an active fish. Low illumination was necessary. High illumination typically caused fish to retreat to shelter. Fish capture is best without lights or major sounds produced by the submarine. The largely insulated 10.0 cm (4 inches) thick

acrylic sphere of the JSLs did not allow sounds from the interior of the sphere to escape to the environment.

A variety of still and video camera systems were used in these studies, some with pan/tilt and zoom capability, color or black and white (Figure 6B). The most effective cameras for fish behavioral work were the SIT (Silicon Intensified) systems that produced black and white images under extremely low light conditions as most deep sea fish are sensitive to any light. Lighting was developed that included rheostat controls on red lights augmenting, and in some cases, precluding elaborate and diverse white light illumination. This is the opposite of the needs by coral and sponge collectors, or archaeologists as they usually want high illumination and then wonder why there are no fish around. Video and still cameras had laser aiming and measurement devices mounted on the cameras. The still camera photo would shut down the laser so that it did not show in the photos. A 15 m (50 ft) roll of 35 mm Ektachrome film was loaded into an Edgerton submarine camera allowing at least 5,000 photos to be taken per 21–30 day expedition. This was extremely valuable in documenting *in-situ* fish color patterns and habitats.

Increased thruster power along with their placement along all axes allowed the JSL submarine to maneuver much like a helicopter, leaving the bottom within seconds to chase a lively fish in the water column. It is very important for the pilot



**FIGURE 8.** Nine shot laser guided spear/tagging system on the Johnson-Sea-Link submarine.

to be capable of quickly maneuvering the submarine along all axes to capture a mobile fish. The dexterity and visual capabilities of the pilot was most important in fish capture. Sponges, rocks, corals and other sessile invertebrates were easily picked up by any submarine fitted with a mechanical arm, but only the *JSL* submarine could effectively chase and capture fish attempting to swim away.

I personally used manned submarine and robotic vehicles to study fish for over 35 years, from 1971 to 2010, making over 350 dives to depths as great as 1,000 m (~3,280 ft). During this time we captured and described hundreds of fish specimens and their behaviors with the tools we developed at the HBOI, including 116 new species of fish never seen by human eyes (Gilmore 1979, 1980, 1983, 1986, 1991, 1993, 1995a, b, 1997, 2001; Gilmore et al. 1981; Reed and Gilmore 1981; Gilmore et al. 1983a,b,c; Gilmore and Jones 1988, 1992; Gilmore and McCosker 1996; McCosker and Gilmore 1996; McCosker et al. 1997; Claro et al 2000; Belleville 2002, 2004; Gilmore et al. 2003; Gilmore et al. 2005; Messing et al. 2013; Tornabene et al. 2016). This was a dream fulfilled!

These tools were designed specifically for use on the *JSL* submarine, but were often copied and used by a variety of other manned vehicles elsewhere in the world. A new species of living organism cannot be described without a specimen in hand; a nice photo is unacceptable. The 1995 Galapagos expedition with John McCosker, Bruce Robinson, and David Stedman captured over 30 new fish species including 2 new sharks with the *JSL* submarine in 18 dives (Belleville 2004).

Despite the advantages of manned submarines, remotely operated vehicles (ROV) have resulted in many deep sea discoveries. The first ROV used for scientific investigations and ocean exploration was the *CORD* vehicle. This was developed by Edwin Link and his engineering team at HBF between 1973 and 1980. I had the opportunity to use this vehicle and several other ROVs for my own research programs. My own experience included extensive use of the *Mini-Rover*, *Hysub*, and the NOAA/NURP *Phantom* ROVs from 1986 to 1993 (including the *Super-Phantom*). I used these vehicles primarily for long term fish behavioral studies on reef formations from North Carolina to the northern Gulf of Mexico and the Galapagos Islands. They

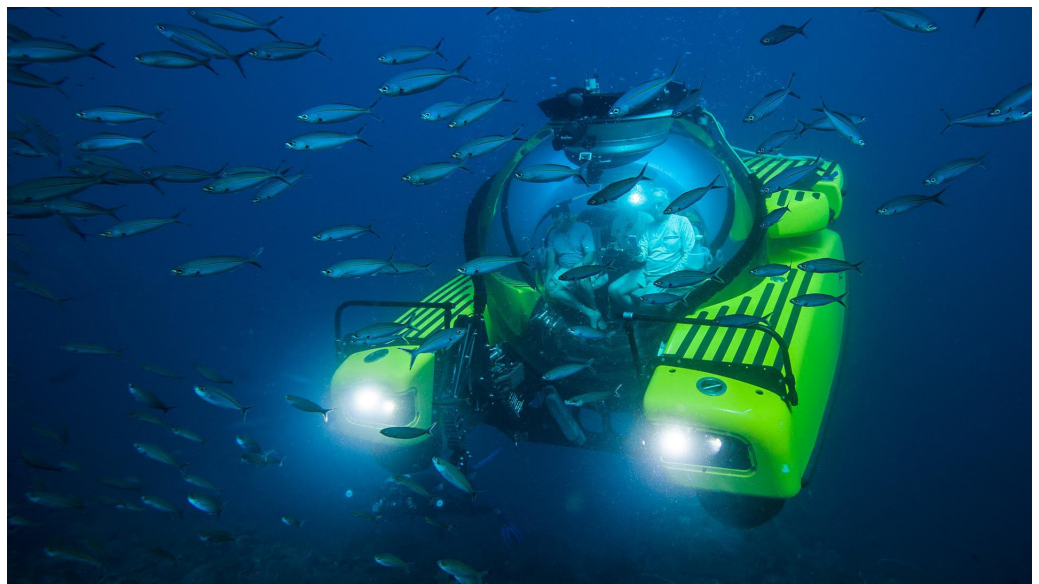
were used for recording shark and grouper mating behavior. We found both sharks and groupers would ignore the ROV vehicle (*SuperPhantom*, *VideoRay*, *Minirover*) swimming or sitting with them. While employed by Dynamac Inc. at the Kennedy Space Center (1999–2004), I used the NASA ROV, the *VideoRay*, for a variety of grouper behavior studies (Figures 3 and 5). ROVs and AUVs were also used in our fish acoustic research programs (Gilmore 2003; Gilmore et al. 2003). A U.S. Navy *REMUS* AUV made successful transects through spawning aggregations of Spotted Seatrout (*Cynoscion nebulosus*) within the Banana River Lagoon at the Kennedy Space Center in 2003 with no recorded change in fish choral displays in the presence of the AUV.

Sadly, in this age of robotics, many robotics experts have stated that manned vehicles are not necessary for ocean exploration. Apparently, none of these authors were interested in capturing actively swimming marine animals, such as fish. Even today, only appropriately designed manned submarine can capture an active marine organism, nearly 42 years after undersea unmanned robotic vehicles became practical research machines.

The only vehicles operational today that could be used for fish capture if mated with effective tools are the *Triton* submarines built by Triton Submarines, Inc. These submarines also benefit from great maneuverability and pilot/scientist visibility in an acrylic sphere (Figure 9). Unfortunately, I do not know of any *Triton* submarine being used in the United States for fish capture.

## CONCLUSIONS

In 2016 are we progressing in developing tools with state-of-the-art manned submarine that can chase and capture new fish species in the deep sea? Forty-three years ago



**FIGURE 9.** Triton submarine, the next generation of acrylic submarines yet to be used for active fish collection as they do not have the same Johnson-Sea-Link generation fish capture tools. Photo courtesy of Patrick Lahey, Triton Submarines, Inc.

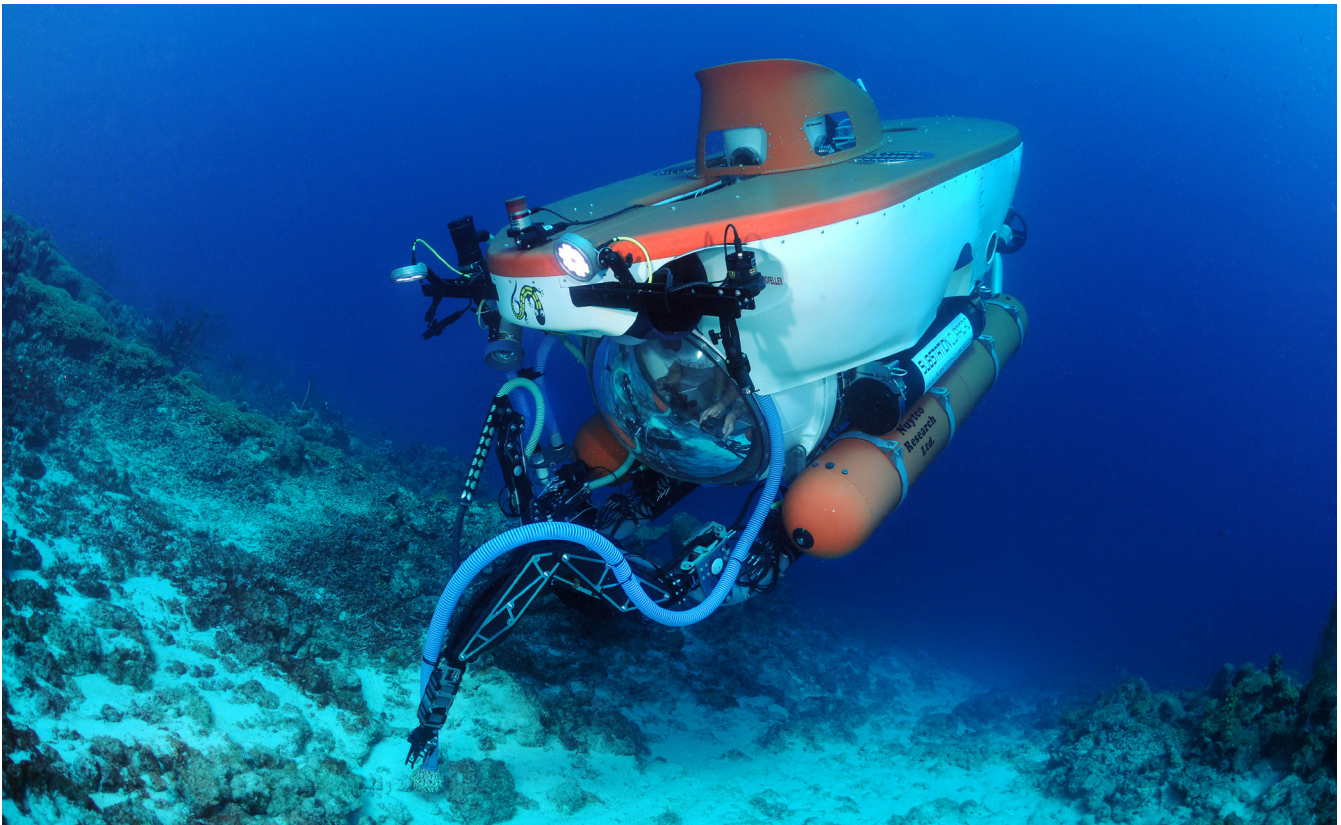
(1973), Edwin Link's wife, Marian C. Link wrote the following lines from her book *Windows in the Sea*:

“Oceanography was coming—of—age at a dangerous moment in time, the peoples of the earth, weary of their polluted surroundings, were crying out for fresh territory. This combination could not help but generate a rapid surge forward in the exploitation of the oceans. It was indeed fortunate that until now the previously unconquerable seas guarded a precious two thirds of the globe. One can only hope that, his lesson learned, man would now assume responsibility for this valuable heritage and cherish it for the future. By the end of the decade (1970), Ed realized, what was now only a bit of experimentation here and there, would be commonplace. The oceans of the world would teem with vast programs of exploration and development made possible by the successors of this small bubble sub and the many other new devices now in the making.”

Now, 45 years later, where are we in ocean exploration, particularly with the capability of capturing actively swimming marine organisms such as fish? The only fish capture operation that I am aware of in the tropical western Atlantic is that of Adrian “Dutch” Schrier, an entrepreneur who operates his own submarine “*Curasub*” for capturing fish sold to aquarists (Figure 10; <http://www.substation-curacao.com/>). He takes tourists on deep dives and most nota-

bly, rents the submarine to ichthyologists from the USNM, Smithsonian Institution (Drs. Carole Baldwin, Ross Robertson, and Luke Tornabene) for exploratory dives in both the Dutch West Indies (Curacao/Bonaire) and destinations further east. They have captured a number of new fish species in dives made over the past decade using quinaldine and suction systems (Baldwin and Johnson 2014; Baldwin and Robertson 2013, 2014, 2015; Baldwin et al. 2016a,b; Van Tassell et al. 2012; Tornabene et al. 2016a,b). The NOAA National Undersea Research Program no longer exists after supporting so many manned submarine operations in the past. HBOI no longer has operational submarine or surface vessels for ocean research. In fact, HBOI does not exist as a separate oceanographic laboratory any longer as it is owned by Florida Atlantic University and is principally dedicated to public education. The U.S. Navy's *Alvin* is still operational with Woods Hole Oceanographic Institution, but is limited to the study of rocks, wrecks and sessile invertebrates. ROVs and AUVs are everywhere.

I was fortunate to have been able to explore the ocean and study fish during a period of rapid technology development and discovery. It was also a period with mostly healthy seas and marine ecosystems. We were able to determine what human limitations were and what could be done to safely capture and observe active marine organisms. Yet, it is obvious that, if in my short career, I never came back to



**FIGURE 10.** *Curasub* collecting fish with suction device on deep slope in Curacao, Dutch West Indies. Photo courtesy of Substation Curacao.

the dock from a submarine expedition without capturing at least a few new fish species when operating at 305–914.4 m (1,000– 3,000 ft) depths, only a fraction of the mean ocean depth, there will be thousands of undescribed fish species waiting for the next generation of ocean explorers with new and superior tools.

#### ACKNOWLEDGMENTS

I would like to acknowledge my late mother, Isabella Marshall Gilmore, for constant excitement and exposure to nature. She taught me to look at rainbows in a different light, read and learn as much as possible, and to keep an incurable curiosity about the natural world. Dr. I.E. Wallen gave me a chance to start a productive career. Dr. Robert Jones allowed my career to happen and was always encouraging me to pursue fish at any depth. I went to sea on several occasions with Mr. Edwin Link and Mr. Seward Johnson Sr. who had great vision for their oceanographic institution and exploration of the ocean from the beach to the deepest depths. Mr. Johnson's passion was to learn from the sea and use that knowledge to protect the ocean from human impacts. I would not have captured fish with a submarine if it were not for the unique design Mr. Link developed or without the talent and dexterity of sub pilots Roger Cooke, Tim Askew, Sr., Mike Adams, Phil Santos and Dominic Liberatore. Finally, I would not have been a research scientist if it were not for the encouragement of my intelligent, patient and beautiful wife of 47 years, Marilyn, for whom my first new species, the Orangebelly Goby, *Varicus marilynae*, was named.

#### LITERATURE CITED

- Baldwin, C.C. and G.D. Johnson. 2014. Connectivity across the Caribbean Sea: DNA barcoding and morphology unite an enigmatic fish larva from the Florida Straits with a new species of sea bass from deep reefs off Curaçao. PLoS ONE 9(5): e97661. doi:10.1371/journal.pone.0097661.
- Baldwin, C.C. and D.R. Robertson. 2013. A new Haptoclinus blenny (Teleostei, Labrisomidae) from deep reefs off Curaçao, southern Caribbean, with comments on relationships of the genus. ZooKeys 306:71-81.
- Baldwin C.C. and D.R. Robertson. 2014. A new Liopropoma sea bass (Serranidae: Epinephelinae: Liopropomini) from deep reefs off Curaçao, southern Caribbean, with comments on depth distributions of western Atlantic liopropomins. Zookeys 409:71-92 doi: 10.3897/zookeys.409.7249.
- Baldwin, C.C. and D.R. Robertson. 2015. A new, mesophotic Coryphopterus goby (Teleostei, Gobiidae) from the southern Caribbean, with comments on relationships and depth distributions within the genus. Zookeys 513: 123-142, doi: 10.2897/zookeys.513.9998.
- Baldwin, C.C., D.E. Pitassy, and D.R. Robertson. 2016a. A new deep-reef scorpionfish (Teleostei: Scorpaenidae: Scorpaenodes) from the southern Caribbean with comments on depth distributions and relationships of western Atlantic members of the genus. Zookeys 606:141-158, doi: 10.3897/zookeys.606.8590.
- Baldwin, C.C., D.R. Robertson, A. Nonaka, and L. Tornabene. 2016b. Two new deep-reef basslets (Teleostei: Grammatidae: Lipogramma), with comments on the eco-evolutionary relationships of the genus. Zookeys 638:45-82. doi: 10.3897/zookeys.638.10455
- Belleville, B. 2002. Deep Cuba: The Inside Story of an American Oceanographic Expedition. University of Georgia Press, Athens, GA, USA, 273 p.
- Belleville, B. 2004. Sunken Cities, Sacred Cenotes, and Golden Sharks: Travels of a Water-Bound Adventurer. University of Georgia Press, Athens, GA, USA, 233 p.
- Brubakk, A.O. and T.S. Neuman. 2003. Bennett and Elliott's Physiology and Medicine of Diving. Saunders Book Company, Collingwood, Ontario, Canada, 800 p.
- Clark, E. 1969. Lady and the Sharks. Harper and Row Publishers, New York, NY, USA, 269 p.
- Claro, R., R.G. Gilmore, C.R. Robins, and J.E. McCosker. 2000. Nuevos registros para la ictiofauna marina de Cuba. Avicennia 12/13: 19–24.
- Cousteau, J.Y. 1952. Fish men explore a new world undersea. National Geographic 102:431–472.
- Cousteau, J.Y. and J. Dugan. 1962. The Living Sea. Harper and Row, New York, NY, USA, 325 p.
- Cousteau, J.Y. and F. Dumas. 1953. The Silent World. Harper Brothers, New York, NY, USA, 266 p.
- Cousteau, J.Y. and S. Schiefelbein. 2007. The Human, the Orchid, and the Octopus: Exploring and Conserving our Natural World. Bloombury, New York, NY, USA, 305 p.
- Finlayson, H.W. 2009. The Pathophysiology of Saturation Diving. Ph.D thesis. University of St. Andrews, St. Andrews, Scotland, UK, 73 p.
- Gilmore, R.G. 1977a. Fishes of the Indian River lagoon and adjacent waters, Florida. Bulletin of the Florida State Museum 22:101–147.
- Gilmore, R.G. 1977b. Notes on the opossum pipefish, *Oostethus lineatus* from the Indian River lagoon and vicinity, Florida. Copeia 1977:781–783.
- Gilmore, R.G. 1979. *Varicus marilynae*, a new gobiid fish from Florida. Copeia 1979:126–128.

- Gilmore, R.G. 1980. Color morphs and the classification of the *Epinephelus niveatus* complex. Book of Abstracts, Association of Southeastern Biologists, Tampa, FL, USA, 18–23 April 1980, p. 27.
- Gilmore, R.G. 1983. Observations on the embryos of the long-fin mako, *Isurus paucus* Guitart Manday and bigeye thresher shark, *Alopias superciliosus* (Lowe). *Copeia* 1983:375–382.
- Gilmore, R.G. 1986. Reproductive strategies in lamnoid sharks. In: T. Uyeno, R. Arai, T. Taniuchi, and K. Matsuura, eds. Indo–Pacific Fish Biology: Proceedings of the Second International Conference on Indo–Pacific Fishes, Ichthyological Society of Japan, Tokyo National Museum, Ueno Park, Tokyo, 29 July–3 August 1985, p. 926–927.
- Gilmore, R.G. 1991. Reproductive biology of Lamnoid sharks. In: S.H. Gruber, ed. *Discovering Sharks: A Volume Honoring the Work of Stewart Springer*. American Littoral Society, Highlands, NJ, USA, p. 64–67.
- Gilmore, R.G. 1993. Reproductive strategies in Lamnoid sharks. *Environmental Biology of Fishes* 38:95–114. doi: 10.1007/BF00842907
- Gilmore Jr., R.G. 1995a. Zoogeographic variation in Antillean and continental deep reef fish faunas at depths between 100 and 700 m in the Caribbean and Bahama Islands. Book of Abstracts, 75<sup>th</sup> Annual Meeting, American Society of Ichthyologists and Herpetology, Edmonton, Alberta, Canada (15–19 June 1995), p. 109.
- Gilmore Jr., R.G. 1995b. Neotropical marine fish distribution, recruitment success and habitat limitation. Book of Abstracts, American Fisheries Society 125<sup>th</sup> Annual meeting, Tampa, FL, USA, 28–31 August 1995, p. 224.
- Gilmore, R.G. 1995c. Environmental and biogeographic factors influencing ichthyofaunal diversity: Indian River Lagoon. *Bulletin of Marine Science* 57:153–170.
- Gilmore, R.G. 1997. *Lipogramma robinsi*, a new grammatid fish from the tropical western Atlantic with descriptive and distributional notes on *L. flavescens* and *L. anabantoides*. *Bulletin of Marine Science* 60:782–788.
- Gilmore, R.G. 2001. A comparative study of manned and unmanned submersible capabilities, generic sensor systems needs for the study of mobile marine fauna. Proceedings, Generic Sensor System Needs for Undersea Research Vehicles Symposium, Miami, FL, USA, 6 May 2001, p. 125–138.
- Gilmore, R.G. 2003. Integrated environmental assessment: new technologies and systems for terrestrial, aquatic and extra-terrestrial applications. Emerging Technologies, Tools, and Techniques to Manage Our Coasts in the 21st Century, Technology Transfer Conference, Sponsored by the U.S. EPA Office of Water, Office of Wetlands, Oceans, and Watersheds, Oceans and Coastal Protection Division, Washington, D.C., USA, 28–31 January 2003, p. 41.
- Gilmore, R.G. and R.S. Jones. 1988. *Lipogramma flavescens*, a new grammid fish from the Bahama Islands with descriptive and distribution notes on *L. evides* and *L. anabantoides*. *Bulletin of Marine Science* 42:435–445.
- Gilmore, R.G. and R.S. Jones. 1992. Color variation and associated behavior in the epinepheline groupers, *Mycteroperca microlepis* (Goode and Bean) and *M. phenax* Jordan and Swain. *Bulletin of Marine Science* 51:83–103.
- Gilmore, R.G. and J.E. McCosker. 1996. Comparative submersible observations of epibathyal fish assemblages: Caribbean Sea and Galapagos Islands. Book of Abstracts, 76<sup>th</sup> Annual Meeting, American Society of Ichthyologists and Herpetologists, New Orleans, LA, USA, 13–19 June 1996, p. 154.
- Gilmore, R.G., J.K. Holt, R.S. Jones, G.R. Kulczycki, L.G. MacDowell, III, and W.C. Magley. 1978. Portable tripod drop-net for estuarine fish studies. *Fishery Bulletin* 76:285–289.
- Gilmore, R.G., P.A. Hastings, and G.R. Kulczycki. 1981. Crystalline rotenone as a reliable and effective fish toxin. *Florida Scientist* 44:193–203.
- Gilmore, R.G., J.W. Dodrill, and P.A. Linley. 1983a. Embryonic development of the sand tiger shark *Odontaspis taurus* Rafinesque. *Fishery Bulletin* 81:201–225.
- Gilmore, R.G., P.A. Hastings, and D.J. Herrema. 1983b. Ichthyofaunal additions to the Indian River lagoon and adjacent waters, east–central Florida. *Florida Scientist* 46:22–30.
- Gilmore, R.G., A.M. Clark, and J. Cooke. 2003. Technologies for sustained biological resource observations with potential applications in coastal homeland security. *Marine Technology Society Journal* 37(3):134–141. doi: 10.4031/002533203787537159
- Gilmore, R.G., O. Putz, and J.W. Dodrill. 2005. Oophagy, intrauterine cannibalism and reproductive strategy in lamnoid sharks. In: W. Hamlett, ed. *Reproductive Biology and Phylogeny of Chondrichthyes*. Science Publishers, Inc., Enfield, NH, USA. p. 435–462.
- Kottler, C.F. 1969. Underwater systems within the scientific, technological, and economic framework. *Journal of Hydronautics* 3:2–11. doi: 10.2514/3.62798
- Limburg, P.R. and J.B. Sweeney. 1973. *Vessels for Underwater Exploration*. Crown Publishers, Inc., New York, NY, USA, 154 p.
- Link, E.A. 1963. Our man in the sea project. *National Geographic* 123:713–717.
- Link, E.A. 1964. Tomorrow on the deep frontier. *National Geographic* 125:778–802.
- Link, E.A. and B. Littlehales. 1965. Outpost under the ocean. *National Geographic* 127:530–533.
- Link, M.C. 1958. *Sea Diver: A Quest for History Under the Sea*. Holt, Rinehart and Winston, New York, NY, USA, 333 p.
- Link, M.C. 1973. *Windows in the Sea*. Smithsonian Institution Press, Washington, D.C., USA, 198 p.
- Marden, L. 1998. Master of the deep: Jacques–Yves Cousteau, 1910–1997. *National Geographic* 193:70–79.
- McCosker, J.E. and R.G. Gilmore, Jr. 1996. Recent studies of the Galapagos ichthyofauna using SCUBA and submersible. Book of Abstracts, 76<sup>th</sup> Annual Meeting, American Society of Ichthyologists and Herpetologists, New Orleans, LA, 13–19 June 1999, p. 154.

- McCosker, J.E., G. Merlen, D.J. Long, R.G. Gilmore, and C. Vilon. 1997. Deep slope fishes collected during the 1995 eruption of Isla Fernandina, Galapagos. *Noticias de Galapagos* (May) 58: 22–26.
- Messing, C.G., K. Stanley, J.K. Reed, and R.G. Gilmore. 2013. The first *in situ* habitat observations and images of the Caribbean roughshark, *Oxynotus caribbaeus* Cervigon, 1961 (Squaliformes: Oxynotidae). *Proceedings of the Biological Society of Washington* 126:234–239. doi:10.2988/0006-324X-126.3.234
- Oceanography in Florida. 1970. R.E. Ring, and C. Ruis, eds. Florida Council of 100, Tampa, FL, USA, 262 p.
- Penzias, W. and M.W. Goodman. 1973. *Man Beneath the Sea: A Review of Underwater Ocean Engineering*. Wiley-Interscience, New York, NY, USA, 831 p.
- Piccard, J. 1971. *The Sun Beneath the Sea*. Charles Scribner's Sons, New York, NY, USA, 405 p.
- Reed, J.K. and R.G. Gilmore. 1981. Inshore occurrence and nuptial behavior of the rougthead stingray, *Dasyatis centroura* (Dasyatidae), on the continental shelf, east–central Florida. *Northeast Gulf Science* 5:59–62.
- Robertson D.R. and K.L. Cramer. 2014. Defining and dividing the Greater Caribbean: Insights from the biogeography of shorefishes. *PLoS ONE* 9(7): e102918. doi:10.1371/journal.pone.0102918
- Stenuit, R. 1964. The deepest days. *National Geographic* 125:534–547.
- Sweeney, J.B. 1970. *A Pictorial History of Oceanographic Submersibles*. Crown publishers, Inc., New York, NY, USA, 145 p.
- Terry, R.D. 1966. *The Deep Submersible*. Western Periodicals Co., North Hollywood, CA, USA, 456 p.
- Tornabene L, J.L Van Tassel, D.R. Robertson, and C.C. Baldwin. 2016a. Repeated invasions into the twilight zone: evolutionary origins of a novel assemblage of fishes from deep Caribbean reefs. *Molecular Ecology*. doi: 10.1111/mec.13704.
- Tornabene, L., J.L. Van Tassel, R.G. Gilmore, D.R. Robertson, F. Young, and C.C. Baldwin. 2016b. Molecular phylogeny, analysis of character evolution, and submersible collections enable a new classification of a diverse group of gobies (Teleostei: Gobiidae: Nes subgroup), including nine new species and four new genera. *Zoological Journal of the Linnean Society* 177:764–812. doi:10.1111/zoj.12394
- Trillo, R.L., ed. 1979. *Jane's Ocean Technology*, 4<sup>th</sup> edition, 1979–1980. *Jane's Yearbooks*, Franklin Watts Inc., New York, NY, USA, 824 p.
- van Hoek, S. and M.C. Link. 1993. *From Sky to Sea: A Story of Edwin A. Link*. Best Publishing Co., Flagstaff, AZ, USA, 319 p.
- Van Tassel, J.L., L. Tornabene, and P.L. Colin. 2012. Review of the western Atlantic species of *Bollmannia* (Teleostei: Gobiidae: Gobiosomatini) with the description of a new allied genus and species. *Aqua, International Journal of Ichthyology* 18:61–94.
- Wicklund, R.I. 2011. *Eyes in the Sea: Adventures of an Undersea Pioneer*. Mariner Publishing, Buena Vista, VA, USA, 289 p.
- Young, D.K., R.M. Avent, L.I. Briel, N.J. Eiseman, R.H. Gore, R.S. Jones, G.A. Kerr, H.H. Seibert, O. Von Zweck, and J.R. Wilcox. 1974. *Harbor Branch Consortium: Indian River Study. Annual Report 1973–1974, Vol. 1–2*. D.K. Young (ed.). Harbor Branch Foundation, Link Foundation, Smithsonian Institution, Woods Hole Oceanographic Institution, Fort Pierce, FL, USA, 385 p.



Open access of this article supported by the Mississippi–Alabama Sea Grant Consortium.