



Michael Lang demonstrating a 1954 Air Lung double-hose regulator made by one of the first U.S. diving equipment manufacturers, Northill Company, Inc. of Los Angeles, California.

SCIENTIFIC DIVING ON CORAL REEFS: A PERSONAL ACCOUNT

BY

MICHAEL A. LANG

My first contact with saltwater was the North Sea Channel. Growing up in Ghent, I spent many family weekends at Knokke on the Belgian coast, walking the flat sand beaches and crawling out onto algae-covered rock jetties. The cold, turbid brown water usually discouraged all but the hardiest souls from swimming, except for perhaps three weeks from the end of July to mid-August. Belgium is internationally renowned for its fabulous variety of beers and the finest chocolates, but not necessarily for its balmy summers. Our main activity was to catch grapsid crabs on a string with a piece of mussel attached by a clothespin. The next level of interest along the beach was to watch the crevettes fishermen ply their trade using huge Belgian draft horses to pull shrimp nets in the sandy shallows of the outgoing tides.

At that early age, I did not know that marine biology and scientific diving would be my calling, but when my family purchased a vacation home in Torrazza, near Imperia on the Italian Riviera in 1972, the blue Mediterranean's pull was intense. Alpine skiing was within an hour's drive during winter and spring breaks, and almost three months of summer vacation in this seaside town were stimulating to a teenager. Italy has its share of world-class free divers. Reading of Enzo Maiorca's lung capacity and breath-hold times and the Confédération Mondiale des Activités Subaquatiques (CMAS) diving championships with Jacques Mayol led to my first snorkeling excursions around Porto Maurizio in Imperia.

With the Musée Océanographique (Fig. 1) in Monaco just a 45-minute drive away, frequent trips to Monte Carlo and its aquarium provided countless viewing hours of marine creatures through glass panes. *Octopus vulgaris* on display was a magnet of fascination. Octopodes were interesting, but would be more so, I thought, if I could get in the water with them. To add to the allure of diving, the Oceanographic Institute's Director was Jacques-Yves Cousteau. Curiously, in Europe the "father of diving" was generally considered to be Austrian professor Hans Hass who, with his wife Lotte, had already made underwater black and white films of sperm whales in the Indian Ocean in the late 1930s. But Commandant Cousteau's business sense made him by far the most visible diver for years to come, especially in the United States through his underwater films and books. It is interesting to note that the history of diving in bells, free-diving or surface-supplied, precedes that of free-swimming scuba diving by over 2000 years (Table I).

Table I. Milestones in the History of Diving

30 B.C.	Alexander the Great's diving bell <i>Colimpha</i> .
+/- 100 A.D.	Active free-diving by Ama of Japan and Korea (Rahn, H. (ed.) 1965. <i>Physiology of breath-hold diving and the Ama of Japan</i> . NAS/NRC Publ. 1341. Washington, D.C., National Academy of Sciences).
1535	Guglielmo de Lorena (Italy): developed a type of diving bell.
1691	Sir Edmund Halley (England): designed a forerunner of the modern diving bell.
1715	John Lethbridge (England): creation of first One-Manned Atmospheric Diving System (OMADS).
1774	Freminet (France): surface-supplied diving to 15 m for 60 minutes of bottom time.
1799	Smeaton (England): dived with "diving chests" that used a forcing pump to replenish air supply.
1808	Friederich von Drieberg: <i>Triton</i> diving apparatus (bellows in a box).
1819	Augustus Siebe: invention of the diving dress.
1823	John and Charles Deane (England): Deane's Patent Diving Dress, a protective suit with a separate helmet and surface-supplied air.
1825	William James (England): first autonomous diving apparatus (compressed air carried in a circular iron reservoir around the diver's waist).
1832	Charles Condert (USA): horseshoe shaped waist-mounted air reservoir that provided a continuous flow of air to a flexible helmet.
1837	Augustus Siebe: full-body, airtight diving suit with attached helmet and free-flow valve.
1865	Rouquayrol and Denayrouze (France): metal back-mounted canister charged to 40 bars and an ambient-pressure demand regulator; semi-self-contained diving suit.
1879	Henry Fleuss (England): closed-circuit oxygen-rebreather SCUBA.
1913	Georghios (Greece): sponge diver free-dived to 61 m.
1918	Ogushi (Japan): Peerless Respirator connected to air cylinder charged to 150 bars.
1920s-1930s	Guy Gilpatrick (USA): used old flying goggles, plugged with putty and painted over. Karamarenko (Russia): first rubber mask with a single-pane window. De Courlieu (France): patented rubber foot fins. Steve Butler (England): first successful snorkel tube.
1926	Captain Yves Le Prieur and Msr. Fernez (France): continuous flow SCUBA system.
1935	Yves Le Prieur: lightweight compressed air apparatus with semi-automatic regulator and full-face mask.
1937	Georges Commeinhes (France): first fully automatic aqualung with full face mask.
1939	Dr. Christian Lambertsen (USA): Lambertsen Amphibious Respiratory Unit (LARU): oxygen rebreathing equipment for neutral buoyancy underwater swimming.
1943	Jacques-Yves Cousteau and Emile Gagnan (France): new fully automatic regulator with inlet and exhaust valve ("Aqua Lung"); first demand double-hose regulator.
1950	First single-hose regulators appear.
1959	Carlo Alinari (Italy): designs SOS decompression meter, a pneumatic device simulating nitrogen uptake through a ceramic membrane.
1962	Edwin Link (USA): first open-sea trial of saturation diving (8 hours at 60 feet in a one-man chamber).
1967	Edwin Link (USA): Perry-Link 4: first modern-day lockout submersible.
1969	Robert Croft (USA): breath-hold dive record to 75 m (1968 Cover of <i>Science</i> Vol. 162).
1975	Jacques Mayol (France): world breath-hold dive record to 99 m.
1970s	Personal flotation devices (buoyancy compensators) in the form of horse-collar bc's appear.
1979	Dr. Morgan Wells (USA): oxygen-enriched air (nitrox) tables published in NOAA Diving Manual.
1983	ORCA Industries mass produces electronic diver-carried decompression computers that allow for multilevel repetitive diving versus the square-wave U.S. Navy table tracking of nitrogen on- and offgasing.

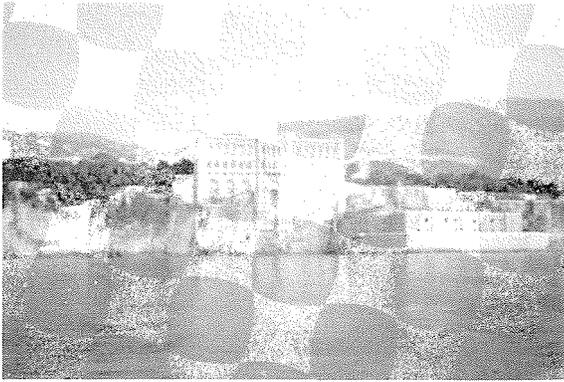


Figure 1. Le Musée Océanographique in Monte Carlo, Principality of Monaco. (Photo M. Lang)

After I completed the classical humaniora curriculum in Belgium, it was time to leave the belt of storminess and its depressing gray climate behind. My father, a research chemist and professor, allowed my siblings and me to select the college of our choice, as long as we enrolled in the same one. My major interest now was oceanography and marine biology. In 1978, Humboldt State University in Arcata, California, became our home for the next two years. Not having much knowledge of the State of

California, I was taken aback by the all-too-familiar northern European weather and rain. Having selected this university campus on the advice of our American friends, we wished in retrospect that they had been more specific when they recommended a California school: what they really meant was any campus located south of Santa Barbara! Many of my early scuba diving training courses through the university took place in harsh northern California ocean, river, and lake conditions. The entrance channel jetty to Humboldt Bay (Fig. 2) was the site of my first observation of *Octopus dofleini* in its natural habitat. Its size alone accelerated my air consumption and shortened my dives considerably.

Arriving in San Diego in 1980, I participated in a National Association of Underwater Instructors (NAUI) scuba instructor course at San Diego State University (SDSU) as the first order of business (Fig. 3). Light-duty commercial diving provided a



Figure 2. An early scuba training dive off the Humboldt Bay entrance jetty, 1978.



Figure 3. First southern California kelp dive at Casa Cove, La Jolla, California, 1979.

reasonable income for the next three years as an undergraduate student. The kelp beds (*Macrocystis pyrifera*) and rocky intertidal areas became my office for the next eight

years. I was hired by the Department of Biology as a staff biologist in charge of marine collections in 1982. During my years of graduate studies I investigated the life history and population dynamics of *Octopus bimaculoides* (Lang, 1997) in Agua Hedionda lagoon in Carlsbad, site of the recent discovery of an introduced green alga (*Caulerpa taxifolia*), known for outcompeting and displacing native species through the northern Mediterranean. During my tenure at SDSU, I participated in numerous scientific diving expeditions to the California Channel Islands (Lang and Hochberg, 1997), Baja California, and a most stimulating trip to the Antarctic on an *Euphausia superba* research diving project with Bill Hamner from UCLA.

Scientific diving in the United States can be traced to Scripps Institution of Oceanography in 1951. Conrad Limbaugh (Fig. 4a) was appointed by Roger Revelle as the first Diving Officer of the University of California's scientific diving program. This program provided for scuba training, equipment maintenance, medical and operational underwater research procedures—elements that are still found in diving programs today. Jim Stewart (Fig. 4b) succeeded Limbaugh in 1960 after his tragic death in a submarine

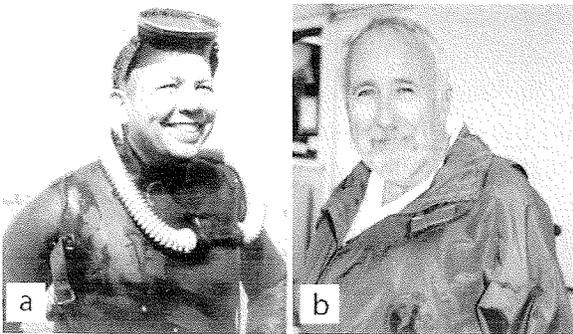


Figure 4. Scripps Institution of Oceanography Diving Officers: (a) Conrad Limbaugh, 1951-1960. (Photo courtesy Scripps Institution of Oceanography) (b) Jim Stewart, 1960-1991. (1993 Photo M. Lang)

cave diving accident in Port Miou, France at the age of 35. The *Capricorn* expedition to the South Pacific in 1954 was the first research diving cruise to study coral reefs. Those were the days of double-hose regulators and twin tanks. There were no buoyancy compensators, submersible pressure gages or dive computers. When it got hard to breathe, divers came up following their smallest bubbles, or sometimes completely disregarding the ascent rate based on the length of time they had been out of air! J-valves were incorporated on scuba cylinders in the 1960s as a safety mechanism in order to provide a reserve

supply of air of approximately 300 psi. At issue was the pull-rod often activating the valve during the dive, unbeknownst to the diver, leaving no reserve air supply. Furthermore, empty cylinders needed to be filled with the valve in the open position to incorporate the reserve volume of compressed air. The advent of submersible pressure gages provided an analogous reasoning as to why you don't run out of gas in your car on the freeway.

Buoyancy compensation was solved in the late 1960s through the introduction of the frontal horse-collar buoyancy compensator (b.c.), which was perhaps the most uncomfortable of all personal flotation devices, riding up around the neck at the surface and providing a continuous reminder to not cinch the crotch-strap too tightly.

Scientific diving techniques had established themselves in the peer-reviewed literature as particularly useful by putting the trained scientific eye in the underwater environment. In a 1953 letter, Roger Revelle, Director of Scripps, wrote to University

of California President Sproul stating that scuba should be accepted as a legitimate means of conducting research. Mainstream journals such as *Limnology and Oceanography*, *Marine Biology*, *Journal of Experimental Marine Biology and Ecology* and *Bulletin of Marine Science* regularly contain articles where scuba techniques are described in their materials and methods sections. Scuba equipment had also evolved from the days of double-hose regulators and twin cylinders with no pressure gauges when scientists monitored their decompression status through the use of the U.S. Navy Decompression Tables. Commercially available diver-carried decompression computers first arrived on the market in 1983, manufactured by ORCA Industries. These dive computers revolutionized the effectiveness of our research time under water by allowing for the tracking of nitrogen loading through a multilevel algorithm compared to the square-wave depth and time profiles the U.S. Navy tables required.

I had become intensely interested in diving physiology and how it affected our scientific diving operational procedures. Through the American Academy of Underwater Sciences (AAUS), with which I had been affiliated since 1980 and during the days of pursuing our Occupational Safety and Health Administration (OSHA) scientific diving exemption from commercial diving standards, I initiated a three-part diving safety research project that involved an interdisciplinary, industry-wide effort. The initial phase (Lang and Hamilton, 1989) was to investigate the applicability and effectiveness of dive computers. Subsequently, rates of ascent and safety stops were examined in an effort to further reduce rates of decompression illness (Lang and Egstrom, 1990). I was also interested in learning how many dives one could make for how many consecutive days prior to having to stay on the surface for a day to allow for significant off-gassing of the slow-tissue compartments of the dive computer algorithms (Lang and Vann, 1992). My colleagues in the hyperbaric medical community and the diving industry can be credited, in part, for the 1991 DAN/Rolux Diver of the Year Award for my significant contributions to diving safety. Further diving research included a two-year National Science Foundation (NSF) Ocean Sciences project evaluating diving safety from research vessels, an NSF Polar Programs project examining diving in extreme polar environments (Lang and Stewart, 1992), critically examining and modifying one of diving's most hallowed rules of "dive deep first followed by subsequent shallower exposures" (Lang and Lehner, 2000) and, most recently, reviewing the status of oxygen-enriched air (nitrox) diving (Lang, 2001). The Undersea and Hyperbaric Medical Society's (UHMS) Craig Hoffmann Award (2000) recognized this diving safety research as an outstanding contribution to the medical and diving communities.

My first diving involvement with corals, other than *Corallium rubrum* in the Mediterranean on a 1983 collecting trip with the Aquarium in Monaco and cup corals *Balanophyllia elegans* and *Paracyathus stearnsi* off California, came immediately after accepting my current position of Scientific Diving Officer at the Smithsonian Institution in January 1990. Jim Norris of the National Museum of Natural History (NMNH) invited me to the Smithsonian Marine Station to dive with Bob Sims and Sherry Reed in the Florida Keys on his *Liagora* project. My first impression of beautiful high-relief coral reefs at Looe Key was of a greatly reduced three-dimensionality compared with

the majestic *Macrocystis* forests I was so familiar with. Nevertheless, tropical water temperatures and visibility were most agreeable. Clyde Roper, Mike Sweeney, Jaren Horsley and I conducted a diving research project on *Octopus chierchiae* in Panama in 1992 to continue the earlier work done at Smithsonian Tropical Research Institute (STRI) (Rodaniche, 1984). In 1993, I accompanied the NMNH Fish Division staff (Jeff Williams, Carole Baldwin, Bruce Collette, Dave Johnson and Dave Smith) to the Kingdom of Tonga for several weeks to collect and document the ichthyofauna in collaboration with the Tongan Ministry of Fisheries. Of note were the pigs foraging in the intertidal, royal fruit bats, and upside down *Pseudanthias* (Fig. 5).

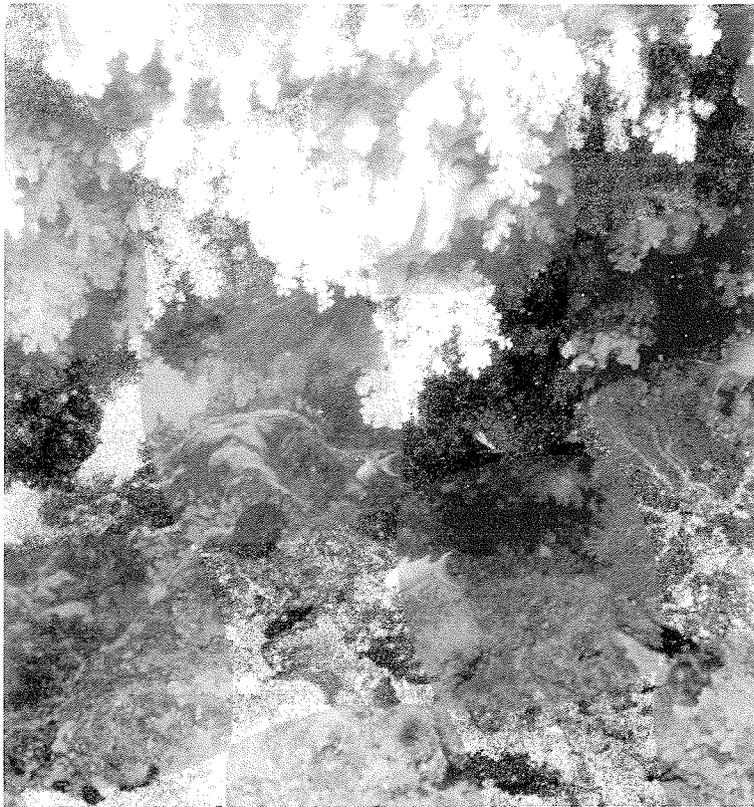


Figure 5. *Pseudanthias* swimming upside down under coral overhang in Tonga. (Photo M. Lang)

Hines, Smithsonian Environmental Research Center (SERC), José Espino, my STRI Diving Officer, and I taught a scientific diving course at the University of Honduras in Tegucigalpa, conducting the open water training dives at the Cayos Cochinos Lab funded by the Honduras Coral Reef Fund (Fig. 6). Several research cruises aboard STRI's *R/V Urraca* to Honduras included Jeremy Jackson as chief scientist and my dive buddy searching for bryozoans at 130 feet on mud bottoms. A Kodak moment materialized as the bottom trawl was near the surface and Captain David West accidentally knocked Jeremy's glasses into the water. Jeremy's immediate response was to cancel the cruise; we were going home because of an imminent onset of severe

The STRI San Blas station in Panama was for many years the home base of many Smithsonian dive buddies, including Jeremy Jackson, Haris Lessios, Ross Robertson, Nancy Knowlton, Ken Clifton, Hector Guzman and scores of visiting coral reef scientists. In 1992, I accompanied Nancy Knowlton on a research cruise to Cayo Salar for her continued work on the *Montastraea* sibling species complex (Knowlton *et al.*, 1992).

Between 1995 and 1997, STRI conducted a major coral reef research project at Cayos Cochinos, Honduras, headed by Hector Guzman (Guzman, 1998). Tuck

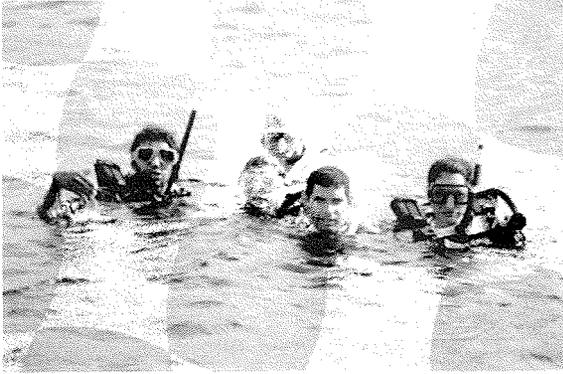


Figure 6. José Espino (2nd from right), STRI Diving Officer from 1992-1999, and Tuck Hines from SERC (3rd from right), with students from the University of Honduras at Cayos Cochinos during scientific diving training course, 1995. (Photo M. Lang)

migraines and his lack of a spare pair of glasses. Captain West said “adelante, pues!” Within two minutes the trawl was hauled. Lo and behold, it contained not only invertebrates, corals, and bottom fish, but also the lost glasses, still intact.

Coral reefs are unique biogeological structures that thrive in clear, nutrient-poor (oligotrophic) tropical oceans and support a rich and diverse biological community. Reef systems are driven by the symbiosis between scleractinian corals and microscopic dinoflagellate algae (zooxanthellae) as their chief energy source. The largest, best-developed, least-polluted and least commercially exploited coral reef in the

Atlantic region is the Belize Barrier Reef. This 250-km-long complex of reefs, atolls, islands, oceanic mangroves, and seagrass meadows has been declared a World Heritage Site. Carrie Bow Cay, in the early 1970s, only three hours by plane and boat from Miami, was found to be an ideal Smithsonian logistical base because of its location on top of the barrier reef, only meters away from a variety of habitat types (reef flat, deep spur and groove, patch reefs, seagrass meadows and mangroves), and its undisputed ownership by a Belizean family. In the years since, the Caribbean Coral Reef Ecosystems (CCRE) Program, under Klaus Ruetzler’s leadership, has amassed an enormous database consisting of thousands of specimens of marine plants, invertebrates, and fishes. CCRE has also helped the Belize government shape its coastal conservation policy, has participated in the Caribbean-wide reef monitoring network (CARICOMP), has established the first meteorological-oceanographic monitoring station in coastal Belize, and above all, has published well over 600 scientific papers in reviewed journals, as well as several books, doctoral dissertations, popular articles, and photo and video documentaries. Several projects in the past several years were centered on the Pelican Cays, an undisturbed and highly diverse group of reef-mangrove islands 15 km SSW of Carrie Bow Cay. The atoll-like reef structure on which the cays are located is obvious only from the air.

Emmett Duffy’s study of a sponge-inhabiting shrimp (*Synalpheus* spp.) confirmed its eusociality and advanced social structure for the first time in a marine animal (Duffy, 1996). I had dived with Emmett at STRI’s San Blas station in 1990, and also at Carrie Bow Cay, to collect sponges in 1992. A monitoring program was established to quantify the long-term temperature change effects on the distribution and progress of black-band disease in reef corals. A bleaching event in 1998 killed almost all the corals in the Pelican Cays and those in the surrounding lagoonal area (Aronson et al., 2000).

Hurricane Mitch (1998) could not claim to have done to Carrie Bow Cay

facilities what a devastating fire did in December 1997. New and improved for the 1999 season, the CCRE program continues to host Smithsonian scientific divers in their quest for increasing knowledge of the marine environment and its component parts. Ruetzler and Macintyre (1982) published the early coral-reef work at Carrie Bow Cay on the Belize Barrier Reef. A significant number of these studies were accomplished using scientific diving techniques. On numerous diving trips to Carrie Bow Cay since 1990, I have had the pleasure of collecting and photographing fish with Jack Randall, scientific diver extraordinaire, Carole Baldwin (Fig. 7), Kassie Cole and others.



Figure 7. Carole Baldwin (NMNH Curator) collecting blennies at Carrie Bow Cay, Belize, 1993. (Photo M. Lang)

Another Kodak moment was snapped when, after a dive on the ridge, Klaus Ruetzler and I had to swim a zodiac with a recalcitrant engine all the way back to the island through swarms of *Linuche*. Zodiacs and old Johnson outboard engines, it turns out, are not very effective as artificial reefs, much to the disappointment of Mike Carpenter, long-time CCRE Operations Chief.

In another diving incident, Wolfgang Sterrer, Molly Ryan, and I were diving in the sand trough at 90 feet collecting the top 5 cm of sand for Wolfgang's Gnathostomulida research.

About 25 minutes into this dive, Wolfgang gave me the out-of-air signal, wanting to share air. I obliged by giving him my AIR II alternate regulator connected to my buoyancy compensator dump hose. After verifying that his submersible pressure gauge did in fact read zero psi of pressure, I motioned for him to dump his 5-gallon bucket of sand, which he wasn't willing to do. Ascending with my left hand on our boat's anchor line, my right hand on his bucket's handle, Molly gracefully swimming up with us, and Wolfgang with lockjaw around my second regulator, I had an enlightening moment. I contemplated dumping the bucket. Then I realized I could not dump air out of my b.c. since Wolfgang had the free end with the regulator in his mouth. Reconsidering, I was now worried that the rusted bucket handle might give way and we would suddenly lose this negative ballast and rocket to the surface together, not a particularly enticing option. After a few Belikins (Belizean beer) and lots of deep philosophical discussions we opted to avoid that scenario in the future.

Also at Carrie Bow Cay, Mark Littler, Diane Littler, Barrett Brooks, and I spent a week diving at 190 feet in 1995 off the outer ridge to collect deep algae (Littler and Littler, 2000). We also further explored the underwater cave at Columbus Cay described in Ruetzler and Macintyre (1982). Some of the CCRE program research focus has shifted in recent years to a greater emphasis on mangrove ecology and the unique environment of the Pelican Cays where teams of divers led by Ian Macintyre, Jim Tyler, Mark and Diane Littler, and Ken Sebens worked on biotic and abiotic aspects of this fragile "mangrove-on-coral" ecosystem. A year earlier, Carole Baldwin and I conducted

a series of “black-out” night dives at 20 m on the outer ridge in search of the same elusive flashlight fish that had been collected just 70 miles away in Roatan. Despite some large swimming shapes outlined by the disturbance of bioluminescent plankton in the pitch-black water, the blue-green blinks of the flashlight fish were not observed.

Coral reef research experienced a banner year at the Smithsonian in 1996. The 8th International Coral Reef Symposium (8ICRS) was hosted by STRI (Lessios and Macintyre, 1997) and included six diving field trips. I was responsible for authorizing its 58 participants under the Smithsonian’s Scientific Diving Program. Field trip destinations were the Galapagos Islands (Wellington, 1997), Belize (Macintyre and Aronson, 1997), Curaçao and Bonaire (Van Veghel, 1997), San Blas (Clifton et al., 1997), San Andres and Providencia (Geister and Diaz, 1997), and the Pacific coral reefs of Panama (Glynn and Maté, 1997). As I had never dived off Galapagos or Curaçao/Bonaire before, both trips as Diving Supervisor were rewarding, especially with Jerry Wellington (Fig. 8) and Manfred Van Veghel serving as fearless trip leaders.

Also during the Smithsonian’s 150th anniversary year, I hosted and chaired the 16th annual AAUS scientific diving symposium “Methods and Techniques of Underwater Research” in Washington (Lang and Baldwin, 1996). Coral reef research papers presented by SI staff (Ken Clifton, Carole Baldwin et al., Bruce Collette, Haris Lessios, Mark Littler et al., Ian Macintyre, and Klaus Ruetzler) focused on scientific diving and collecting techniques of sponges, fishes, algae and drill cores.



Figure 8. Jerry Wellington in the Galapagos during 8ICRS field trip with a pair of mockingbirds, 1996. (Photo M. Lang)

Several of Ross Robertson’s STRI underwater research projects investigated the biological characteristics of small-island endemics in the eastern tropical Pacific and have taken his team of Smithsonian scientific divers to the Revillagigedos Islands, Clipperton Island, Cocos Island, Galapagos Islands and Malpelo Island (Allen and Robertson, 1994). Clipperton Island, which is the only atoll and the largest coral reef in the eastern Pacific, is the most isolated reef in the tropical Indo-Pacific, 950 km from the nearest shoals (Sachet, 1962). The following four biological aspects of endemics relevant to the question of mechanisms of their persistence at the island were studied in 1998: population size, longevity, larval biology and historical biogeography. The transit time aboard the R/V *Urraca* from Acapulco to Clipperton was three days. The two weeks of diving on site provided for encounters with silvertip and Galapagos sharks (Fig. 9a), manta rays (Fig. 9b), and

Mexican tuna fishing boats at this remote French territory. Our standard diving procedure was to launch two rigid-hull inflatable boats (RIBs) from the R/V *Urraca* with a team of eight divers. Toward the end of one dive, as we approached the anchors of the two RIBs moored side by side, I noticed two anchors but only one attached to an anchor line and ascending rope. Looking up, the silhouette of only one boat was visible. The 5-m RIB’s shackle pin had unscrewed itself (no safety wire) and set the boat adrift. Ross and I immediately surfaced to see the 5-m inflatable rearing vertically and performing headstands in the 4-m high breakers in the surf zone about 400 m away. We ditched the anchorline of the 4-m RIB and our dive buddies and rescued the 5-m from a

potentially terminal reconfiguration.

A two-week research diving cruise to Cocos Island, Costa Rica in 1997 with Robertson (Fig. 10) and others ranks among the greatest fish biomass dives I have ever logged, bar none, including Galapagos in 1996 and 1998. Noted in my dive logs are records of huge schools of *Caranx sexfasciatus*, baitballs, 300-pound yellowfin tuna

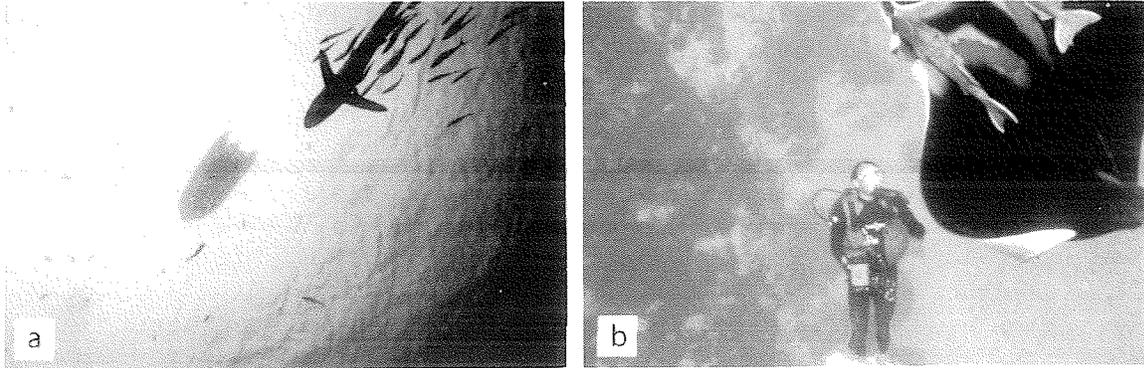


Figure 9. Underwater wildlife at Clipperton Island, 1998. **a** A precarious ascent from a dive. (Photo M. Lang); **b** Michael Lang eclipsed by a manta ray with attached remoras. (Photo K.Clifton)

feeding on reef fish, enormous schools of hammerhead sharks, huge Galapagos sharks, and manta rays. Perhaps the most unusual observation was the schooling behavior of white-tip reef sharks (50 or more) due to their sheer abundance on the reef.

A week of night diving at Bocas del Toro in 1999 to observe coral spawning came close to some of the underwater scenes in the movie *The Abyss*. Transects were marked at 5-m intervals with chemical lights and divers swam around with bright underwater lights searching for coral colonies. In the *Montastraea annularis* complex in the Caribbean, mass spawning usually occurs over a several-day period following the August full moon. Polyps in a colony produce gamete bundles (one per polyp) that contain both sperm and eggs. These bundles are constructed before spawning and become obvious about 30 minutes prior to spawning as the bundle works its way



Figure 10. Ross Robertson (STRI) collecting cryptic fishes at Cocos Island, Costa Rica, 1997. (Photo M. Lang)

through the pharynx of the polyp (termed “setting”). After release, the gamete bundle floats slowly to the surface. As it approaches and reaches the surface, the gamete bundle breaks apart releasing the eggs and sperm into the water column. The eggs are positively buoyant, but the sperm are neutrally buoyant. Because self-fertilization is rarely successful, sperm from one colony must find eggs from another colony. Members of the *M. annularis* species complex (Knowlton et al., 1992) are the major reef-building corals in the Caribbean and

a model group for studies of the ecology and reproduction of reef-building corals. The major focus of Nancy's spawning study was to provide a comprehensive understanding of the spawning behavior, gamete compatibilities, and fertilization rates of the three species that make up the complex (*M. annularis*, *M. franksi* and *M. faveolata*). All three spawn in approximate synchrony, typically seven to eight days after the full moon in August. However, *M. franksi* spawns one to two hours before the other two species, and the two species that spawn together have barriers that block fertilization between them.

When a "setting" colony (Fig. 11a) was encountered at Bocas del Toro, Panama, a numbered chemical light (attached to a weight with an identification number) was activated to mark the colony. The matched numbers allowed for mapping of the coral colonies and matching them with the fertilization samples. When a colony started to spawn (Fig. 11b), the diver recorded the time and detached the chemical light from the weight. The gamete bundles were followed to the surface (off to the side to minimize scuba bubbles interfering with the gamete bundles) and periodically during the ascent a sample of gamete bundles were collected with 60 cc syringes (Fig. 11c). The chemical

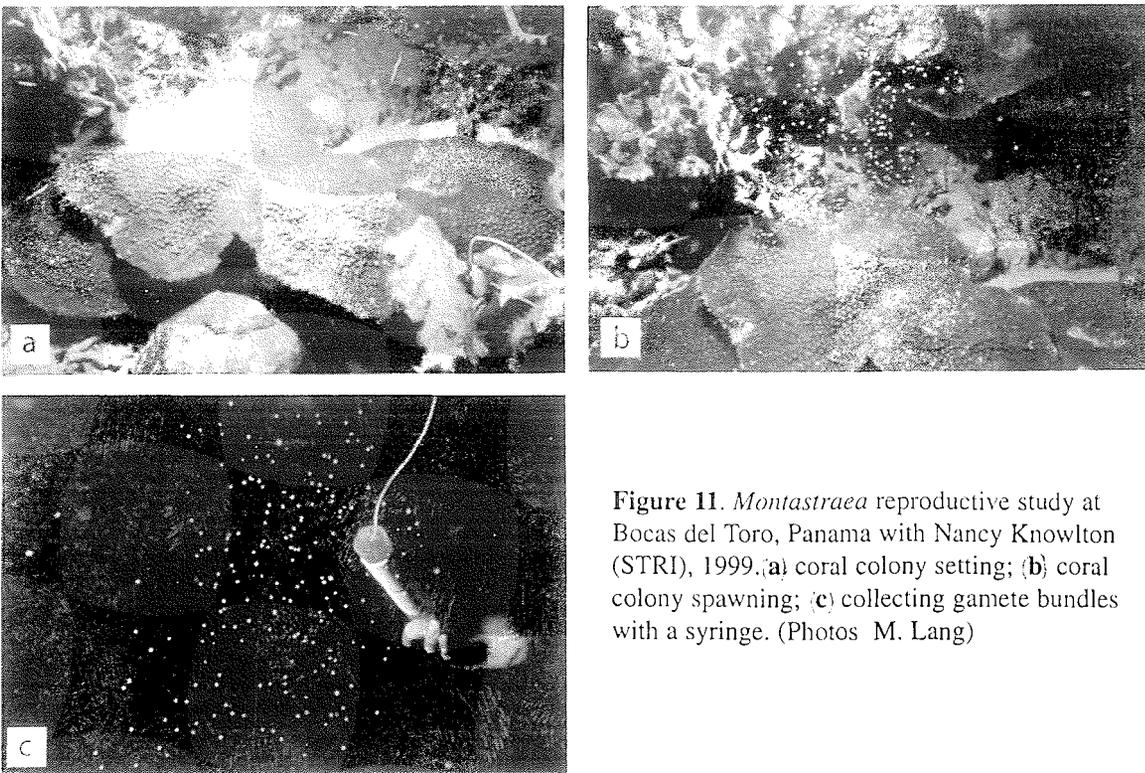


Figure 11. *Montastraea* reproductive study at Bocas del Toro, Panama with Nancy Knowlton (STRI), 1999. (a) coral colony setting; (b) coral colony spawning; (c) collecting gamete bundles with a syringe. (Photos M. Lang)

light on the water's surface then acted as a drogue around which plankton sweeps were made to collect eggs by other scientists in boats, during which the time and a Global Positioning System (GPS) reading were also recorded. By following the lights over time, the distances typically traveled by eggs and sperm can be estimated. This work provided the first information on in situ rates of fertilization success and the mechanisms that influence fertilization rates for any Caribbean hard coral. This fundamental process is often difficult to study because small larvae are inherently

difficult to track, and reproduction itself may be a brief event, which is easily missed by divers (especially at night) who necessarily spend a relatively limited amount of time under water.

In case you have hung up your fins or are not a scuba diver, the closest you might come to reminiscing about the underwater world or contemplating certification is to visit the NMNH Johnson IMAX Theater. The Smithsonian's 3-D IMAX film *GALAPAGOS* is your virtual ticket to the underwater world. We spent June and July of 1998 aboard Harbor Branch Oceanographic Institution's R/V *Seward Johnson*, complete with underwater film crew, scientific staff and the *Johnson Sea-Link* submersible. A number of the Galapagos islands were visited and most spectacular were Wolf and Darwin, the northernmost islands. The El Niño conditions of 1998, a tragic ultralight accident, and the technological difficulties of filming with a 1,700-pound underwater 3-D IMAX camera and housing made it necessary to reshoot certain sequences in February and March of 1999.

The Smithsonian Marine Science Network (Lang and Hines, 2001) is uniquely positioned to monitor long-term change at its component sites (SERC, SMSFP, Carrie Bow Cay, Bocas del Toro, Galeta, Naos and Coibita Island). It has an extensive array of programs involving scientific diving that address many of the most pressing environmental issues in marine ecosystems including: biological invasions, eutrophication, harmful species and parasites, plankton blooms and red tides, linkages among coastal ecosystems, global warming including sea-level rise, El Niño/La Niña, UV radiation impacts, habitat destruction, fisheries impacts, ecology of key habitats (estuaries, coral reefs, mangroves, seagrasses, wetlands), and biodiversity inventories.

More complete and continuously updated information on the Smithsonian's Scientific Diving Program (www.si.edu/dive) and the Institution's Marine Science activities (www.si.edu/marinescience) can be found on the Smithsonian web site.

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