Smithsonian Marine Station at Fort Pierce: Thirty-Eight Years of Research on the Marine Biodiversity of Florida

Valerie J. Paul, Julianne Piraino, and Laura Diederick

ABSTRACT. The Smithsonian Marine Station at Fort Pierce, located on South Hutchinson Island in Fort Pierce, Florida, has had an ongoing program in the marine sciences since the early 1970s. Funded by a private trust from J. Seward Johnson, Sr., to the Smithsonian, the marine program has supported the research of Smithsonian scientists and their associates, postdoctoral fellows, resident scientists, and the operations of the station, including a small support staff. The station is administered by the National Museum of Natural History as a facility for research dedicated to the marine sciences. The Smithsonian Marine Station at Fort Pierce has developed a strong, broadly based research program focusing on ecology, evolution, systematics, and life histories of marine organisms. Ongoing studies address important issues in biodiversity, including global climate change, invasive species, harmful algal blooms, larval ecology, and evolutionary developmental biology.

INTRODUCTION

The Smithsonian Marine Station at Fort Pierce (SMS) is dedicated to studying the rich diversity of marine life of the Indian River Lagoon and Florida coast. In sharing its findings with the scientific community, resource managers, and the general public, the Marine Station promotes the conservation and stewardship of Florida's vast marine resources. Research activities focus on the Smithsonian Institution's core scientific emphasis of discovering and understanding life's diversity. Although most research projects focus on biodiversity, life histories, and ecology of marine and estuarine organisms, complementary studies of physical and chemical processes related to the marine environment are also part of the Station's investigations. The insights gained by the research conducted at SMS are widely disseminated through scientific publications (more than 780 to date; see complete listing on the Station's website www.sms.si.edu), scientific and public presentations, popular articles, and the media, thus contributing to the broader mission of the Smithsonian Institution for the "increase and diffusion of knowledge."

The Smithsonian's presence in Fort Pierce, Florida, began in 1969 through an association with Edwin Link, an inventor and engineer who was involved at that time in the design of research submersibles, and J. Seward Johnson, Sr.,

Valerie J. Paul, Julianne Piraino, and Laura Diederick, Smithsonian Marine Station at Fort Pierce, 701 Seaway Drive, Fort Pierce, Florida 34949, USA. Corresponding author: V. Paul (paul@si.edu).
Manuscript received 29 August 2008; accepted 20 April 2009.

founder of the Harbor Branch Foundation, now known as the Harbor Branch Oceanographic Institute (HBOI) at Florida Atlantic University (Figure 1). In late 1969, the Smithsonian was given two trust funds through the generosity of J. Seward Johnson, Sr., for the development and maintenance of a submersible (then under construction) and for research in underwater oceanography. At its completion in 1971, the submersible, the Johnson Sea-Link I, was donated to the Smithsonian. In 1973, after a tragic accident in the Johnson Sea-Link in which two men died, the Smithsonian transferred ownership of the submersible to Harbor Branch. Following the transfer of the submersible, the Smithsonian's marine research program in Fort Pierce continued to be supported by income from both trust funds, then later, after certain legal resolutions, by one of the two funds, designated as the Hunterdon Fund. The Smithsonian carried out its activities in Fort Pierce on the grounds of the Harbor Branch Foundation (Link Port) under the auspices of the Fort Pierce Bureau, a unit administered directly by the Office of the Secretary and then later by the Assistant Secretary for Science. In March 1981 this Bureau was dissolved as an organizational entity, and the administrative responsibility for the Smithsonian research programs at Link Port was transferred to the Director of the National Museum of Natural History (NMNH). The organization was then retitled by the Secretary of the Smithsonian as the Smithsonian Marine Station at Link Port. At the time of the transfer of administrative responsibility, the directive from the Office of the Assistant Secretary for Science was that a strong research program in marine science should be established and that the program should be open to all marine scientists in the Smithsonian Institution. In response, Richard Fiske, then Director of NMNH, established an inter-unit advisory committee, appointing Catherine Kerby, his administrative assistant, as chair of the committee, and Mary Rice, Department of Invertebrate Zoology (on assignment to the Fort Pierce Bureau), as director of the facility and research programs at Link Port. Rice held this position until her retirement in 2002, at which time Valerie Paul was selected as her successor.

The Smithsonian Marine Station at Link Port was initially set up with a small on-site staff and well-equipped laboratories and field facilities to provide opportunities for Smithsonian scientists and their colleagues to conduct field research in a highly diverse subtropical marine environ-

FIGURE 1. J. Seward Johnson, Sr. (left), and inventor Edwin Link were instrumental in providing funding and submersibles for the Smithsonian's marine research program in Fort Pierce, Florida.

ment. This plan gave Museum scientists the opportunity to extend and broaden their research from museum collections to field studies in such areas as behavior, ecology, physiology, and life histories. Moreover, it provided the opportunity for all Smithsonian marine scientists to carry out comparative studies of the diverse ecosystems and biota within the Fort Pierce vicinity and peninsular Florida and, most importantly, to establish long-term databases and to conduct long-term studies. An important component of the plan was to include postdoctoral fellows, both to complement the research of Smithsonian scientists and to contribute to training of future generations of marine scientists. In addition, by serving many Smithsonian scientists (as opposed to a few resident scientists), the program was conceived to yield maximum productivity of high-quality modern science and to be the most equitable and effective use of available funds.

For the first 18 years the Smithsonian Marine Station at Link Port used a vintage WW II barge as a floating laboratory docked at Harbor Branch (Figure 2) as the base of operations for its highly successful research program, which was carried out primarily by visiting scientists from the Smithsonian, their colleagues, and postdoctoral fellows. Restrictions imposed by the space and structural limitations of the barge for many research activities as well as its high maintenance requirements led the Smithsonian to pursue plans for a land-based laboratory.

In May 1999 these plans were realized when, with the approval of J. Seward Johnson, Jr., and a signed Memo of Understanding, the Smithsonian Marine Station relocated to an 8 acre site acquired from the MacArthur Foundation near the Fort Pierce Inlet, 7 miles south of Harbor Branch. At this time the official name of the station was changed to the Smithsonian Marine Station at Fort Pierce. The move was made into a newly constructed 8,000 square foot building with offices and laboratories for visiting scientists, resident staff and postdoctoral researchers, general-use laboratories for chemistry, microscopy, and molecular research (Figures 3, 4), and a wet laboratory supplied by a small seawater system. In March 2003, a 2,400 square foot storage building was completed. The building includes a workshop and storage for scientific supplies, scuba equipment, and other marine research equipment. In April 2004 a research dock was completed on the Indian River Lagoon, which is accessible by an easement on adjacent property. A flow-through seawater building was

FIGURE 2. A retired World War II Army barge was remodeled to include two levels of offices and laboratories for use by the Smithsonian Marine Station scientists from the early 1970s to 1999.

FIGURE 3. This aerial view shows the location of the Smithsonian Marine Station on the Fort Pierce Inlet of the Indian River Lagoon in Florida.

added to the campus in August 2005. The relocation to the new research building and campus provided the opportunity for the Smithsonian Marine Station to increase and strengthen the breadth and diversity of its research as well as to establish new collaborative interactions. The move also made it possible to expand the Station's educational mission, initiating new cooperative ventures in education and public outreach.

In the struggle to understand life, how its diversity has come about, and the current rapid loss of biodiversity on a global scale, the Smithsonian Marine Station is positioned as are few laboratories in the world to study this exceptional diversity from an array of environments. The Smithsonian Marine Station is located on the Fort Pierce Inlet of the Indian River Lagoon (IRL) (see Figure 3), an estuary extending along one-third the length of the east coast of Florida. The IRL is widely recognized as one of the most diverse estuaries in North America, and it has been designated an estuary of national significance by the Environmental Protection Agency. The Marine Station's unique location on the Fort Pierce Inlet puts it in a prime position to access oceanic waters and to sample organisms from the Florida Current and other offshore habitats. This region of Florida's coast, characterized as a transitional zone where temperate and tropical waters overlap, offers access to a great variety of habitats and an extraordinary diversity of species. To the south of Fort Pierce, within a few hours of travel, are Florida Bay and the Florida Keys, the only living tropical coral reefs in the continental United States.

Specialized equipment and instrumentation at the Smithsonian Marine Station include temperature-controlled aquaria and incubators, equipment for preparing tissues for light and electron microscopy, an ultracold freezer, equipment for electrophoresis, a thermocycler for DNA amplification, high performance liquid chromatographs, a gas chromatograph/mass spectrometer, and a UV-visual spectrophotometer. For microscopic studies, equipment is available for light, epi-fluorescent, and Nomarski microscopy, time-lapse and normal-speed cinematography, photomicrography, video recording and editing, inverted microscopy, scanning and transmission electron microscopy (Figure 5), and confocal laser scanning microscopy.

Confocal laser scanning microscopy (CLSM) has become an increasingly important tool in modern environmental microbiology, larval ecology, developmental biology, and biochemistry. CLSM involves the use of a light microscope, laser light sources, a computer, and special software to image a series of in-focus optical sections through thick specimens. The specimens, which can be live or fixed, are stained with fluorescent dyes that highlight specific structures when excited by the lasers. Once the stacks of two-dimensional (2-D) images are collected, the computer software constructs spectacular, information-rich, three-dimensional (3-D) images that yield a wealth of information. In June 2008, the Smithsonian Marine Station acquired a Zeiss LSM510 confocal system that is already providing data in the cutting-edge studies of Postdoctoral

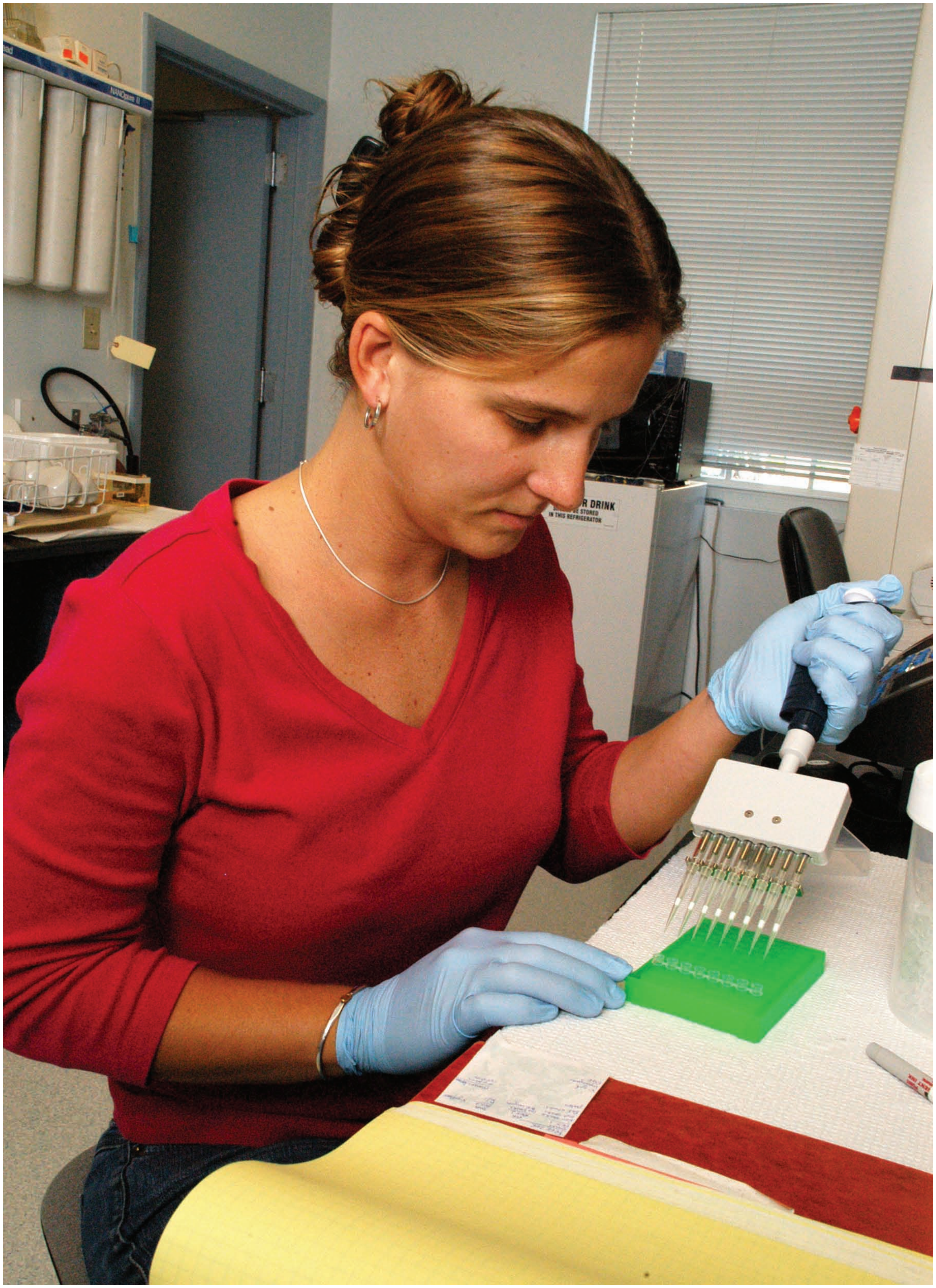


FIGURE 4. Smithsonian Marine Science Network Postdoctoral Fellow Koty Sharp uses molecular methods to determine the diversity of bacteria associated with corals.

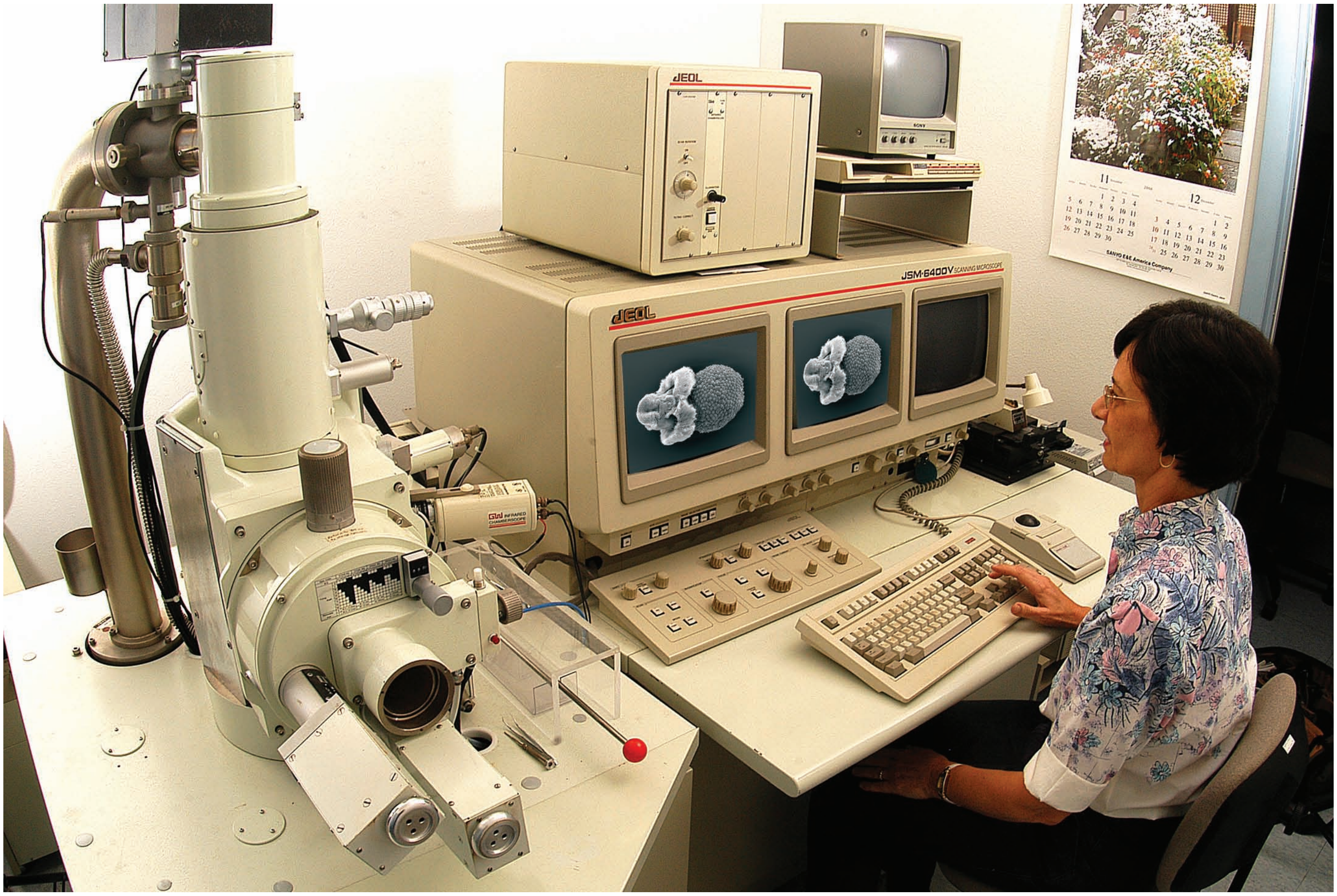


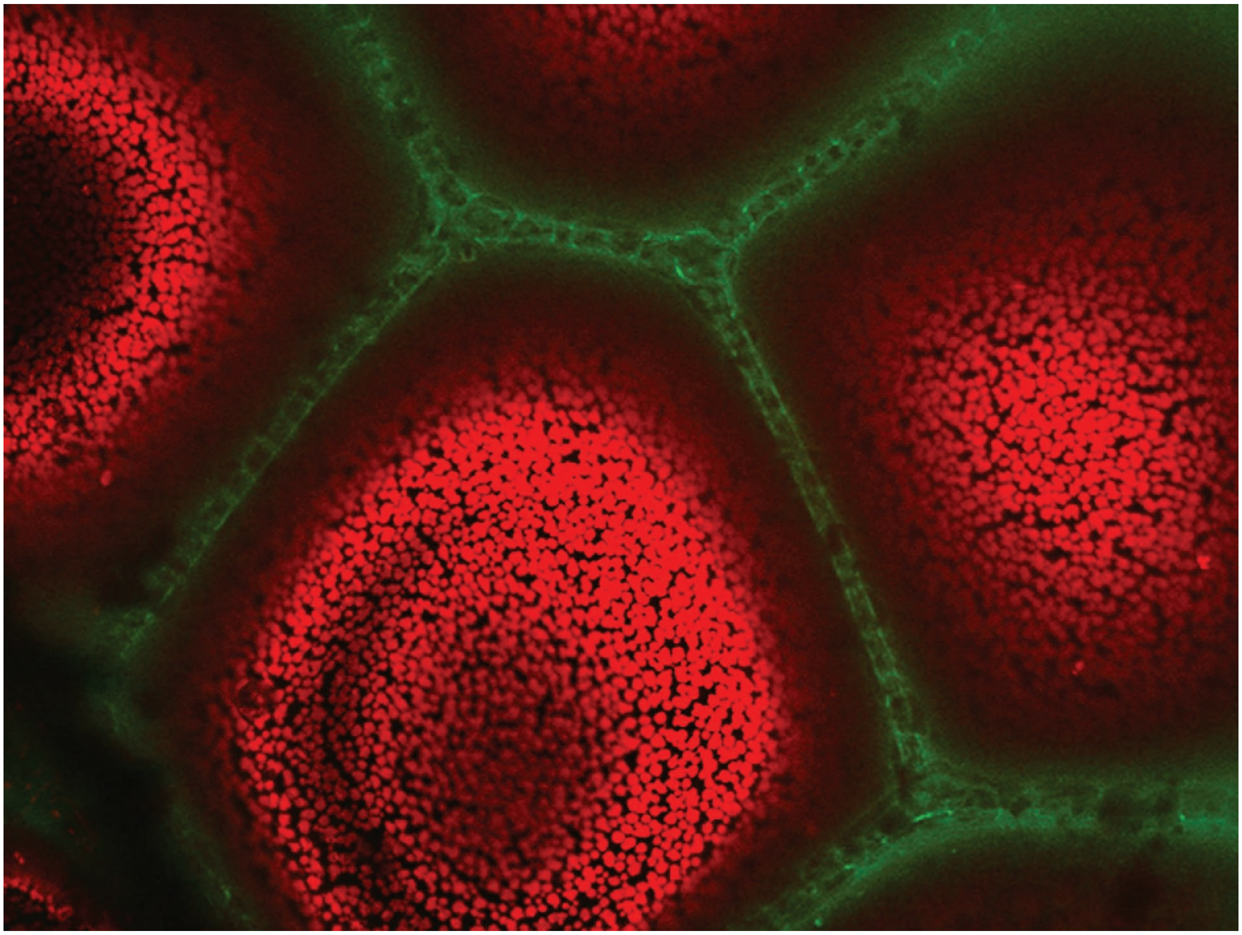
FIGURE 5. Julie Piraino, Laboratory Manager, examines the larva of a sipunculan worm on the scanning electron microscope.

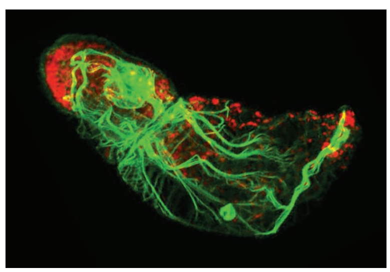
Fellow Koty Sharp on the presence and transmission of bacteria in corals, and in research conducted by Postdoctoral Fellow Kate Rawlinson on the fate of individual cells in the development of embryos of polyclad flatworms. This new microscope will greatly increase the capabilities of Smithsonian marine scientists to conduct probe-based subcellular studies in biochemistry, microbiology, and developmental biology (Figure 6).

The Marine Station owns four boats for use in field studies: a 17 foot Boston Whaler and a 21 foot Carolina Skiff for work in the shallow waters of the IRL, a 21 foot center-console boat to access nearshore waters, and a 39 foot vessel, the R/V *Sunburst*, for offshore research activities. These vessels provide access to the diverse marine and estuarine environments in the vicinity of SMS. The excellent location, facilities, instrumentation, and skilled staff of the Smithsonian Marine Station facilitate research on many diverse topics in marine biology and marine biodiversity.

RESEARCH ACTIVITIES

The Smithsonian Marine Station at Fort Pierce is an important contributor to the marine research and collections at the National Museum of Natural History. It provides a vital link between tropical and temperate ecosystems in a coastal network of marine research stations known as the Smithsonian Marine Science Network. The Marine Science Network (MSN) is an array of laboratories spanning the western Atlantic coastal zone and across the Isthmus of Panama, facilitating long-term interdisciplinary, comparative research among MSN sites, including the Smithsonian Environmental Research Center (SERC)





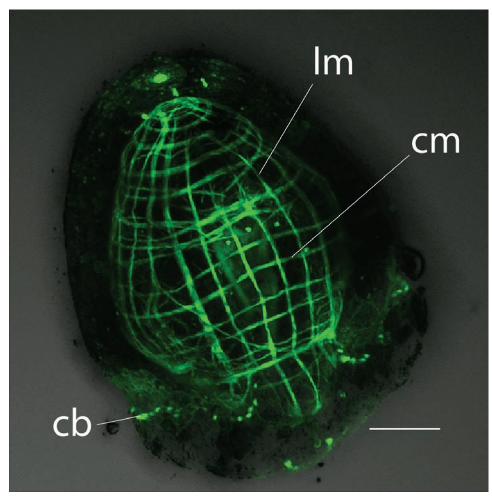


FIGURE 6. Left: Confocal microscopy captures an oxidative burst reaction by the green alga *Dictyosphaeria cavernosa* following exposure to the fungus *Lindra thalassiae*. An oxidative burst is an explosive production of reactive oxygen species (hydrogen peroxide is an example) intended to act as first defense against invading pathogens. Middle: Confocal image shows development of musculature and nervous system in a larva of a sipunculan worm. Right: Confocal laser scanning micrograph of the musculature of a Müller's larva of the flatworm *Cycloporus variegatus*. Phalloidin staining shows circular and longitudinal muscles (cm, lm, respectively) and the ciliary band (cb). Scale = 30 μm.

in Maryland, the Carrie Bow Cay Marine Field Station in Belize, and the Smithsonian Tropical Research Institute (STRI) in Panama.

Research at SMS continues to be carried out by Smithsonian scientists from various units within the Institution along with their colleagues from other national and international institutions, as well as by resident SMS scientists, postdoctoral fellows, and graduate students (Figure 7). Ongoing research programs by resident scientists at the Smithsonian Marine Station involve coral reef research,

FIGURE 7. Visiting Scientist Anastasia Mayorova (kneeling) collects sipunculan worms with the assistance of Mary Rice, Director Emeritus of SMS (left), and Research Technician Woody Lee.

monitoring that is supporting restoration of the Florida Everglades, harmful algal blooms, marine natural products, and invertebrate larval life histories, evolution, and development. The Smithsonian Marine Station promotes the education of emerging scientists by offering pre- and postdoctoral research fellowships and supporting the work of student interns. Examples of ongoing research activities are discussed below.

Marine Biodiversity

The Smithsonian Marine Station has long had a central focus on documenting biodiversity of marine life in the most diverse coastal waters of the continental United States. NMNH invertebrate zoologist David Pawson has discovered and documented echinoderms (sea urchins, sand dollars, sea cucumbers) in shallow and deep waters of Florida for more than 25 years (Hendler et al., 1995). He has found sand dollars that are probably hybrids between two species in the offshore waters of Fort Pierce. Other groups of organisms that have been well studied by NMNH researchers for many decades include the marine algae (Mark and Diane Littler), foraminifera (Marty Buzas), crustaceans (Rafael Lemaitre and colleagues), deep- and shallow-water mollusks (Jerry Harasewych and Ellen Strong), and meiofaunal organisms (animals less than 1 mm in size that live in sand and sediments) (Jon Norenburg and coworkers). Additionally, many SMS scientists, including former director Mary Rice, have focused on understanding the diversity and distribution of larval forms of different groups of marine invertebrates. These larval stages are morphologically and ecologically very different from adult life stages and are extremely important for the transport and propagation of marine species, sometimes over long distances (Figure 8). Tuck Hines and Richard Osman (SERC) have also studied recruitment patterns and larval ecology for a variety of invertebrate larval forms in the IRL. A few examples of the many biodiversity studies conducted at SMS are highlighted below.

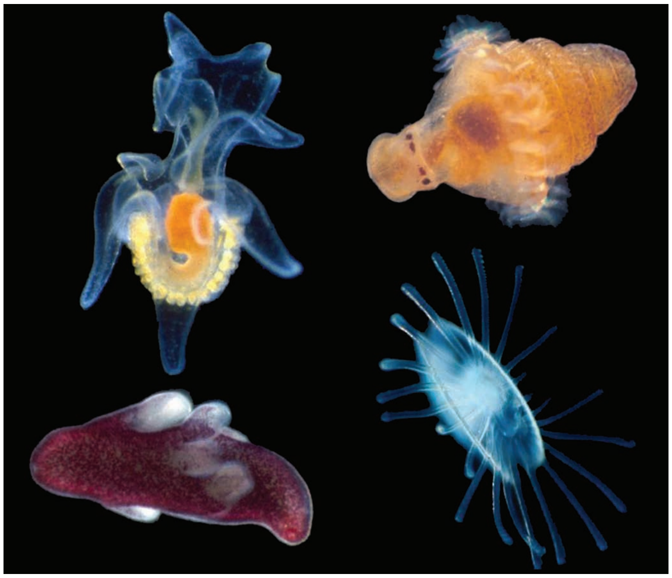


FIGURE 8. Examples of marine invertebrates, the larval development of which has been studied by Mary Rice and colleagues at SMS for more than 30 years. Organisms shown here, clockwise from upper left, are a starfish brachiolarian larva, a sipunculan pelagosphera larva, a brachiopod larva, and a flatworm Muller's larva.

With much of their research focused on ecology, physiology, and pollution-oriented work, Mark and Diane Littler observed a growing need for an easier means for field scientists and resource managers to identify the diverse and abundant marine algal species in the field. They have published user-friendly field guides, including the award-winning book *Caribbean Reef Plants* (Littler and Littler, 2000), with much of their laboratory and field research based at SMS. More recently, with co-author M. Dennis Hanisak (Harbor Branch Oceanographic Institute), they published *Submersed Plants of the Indian River Lagoon: A Floristic Inventory and Field Guide* (Littler et al., 2008), a book rich with photography and illustrations depicting the taxonomy and distributional patterns of more than 250 species of submersed plants in the Indian River Lagoon. The book was based on six years of field and laboratory work along the central east coast of Florida.

D. Wayne Coats, a protistan ecologist at the Smithsonian Environmental Research Center, has worked on the biology and ecology of free-living and symbiotic protists for 20 years. His work has enabled comparisons between the Chesapeake Bay and Indian River Lagoon estuaries and provided enhanced understanding of how eukaryotic microbes influence the structure of marine food webs (Snoeyenbos-West et al., 2004). Much of Coats' work at SMS has considered the biodiversity and trophic biology of protists living in coastal waters of Florida or associated with local marine fauna. He has shown parasitism of planktonic ciliates in the Indian River Lagoon to be a major pathway for recycling material within the microbial loop. Coats and his graduate students have also shown that many free-living photosynthetic dinoflagellates have the ability to feed on ciliate protozoa. Although ingestion rates are typically low, the high densities attained by red-tide dinoflagellates in the Indian River Lagoon and Chesapeake Bay make their ability to ingest ciliates an important microbial food web interaction. Feeding on ciliates and other protists may help sustain blooms when nutrient resources for photosynthesis are limited. Coats and his colleagues have also revealed a rich and poorly known ciliate fauna associated with the respiratory tract of bottle-nosed dolphins and other cetaceans (Ma et al., 2006). Previously reported to be parasitic, these ciliates appear not to directly impact the health of animals held in captivity. Through his work at SMS, Coats has helped define the significance of protists within the marine ecosystem. In some instances, these protists compete directly with zooplankton for food resources, thus limiting the upward movement of energy and matter in the food web. In other instances, they can recycle biomass not readily grazed by zooplankton, thus repackaging it in a form that can move more readily through the food web.

Mary Rice, former director of SMS, established a program of life history studies more than 30 years ago involving numerous postdoctoral fellows and visiting scientists who have worked on a variety of marine invertebrates. Her research has focused on an enigmatic group of marine worms known as sipunculans. Presumably a primitive group related to annelids and mollusks, sipunculans are unique in their complete lack of segmentation and single unpaired ventral nerve cord. One of several objectives of her studies has been the use of developmental studies to understand phylogenetic affinities both within the group and with other spiralian phyla (Schulze and Rice, 2009). Other objectives have been comparative studies of reproductive biology and ecology of shallow-water and deep-sea species, an investigation of the biology of oceanic larvae, including their metamorphosis and their role in species distribution, and a systematic survey of the Sipuncula of Florida and the Caribbean.

In studies of reproductive biology, comparative information was gathered for numerous species on gametogenesis, spawning, egg sizes, egg maturation, fertilization, and reproductive seasonality (Rice, 1989). Year-long observations of reproductive activity in *Phascolion cryptum*, a small species inhabiting discarded gastropod shells in the subtidal waters of the Indian River Lagoon, revealed that—in contrast to temperate species—animals were reproductive throughout the year. A collaborative ultrastructural study of spermiogenesis was also conducted. The most abundant sipunculan of the Indian River Lagoon, this species was recorded in densities up to 2,000 to 3,000 per square meter. No longer found in these densities, the population has declined for reasons unknown (Rice et al., 1983).

Studies of larval biology by Rice and collaborators have concentrated on the oceanic pelagosphera larvae of sipunculans that occur in abundance in the Florida Current, a component of the Gulf Stream System that flows along the edge of the Continental Shelf offshore from Fort Pierce. Reported in warm water currents throughout the world's oceans, these larvae are known to be long lived, existing in the larval stage for 6 to 7 months, and hence to have the potential for widespread species dispersal (Rice, 1981). Continuing for more than three decades, the studies have included descriptions of the various larval morphotypes through light and scanning microscopy, as well as an investigation of factors inducing metamorphosis and the identification of species by rearing larvae to adulthood. Several of the larvae were identified by rearing, surviving in the laboratory for periods of 3 to 26 years as adults. In more recent collaborative studies (with Postdoctoral Fellow Anja Schulze and staff of the NMNH Laboratory of Analytical Biology), genomic analysis, comparing larval and known adult sequences, was utilized to identify additional larval types. These analyses suggested the presence of two cryptic species, characterized by morphologically similar adults but different larval types.

Jon Norenburg (NMNH), together with students, postdoctoral fellows, and collaborators, has been and is focused on discovering nemertean diversity in Florida and using that diversity to address broader questions. In short visits over the course of 20 years they have collected as many as 70 putative species, primarily from the shoreline and shallow coastal waters, from a region with 24 previously known species. Many of the additional species are potential range extensions that await confirmation with specimens from type locales, especially those in southern Brazil, which is the nearest subtropical nemertean fauna that also is well documented. There also are tantalizing preliminary data for close genetic links with European species (Maslakova and Norenburg, 2008). New species have been named, and another 10 to 15 potential new species await additional specimens or genetic work. Most nemerteans have few to no external diagnostics to characterize and discriminate species unambiguously. Almost all the species collected in Florida by Norenburg and coworkers in the past 15 years were processed with genetic work in mind, which will resolve some questions of identity and yield realistic estimates of true diversity and contribute important samples for studying diversification of the phylum (Thollesson and Norenburg, 2003). That effort in Florida is an important component of two global-scale nemertean projects headed by Norenburg: (1) diversity and coevolution of the specialized, ectosymbiotic carcinonemertid worms with their decapod crustacean hosts (mostly crabs), and (2) phylogeny and biogeography of *Ototyphlonemertes*, which are specialized and miniaturized worms occupying the aqueous pore space in coarse sediments, such as coarse sand beaches and in high-current subtidal habitats. Norenburg's study of nemerteans in Florida has contributed important original observations about developmental biology of nemerteans, and one species in particular has revolutionized our understanding of nemertean evolution (Maslakova et al., 2004).

Carole Baldwin and Lee Weigt from the National Museum of Natural History are studying fish diversity, including larval fishes, through DNA barcoding methods. Fish taxonomists have traditionally classified fishes based on morphological features that can be seen and described. However, many families of fishes, such as parrotfishes and gobies, have members that look so similar they are virtually indistinguishable without examining the genetic material. Baldwin and her research team have now cataloged more than 200 species (from more than 1,000 specimens) from the Indian River Lagoon. Processing involved identifying and measuring each fish, photographing its live coloration, taking a tissue sample for DNA analysis, and preserving the rest of the specimen as a voucher for NMNH archival collections. Tissue samples from each specimen were used to create a DNA barcode, which is unique to the individual fish species and can be used for identification purposes. Not only will this work be important for establishing a database of genetic information for fishes of the Indian River Lagoon, it will greatly increase our understanding of shorefish diversity. The overall goal of the work is to provide a new, more realistic estimate of species diversity in the Caribbean, Florida, and adjacent areas. Having amassed DNA extractions from fishes from a variety of taxa and from multiple localities in the tropical Atlantic, the investigators can now examine interspecific phylogenetic relationships to investigate patterns of speciation and potential patterns of morphological divergence accompanying speciation.

Important reasons often cited for understanding biological diversity are the possible benefits these species might yield as foods, medicines, or for other human uses. Valerie Paul, Director of SMS, and members of her research group investigate the chemical diversity of marine organisms by studying marine natural products, small molecules produced as chemical signals or as toxins or chemical defenses. Members of Paul's research team isolate and characterize natural products from Florida's marine life (seaweeds and invertebrates) and have discovered compounds that have never previously been found in nature. A current area of interest for her research group is the biodiversity and chemical diversity of benthic marine Cyanobacteria. Through collaborations with medicinal chemists, they are actively investigating the beneficial uses of these compounds for treatment of human diseases such as cancer and bacterial infections.

Marine Ecology

Valerie Paul studies marine plant–animal interactions in coral reef habitats. Coral reefs in Florida and throughout the world are declining, in part the consequence of shifts from coral- to algal-dominated communities. Paul and members of her research team study grazing by reef fishes and sea urchins and the effects of herbivory on coral reef community structure (Paul et al., 2007). They have found that chemical defenses of marine algae allow some well-defended marine plants to dominate on coral reefs despite grazing pressure. Key to the recovery of coral reefs is the successful recruitment of coral larvae to become juvenile and eventually adult corals (Ritson-Williams et al., 2009). Paul's research group and their collaborators examine positive and negative interactions between coral larvae and the marine algae that dominate coral reef habitats. Some of the same species of algae that are chemically protected from grazers can inhibit the settlement of coral larvae, thus preventing the successful recovery of coral reefs.

Algae are an essential part of marine ecosystems and when maintained in balance can provide food, shelter, oxygen, and more to millions of organisms, including people. But some algae can produce harmful toxins and, under certain conditions, can grow out of control. These so-called harmful algal blooms have been increasing in frequency and severity along the world's coastlines. NMNH scientist Maria Faust has been investigating the types of planktonic harmful algae, often called red tides, which occur along Florida's east coast (Faust and Tester, 2004). Valerie Paul, NMNH Statistician Lee-Ann Hayek, and Postdoctoral Fellows Karen Arthur and Kate Semon have been studying formation of blooms of marine cyanobacteria in Florida's estuaries and coral reefs and trying to elucidate environmental factors that contribute to bloom formation (Paul et al., 2005). Increased nutrients from land-based sources, such as runoff from fertilizers and sewage treatment plants, may help to fuel some of these algal blooms. The biological and biochemical diversity of harmful algae is the subject of ongoing research, which has led to the discovery of novel toxins produced by these cyanobacteria.

Estuaries and coasts around the world are approaching critical levels of degradation, and the southern Indian River Lagoon is no exception. Large-scale, collaborative efforts are underway to restore biodiversity and the vital ecological functions these ecosystems provide. Bjorn Tunberg and members of his benthic ecology research team at SMS are involved in one of the most ambitious of these projects, the Comprehensive Everglades Restoration Plan (CERP). Extensive modifications to the southern IRL watershed over the past 100 years have decreased the system's ability to store water and have increased nutrient-rich stormwater runoff. The CERP plan, under the direction of the South Florida Water Management District and the U.S. Army Corps of Engineers, aims to restore wetlands and build water storage basins to improve estuarine health. Tunberg and his team established a benthic monitoring program five years ago to provide a baseline data set of species distribution and abundance in the sediments of the Indian River Lagoon. This team is acquiring quarterly data that will allow them to detect and predict long-term changes in the benthic communities throughout the central and southern Indian River Lagoon.

The location of the Smithsonian Marine Station on the Indian River Lagoon for 37 years has allowed Smithsonian researchers to establish long-term and intensive research projects that are valuable in understanding and assessing marine biodiversity. Long-term biological monitoring is most effectively carried out on organisms with high densities, many species, short generation times, quick responses to changes in environmental variables, and a long history of extensive study on a worldwide basis. The benthic foraminifera fit these requirements, and their populations have been monitored in the Indian River Lagoon for more than 30 years by Marty Buzas (NMNH).

At one station near the Harbor Branch Oceanographic Institute, monthly replicate sampling of foraminifera living in the sediment has been carried out since 1977. These data indicate significant differences between seasons, as well as among years, but no overall increase or decrease over a longer time span. The spatial distribution of the foraminifera forms an environmental mosaic of patches whose densities change with time. This newly discovered phenomenon was termed pulsating patches (Buzas et al., 2002; Buzas and Hayek, 2005). At the St. Lucie Inlet, observations were made in 1975–1976 and again 30 years later in 2005. Species richness had greatly declined over 30 years, and the community structure of the foraminifera in this area was completely destroyed (Hayek and Buzas, 2006). Monitoring at this Inlet during 2007–2008 has shown that species richness has increased; however, except for the abundant species, the fauna does not contain the same species as it did 30 years ago. Monitoring efforts are continuing, and Buzas and Hayek have also begun a coring program to determine the effects of both natural and anthropogenic effects on community changes during the past 150 years.

Candy Feller, Dennis Whigham, coworkers from the Smithsonian Environmental Research Center (SERC), and national and international collaborators have conducted long-term studies of the mangrove ecosystems of the Indian River Lagoon. The overall goal of this project is to collect hydrological, nutrient, microbial, and vegetation data in support of their long-term ecological studies of factors that control the structure and function of mangrove ecosystems (Figure 9, top). Feller has continued a study of how nutrient enrichment affects the mangrove communities along the Atlantic coast of Florida for the past 10 years. Fertilization experiments designed to enrich nitrogen (N) and phosphorus (P) in sediments have shown that black mangrove forests in Florida are nitrogen limited. When nitrogen was added in the IRL, the black mangroves grew out of their dwarf form (Feller et al., 2003). Addition of N also affected internal dynamics of N and P, caused increases in rates of photosynthesis, and altered patterns of herbivory (Lovelock and Feller, 2003). These findings contrast with results for mangrove forests in Belize and Panama where the seaward fringe was N-limited but the dwarf zone was P-limited. Their studies have demonstrated that patterns of nutrient limitation in mangrove ecosystems are complex, that not all processes respond similarly to the same nutrient, and that similar habitats are not limited by the same nutrient when different mangrove forests are compared (Lovelock et al., 2006; Feller et al., 2007).

Feller and her colleagues have also studied the effects of the 2004 hurricanes Frances and Jeanne on the mangrove communities (Figure 9, bottom). Over the past 4 years they have continued to monitor and quantify the recovery of the mangroves, documenting tree height, leaf area index, mangrove type, mangrove defoliation and recovery, hydrology, and salinity. Damage to the mangroves was higher in the fringe and transition zones than in the dwarf zone. The N-fertilized trees sustained significantly higher damage than controls in all zones and have been slower to recover. After 2.5 years, the leaf area index (LAI) of P-fertilized and control trees was equal to pre-storm levels, whereas +N trees were less than 90% recovered. LAI again decreased dramatically in January 2007, presumably as the result of an intense 2 year drought in Florida.

Dennis Whigham and colleagues from the University of Utrecht, The Netherlands Institute for Ecology–Centre for Limnology, and the University of South Florida are determining the relationships between the structure and productivity of different mangrove habitat types and hydrological processes and nitrogen cycling, including characteristics of the microbial community associated with nitrogen cycling. Their hydrological studies have shown that there is no evidence of freshwater input from groundwater into their study site and that the groundwater chemistry is primarily influenced by evapotranspiration. Subsequently, salt pans and dwarf mangrove communities develop in areas that are characterized by hypersaline conditions associated with evapotranspiraton. Growth rates are lower in the salt pan and dwarf mangrove habitats, and preliminary results indicate that the microbial community in those habitats differs from other habitats.

The studies described above document the morphological, genetic, and biochemical diversity of Florida's marine life. Collectively, these biodiversity and ecological studies and investigations of long-term changes in Florida's coastal waters, including the Indian River Lagoon, mangrove ecosystems in Florida, and coral reef habitats of southeast Florida and the Florida Keys, give us the background essential to document changes in biodiversity resulting from human and climatic impacts on Florida's coastal environments.

EDUCATION AND OUTREACH

As a resource for educators, students, researchers, and the public, the Marine Station maintains a species inventory of plants and animals in the Indian River Lagoon. The Indian River Lagoon Species Inventory website (www.sms.si.edu/IRLspec) is continually expanding and now includes more than 3,000 species with many photographs and scientific references. In addition to individual species

FIGURE 9. Top: From front to back, Smithsonian Marine Station graduate fellow Juliane Vogt (University of Dresden), postdoctoral fellow Cyril Piou, and volunteer Rainer Feller explore the mangrove at Hutchinson Island, Florida, looking for light gaps. Bottom: Sharon Ewe (on left) and Anne Chamberlain examine damage to the mangroves at Hutchinson Island, Florida, immediately after Hurricane Jeanne.

reports that give habitat, distribution, life history, population biology, physical tolerance, and community ecology information, the database includes information on nonnative and endangered, threatened, and special-status species. An electronic companion publication to the Species Inventory is the Field Guide to the Indian River Lagoon (www.sms.si.edu/IRLfieldguide). Both projects have been supported by the Indian River Lagoon National Estuary Program administered by the St. Johns River Water Management District. Features such as an interactive glossary, enhanced indexing, and links to other relevant websites add to the educational value of these websites.

The Smithsonian Marine Ecosystems Exhibit in the St. Lucie County Marine Center celebrated its seventh anniversary in August 2008. Administered by the Smithsonian Marine Station, the exhibit showcases the Caribbean coral reef ecosystem that was a popular exhibit at the National Museum of Natural History for more than 20 years and the first living model of an Atlantic coral reef ecosystem available for public viewing. Through an outpouring of local interest and support, the exhibit was transferred to Fort Pierce to a building constructed and maintained by St. Lucie County for the sole purpose of housing this educational attraction. At the Ecosystems Exhibit, visitors are invited to explore six Florida marine habitats and learn about the complexity and importance of these ecosystems (Figure 10). The largest aquarium houses a Caribbean coral reef display. Additional aquaria depict a seagrass bed, red mangrove coastline, estuarine and nearshore habitats, and a deep-water *Oculina* coral reef. Smaller aquarium displays highlight single species of interest, and a touch tank offers visitors personal interaction with various local invertebrates, such as horseshoe crabs, sea urchins, sea cucumbers, and peppermint shrimp.

This public aquarium is unlike any other, providing an accurate representation of the underwater worlds of the Indian River Lagoon and Atlantic Ocean. Although these waters are a common sight to many coastal Florida residents, few have experienced the unsurpassed diversity of life just below their surface. By highlighting this diversity and displaying local ecosystems as complex communities of organisms interacting in their environments, the Exhibit aims to provide the public with a better understanding of the fragile coastal ecosystems of the Indian River Lagoon and the surrounding area, including the impacts people have on them.

The Smithsonian Marine Ecosystems Exhibit is a field trip destination for thousands of school-aged children each year (Figure 11). Although some choose a self-guided visit, most participate in one of several structured programs facilitated by Education staff members. Program options are age- and grade-appropriate and are structured in compliance with Florida's Sunshine State Standards. Activities include scavenger hunts, water quality experiments, food web and energy transfer studies, simulated benthic sampling, and field experiences in the Indian River Lagoon.

In 2005, education staff at the Exhibit began offering community and visitor programs. Ranging from informative breakfast programs to sleepovers and summer camps, the new programs target traditional visitor groups in new ways, providing more focused and in-depth learning experiences for those interested in taking advantage of the many resources the Smithsonian has to offer. The enthusiastic response from the community has resulted in continual additions to the events calendar.

In addition to being a physical destination for the local community, the Ecosystems Exhibit has also established itself as a valuable resource for local schools and community organizations that do not have the means to travel. Education staff provides classroom outreach programs, bringing the wonders of the underwater world to hundreds of students each school year. Education staff members have also developed Resource Loan Kits for area teachers to borrow for in-classroom use for a two-week time period. The Exhibit website also hosts three webcams that provide live feeds to three of the Exhibit's displays. Online visitors have alternate, unparalleled views into the seagrass and coral reef model ecosystems, as well as through the lens of a laboratory microscope. Future plans include the development of online curricula and activities based on observations made via the webcams.

LOOKING TO THE FUTURE

During the past 37 years the Smithsonian Marine Station at Fort Pierce has developed a strong, broadly based program in marine biodiversity research focusing on systematics, ecology, and life histories of marine organisms. With nearly four decades of research along the IRL, the Smithsonian Marine Station has been able to establish long-term and intensive research projects that are valuable in understanding and assessing marine biodiversity as well as the changes in biodiversity occurring on a global scale. As a result of its excellent location, modern facilities, and experienced staff, the Marine Station is well positioned to continue to address important research topics including global climate change, invasive species, harmful algal blooms, systematics, larval ecology, and evolutionary developmental biology.

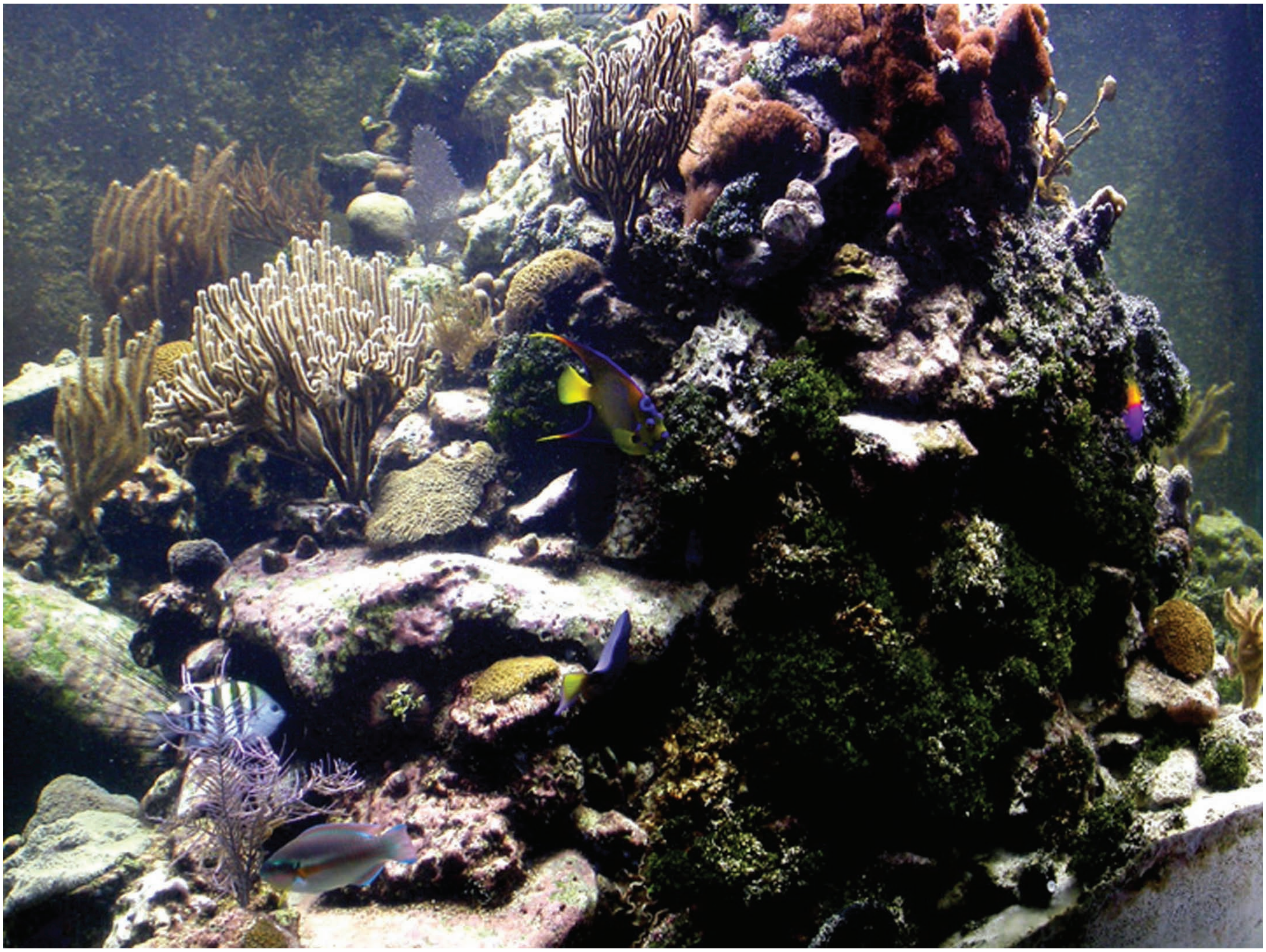


FIGURE 10. The coral reef at the Smithsonian Marine Ecosystems Exhibit.

The Smithsonian Marine Ecosystems Exhibit makes the work of Smithsonian marine researchers accessible to a broad, non-scientific audience. The living displays capture the dynamic quality of natural ecosystems, and the educational offerings are a reflection of the same. Programs, displays, and live exhibits are constantly changing, evolving, and taking on new life, providing a foundation to ensure the Exhibit's future in an ever-changing community.

Acknowledgments

The authors thank the Hunterdon Oceanographic Research Fund and the Florida Fish and Wildlife Conservation Commission (agreement numbers 05011 and 08017) for financial support. We are grateful to the many Smithsonian scientists who provided input about their past and ongoing research activities at SMS. Mary Rice provided many helpful comments that greatly improved this manuscript. This is Smithsonian Marine Station at Fort Pierce Contribution No. 764.

LITERATURE CITED

Buzas, M. A., and L. C. Hayek. 2005. On Richness and Evenness within and between Communities. *Paleobiology*, 31:199–220.

Buzas, M. A., L. C. Hayek, S. A. Reed, and J. A. Jett. 2002. Foraminiferal Densities over Five Years in the Indian River Lagoon, Florida: A Model of Pulsating Patches. *Journal of Foraminiferal Research*, 32:68–93.

Faust, M. A., and P. A. Tester. 2004. "Harmful Dinoflagellates in the Gulf Stream and Atlantic Barrier Coral Reef, Belize." In *Harmful*

FIGURE 11. Top: A young girl takes a closer look at the inhabitants of the seagrass ecosystem. Bottom: Excited children view the nearshore reef ecosystem.

Algae 2002, ed. K. A. Steidinger, J. H. Landsberg, C. R. Tomas, and G. A. Vargo, pp. 326–328. Florida Fish and Wildlife Conservation Commission, Florida Institute of Oceanography, and Intergovernmental Oceanographic Commission of UNESCO, St. Petersburg, Fla.

Feller, I. C., C. E. Lovelock, and K. L. McKee. 2007. Nutrient Addition Differentially Affects Ecological Processes of *Avicennia germinans* in Nitrogen Versus Phosphorus Limited Mangrove Ecosystems. *Ecosystems*, 10:347–359.

Feller, I. C., D. F. Whigham, K. L. McKee, and C. E. Lovelock. 2003. Nitrogen Limitation of Growth and Nutrient Dynamics in a Disturbed Mangrove Forest, Indian River Lagoon, Florida. *Oecologia (Berlin)*, 134:405–414.

Hayek, L. C., and M. A. Buzas. 2006. The Martyrdom of St. Lucie: Decimation of a Meiofauna. *Bulletin of Marine Science*, 79:341–352.

Hendler, G., J. E. Miller, D. L. Pawson, and P. M. Kier. 1995. *Starfish, Sea Urchins and Allies: Echinoderms of Florida and the Caribbean*. Washington, D.C.: Smithsonian Institution Press.

Littler, D. S., and M. M. Littler. 2000. *Caribbean Reef Plants*. Washington, D.C.: Offshore Graphics, Inc.

Littler, D. S., M. M. Littler, and M. D. Hanisak. 2008. *Submersed Plants of the Indian River Lagoon: A Floristic Inventory and Field Guide*. Washington, D.C.: Offshore Graphics, Inc.

Lovelock, C. E., and I. C. Feller. 2003. Photosynthetic Performance and Resource Utilization of Two Mangrove Species Coexisting in a Hypersaline Scrub Forest. *Oecologia (Berlin)*, 134:455–462.

Lovelock, C. E., I. C. Feller, M. C. Ball, B. M. J. Engelbrecht, and M. L. Ewe. 2006. Differences in Plant Function in Phosphorus- and Nitrogen-Limited Mangrove Ecosystems. *New Phytologist*, 172:514–522.

Ma, H., R. M. Overstreet, J. H. Sniezek, M. Solangi, and D. W. Coats. 2006. Two New Species of Symbiotic Ciliates from the Respiratory Tract of Cetaceans with Establishment of a New Genus *Planilamina* n. gen. (Dysteriida, Kyaroikeidae). *Journal of Eukaryotic Microbiology*, 53:407–419.

Maslakova, S. A., M. Q. Martindale, and J. L. Norenburg. 2004. The Vestigial Prototroch in a Basal Nemertean *Carinoma tremaphoros* (Nemertea; Palaeonemertea). *Evolution and Development*, 6: 219–226.

Maslakova, S. A., and J. L. Norenburg. 2008. Revision of the Smiling Worm, Genus *Prosorhochmus* Keferstein, 1862 and Descriptions of a New Species, *Prosorhochmus belizeanus* sp. nov. (Prosorhochmidae, Hoplonemertea, Nemertea) from Florida and Belize. *Journal of Natural History*, 42:1219–1260.

Paul, V. J., K. E. Arthur, R. Ritson-Williams, C. Ross, and K. Sharp. 2007. Chemical Defenses: From Compounds to Communities. *Biological Bulletin*, 213:226–251.

Paul, V. J., R. W. Thacker, K. Banks, and S. Golubic. 2005. Benthic Cyanobacterial Bloom Impacts the Reefs of South Florida (Broward County, USA). *Coral Reefs*, 24:693–697.

Rice, M. E. 1981. Larvae Adrift: Patterns and Problems in Life Histories of Sipunculans. Past-Presidential Address. *American Zoologist*, 21:605–619.

———. 1989. "Comparative Observations of Gametes, Fertilization, and Maturation in Sipunculans." In *Reproduction, Genetics and Distributions of Marine Organisms, 23rd European Marine Biology Symposium*, ed. J. S. Ryland and P. A. Tyler, pp. 167–182. Fredensborg, Denmark: Olsen & Olsen.

Rice, M.E., J. Piraino, and H. F. Reichardt. 1983. Observations on the Ecology and Reproduction of the Sipunculan *Phascolion cryptus* in the Indian River Lagoon. *Florida Scientist*, 46:382–396.

Ritson-Williams, R., S. N. Arnold, N. D. Fogarty, R. S. Steneck, M. Vermeij, and V. J. Paul. 2009. "New Perspectives on Ecological Mechanisms Affecting Coral Recruitment on Reefs." In *Proceedings of the Smithsonian Marine Science Symposium*, ed. M. A. Lang, I. G. Macintyre, and K. Rützler, pp. 437–457. Smithsonian Contributions to the Marine Sciences, No. 38. Washington, D.C.: Smithsonian Institution Scholarly Press.

Snoeyenbos-West, O. L. O., J. Cole, A. Campbell, D. W. Coats, and L. A. Katz. 2004. Molecular Phylogeny of Phyllopharyngean Ciliates and Their Group I Introns. *Journal of Eukaryotic Microbiology*, 51:441–450.

Schulze, A., and M. E. Rice. 2009. Musculature in Sipunculan Worms: Ontogeny and Ancestral States. *Evolution and Development*, 11(1):97–108.

Thollesson, M., and J. L. Norenburg. 2003. Ribbon Worm Relationships–A Phylogeny of the Phylum Nemertea. *Proceedings of the Royal Society of London, B Biological Sciences* 270:407–415.