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The History of Research at the California Academy of Sciences' Steinhart Aquarium and Department of Aquatic Biology

John E. McCosker
Chair of Aquatic Biology and Director Emeritus, Steinhart Aquarium, California Academy of Sciences, 875 Howard Street, San Francisco, CA 94103; Email: jmccosker@calacademy.org

Speaking on September 29th, 1923, the opening day of Steinhart Aquarium, David Starr Jordan of Stanford University said "the people of this city, the children especially, will look with wonder and profit on the hundreds of varied forms of fishes; the men of science will make use of them for extending our knowledge of marine life. The most famous aquarium in the world is the one of Naples. Not for its variety of fishes, for in this regard the Mediterranean cannot compare with Hawaii and the South Seas. It is, however, the center to which hundreds of naturalists all over the world have been drawn for most important studies." Since its founding, the Academy's Steinhart Aquarium has been dedicated to educating the public about its inhabitants and providing research opportunities to its staff, students, and visiting scientists.[1]

The unique facilities possessed by a large public aquarium such as the Steinhart allow research opportunities unavailable to most universities and research laboratories (Figs. 1–2). The diversity of living creatures, as well as the immense water systems, quality control and monitoring systems, which can duplicate various aquatic environments for controlled experimental studies, as well as the "green thumbs" possessed by the staff biologists, have resulted in both serendipitous and directed discoveries, as is evidenced by the resultant myriad publications. In that it is a division of the California Academy of Sciences, the Steinhart shares the same dedication to diversity in its research and display, and it has been recognized throughout its history for the comprehensiveness of its collection of macroinvertebrates, fishes, amphibians and reptiles, as well as aquatic birds and mammals.

With as many as 500–600 species on display, it has been a showcase for teachers and students of evolutionary biology. No other aquarium can boast living exhibits of every (except, alas, a coelacanth) major group of fishes, ranging from hagfish to lungfish and from *Abudefduf* to *Zalieutes*. It is no small coincidence that the first three directors of the Steinhart, Alvin Seale, Earl Herald, and I, trace their taxonomic training to David Starr Jordan, America's most famous ichthyologist and the President of Stanford University and the California Academy of Sciences. Alvin Seale was his student, and Earl S. Herald was also a Stanford graduate, having studied under George S. Myers, who earlier had been a student of David Starr Jordan, J.O. Snyder, and Edwin C. Starks, also at Stanford (see Walford 1970). Although I attended the Scripps Institution of Oceanography (the marine laboratory of Stanford's arch rival, the University of California), members of my doctoral thesis committee included Carl L. Hubbs (who, like George Myers, laid claim to having been Jordan's last student; Hubbs, like Myers, was also a recipient of the Academy's Fellows Medal) and Richard H. Rosenblatt (a student of Boyd Walker of the University of California, Los Angeles

[1] See McCosker (1999a) for an extensive history of the Steinhart Aquarium, and Leviton and Aldrich (1997) for the history of the early Academy.

FIGURE 1. Living adult specimen of midwater eelpout, collected at 600 m depth, and on display in the Aquarium. This was the basis of M. Eric Anderson's master's thesis and demonstrated the unique research opportunities provided by the Steinhart. Photograph by John E. McCosker.

FIGURE 2. Rooftop fish breeding laboratory in the early Steinhart. Photograph courtesy California Academy of Sciences.

[UCLA], who was a student of Hubbs). Seale, Herald, and I were thereby trained in systematic biology and much of our research careers involved studies of the relationships of fishes and the capture, identification, and naming of new species. Seale named 343 new species, mostly in co-authorship with David Starr Jordan; Herald named 23; and at the time of this writing, I am responsible for 93 new specific and 18 new generic names. Excluded from this paper's bibliography are the taxonomic works of Seale, Herald, and the author. Titles of publications involving those systematic studies are listed in Eschmeyer (1998).

The Steinhart's first director, Alvin Seale (1871-1958) (Fig. 3), was a colorful naturalist and explorer who surveyed much of the central and western Pacific, making collections for the Bernice P. Bishop Museum in Honolulu, for Stanford University, and for the Academy (CAS). Much of that material is now housed at CAS. Born in Indiana, he listened intently while David Starr Jordan spoke at his high school graduation. Jordan advised the students to "go where the masters taught," so Seale rode his bicycle across the country to enter Stanford in 1892. His education was interrupted by the Klondike Gold Rush and his tropical Pacific surveys, and he finally graduated in 1905. His later fisheries work in the Philippines and the creation of the Manila Aquarium was followed by an ichthyological curatorship at Harvard University's Museum of Comparative Zoology (MCZ), after which he retired to Santa Cruz, California in 1920. This is all recorded in his intriguing biography (Seale 1946) titled *Quest for the Golden Cloak*.

Seale's retirement was short-lived in that Jordan and then Academy director Barton Warren Evermann invited him to assist in the design of the new Steinhart Aquarium and to become its first Superintendent[2], a position he held until 1941. Seale's research interests were mostly in systematic ichthyology and fishery development. At the Aquarium, he was credited with the of fathering an industry centered on the brine shrimp (*Artemia salina*), a minute crustacean that existed in vast

FIGURE 3. Alvin Seale in his aquarium office. Photograph courtesy California Academy of Sciences.

[2] The formal title 'Director' of Steinhart Aquarium was first used in 1976. Seale was entitled 'Superintendent' and Herald was its 'Curator.' Photograph courtesy California Academy of Sciences.

quantities in San Francisco Bay. His findings were turned over to the San Francisco Aquarium Society (SFAS), founded in 1923, which subsequently marketed live brine shrimp to the growing popular aquarium industry. The SFAS became one of the aquarium's primary benefactors over the years, purchasing specimens such as the Amazon freshwater dolphins and supporting research projects and expeditions. Seale and his staff used their husbandry skills to facilitate the breeding of mosquito fish (*Gambusia affinis*) in order to help control that ubiquitous pest of the Central Valley. Aquarium collectors sampled throughout California and provided both display specimens and valuable data that now reside in the CAS research collections. Regretfully, few other research projects were undertaken during the Steinhart's early years largely because of fiscal and staffing limitations.

Upon reaching the age of seventy, Seale stepped down and was replaced by his assistant, Robert J. Lanier, who served as the Acting Superintendent from 1942 to 1944. Lanier was not a research biologist but studied tropical freshwater fishes, published in popular aquarium journals, and wrote a popular book with Ida Mellen, *1001 Answers to Questions About Your Aquarium* (Mellen and Lanier 1935). Lanier was followed by Wilbert "Wib" Chapman (1910–1970) who was trained in fisheries and systematics and who served CAS both as Curator of Fishes and Interim Superintendent of the Aquarium. Chapman also had a keen interest in tropical aquarium fishes and was responsible for rejuvenating the *Aquarium Journal*, the publication of the SFAS. During the war, Chapman was called to the Pacific to perform government service for the Office of Economic Warfare. The President of the Academy's report states "While details of his work cannot at present be divulged he brought back with him a very large collection of marine fishes which will prove a valuable addition to the Department's series." We now know that Chapman traveled the Pacific to set up local fisheries at island bases so that GIs could dine on fresh fish rations rather than dried haddock. He later became a fisheries advisor for the State Department and the Director of the Van Camp Foundation.

In 1945, Chapman was followed as the Aquarium's Interim Superintendent by John L. Kask, a Canadian fisheries biologist from the University of Washington. Kask's tenure lasted but a year as he was sent to occupied Tokyo on military leave to oversee the Scientific Investigation of the Fisheries Division. He was not involved in aquarium-related research activities. After he left the Steinhart to become head of the Pacific Oceanic Fisheries Investigation, he then moved on to became Director of Fisheries for Canada, and later became the head of the Inter-American Tropical Tuna Commission. Kask was followed in 1946 by Wilbur I. Follett (1901–1992), a lawyer by profession but a passionate ichthyologist by avocation. Bill was also the Academy's Curator of Ichthyology. And, finally, amidst the post-war turmoil, Academy Director Robert C. Miller (Director of CAS from 1935–1963) stepped in to run the Steinhart during 1947 and remained until August 1948, just weeks before the Aquarium celebrated its twenty-fifth anniversary. At that time, Earl S. Herald, a young Stanford graduate who had just returned from military service in the Philippines, was hired as the Aquarium's next Curator, a position he was to hold for the next quarter century (Myers et al. 1974; McCosker 1999a, 2003).

As mentioned earlier, Earl was a product of Stanford and a student of George Myers. His systematic interests concerned syngnathids, the subject of his Ph.D. thesis, but those interests rapidly broadened to include fishes and invertebrates of San Francisco Bay, the population dynamics of elasmobranchs, the biology of freshwater dolphins, and the experimental design and operation of aquatic systems. Much of Earl's career at the Steinhart was devoted to the improvement and ultimate rebuilding of the aquarium, aided in large part by his successful career as the host (from 1952–1966) of the Academy's popular television program, *Science in Action.* Nonetheless, he found time for research and published a number of important works (Fig. 4). Assisted by his wife Olivia ("Pinkie"), and Steinhart secretaries Phyllis Ensrud and Judy McClennahan, he was a prolific

FIGURE 4. Robert Dempster (left) and Earl Herald (right) in the Aquarium's chemistry/pathology laboratory. Photograph courtesy California Academy of Sciences.

writer, participating in the creation of many of the 626 *Science in Action* episodes and authoring 93 publications, mostly scientific, and three books, *Living Fishes of the World* (Herald 1961) (translated and published in eleven languages), *Fishes of North America* (Herald 1972), and the Peterson *Field Guide to Pacific Coast Fishes* (Eschmeyer, Herald, and Hamman 1983).

Herald was eager to add marine mammal display facilities to the Steinhart. Marine and freshwater cetaceans provided research opportunities, as did the serendipitous arrival of an Amazon Manatee (*Trichechus inunguis*). Dubbed "Butterball" (Fig. 5), it resided in the aquarium for 17 years. It made history as one of the few *T. inunguis* ever in captivity and participated in two masters' theses and two doctoral dissertations, as well as six research publications ranging from hematology to chromosomes to vocalizations. Earl's interest in freshwater dolphins led to the capture and display of several Amazonian boutu (*Inia geoffrensis*). They did not survive well in captivity and were susceptible to diseases, which were identified and studied by Stewart Madin, the Aquarium's consulting veterinarian (Pier and Madin 1976). Earl attempted to achieve another Steinhart first with the capture and display of a susu, the blind river dolphin (*Platinista gangetica*) of the Ganges, Indus, and Brahmaputra river systems of southern Asia. Susu were known from the time of Pliny the Elder (72 AD), who wrote about their curious anatomy and the muddy rivers that they inhabited. Earl and associates Robert Brownell (Fig. 6), Frederic Frye, and Elkan Morris obtained three susu while on expedition to Sukkar, West Pakistan, but then they were faced with the formidable task of transporting them half way around the world. Returning with them via Karachi, they made a brief rest stop and left the dolphins in a clearwater swimming pool. There, the researchers were

FIGURE 5. Butterball, the Amazonian manatee that lived 17 years in the Steinhart and was the subject of numerous research projects. Photograph courtesy California Academy of Sciences.

apparently the first to discover that these dolphins swim on their sides, a unique and curious adaptation. The rigors of capture and transport were such that none of them survived for long; however, the results of Herald's research concerning susu anatomy, swimming behavior, and echolocation were published in 1969 as a cover story in *Science* magazine.

Incorporated into the Steinhart's 1963 rebuild were seawater holding facilities and a small laboratory that facilitated research. Visiting researchers and their students used the Steinhart displays and new facilities for studies of *Artemia salina* (by Sarane Bowen of San Francisco State University [SFSU] and her graduate students), immunological reactions of shark blood (by Ben Papermaster of University of California, Berkeley [UCB]), the response of the elasmobranch cardiovascular system to drugs (T.N. Burbridge and S.J. Feinglass of the University of California San Francisco [UCSF]), and the growth of sand dollars (J. Wyatt Durham of UCB). Additional holding facilities were built on the Aquarium's roof for studies of the schooling of clupeoid fishes by Anatole Loukashkin and his associates. The Academy's first biochemical systematics laboratory was installed off the hallway separating the Department of Herpetology from the Aquarium's engine room. In that lab, Earl and Academy herpetologist Alan Leviton and his associates investigated the plasma proteins of elasmobranchs, while Leviton and students pursued additional studies of salamanders and toads, as well as the ontogeny of reptile venoms (e.g., Leviton et al. 1964).

I followed Earl Herald in 1973 as the Aquarium's third long-term director after Earl's untimely death in a diving accident in Mexico. Trained as an evolutionary biologist with a specialization in fish systematics, I broadened my research interests at the Aquarium to range from a combination of field and laboratory studies of aquatic animal evolution and behavior, to microscopic bioluminescent bacteria to macroscopic man-eating elasmobranchs. I held the position of Director until

FIGURE 6. Robert Brownell (left) and Earl Herald (right) returning to San Francisco with a living susu. Studies of the captive susu resulted in a cover article in *Science*. Photograph courtesy California Academy of Sciences.

1994, at which time I became the first occupant of the McCosker Chair of Aquatic Biology. The Academy's research Department of Aquatic Biology officially arose at that time when the Chair of Aquatic Biology was established. Supported by gifts and grants from foundations and individuals, it has been located within the Academy's research Department of Ichthyology. Previous references to the Academy's Department of Aquatic Biology (the title first appeared in the 1940s) concerned the public exhibition function of the Steinhart Aquarium.

Shortly after my arrival in 1973, I discovered that the holy grails of the aquarium profession were the maintenance of a living coelacanth (*Latimeria chalumnae*) and a white shark (*Carcharodon carcharias*). Neither had been successfully kept in captivity and both provided unsurpassed research opportunities. Earl Herald and other aquarium directors had tried but failed in solving the capture and transport dilemmas of both species. Herald made an unsuccessful attempt to obtain permission to collect a living coelacanth at Grande Comoro Island in the far western Indian Ocean. His redesign of the Steinhart in 1963 saved the central tank for a living *Latimeria*. The Comores had been a French colony but in 1974 were soon to be granted independence. Working with filmmaker Al Giddings, algologist Sylvia Earle, pathologist Michael Lagios, Danielle Robineau of the Muséum National d'Histoire Naturelle of Paris and others, an American-French expedition team was quickly assembled that would attempt to film and capture a specimen (see McCosker and McCosker 1976). A preliminary survey team set out in October 1974, and it was followed by the expedition, which ran from January to March 1975. Although the expedition did not

capture a living coelacanth, one effect of a drought that had spread across East Africa, it did return with two frozen coelacanth specimens that had been previously captured, living specimens of flashlight fishes (family Anomalopidae) for the Aquarium, and large collections of preserved fishes, invertebrates, and algae that had been collected by divers between the surface and -75 m. Those materials resulted in the description of numerous new taxa, range extensions, and behaviors. And, in recognition of the importance of our work, then-president Ahmed Abdallah had a postage stamp printed that commemorated the Academy's expedition. One of the frozen *Latimeria* specimens was sold to the Scripps Institution of Oceanography for research and display and fresh tissues of the remaining CAS specimen were made available to researchers associated with a legitimate society having the odd name of Society for the Protection of Old Fishes (SPOOF), resulting in numerous publications, which inspired phylogenetic controversy and progress in the understanding of coelacanth phylogeny (see McCosker and Lagios 1979 and papers by Lagios and Compagno) (Fig. 7).

Among the discoveries made during the 1974/1975 coelacanth expedition was the first capture of living flashlight fishes (family Anomalopidae) from east Africa. Living specimens of *Photoblepharon steinitzi* were returned to the Aquarium and provided visitors an opportunity to observe bioluminescence and research biologists including Jim Morin of UCLA, Kenneth Nealson, and Margo Haygood of the Scripps Institution of Oceanography, and Yaye Herman, Ed Miller, and me of the Steinhart staff with an opportunity to study the behavior of these rare fishes and the symbiotic bacteria that illuminate them (McCosker 1977a).

Attempts to maintain a living white shark involved several Steinhart staff, including David Powell (previously of Sea World, San Diego, and subsequently with the Monterey Bay Aquarium), John Hewitt, Ed Miller, and others. A reward was offered to fishermen who accidently caught juveniles in their gill nets if they would follow a protocol that we had developed to minimize the trauma to the shark until our arrival (see McCosker 1981b; Ellis and McCosker 1991a). After several unsuccessful attempts, a young female was snared in 1980 off Bodega Bay and survived the capture, transport, and introduction to the new Roundabout facility. Our initial success was complicated by the discovery that white sharks are extremely sensitive to weak electrical discharge (Merkel and McCright 1985) in this case due to an electrical leak that was grounded in the tank, and the shark was subsequently returned while alive to the Farallon Islands (Figs. 8, 9). Other studies of white sharks by the author and students in Chile, Australia, Baja California, and at the Farallon Islands involved their life history, thermal physiology, and feeding and attack behavior (Tricas and McCosker 1984; McCosker 1985a; Tricas 1985; McCosker 1987a; and papers by Goldman et al.). With Robert Lea of the California Department of Fish and Game (CDFG), I documented all previous and recent white shark attacks in the eastern Pacific Ocean (McCosker and Lea 1996, 2006). Much of the research accomplished by the staff has appeared in a series of documentary films (broadcast by NOVA, BBC, National Geographic, and others) that have changed our understanding of white shark behavior and helped to formulate public safety policies for coastal waters and create legislation to protect that species. And, as a result of our studies, white shark behavior is now explainable and somewhat predictable, providing recreational ocean users with lifesaving advice.

Also bridging the gap between research and public education was the Aquarium's experience with the loud humming sound that troubled houseboat owners of Sausalito, Richardson Bay during 1985. The monotonous drone was a mystery until a SFSU biologist and Academy Fellow, Tom Neisen, suggested that the source might be a fish. The Aquarium, at the request of the Marin County Noise Abatement Bureau, ultimately demonstrated to an incredulous public that it was caused by mating midshipman (*Porichthys notatus*, also called humming toadfish) (Fig. 10), of the family Batrachoididae (McCosker 1986a, 1986b).

My taxonomic research at the Academy has primarily concerned the snake eels (family

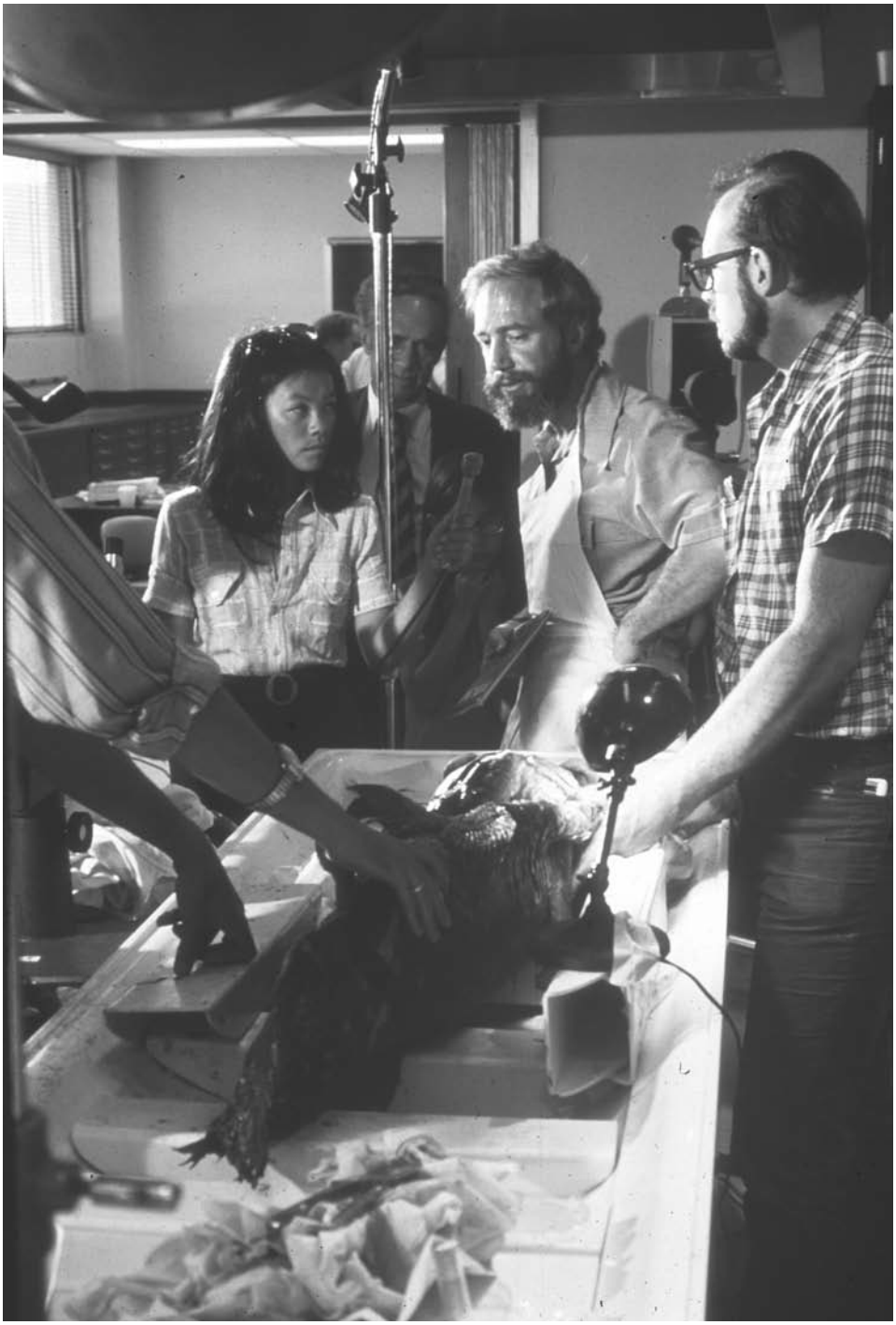

FIGURE 7. One of two coelacanths captured at Isle Grande Comore during the 1975 CAS Expedition. This specimen was dissected by Michael Lagios (second from the right) and several other researchers and the results were published in the 1979 volume entitled *The Biology and Physiology of the Living Coelacanth*. Photograph courtesy California Academy of Sciences.

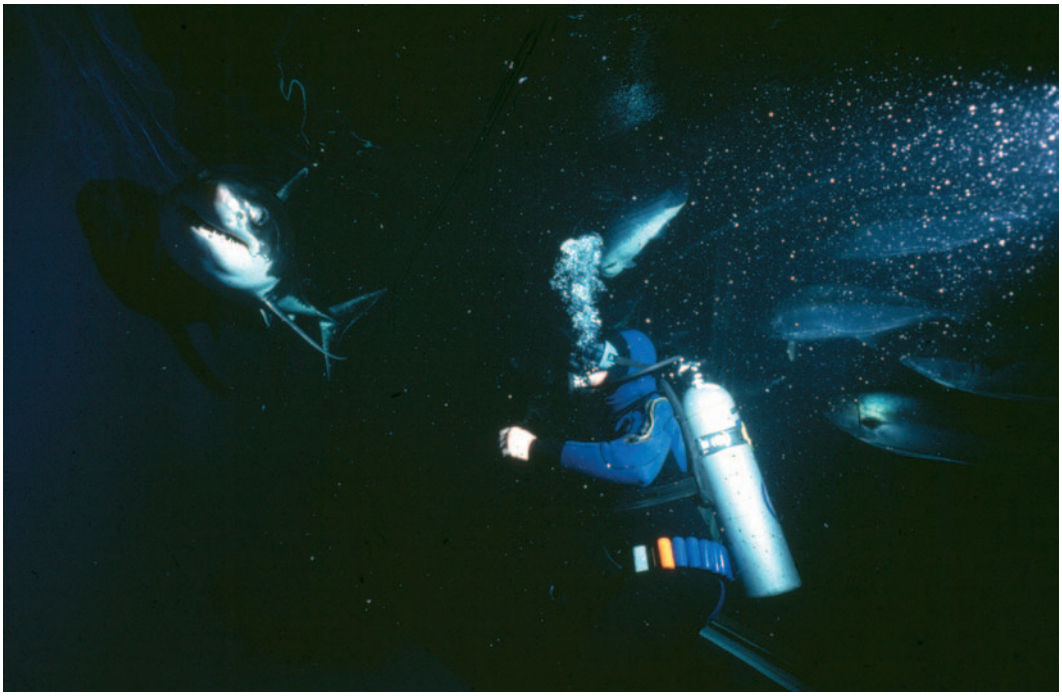

FIGURE 8. Sandy, the white shark that resided in the Roundabout in 1980, allowed the discovery of the extraordinary electrosensitivity of the species. Photograph courtesy of Al Giddings.

Ophichthidae), which were the subject of my dissertation. Subsequent work has involved revisions and descriptions of new taxa of moray eels (family Muraenidae) and of several other families. The eel work provided an important dimension to the understanding of bony fish evolution. These successful but poorly-known groups have, through their evolution, become specialized through anatomical reduction rather than elaboration.

I have continued in the Academy's century-long tradition of Galápagos studies (Fig. 11). The insular endemism of the ichthyofauna is not unlike that of the terrestrial fauna. Colleagues and I made numerous collections and studies using scuba as well as deepwater submersibles to 1000 m depth. As Chief Scientist for expeditions funded by the Discovery Channel (1995) and by IMAX (1998) involving the research submersible *Johnson Sea-Link*, I was able to capture 30 new species of fishes and many new invertebrates, as well as numerous new records and the addition of two fish families (Myrocongridae and Anguillidae) previously unknown from the Galápagos. Other expeditions to Cocos Islands (eastern Pacific), Cuba, Indonesia, New Guinea, Melanesia and Micronesia resulted in the capture of additional new fish species.

Numerous research opportunities arose within the Aquarium's pathology and water quality laboratory as Jordan had predicted on opening day. Many discoveries in aquatic animal husbandry were made in the Steinhart lab, and were later adopted in aquaculture and aquarium practice. As mentioned previously, Seale was also involved with the development and utilization of brine shrimp as an aquarium food stock, with later important contributions made by staff biologists Maurice Rakowicz and Robert P. Dempster (Fig. 4). As Curator and Pathologist, Dempster (at CAS from 1941–1990) was responsible for aquarium prophylactic medication such as the now universal treatment with copper sulfate to counter *Oodinium* parasites. Dempster worked with Mel Donaldson, a Bay Area physician who served in the veterinary lab and performed an important study of the

FIGURE 9. The author feeding a temperature-sensitive transmitter to a white shark off South Australia. Photograph courtesy of Al Giddings.

FIGURE 10. Juveniles of the humming toadfish. Steinhart researchers demonstrated that this species was the source of the bothersome noise in San Francisco Bay. Photograph courtesy of Ken Browning.

effects of cyanide collecting of reef fishes, and published a seminal work on flagyl as a treatment for amebiasis (Donaldson et al. 1975). Herald worked with Dempster on several projects and also studied and promoted the ultraviolet sterilization of seawater for aquarium systems. In a seminal serological study, Herald, Academy herpetologist Alan Leviton, and Dempster examined the role of albumin in the osmolality of captive elasmobranchs (Herald et al. 1970). Other discoveries often had serendipitous results that improved aquarium standards and practices, as occurred during parasitologist John D. Mizelle's (Sacramento State University) visits to the Steinhart. By bathing live fishes in a very dilute formalin bath, he was able to collect ectoparasites without injury to the hosts. Many of these were described as new taxa. The practice then became standard within the quarantine protocol for all incoming fishes. Dempster's successor, George Blasiola (at the Aquarium from 1973–1979), developed the use of quinaldine sulfate as an anaesthetic while he assisted Dempster with water chemistry and pathology. He was followed by Patricia Rainford Morales (at CAS since 1978 but now retired), who had studied and published upon a variety of treatments and conditions, including tuberculosis in fishes, manatees, and reptiles.

Other staff research accomplishments involving aquarium husbandry practices included those of Christina Slager (maintenance of chambered nautilus and the breeding of jackass penguins), followed by Pamela Schaller who continued in the penguin breeding projects; David Powell, John Hewitt, and Edward Miller (maintenance of white sharks); propagation of living coral reefs (Martin Wisner, Lloyd Gomez, and Bart Shepherd); the captive breeding of bushmasters (*Lachesis muta*) by Karl Switak; the breeding of numerous cichlid and other freshwater fish species by Francis Glennon; the breeding of lingcod (*Ophiodon elongatus*) by Robert Dempster and William Rohrs; and the husbandry and breeding of threatened, or rare and endangered species in captivity, includ-

FIGURE 11. The author about to descend to 1000 m off the Galápagos in a submersible. Photograph by John E. McCosker.

FIGURE 12. Jorge Gomezjurado in the Aquarium's seahorse-rearing laboratory. Photograph courtesy California Academy of Sciences.

ing the Pahrump killifish (*Empetrichthys lates*) by Alfred Castro, Pacific giant seahorses (*Hippocampus ingens*) by Jorge Gomezjurado (Fig. 12), red-legged frogs (*Rana aurora*) by Richard Lacer and Ed Ely, and Sacramento River winter-run chinook salmon (*Oncorhynchus tshawytscha*) by David White (Fig. 13).

Several Aquarium staff published numerous articles in popular journals such as the *Aquarium Journal* and the *Drum and Croaker*. Although not the result of their technical researches, it represented their knowledge, wisdom and their passion, and helped educate a large and devoted audience. (The references for popular articles are not included in this article's bibliography.) Herald, Dempster, Switak, Glenn Burghardt, this author, and others actively appeared in those and other journals, but the peerless publisher was Aquarium Collector Donald A. Simpson. Employed from 1945-1961, he published 59 articles on a variety of species and their behaviors, with intriguing titles ranging from "Pantodon keep Don panting" to "Tunnel of love — blind gobies!"

Since its beginning, the Aquarium has had an excellent relationship with the California Department of Fish and Game. Alvin Seale and his staff advised the department about husbandry matters associated with hatcheries and often received specimens for display. John Fitch, the director of the CDFG's State Fisheries Laboratory and a world's expert on fish otoliths, benefitted from the ear bones that were saved for him whenever an exotic fish passed on. Dempster shared his knowledge of parasitology and fish nutrition with the CDFG on a variety of projects. The disappearance of the California sardine (*Sardinops caerulea*) from Monterey Bay in the 1950s motivated the CDFG to begin a series of studies into the life histories of that species and the northern anchovy (*Engraulis mordax*). Between 1950 and 1970, the California Cooperative Oceanic Fisheries Investigations (CALCOFI) supported Anatole S. Loukashkin and other Academy researchers who performed studies concerning the behavior of those important species. In 1991, the Sacramento River winter-run chinook salmon were found to have decreased from historical levels

FIGURE 13. David White (center), manager of the winter-run chinook salmon project, examines a juvenile specimen. Photograph courtesy California Academy of Sciences.

of hundreds of thousands to 191 individuals. Relying on the facilities and skills of the Steinhart Aquarium and its staff to maintain a captive population, and the expertise of geneticists at the UC Bodega Laboratory to maximize the fish's genetic diversity, CDFG and federal agencies asked us to warehouse some of what remained of that endangered population, and the UC lab to develop the technology to genetically identify individuals and stocks. Between 1992 and 2002 we did so, dramatically increasing their number (to several thousand) and probability for survival, educating the public through displays and other educational activities, and designed rapid allele assessments that for the first time identified stocks to allow critical decisions to be made. Konstantin Karpov, a marine biologist at the CDFG Fort Bragg office, developed rockfish (*Sebastes* spp.) tagging techniques within the Aquarium's displays. And, at the request of CDFG, I performed a study (McCosker 1989a) of the inherent dangers of live freshwater eels (*Anguilla* spp.) in California, which became the basis of legislation disallowing their importation. Numerous articles have been published by Aquarium staff in the Department's fine journal, *California Fish and Game*.

Other researchers and agencies have taken advantage of the Aquarium's resources. The following is but a short and incomplete list that demonstrates the variety of those projects. Mwenda Kudumu, a research biologist at the NOAA Tiburon Laboratory, studied the growth of lingcod (*Ophiodon elongatus*) within the Aquarium's displays. Michael Lagios of UCSF and Children's Hospital, San Francisco, investigated primitive and euryhaline fish physiology and anatomy, and was an active member of the 1975 coelacanth expedition. Syd Kraul of the University of Hawaii and Steinhart biologist Edward Miller raised pelagic fishes such as yellowtail (*Seriola lalandi*) and mahi-mahi (*Coryphaena hippurus*). Norman Buell of the National Association of Corrosion Engineers and Ed Miller investigated the weak electric fields within the Roundabout tank relative to shark behavior. Ellen FitzSimmons-Porzig, a professor of human biology at Stanford University,

and her students employed video techniques to photograph living fishes for her research on "Virtual Vertebrates." Aquarium Research Associate William Bennetta and the author solved an eel problem for the Chevron Corporation, which had attempted to reconnect deep sea oil rigs in the Mediterranean. They were thwarted by the presence of large conger eels that had inhabited the pipes; we developed a chemical mixture that repulsed the eels without harming fish or pipe fitters. CAS Associate Larry Eng investigated the invasion of exotic *Corbicula* clams into the Delta-Mendota Canal system. Nancy Baum and Doug Conklin of the UC Bodega Bay laboratory established the absence of gulonolactone oxidase enzyme in their study of ascorbic acid synthesis in osteoglossid bonytongues. Les Timpe and Kathy Logee from the UCSF School of Medicine examined pacemaker currents in ventricular and atrial mRNA of sharks. And (see above) researchers from numerous laboratories benefitted from the tissues of the frozen coelacanth (*Latimeria chalumnae*) that returned with the 1975 expedition.

Several research projects undertaken in the Aquarium involved its plumbing rather than its living collection. In the mid-1970s, with energy consumption recognized as a national concern, the heating, circulation, and illumination of aquarium displays were carefully examined. A number of efficiency measures were undertaken after studies were performed by Pacific Gas and Electric, Interactive Resources Inc., the City's Bureau of Architecture, and FAFCO Solar, resulting in numerous savings and the first installation of a passive solar pass-through aquarium water heating system (McCosker and Tucker 1982). The heated aquarium water was recirculated through the rooftop glazed solar collecting panels and saved the equivalent energy needed to heat 20 San Francisco homes. And even better, the fishes became more amorous in the springtime with increasing solar activity. A spinoff of that project involved the Governor of California's Energy Advisor and Steinhart Research Associate Wilson Clark, who with this author studied "*Dispersed, decentralized and renewable energy sources as alternatives to national vulnerability and war*" (Clark and McCosker 1980) for the US Defense Civil Preparedness Agency. Other projects, such as Dow Chemical's testing of reverse osmosis membranes using Steinhart's various seawater systems, benefitted the scientific and industrial communities.

Many students from San Francisco State University (SFSU), Moss Landing Marine Laboratory (MLML), and beyond have received their graduate degrees working at or closely associated with the Steinhart. Several are particularly noteworthy. M. Eric Anderson, currently one of South Africa's leading ichthyologists, was a MLML student whose thesis concerned the deep sea creatures of the Monterey Canyon. He spent several years experimenting with the husbandry of living deep sea fishes, resulting in his masters degree ("Systematics and natural history of *Lycodapus mandibularis* in California waters" 1977) and the first public display of marine deepwater eelpouts (*Melanostigma pammelas*), which had been captured at a depth of 600 m (McCosker and Anderson 1976). Kenneth J. Goldman, a staff biologist and student at SFSU, received his MS in 1996 for a project entitled "Thermal physiology and behavioral ecology of white sharks, *Carcharodon carcharias*." The design and testing of his telemetric tracking equipment occurred in the Steinhart's tanks, resulting as well in studies of the thermoregulatory activity of California yellowtail (*Seriola lalandi*), giant seabass (*Stereolepis gigas*), and sevengill sharks (*Notorynchus cepedianus*). Other masters theses included Todd W. Anderson's "Identification and development of nearshore juvenile rock fish" (1983); Brooke S. Antrim's "Habitat and food resource utilization of three species of embiotocids in Elkhorn Slough, Monterey Bay, California" (1981); Candis L. Cooperrider's "Toxicity and sublethal effects on fish behavior of the antibiotic, Tylosin" (1982); Leon E. Hallacher's "The comparative morphology of extrinsic gasbladder musculature in the scorpionfish genus *Sebastes*"; Carol A. Wolf's "Reproductive behavior of captive yellowhead jawfish, *Opistognathus aurifrons*" (1982); David A. Ebert's "Aspects of the life history of California's two cow-

shark species, *Notorynchus cepedianus* and *Hexanchus griseus*" (1984); Leslie A. King's "Adult and fetal hemoglobins in the swell shark, *Cephaloscyllium ventriosum*" (1992); Cheryl R. Aday's "Environmental enrichment for dolphins and seals" (1993); and Gabrielle J. Goffinet's "Play behavior in the natural history of captive, black-footed penguins, *Spheniscus demersus*" (1994). Several doctoral dissertations have been based on Steinhart specimens or used other of its resources, such as Gerald T. Todd's (UCLA) "Evolution and the problem of buoyancy in cartilaginous and bony fishes" (1981), Samuel M. Taylor's (UCB) "Understanding processes of informal education: A naturalistic study of visitors to a public aquarium" (1986), and Margo G. Haygood's (UCSD) "Iron regulation of luminescence: Implications for the ecology and symbiotic associations of the luminous bacteria" (Fig. 14) (1984), and others such as Eric Anderson (UCSB), and Fred Schuierer (Stanford).

Subsequent to the Loma Prieta earthquake of 1989 and other temblors in California and elsewhere along the Pacific rim, the staff and trustees of the Academy recognized the need for major seismic reinforcement and rebuild of portions of the Academy, particularly its aquarium. After several studies and deliberations, the decision was made to demolish and rebuild all of the buildings that housed the California Academy of Sciences and its Steinhart Aquarium. The architectural firm of Renzo Piano was enlisted to provide the plans for the new Museum facilities, and planning for the new Steinhart was begun by Academy staff, led by its then-Director Robert Jenkins, and consultants. Jenkins left the Academy in 2004 and I undertook the helm until Dr. Chris Andrews, formerly the Director of the South Carolina Aquarium in Charleston, was hired in 2005. At the time of this writing, the new museum is largely constructed, and it and the Steinhart Aquarium are expected to reopen in late 2008. The new museum will incorporate vastly improved research laboratories for the Aquarium and the Department of Aquatic Biology. The new facilities will allow staff, students, and visiting researchers unique opportunities to continue the study of the aquatic denizens of life on Earth. David Starr Jordan would be proud.

FIGURE 14. *Kryptophanaron alfredi*, the forgotten flashlight fish, on display at the Steinhart and the subject of several research projects. Photograph courtesy of Ken Lucas.

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