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General Introduction: Advances in coral husbandry in public aquaria

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INTRODUCTION

The history of living reef aquariums began nearly fifty years ago at a time when it was inconceivable that a book like this one could be written. Back then, most scientists and aquarists believed that corals were too delicate to survive in an aquarium. Today only a few people hold to that outdated belief, thanks to the efforts of dedicated people over the decades who have solved many of the fundamental problems of coral husbandry and have developed the techniques discussed in this book.

In this introduction, the related stories of coral reef science and the development of reef aquarium systems in public aquariums will be woven together along with the critical role that hobbyists have played in our understanding of coral husbandry techniques. Surprisingly, coral reef scientists, public aquariums and hobbyists do not have a history of close collaboration. However, given the rapid destruction of coral reefs worldwide this situation has changed and today scientists, managers of public aquariums and hobbyists all have a shared desire to learn as much as possible about corals and apply this to the conservation of corals reefs. Reef aquariums have played an important role in the development of our understanding of corals and coral reefs, and they will play an increasingly important role for public aquariums as we seek to foster a greater conservation ethic among our visitors and reverse the environmental factors that have resulted in the destruction of reefs worldwide.

A BRIEF HISTORY OF REEF SCIENCE AND THE DEVELOPMENT OF LIVING REEF EXHIBITS

Charles Darwin's seminal theory on the formation of atolls (Darwin, 1842) was the inspiration for subsequent generations of scientists to begin serious research on the biology and diversity of corals and coral reef ecology. Examples of notable coral researchers and publications of the late 19th century and early 20th century include James Dwight Dana (1846), William Saville-Kent (1893), Alexander Agassiz (1903), Thomas Wayland Vaughn (1907), Charles Maurice Yonge (1930), Siro Kawaguti (1937), John Wells (Vaughan and Wells,1943) and many others.

After a hiatus during World War II, many view 1955 as the start of the modern era of coral reef research with the work of Howard and Eugene Odum on Enewetak atoll in the Pacific (Odum and Odum, 1955). Throughout the 1950's, Enewetak was the site of nuclear testing, but funding was also devoted to biological research at Enewetak and this continued through the end of the 70's. While the Odums' research had some significant shortfalls in experimental design as well as their conclusions about how coral reefs cycle nutrients, their work remains a milestone in coral reef science.

During the same era in another part of the Pacific, the first public exhibits of reef corals went on display at the Noumea Aquarium in New Caledonia under the direction of Rene Catala (the coral *Catalaphyllia* is named in his honor). One of Catala's primary interests was fluorescence in corals – a subject he discussed in detail in his book, Carnival under the Sea (Catala, 1964). For many years, the Noumea Aquarium was the only aquarium in the world with displays of living corals, which was made possible using natural seawater piped in from the ocean.

At nearly the same time, the era of living reef aquariums began with an article by Lee Chin Eng in a 1961 issue of Tropical Fish Hobbyist magazine (Eng, 1961). Eng's "natural system" was further promoted by R.A. Risely (1971) in his book Tropical Marine Aquaria. The "natural system" approach, as it was originally described, is generally no longer accepted, but in the 60's and 70's this work sparked a great deal of interest in the possibility that corals could be successfully kept in aquariums.

In the United States during the 1960's, most aquarists followed the cookbook advice of Robert P.L. Straughan by creating scrupulously clean "sterile" system aquariums (Straughan, 1959, 1975). Corals were thoroughly bleached and cleaned weekly to rid them of algae and detritus. In contrast, Lee Chin Eng's system represented a paradigm shift that broke all of the rules advocated by the sterile system proponents. And yet somehow Eng's system seemed to work, and that sparked a desire among many aquarists around the world to attempt keeping living corals in aquariums.

Inspired by Eng's articles, my first opportunity to work with living corals began in 1972 when I lived in the Fiji Islands. I built my own aquariums and located them near a window since I knew from studies of coral biology that sunlight was important. There are hundreds of species of corals in Fiji and I tried keeping as many different types as possible (as an example of how little was known of corals in the west Pacific at that time, those of us working in Fiji from 1968 – 1975 easily doubled the number of coral genera previously reported from those islands). I had no way to manage water quality in my aquariums other than frequent water changes, and I had only the old "Dyna-flo" filters and undergravel filters to maintain water motion, but this simple system with live rocks, live sand and sunlight allowed me to keep a variety of large-polyp stony corals alive for a year and more.

In 1976 I joined the Waikiki Aquarium in Honolulu, Hawaii. I brought with me the knowledge gained from keeping living corals and giant clams in Fiji and established a living coral exhibit at the Waikiki Aquarium in the fall of 1977. This was the first exhibit of living Pacific corals in the United States (the Noumea Aquarium, as noted earlier, was the first public aquarium to display living corals). The first Waikiki Aquarium exhibit was expanded in 1978 - 79, and some of the corals from that early experimental exhibit are still alive today three decades later, including a very large colony of *Goniopora* that has flourished at the Waikiki Aquarium. More recently, in 2000-2001, I had the privilege of working with Charles Delbeek and assisted him in creating a much larger Pacific Reef exhibit at the Waikiki Aquarium. This exhibit and others like it represent the state of the art for public aquariums today – some of which are featured in these proceedings.

PUBLIC AQUARIUMS AND HOBBYISTS COME TOGETHER

Today there are many outstanding exhibits of living corals in public aquariums throughout the world. But unlike the early exhibits at Noumea and Waikiki, many of the new generation of public aquarium exhibits are fundamentally different and their origins draw almost entirely from advances made by hobbyists. Arguably, the most important advances came from the pioneering work of Peter Wilkens and his colleagues in Germany. In 1973 Wilkens published (in English) the first in a series of books and articles describing a new system for keeping living corals: The Saltwater Aquarium for Tropical Marine Invertebrates (Wilkens, 1973). Wilkens noted that light and water motion were certainly important, but he went further and observed that without the proper water chemistry nothing else mattered. This was not a problem for open-system public aquariums such as Noumea and Waikiki, but for closed-system aquariums breaking through this barrier was the fundamental revelation that made it possible to keep corals alive in home aquariums as well as in public aquariums located far from the ocean. Improving practices and technology for managing water quality continues to be a major topic of concern as can be seen by the topics and discussions in this book.

Wilkins' publications and the many others that followed sparked a revolution in the design and management of reef aquariums. The sterile bleached corals of the 1960's gave way to vibrant coral reefs in living rooms, bedrooms, basements, offices and schoolrooms around the world. Anyone anywhere could now keep corals alive in an aquarium provided he or she had an understanding of the biology of corals, could handle some basic water chemistry, and had the financial wherewithal to buy the necessary equipment and pay for the electric bills!

The rapid growth in the number of hobbyists worldwide keeping reef aquariums has led to the development of newer and better technologies and techniques for culturing, shipping and managing corals, as well as a wealth of books and publications that did not exist prior to 1980. And as often happens with new ideas, alternative methods evolve. Wilken's system of water chemistry management is usually referred to as the "Berlin Method". Jean Jaubert, working with the Monaco Aquarium, proposed a new system primarily for reducing nitrate by creating hypoxic zones in the sand bed and installing an undergravel plenum to improve the efficiency of the process. This has become known as the "Jaubert Method". In the United States, Dr. Walter Adey developed a different system for controlling excess nutrients by growing algae in external trays called algal turf scrubbers. The "Algal Turf Scrubber" system (ATS), as well as the other two systems are in use at public aquariums and home aquariums around the world. Newer systems incorporating mud, sponges, and other innovations are now in use or in development by some aquarists. Time will tell which of these will become the predominant system, or if a combination of systems evolves. Several papers in this book discuss these systems and their strengths and weaknesses.

Concomitant with the development of new water quality management systems has been a growing market demand for new and better life support equipment. This has led to the development of many new products such as calcium reactors, and the Nilsen kalkwasser reactor, as well as dozens of models of foam fractionators, and newer and better lighting systems, including the newest systems using Light emitting diodes or LED's.

The demand for live corals has led to improved methods for collecting, handling and shipping live corals to destinations around the world. Shipping corals submerged in water but protected by floating them from a Styrofoam (styrene) block is the preferred method, but corals may also be shipped without water (the "dry method") provided they are kept damp and are not chilled during shipment.

Hobbyists have also perfected methods for culturing corals in their home aquariums, and also in larger culture facilities maintained at public aquariums, and at commercial coral farming operations. The proof that these methods are successful has been reported hundreds of times and documented in photographs that show how quickly corals grow, as well as by the success of commercial operations involved in coral culture. The skeptics who once argued that corals would not live in aquariums really have no arguments left in the face of this overwhelming evidence.

Giant clams have likewise become a regular part of most reef aquariums. They are now cultured in many Pacific Island countries for food and to replenish wild populations that have been depleted by overfishing but the real market for giant clams has been the aquarium hobby. Sales of cultured giant clams have provided direct economic benefit to many Pacific Island nations. Likewise, the collection and sale of live rocks has provided hard cash for many villages, and more recently cultured live rocks made from concrete have been produced to eliminate any possible criticism that removal of rocks from reefs has a deleterious environmental effect. Coral reef aquariums have even sparked interest in related habitats such as mangroves and sea grass beds and these exhibits can now be seen in public aquariums and even some home aquariums.

BACK TO NATURE

The rapid evolution and proliferation of reef aquarium systems has resulted in many aquarists wanting to travel and experience diving on a real coral reef. One of the first experiences while diving is the realization that there is no "typical" coral reef habitat. Almost everywhere you look the reef seems to change in composition of species. This is true in the Caribbean, but even more so in the Pacific which is far richer in diversity of habitats and species. In the Pacific ocean, there are atolls such as those found in the Marshall Islands and the Line Islands (now part of the island nation of Kiribati). These islands are entirely made up of coral sand and rock. Elsewhere are high islands such as Palau, Fiji and Hawaii. These islands are surrounded by barrier reefs and fringing reefs.

Using a Fiji windward barrier reef as an example of habitat diversity, the outer reef slope at depths of about 10 – 25 meters is often dominated by acroporid corals including large table *Acropora*. In shallower water near the reef crest, the corals are usually smaller and much more compact. This is the result of heavy pounding from waves especially during strong storms and hurricanes. Here the reef surface is hard and pink from the overgrowth of coralline algae and has the appearance of smooth concrete, and in the shallowest water surgeonfish are abundant as this is a zone where algae grows best in heavy surf and bright light. The reef crest itself may be completely exposed to the air (or rain!) at low spring tide. On the Fiji barrier reefs this area is dominated by tough algal species, coralline algae and a few sturdy corals.

Behind the reef crest extends a broad, shallow reef flat that may extend all the way to shore, but on barrier reefs the reef flat gives way slowly to slightly deeper back reef habitats before dropping off into the lagoon. In Fiji, the backreef habitats are filled with a high diversity of stony and soft corals, including more delicate species that cannot survive the pounding of direct surf. Sand is a dominant part of the backreef habitats and many of the corals in this area are in constant danger of being smothered when major storms shift the sands around on the reefs. But while sand is a "waste product" of coral reefs and a hazard for corals, it is necessary for the growth of sea grasses that often dominate in the shallow back reef habitats closest to the lagoons. Sea grass beds are also a prime area to locate some of the prized corals such as *Catalaphyllia* – which would seem at first to be an odd location to find such an interesting and beautiful coral.

In Fiji and other Pacific Islands, such as the Solomon Islands and Palau, there are numerous sheltered lagoons that provide ideal conditions for the growth of many species of corals. In fact, these hard reef habitats, devoid of extensive sand beds, probably come closest to resembling the exhibits we have in our aquariums. But other sheltered lagoon habitats have very little circulation and become almost stagnant. Here the water is turbid and apparently rich in phytoplankton. This does not seem to be an ideal habitat for corals but in fact a wide diversity of large-polyp-stony (LPS) corals are found in such areas, e.g., *Lobophyllia, Symphyllia, Euphyllia, Plerogyra, Physogyra, Goniopora, Heliofungia, Porites, Pavona* and many others. The genus *Acropora* is not absent but few species are found here.

HOW DO OUR AQUARIUM REEFS COMPARE TO REEFS IN NATURE?

Our aquariums can and often do include corals from many of the different reef habitats just described, and surprisingly, they often all thrive under the same conditions, even though in nature they might never be found side-by-side. Most reef aquariums are therefore not very good approximations of any particular reef zone. Furthermore, when we carefully examine our captive reefs and compare them to nature we find that our reef aquariums are really more like gardens.

Reef aquariums are:

- Low in diversity of plants and animals
- Deficient in plankton, larvae, corallivores, and (some) parasites and pathogens
- Relatively high in bacteria and dissolved organic compounds

and they have:

- Lighting that is usually unidirectional
- Essentially no ultraviolet light, and
- Water motion conditions that are low compared to most reefs

Not many reef aquarists are keeping coral-feeding butterflyfishes in their reef tanks, nor are crown-of-thorns seastars very popular, and yet these are animals that play important roles in the development of coral reefs.

One could make the extreme case that our reef aquariums are simply perfect culture systems for zooxanthellae and that our success keeping a wide diversity of corals is a happy side benefit! This is an exaggeration of course, but it helps make the point that reef aquariums (as of 2008) are not good approximations of nature since many key reef organisms will not survive in our present-day systems. Developing new systems to maintain these "missing" organisms remains one of our biggest challenges. Examples of the "missing" animals are hydrozoan corals such as *Distichopora* and *Stylaster*, nearly all of the sea fans, all of the crinoids, tunicates, nearly all of the macro sponges, clams (other than giant clams), and nudibranchs. And then there are the magnificent soft corals in the genus *Dendronephthya* and their relatives such as *Scleronephthya* that have almost become a holy grail for aquarists to try to maintain.

These missing animals are primarily filter feeders (or animals that feed upon them like nudibranchs). But unlike our success with zooxanthellate corals where one solution fits many species, there may not be a single suite of factors that will suffice to keep all filter feeding animals alive. Most of them specialize on specific types of food ranging from bacteria, to zooplankton, to detritus and marine snow. And even with the right type of food, they may require very specific water flow regimes in order to capture these food items. For these reasons, it may be a long time before we see reef aquariums dominated by sea fans, dendronephthyid soft corals, bryozoans, tunicates and other filter feeders (there are encouraging recent reports that some breakthroughs are being made. Read an on-line report by Dr. Charles Matthews (www1)).

Despite the imperfect nature of reef aquarium systems as model ecosystems, what contributions can reef aquariums make to our understanding of coral reefs and their conservation?

1. Reef aquariums can serve as simple model ecosystems allowing researchers to test conditions in a controlled environment that would be difficult or impossible to conduct in the ocean. For example, as atmospheric carbon dioxide increases, what will the long-term impact be on coral reefs? Will ocean acidity increase as more CO_2 dissolves into the water and if so how will this affect calcification? Also, to what extent are corals able to acclimate or adapt to higher sea temperatures that have caused extensive bleaching and mortality in recent years?
2. Hobbyists have created a demand for many reef animals that can now be cultured such as corals, giant clams and live rocks. These techniques can be applied to corals used in research, but another important benefit is the economic impact of this new market in island countries. There is no doubt that in many islands and villages, this has increased the value of the reefs to these communities and therefore they are more interested in their long-term protection.
3. Damage to reefs from ship groundings and other destructive events can be mitigated by replanting corals using techniques developed by aquarists. In other cases, some corals such as *Acropora cervicornis* are rapidly disappearing and may be heading towards extinction in the wild. It is possible that someday this species may only survive in aquariums, awaiting the day when it can be reintroduced to restored habitats.
4. Much has been learned about coral spawning in aquariums, including some of the first observations of spawning corals collected from the Great Barrier Reef. Project SECORE is a great example of how aquarists, mostly from public aquariums, are using this knowledge and their skills with coral husbandry to help ensure the survival of disappearing species of corals.
5. Coral diseases appear in aquariums nearly as often as in nature. We are learning more and more about these diseases and how to treat them, and this may eventually help conservation biologists faced with rampant coral diseases in the field.
6. There are also secrets yet to be unraveled but that have only become apparent after trying to keep some corals alive in our aquariums. Why is *Goniopora* so difficult to keep for most

1. aquarists, and likewise *Heliofungia*? Is there some water chemistry factor that is missing or in the wrong proportions, or is it a problem of insufficient supplemental food, or perhaps incorrect lighting? When we find the answer, we may also learn something more about the environment where these corals live.

Overall the most important contribution that reef aquariums have made towards research and conservation is in education, and the opportunity for people of all ages to see, appreciate and understand what corals and coral reefs are all about. Creating this excitement and interest about coral reefs through exhibits in public aquariums, in home aquariums, and in schools, is by far our most important contribution towards conservation. Our literacy of corals and corals reefs and our understanding of them has increased tremendously largely due to reef aquariums.

LOOKING TO THE FUTURE – CHALLENGES AND OPPORTUNITIES

The future is always uncertain, but at this moment in history the challenges ahead seem daunting, particularly for those concerned about the diversity of life and habitats on this planet. Coral reefs are an area of great concern as formerly pristine areas have become degraded due to chronic pollution, over-fishing, dynamite blasting, and dredging associated encroachment by human populations. More recently, even the most remote regions of the ocean have been affected by rising sea surface temperatures causing catastrophic coral bleaching events world-wide. The unresolved question debated today is the resilience of corals and coral reef ecosystems to withstand these changes and whether they will ultimately adapt to new environmental conditions.

Public aquariums will be challenged to help contain adverse environmental trends that affect wildlife in the field, while at the same time controlling escalating costs at home. Aquariums are terribly expensive to maintain and as energy costs escalate, revenues that could go to research and conservation will be diverted to pay electric bills. Finding less expensive means to move water, provide adequate light, and maintain proper water chemistry will be imperative. In the future, discussions about large-scale reef aquariums may have a greater focus on cost-effective life support systems and alternate energy sources to maintain them.

Coral reef conservation programs will be critically important in the future, as they are today, but new collaborations and associations should be created. A consortium of public aquariums working with other conservation organizations may have more effect than individual organizations working on their own. Already the SECORE project has provided an example of the effectiveness of this approach. This coordination of efforts could also produce more effective exhibits, publications, and documentaries expanding our regional efforts to a global impact to protect coral reefs.

This book, resulting from the first International Symposium on Coral Husbandry in Public Aquaria, provides the first comprehensive summary of advances in coral husbandry techniques from public aquariums around the world. These public reef aquaria are seen by millions of visitors each year. These exhibits have the power to inspire people, especially children, who will become the next generation of scientists and conservation biologists who will help to ensure that coral reefs will endure well into the future. These proceedings will help all of us become more knowledgeable caretakers and the creators of ever more inspiring coral reef aquarium exhibits.

REFERENCES

Agassiz, A., 1903. Coral Reefs of the Tropical Pacific. Harvard University, Museum of Compartive Zoology, Bulletin 33.

Dana, J.D., 1846. Zoophytes. United States Exploring Expedition during the years 1838 - 1842. Volume 7:740 pp.

Darwin, C., 1842. The Structure and Distribution of Coral Reefs. Smith, Elder and Co., London. 355 pp.

Kawaguti, S., 1937. On the physiology of reef corals. I. On the oxygen exchanges of reef corals. II. The effect of light on colour and form of reef corals. III. Regeneration and phototropism in reef corals. Palao Tropical Biological Station Studies 1:187-216.

Odum, H.T. and E.P. Odum, 1955. Trophic structure and productivity of a windward coral reef community on Enewetak Atoll, Ecological Monographs, 25:291-320.

Saville-Kent, W., 1893. The Great Barrier Reef of Australia; its Products and Potentialities. London: W.H. Allen & Co., Limited.

Vaughan, T.W., 1907. Recent Madreporaria of the Hawaiian Islands and Laysan. United States National Museum Bulletin 59:427 pp.

Vaughan, T.W. and J.W. Wells, 1943. Revision of the suborders, families and genera of the Scleractinia. Geological Society of America, Special Paper 44:1-363.

Yonge, C.M., 1930. A year on the Great Barrier Reef: The Story of Corals and of the Greatest of their Creations. London and New York, Putnam.

INTERNET RESOURCES

www1. http://www.reefkeeping.com/issues/2008-02/feature/index.php