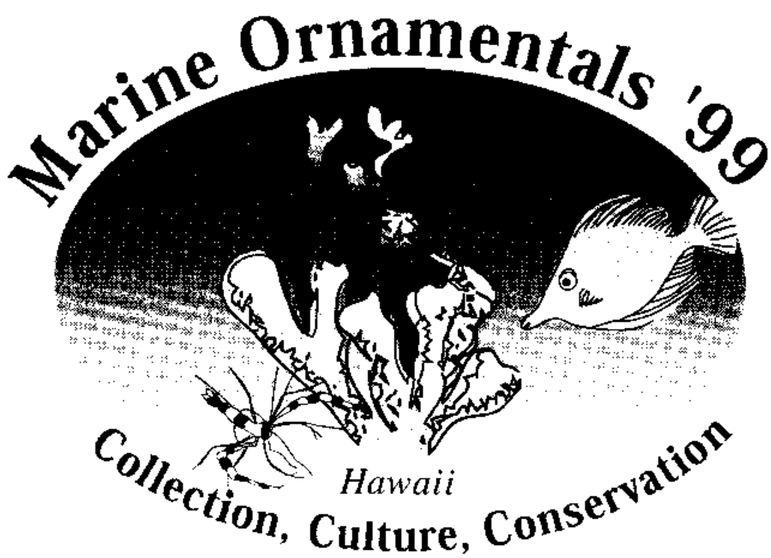
Proceedings of the Marine Ornamentals '99



Waikoloa, Hawaii
November 16-19, 1999

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Marine Ornamentals '99
Hawaii
Collection, Culture, Conservation

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FOREWORD

Marine Ornamentals '99 was a significant meeting owing to the fact that it brought together academics, conservationists, business people and hobbyists for the first time. The papers in this volume are a snapshot of where the ornamentals industry has been and the current trends involving marine ornamentals. Issues that hobbyists and academics must confront are clearly defined, along with the perceptions and concerns of specimen collectors, transshippers, distributors and retailers. The standing stocks of wild invertebrates, finfish and algal ornamental species, are in danger of not having sustainable populations owing to current practices. There is a need to move from the current 2% share of the total trade that is of aquaculture origin to a larger market share. There is a need to develop and rely on sustainable methods and practices that allow for all ornamental species to growout and reproduce. Aquaculture is a promising technology, viewed by many as essential to the future of marine ornamentals. How do we move into an active phase for development of the marine ornamental industry? The papers gathered within this volume are important from the real-world perspective because they

1. Represent the dedication, lifetime work and personal observations of individuals that have built an industry;
2. Present the ground truth as to what is going on in terms of business;
3. Point to problems that required solutions yesterday;
4. Indicate large issues or problems that require solutions for the industry to continue to grow in the future; and,
5. Show resourcefulness of the practical and partial solutions in place that allow the present industry to be profitable.

Ideas and perspectives presented by industry pioneers Martin Moe and Elwyn Segrest are the foundation of the hobby and business. Trends outlined by Stan Brown and Jim Stime indicate that despite the important role of traditional publications, the Internet is changing the face of the hobby and industry too. John Dawes and William Walsh present different sides of the large conservation issues that is shaping the behavior of consumers for this industry. The other papers cover the technical details of culture methods and issues for the industry.

A collective viewpoint suggested by the Oceanic Institute is to take a scientifically-integrated team approach to enhance the culture and production of marine ornamentals, based on advances in other areas of aquaculture. Gary Pruder presents the overview of this approach, with individual contributions from several of the specialists within that institution.

The closing thought we would like to leave with you is this: The diversity of ideas and information shared herein is enough stimulus for future direction. What will you add to this fermenting broth of ideas, to carry the industry forward?

Christopher Brown, Miami, Florida
Leonard Young, Honolulu, Hawaii
March, 2001

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STICKS AND STONES AND BROKEN BONES - CAN ANY WORDS HELP SAVE THE REEFS?

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ABSTRACT

The obligation of aquarium publications in contributing to the responsible development of the marine ornamentals industry is a grave one. The information we decide to present - or choose to omit - can have a great impact on the trends in the hobby. Likewise, in this fast-paced, high-tech industry, publishers have the primary responsibility for the dissemination of information, which will make readers aware of the controversies and of the options they have in dealing with conservation-related issues. Even as far-reaching a conference as Marine Ornamentals ’99 can be, it will directly affect a few hundred people and their immediate contacts. It is the duty of aquarium publications to get the word out to the hobby, in general, for this conference and other related topics. These publications have been instrumental in the growth of the freshwater tropical fish hobby and its supporting industries, and they are currently an integral part of the development of collection, culturing and conservation practices in the marine ornamentals hobby. The commitment of the publications industry to the establishment of an ecologically sound marine hobby will be manifest in its attention to educating their readers, taking a firm editorial stance in the various issues facing the hobby, reporting research and development, and inspiring readers to take a proactive role. A close, sincere, and meaningful alliance between the wordsmiths and the other professionals in the marine ornamentals industry is the key link between the research, innovation, and commitment of exporters, breeders, and environmentalists and the practical reality of an aquarium hobby which will support with its dollars a sane and sound solution to the ecological challenge facing us.

Keywords: publishing, magazines, culture, collection, conservation

Information is Vital

What’s the difference between a minireef aquarist and an ecological terrorist? Your answer to that question will depend on several things: what you know about the ornamental marine hobby, what you know about the environment, what you know about conservation efforts, and so on. In other words, it depends on the information available to you. And information is what the publishing industry is all about. On behalf of TFH’s CEO, Glen Axelrod, whose regrets at being unable to attend this unique conference I bring, and on behalf of TFH Publications and myself, I express gratitude for this opportunity to address you on the topic of the obligations of aquarium hobby publications with respect to the responsible development of the marine ornamentals industry. We take this responsibility very seriously, and I welcome this opportunity to speak to this concern this morning.

As a pioneer in the aquarium publishing field, TFH Publications might be in part credited with - or blamed for - the existence of this industry, but that is really a chicken and egg question, since the growth of the tropical fish hobby and of our publications were simultaneous and mutually interactive. I feel I am on friendly ground here among so many from different facets of the marine ornamental industry; all of us united in the goal to act responsibly toward marine life which gives us such enjoyment and, in many cases, a livelihood as well. We at TFH feel a very deep responsibility to this hobby with which we have had a nurturing and nurtured relationship, and we feel a true kinship with the spirit of this conference.

I said that information is basic to the publishing industry, but aquarium magazines and books provide much more than simple information. We publish stories and articles and reports and editorials, which not only give the reader information about the tropical fish hobby, they present various points of view-philosophies even, ideas which help shape the attitudes of the people who come to us for information. Obviously, we need to provide ecologically responsible viewpoints as well as factually correct information.

This is not always a simple matter. A classic example here concerns the symbiosis between Pomacentrid fishes and Cnidarians. This marvel of nature unfortunately combines some of the best fish for neophyte marine aquarists with invertebrates that have no place in their tanks. A writer may wax poetic about clownfish and anemones, but we must temper the enthusiasm with practical, realistic admonitions about the absolute unsuitability of invertebrates with photosynthetic zooxanthellae for anyone other than an advanced reef hobbyist, and we must do this without making the new aquarist feel overly deprived and therefore reluctant to heed our advice. It benefits all, however, if we also do so in a way, which encourages the new aquarist to hone his or her skills with the goal of being able to manage a reef setup. We walk a literary tightrope between dissuading would-be reef aquarists and irresponsibly encouraging them. We must wear different hats with different readers - giving the experienced reefer the information needed to improve success with raising coral frags, and helping steer the beginner toward more suitable invertebrates like *Lysmata* shrimp. Think of us as your Good Guy/Bad Guy Department.

Even when we are just publishing an article about an individual species or group of species, we must realize that the nature and substance of the information we present can in fact influence the behaviors of aquarists. As editor of *Tropical Fish Hobbyist* Magazine, I was keenly aware of how fine the line occasionally becomes between illustrating an interesting marine organism and fostering a demand for that species. Deservedly or not, materials and ideas presented in hobby magazines can be trend setting. This makes it irresponsible, for example, to do a photo spread of impossibly gorgeous marine nudibranchs without stressing on just about every page their unsuitability as captive specimens. Nevertheless, should some enterprising researcher establish that the Spanish dancer *Hexabranchus sanguineus* can be maintained indefinitely when fed a formula based on Grandma’s chicken liver recipe, we certainly would want to know about it!

On occasion it is our principal intent to influence our readers. One of the first theme issues I put together was on the captive breeding of marine species, and we made every effort to encourage our readers to “buy captive.” The editorial and several articles dealt with the timeliness and importance of this topic, and we even featured a couple of commercial concerns that were leading the way in this field. In the 1950s, hobbyist publications played a key role in the development and acceptance of captive-bred freshwater species, largely by helping to create a keen demand for these fish. Simultaneously, these publications disseminated the information necessary for the successful maintenance of these species, and the exposure the animals got worked to generate an interest in developing successful strategies for breeding these and other fishes. We once again have an opportunity to have this kind of positive effect, this time in the marine sector of the hobby.

History’s Lesson

One might argue that the domestication of freshwater fishes was fueled by economic factors, not ecological ones, and that it is economics, which is holding up the rapid development of captive breeding programs for marine species. After all, the argument would go, today’s world is very different - if 747's, plastic bags, fish tranquilizers, and Styrofoam boxes were widely available in 1954, who would have bothered to learn to breed *Pterophyllum* angelfish?

Probably just about as many as actually did. Very few people who set out to make a fortune breeding a rare or expensive fish realize that goal. On the other hand, fish farmers who build on hobbyists’ successes in breeding particular species are often able to produce economically viable stock. Hobbyists do not breed fish for fortune; they do it out of dedication and interest. Unhindered by gross economic constraints and mass production concerns, they experiment until they find one or more practical protocols which will produce replicable success. As a bonus, their breeding successes produce fish superior in their adaptation to aquarium conditions. At this point, commercial concerns can step in with some possibility of at least breaking even.

I remember standing in awe before the first *Pseudotropheus* cichlids I ever saw. I was in awe both of the spectacular fish and of their price tag. You can buy Malawi cichlids today for prices much less that those original specimens cost - in actual dollars! When you figure in the purchasing power of the dollar back in the 70s, the fish today appear as a genuine bargain. I had the same experience more recently with marines. Examining a tankful of mixed damsels at a local retailer, I noticed that the price on these fish was lower than that of the cichlids I had just been admiring - so much for marine fish being more expensive.

What makes economic viability? Supply and demand are important, of course. But what is often left out of this economic equation is the realization that supply can *stimulate* demand. That’s because aquarists are dreamers and pragmatists at the same time. Each of us has their dream tank all planned out, but each of us knows it’s unlikely we’ll ever have it. It is the spare change in our pocket, which most often determines our next fish purchase. Get the price of a fish down low enough, and usually people will want it - provided they know about it and how to care for it, which is where the magazines come in. Think of us as your Public Database Department. We must, however, be particularly careful in providing data and “advertising” a particular species as a desirable aquarium animal.

The Travelogue Problem

The marine hobbyist today is more likely than any of his or her predecessors to pack a wetsuit and fly off to some tropical locale for diving, photography, and perhaps collection. An article, which a few decades ago would have served armchair hobbyist adventurers as an interesting travelogue, might today serve to give readers ideas for their next vacation. At an American Cichlid Association banquet, I sat at a table with several couples who take regular trips to the Amazon together - something hobbyists of earlier generations left to the likes of Harald Schultz.

Aquarists are as interested as ever in learning the natural history of the species they keep in their tanks, but the cause of conservation is not served when ignorant, untrained, and irresponsible if well-intentioned amateurs descend on the reef to check out the pretty fishes. Camera safaris may help save the elephant, but the fragile reef ecosystem already sees too much traffic. Perhaps we should take our cue from a popular movie and place travelogue posters in our magazines depicting divers being eaten by great white sharks and captioned, “It could happen to you.”

The Nature of the Beast

Aquarium publications are an unusual editorial beast. They combine journalism, the reporting of news and commentary, with scientific writing. Ours are hobby publications, but they are also trade magazines, and many of our readers consider the advertising a vital part of the information for which they purchase them. They provide quality literary material as well as question and answer forums and even cartoons. Our readers include PhDs and schoolchildren, microbiologists, who could easily lecture on the ion transport in a live sand-plenum system and scientific illiterates for whom a distinction between ammonia molecules and ammonium ions is too esoteric.

Well, one might argue, in the marine ornamentals end of the spectrum, we are not interested in schoolchildren or scientific illiterates, but oh, how wrong such an argument would be if you are concerned with the future of this industry! One of the regular contributors to TFH is a young man who began writing for the magazine before he was in high school, and who, because of his youthful fascination with the hobby and breeding tetras and platies and gouramis, has become one of the most successful hobbyist breeders of marine species, having succeeded with over 15 marine species by the age of 18. How many of you can boast such a record?

And, the history of science has plenty of stories about people ignorant of current scientific thinking who made extremely important discoveries and breakthroughs, such as the colorful and controversial Bill Lear, who encumbered only by an eighth-grade education and none of the limitations of a rigid training in engineering, invented both the car radio and the business jet. He was also instrumental in the development of 8-track tapes. Don't laugh - to those whose fortunes were made by hula-hoops or 8-tracks, these fads are no joke, and those of my generation here may need to be reminded that today's kids laugh about LP records. At future marine conferences, references to algal turf scrubbers and powerhead-driven surge devices may raise similar snickers. Aquarium hobbyists are like the rainforest - you never know which part will prove valuable in the future - and both need our conservation and nurturing to survive. Think of the pool of all aquarists as a melting pot of experiences, from which come most of the advancements in the hobby, and think of us publishers as the carrot dangling in front of young, impressionable, and curious minds.

Aquarium publications, therefore, have to have something for everyone. They must remain independent and objective, but they must also be able to identify and advocate the more responsible commercial practices in the industry. And, unavoidably, they will get flack from somebody no matter what stands they take.

Between a Rock and a Hard Place

In today's world of zealous factions on all fronts, we in the marine ornamentals industry find ourselves damned if we do and if we don't. The art of skillful misinformation has been honed to a razor edge, while at the same time, the ability of people to live with self-contradiction seems to be at an all-time high. The activist who monkey wrenches a logging operation will disdainfully decline the clerk's offer of plastic grocery bags in favor of the ecologically friendlier paper. The lobbyist who advocates prohibiting the incarceration of defenseless fish in glass boxes goes home and slathers flea shampoo all over the family dog. Likewise, an article headlined *Aquarium Hobbyists Destroy Fragile Reefs* would immediately get people aroused because of the mortality figures - figures which are caused not by the existence of the aquarium industry, but by the political, social, and technological environment in which the fish collectors live and the exporters and wholesalers work.

If we call for a reduction of fish imports, we are maligned for showing no concern for native peoples whose livelihood depends on them. If we on the other hand encourage such patronage, we are ecological monsters. The jeers are not only from without, however. Our readers are often quick to complain that we and the rest of the industry are trying to rip them off. We can explain that only with captive-bred marines does the hobby have a future, and that a slightly more expensive captive-bred specimen is worth many times the value of an import in terms of hardiness and adaptability. We can argue until we're blue in the face that saving a few dollars with mail-order purchases will eventually drive out the retailers, whose most valuable commodities - advice and experience - are free. It's all to no avail, and we're labeled by some hobbyists as in collusion with the imperialistic "them."

This, of course, is another reason captive-bred marines must become economically viable. All of you mariculturists out there can do your research and development. You can learn and struggle and succeed. But until and unless the public is oriented toward purchasing your product, it will remain out of the mainstream. Lowering its price would certainly turn public opinion in a favorable way, and we, the publishing industry, can also be a major force in that all-important orienting of the public. Think of us as your Education Department, informing the public so that they can make intelligent choices and are motivated to seek out your livestock.

Cutting Some Slack

Aquarium publishing requires us to be conversant in a number of technically complex topics. If I had an ailing coral, I'd certainly turn to Eric Borneman for advice, but I wouldn't expect him to help me deal with Malawi bloat. Dr. Carlson would be a great choice for assistance with a question about the intricacies of ion balance in natural and artificial seawater, but I'm not sure he'd be the one to ask for help in identifying a particular *Cryptocoryne* species. (For all you freshwater-challenged out there, that isn't a fish disease; it's an aquatic plant genus.) Aquarium editors, however, have to get it *all* right, or at least our readers expect us to.

Although you might think I'm leading up to it, this is not going to be an appeal for cutting us editors some slack, though that would be nice, too. Instead, I suggest that we all cut each other some slack. Sometimes the editorial requirement to be jack-of-all-trades offers objectivity not immediately available to those who are more down in the trenches. Despite how it might appear, the importers are not the enemies of the mariculturists, or vice versa. The war between hobbyists and public aquariums exists only in the minds of those who wish such a war. Even such a popular target as the government is neither entirely nemesis nor saint in matters like conservation legislation and import regulations.

In the four-color world of aquarium publishing, we get to see a lot of grey. The same CITES restrictions, which save one species from extinction, can hasten another one to it. Regulations, which favor collection for public aquariums over that for retail sale, can ultimately serve everyone, but they are an area ripe for abuse and for the fostering of ill feelings. If importers do not keep up the flow of marine fish into the marketplace while the mariculturists plant seeds and take root, there won't be any hobbyists around to buy the fish once they are bred on a commercial scale.

Aquarium publishers - think of us as the Great Arbiters.

From This Side of the Editorial Desk

What are some of the things that I look forward to seeing in aquarium publications? From my vantage as an objective observer, as a jack of all aquarium trades, do I have any insights or advice? Sure, else why ask the rhetorical question?

I believe that as has been mentioned, the key to conservation is *domestication*, and aquarium publications will be instrumental in the domestication of marine organisms. I mean by this much more than simply captive breeding of marine species, though that is obviously of paramount importance. I also see a need for a change in viewpoint, from the conceptualization of the marine hobby as an Ark, where natural genotypes can be preserved and maintained in viable numbers, to considering the hobby to be an ornamental and educational re-creation of the natural environment, but an artificial one. We need a shift from a focus on micromanaging a score of ion levels to a more generalized, user-friendly approach.

This is not to say that the current effort by many reef keepers to duplicate as closely as possible the conditions found on the natural reef is invalid. Such a specialized scientific approach, however, is not the way to ensure the future of the marine ornamental industry. We must think of these aquarists as biotope specialists, whose research and development can ultimately benefit the general hobby, though some of their practices will remain only for a select few. For example, many excellent reef aquarists use one or more techniques to provide almost complete nutrient cycling in their tanks. Their procedures, however, which they perform by second nature, are so delicate and complex that many experienced aquarists, let alone neophytes, could never duplicate them. For this majority there is nothing better than that time-honored friend of the beginner. Dare I utter the term in this company? Regular partial water changes. Managing plenums or detritivores or turf scrubbers is and will remain an important part of aquarium science, but it must not cause us to ignore the fact that a very successful marine tank can be maintained without them-for years.

For some hobbyists, the bleaching of a coral specimen and its subsequent taking up of new zooxanthellae might be seen as a failure, but for hobbyists in general, not only might this be perfectly acceptable, it can be a real boon, since domesticated zooxanthellae are often much hardier under aquarium conditions. Are designer corals the way to go, with a long-captive *Acropora* specimen being fragmented, purposely bleached, then recolonized by specific strains of zooxanthellae chosen for color and other attributes? Why not? In fact, it’s already starting to be done!

This is not cheating. It isn’t bad. And it’s great for the industry. Domesticated plants and animals often bear little resemblance to wild species. In the case of freshwater aquarium species, most of the selective breeding has been for different looks-colors, shapes, fin types, etc. The production of such varieties has the advantage of increasing the popular appeal of the hobby, which, in turn, expands the market base and improves the bottom line.

There will always be a place for the specialist. Specialized aquarists play an important role by keeping separate stocks of *Xiphophorus montezumae* and *X. cortezi* , a wonderful example of equal billing among taxonomists, but the aquarium industry is hardly sustained by such specialists. The mass-produced swordtails, which have been hybridized and selectively bred beyond recognition as any particular species varieties, are the lifeblood of the trade.

As generations of captive bred marine fish are produced, latent recessive traits will appear, as they do in nature, but instead of the predators picking out the odd-colored animal, aquaculturists will rush in with their nets, and soon perhaps black and white *ocellaris* clowns, veiltail *Pseudochromis* (or Joyce’s highfin ones), or hot pink *Hippocampus zosterae* will be the hottest items at inflated prices in trendier dealerships. Who knows, we may even have to put up with balloon morphs of our favorite marine species, but the fueling of an insatiable public demand for inexpensive, tank-hardy marines in a plethora of varieties will do more for the economic well-being of this hobby than you could imagine.

Live rock is another good example. Suspend your beliefs and disbeliefs for a moment. Imagine that we have identified from all the organisms which inhabit, encrust, and pop up on live rock, those which can survive in the aquarium. Imagine further that domesticated strains of all these plants and animals and monerans exist, and that their culture has become straightforward. Now imagine that all aquarium rock is quarried on land or created in an aragocrete factory. Lastly, imagine that any hobbyist can go to a dealer and pick up aquacultured rock which was never in the ocean, and which can be custom blended to have whatever colors, shapes, or animations the hobbyist wants on it. Makes any ban on Fiji importations seem trivial, doesn't it?

Am I being too simplistic? Certainly. Few things in this universe are as easy as I've just made this, but I do know that making things complicated from the start is a sure-fire recipe for failure. Reef hobbyists today are pioneers. Like all pioneers, they will probably be immortalized but quickly forgotten, and their trials and accomplishments will be taken for granted, if they're thought about at all. Oh, they will not die out. There will always be a segment of the hobby for these specialists, people with more than average education, scientific training, money, time, and insane obsession. But the things they have learned can be the basis for the growth, the exponential growth of an industry which brings the beauty of the reef into thousands of homes - without destroying the reef being imitated.

Human reefers aren't the only species we can save through these efforts. If we are producing all sorts of domesticated varieties, it will be a simple matter to keep the wild-type stock going as well, and they will undoubtedly be the cheapest. Witness the continued popularity of the plain silver *Pterophyllum* angelfish and the normal oscar *Astronotus ocellatus* even among various pricier mutations. Paradoxically, by broadening the appeal of the hobby with domesticated strains of marine animals, we may be able to partially achieve that Ark status. A situation already exists in the freshwater hobby where several subspecies and perhaps even entire species are extinct in the wild but maintained in captive breeding stock. It isn't the same thing as having the natural populations, but it's the next best thing, and it's a nice ancillary benefit of the maturation of captive breeding techniques, and it will be all we have if the reefs continue dying.

Is this selling out? Is it letting crass mass appeal drive captive breeding programs? You bet! And it's what we need to get those programs jumpstarted.

Domestication

Can the reefs, and reef hobbyists, and other marine hobbyists, the marine ornamentals industry, and worldwide coastal developments all continue indefinitely? No, not as they currently exist - we all would agree to that. If the industry continues as it is, it will undoubtedly be one of several major factors which destroy these unique natural ecosystems. Unfortunately, it is equally certain that if the marine industry were to voluntarily shut down completely tomorrow, the demise of the reefs could still easily occur. This is why conservation would remain an important priority even if all aquarium specimens were captive bred.

The wholesale domestication of reef species, however, can ensure the survival of the marine ornamentals industry. Whether open-ocean farming as with several food species, large-scale farming as with many freshwater species, or commercial aquarium breeding as is typical now, the controlled production of marine ornamentals will do much more than relieve the collection pressures on natural populations; it will also move the industry into a new plane of existence, one parallel to the highly successful freshwater ornamentals industry. It will also lessen the loss if the natural reefs are destroyed.

Publishing's Role

This conference emphasizes a number of areas in which the industry must focus

Its attention, and aquarium publications can assist in all of these areas. Our success depends on you. Whether you work in a public aquarium, a research facility, an import or export concern, a retail establishment, or some other facet of the industry, it is vital that you keep us, the aquarium publishing industry, in mind. We publishers can only serve as a vehicle for the transmission of information if you keep the information coming to us. We need to know of your successes, and of your significant failures - failures whose publication could lead to saving many others from the same dead ends and blind alleys. Aquarium magazines need well-written pieces and crisp photographs which will encourage people to buy only from ecologically responsible sources, which will help counteract the negative opinions about both wild-caught and captive-bred fishes, and which will educate hobbyists in general to set the same goals as we are setting here at Marine Ornamentals ‘99.

Magazines can only publish what you provide. Yes, you. We need everyone’s ideas. Well-polished articles are great, but no editor will turn down important information presented in less than perfect form. As an industry, we agree that an ecologically sound approach is the only economically viable one for this industry. Let us, the publishing component of the industry, assist you.

I repeat here a personal promise I have made at similar public forums - send me *any* information about the ecologically sound collection, conservation, or successful captive culturing of marines, and I will do my personal best to get the material before the public. I say this because I am totally committed to saving the reef, ensuring the survival of the hobby, and promoting the marine ornamentals industry.

The wrong kind of publishing would contribute to the destruction of the reef. The right kind of publishing, however, can be a powerful, positive force in the conservation of the reef and the growth of the marine ornamentals industry.

In defiance of the sing-song children’s taunt, I declare that words *can* hurt the reef, but I guarantee that any words over which I have control will instead be a powerful tool in helping to save it.

INFORMATION EXCHANGE AND CAPTIVE PROPAGATION

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ABSTRACT

The reproductive behaviors and larval rearing techniques for captive marine ornamental livestock are not well documented. Information is scattered among peer reviewed and popular (non-reviewed) publications. Books devoted to the propagation of marine ornamental species are few. Most reports by hobbyist of species spawning and larval rearing are considered “anecdotal” and based on isolated observations. Attempts to scale-down techniques presently used for commercial (food) species have not been successful with many ornamental species. Efforts should be undertaken to establishing a unified resource for related information, drawing from the many and varied reference sources available. The role of the hobbyist should not be overlooked or underestimated and represents individuals or groups which could be incorporated into the data collection process and testing of new methods and techniques. The open exchange and accessibility of information could help reduce the duplication of unsuccessful efforts, shorten the period of time between research and getting a new species into the marketplace, and could make captive bred marine ornamental livestock commercially attractive for both aquaculturist and consumer. The open exchange of information may be the quickest means of increasing the number of marketable species.

Keywords: captive propagation, marine ornamental livestock

Presentation

We live in the information age and the rapid exchange of information can hasten the wheels of progress. Captive propagation of marine ornamental livestock is still in its infancy. Many consider it the savior of the marine aquarium industry. Public opinion can be quickly swayed by this rapid dissemination of information. There is an increasing public awareness about the marine aquarium and it is not all cast in a positive light. Marine aquarists are raiders of the reef and a consumer base with an insatiable appetite for exotic organisms, with little regard for the long-term well being of animals. The pastime of an affluent society is taken at the expense of third world countries.

Information helps distinguish reality from myth. Not only can many marine organisms live in captivity, they will reproduce, and can reach natural size and live long life spans. The marine aquarium is not so complex that only a biologist can be successful. The consumer as well as the general public benefit from the open exchange of information. Consumers need to have access to information that will insure their success. The successful hobbyist is the best form of public relations and represents repeat business. The unsuccessful hobbyist is unlikely to introduce someone to the hobby or continue spending money. Captive propagation should be considered *breeding for success*, not only for the hobbyist-consumer, but also for the industry as a whole. It has been written many times that captive bred animals acclimate better to a captive environment and prepared foods. While I believe it unlikely that captive propagation will ever completely eliminate collection, it can play an important role in the management of resources.

The rapid exchange of information can speed up the wheels of progress. Considering the condemnation received from various groups, hastening the progress of captive propagated species (broader selection and greater availability) would seem to be in the industry's best interests. A *trickle down* approach helps to inform everyone from the collector, wholesaler, retailer, consumer and the general public. Protecting market share cannot be argued as a frivolous business activity, but growing pressures to close or limit collecting areas could result in a very limited market. There is little advantage to being the only game in town if no one is playing your game. While trade secrets and proprietary information are to be respected, I do not believe it realistic to suggest that any operation producing captive bred animals can satisfy a global demand. *Cornering the market* is a shortsighted pitfall.

One must also question how much emphasis is actually placed on captive bred animals. I recently compared three "hobbyist" magazines for advertisers of livestock, who included some mention of having captive bred, tank reared, farmed or cultured livestock, including "live rock". The most recent issues of *Aquarium Fish* magazine (December 1999), *Freshwater and Maine Aquarium* magazine (November, 1999), and *Marine Fish Monthly* (November, 1999), were examined. One out of nineteen advertisers in *Aquarium Fish* magazine offered aquacultured animals, 10 of 38 advertisers in *Freshwater and Marine Aquarium* magazine offered aquacultured animals (or live rock). Two out of seven advertisers in *Marine Fish Monthly* offered aquaculture animal. *Tridacna* clams were offered by many advertisers without mention of its more environmentally friendly status. Hobbyists (and even some retailers) cite the poor availability of captive propagated species as the main reason for continuing to purchase wild collected animals, yet commercial breeders have difficulty establishing a market.

The accessibility of information is a main concern. Many of the techniques used to produce marine ornamental species is adapted from food species. Research on marine ornamentals, while increasing, is still a lower priority. Commercial ventures often have to re-invent the wheel because information was not readily available. A central source for information is presently lacking and represents a time consuming, and often frustrating endeavor.

Conferences, seminars, and local aquarium societies represent sources of information as speakers and attendees present information both formally and casually. Published proceedings are sometimes available but not all material presented becomes part of a published proceeding. Attendance may be restricted by geographic location and the associated costs of attending. Presentations can be more entertaining than enlightening.

Published materials represent a more permanent source that can be used for future reference. Published materials can become outdated and to the unwary reader provide information that is no longer considered valid. Books devoted to marine ornamentals often target the hobbyist. Books devoted to the propagation of marine organisms are even fewer, for example, Moe, 1982, Moe, 1998, and Wilkerson 1998. Reproduction in Reef Fishes (Thresher, 1984) could be included in this very short list. The book was not focused exclusively on marine ornamental fishes, but remains the most comprehensive reference that covers marine ornamental fishes. Scientific journals typically provide peer reviewed papers, which increases the theoretical credibility of the information presented. Small circulation numbers typically result in increased subscription costs which can be a deterrent, especially as there may not be anything relevant to marine ornamental livestock. Popular magazines often more written text but validity is sometimes questionable.

Information presented on CD-ROM and video represents a recent form of media which can offer extensive graphics and audio. CD-ROM's require a computer to *read* , making them less *portable* than printed materials. CD-ROM resources are presently limited. The CD-ROM has great potential as a tool and searchable reference source. *FishBase* (ICLARM, work in progress), *Marine Fish Database System* (Marsden, 1998), *The New Marine Fish and Invert Reef Aquarium* (Thiel, 1998), *Catalog of Fishes* (Eschmeyer, editor, 1998), and *Staghorn Corals: A Key to Species of Acropora* (Wallace, 1999), are all examples of commercially available CD-ROM's, which may be applicable to marine ornamental livestock. All "hard copy" sources of information share a common weakness; they are not readily revisable.

Next we consider the Internet and the Information Highway. Sadly, many might agree that the highway is gridlocked in rush hour traffic. The World Wide Web can be both useful and black hole into which hours of effort yield disappointing results. The credibility of information found on the "web" is a concern. Literally anyone can have a web page and present fact or fiction at will. A recent search of the Internet revealed some startling results. A search was made for "clownfish" using six commonly available search "engines". Results (or "hits" ranged from 25 to 1069. I looked at the first 30 results. 3 search engines yield 1, 2 and 2 resources, which could be commercially obtained as published material. Greater than 10% of all searches were unrelated to the marine clownfish. A smaller percentage was in a language other than English. The majority of sites were commercial sites offering livestock, underwater photography, tourism, or photos and text of personal (individual) aquariums. I attempted to refine the results by searching under "*Amphiprion*". Results (using the same 6 search engines) yielded 7 to 296 results. The first 30 results for each search were looked at. Information, which was commercially available as published materials, yielded better results (5,4,4,7,2,0). The proportion of unrelated sites did not significantly change. Non-English sites increased significantly, almost equaling the published material. Commercial cites remained the major result of the search. The endeavor was time consuming and disappointing.Some sites required "subscriber-ship" to view the entire document. The Information Highway is still under construction but it does represent a means of quick access to information that can be continually updated.

Word of mouth is among the oldest forms of human communication. Whether it is by a lecturer at a conference or a casual conversation at a retail counter, information is exchanged quickly. Credibility is based upon the source and the value of the information as a reference is often restricted to the listener's memory. "Anecdotal" by definition is a story, tale, yarn, and often humorous. Articles and papers published in non-reviewed publications are often labeled as "anecdotal". A noted authority may be spared such skepticism, however many of the popular publications have been guilty of publishing articles filled with vague assertions, weak arguments, few references, biased opinions, and questionable conclusions.

Anecdotal observations do have a place in the exchange of information. If a lone individual makes statements, which contradict the presently held beliefs, we may discount the information. If a number of individuals report similar observations their credibility strengthens. In the area of marine ornamental there is a growing number of serious aquarists with sophisticated systems who are capable of making valid observations and reporting results under a variety of repeatable conditions. Many are neither hindered by funding restraints nor motivated by commercial ambitions and profitability.

Conclusion

The marine ornamental industry can benefit by an open exchange of information. Information must be more readily accessible to those who endeavor to make advances. Needlessly duplicating the efforts (and failures) of others, or spending large amounts of time trying to locate information is counter-productive. One person's "failure" may be the inspiration for another's success. We all perceive things slightly different. Another may overlook what is significant to one person. Comparing and compiling our observations will allow us to more clearly see the whole picture. This concept is one of the founding precepts of the Breeder's Registry. Whether the decision to share information includes our organization or some other means of dissemination is of lesser importance, provided the information is readily available. Time may not be the marine ornamental industry's ally.

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The Breeder's Registry website can be accessed at: http://www.breeders-registry.gen.ca.us

A STUDY OF CORAL NUTRITION IN A CLOSED ENVIRONMENT

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ABSTRACT

Research conducted at St. Louis Children’s Aquarium on a living coral reef exhibit consisting of several thousand living organisms has allowed a better understanding of the chemistry and biology of this complex community. By limiting the chemical changes in the ecosystem and feeding various foodstuffs this research has illuminated some variables in coral nutrition in closed systems.

The effects of adding green algae and brown algae and fish flake food (as a zoo- & photo-plankton replicant) were studied in a 600 gallon living reef ecosystem. Four types of soft coral and five types of hard coral were studied. Regular observations were made in regards to visual appearance, soft-tissue volume (coral volume) calculations, and water chemistry. Green and brown algae from a saltwater greenhouse culture were harvested, pulverized, osmotically shocked, filtered and frozen. Ground-up Wardley Total Tropical Flake Food was homogenized as were the algae additives, in a iso-osmotic saltwater solution. From Awild@ population measurements of plankton the quantity of the additive treatments was determined. Prior to the experiment the coral population was maintained for several months using chemical additives only. Separate trials were run: Brown Algae, Green Algae, and Flake Food nutrients.Coral volume and deportment were assessed prior to, immediately after, and 24 hours after each treatment.

Keywords: coral nutrition, color, volume

Introduction

Coral reefs are called the rainforests of the ocean. And for good reason - while coral reefs only cover about 0.2% of the Earth’s surface, approximately one in four ocean species can be found inhabiting them. More than 5,000 species of fish have been identified, along with over 2,500 species of coral (Reef Relief, 1998). This staggering biodiversity is vitally important to an estimated 30 to 40 million people who use reef fish, mollusks, and urchins as sources of protein. The many different organisms found in reefs also produce compounds that combat inflammations, asthma, heart disease, leukemia, tumors, bacterial and fungal infections, and viruses, including HIV (Chadwick, 1999). Reefs are important to coastal people because they act as a barrier against waves, thus preventing shoreline erosion. The calcium carbonate from sand, shells, and corals living on reefs also helps maintain the pH of the ocean, thus affecting marine life and, by extension, all life on Earth (Reef Relief, 1998).

Unfortunately, an estimated two-thirds of the world’s reefs are dying due to human activities, such as over fishing, mining with explosive devices, careless recreation (i.e., grounding and anchoring of boats), use as decorations, and pollution. Seventy-five percent of all ocean pollution originates on land as oil, fertilizers, pesticides, and silt that results from land development (Reef Relief, 1998).

Concern for the future of corals and a desire to educate others on the importance of coral reefs lead public aquariums to keep coral reef tanks. Home aquarium books, such as Martin Moe's *The Marine Aquarium Handbook* (1992), recommend certain parameters for coral tanks: pH of 8.2, specific gravity of 1.022 to 1.024, and water temperature of about 76 degrees F. Due to a lack of studies on coral nutrition, coral reef tanks are difficult to maintain.

It is known that many coral species have a symbiotic relationship with a type of photosynthesizing algae known as *zooxanthellae*. These corals, called hermatypic corals, obtain up to 98% of their nutritional requirements from the byproducts of the zooxanthellae. The remaining sustenance is believed to come from zooplankton. These tiny animals, plentiful at night, are immobilized by a coral polyp's nematocysts, ensnared on the polyp's tentacles, and then swallowed (Veron, 1993). Ahermatypic corals, those that do not have zooxanthellae living in their tissues, are believed to be carnivores (Veron, 1993); however, their exact sources of food are uncertain.

It is believed that simulating nutrients found in reef ecosystems through the addition of algae, flake food, and live zooplankton will improve the condition of corals in the St. Louis Children's Aquarium's 600-gallon coral reef tank, as shown qualitatively by brighter colors and quantitatively through larger coral volumes.

Materials and Methods

Regular, daily observations of the tank were made so that an understanding of the daily cycles of the different corals, as well as, their overall condition could be reached. These observations span the period of May 28 to July 22, 1999.

On May 28, 1999, a 20-gallon tank, a 30-gallon tank, and a 40-gallon tank were set up in the greenhouse outside the Aquacenter. Each was filled with water made from Instant Ocean ™ salts that had been filtered out of the Aquacenter's shark tank. This water was used because water mixed with salts immediately before use would require time to cycle both chemically and biologically, whereas the recycled water had already been through these processes. An air stone was placed in each tank. Temperature, specific gravity, ammonia, nitrite, and nitrate levels were tested every weekday. On June 4, algae were taken from a saltwater tank inside the Aquacenter, pulverized into a gel-like substance, and added to each greenhouse tank. When a plankton sample taken from the Gulf of Mexico by Gulf Specimen Marine Laboratory (Panacea, FL) arrived on June 8, an equal amount of plankton was added to each of the three tanks (thus, the greatest concentration could be found in the 20-gallon tank). A fourth greenhouse tank was set up on June 16, with two gallons of salt water, also recycled after use in the shark tank, and an air stone. This was the control tank.

On June 18, the dimensions of the tank's corals and sponges were measured, using a plastic ruler to approximate length, width, and height of each of these animals. The corals were measured throughout the experiment to quantify the effects of the added nutrients.

The Leather Corals have a thick stem and then fan out at the top, providing a large, flat round surface from which tentacles emerge. When the Leather Corals are closed, this top becomes fist-shaped and the stem shrinks. These corals were measured in two parts, the stem and the top, with the length of tentacles included in the height measurement of the top. Although the top does have many tentacles, it is not densely packed, resulting in an overestimation of the volume.

The Green *Goniopora* was divided into two sides for measurement. Even when the polyps were extended, one side was droopier and shorter than the other. The two sides were measured separately and then the volumes were added together to provide an approximation of total volume.

At the end of the study, before any data were analyzed, an objective decision was made as to which corals were healthy enough to be included in the analysis. The corals decided upon were a mushroom polyp (only one was measured each time due to the large number of mushroom polyps in the tank), two types of Leather Coral (referred to as the Big Leather and the Baby Leather), Elegance, an open brain coral that had separated from its skeleton, referred to as the Separated Brain, Button Polyps, Bubble Coral, Pearl (a type of bubble coral), and a Green *Goniopora*.

Through the daily observations, it was observed that corals appeared to be healthier one to two days after the tank was algae scrubbed. The cause for this could be either the algae providing nutrients to the corals or the water motion created by the movement of the algae scrubber. In addition to using algae to feed the corals, it was decided to do a simulated algae scrub - using the algae scrubber to make the same movement in the water that would be made during an algae scrub without actually freeing algae from the side of the tank. This simulated algae scrub was completed June 28.

Adey and Loveland (1991) noted that, for every square meter (m^2) of ocean surface area of a St. Croix reef, approximately two grams (g.) of dry plankton are available for consumption each day. The surface area of the Aquacenter’s tank, along with the tanks below, was determined to be 3.53 m^2. From this, it was decided to add 7 g. of dry algae, flake food, or zooplankton each day. For several months before this experiment, the tank was maintained using only chemical additives.

Algae were collected from the greenhouse tanks on June 30. As these algal samples were dark brown, this trial will be referred to as the brown algae trial. The algae was osmotically shocked, by being mixed with freshwater, to kill any living plankton or bacteria. It was then left to filter overnight. On July 1, approximately 7 g. of algae were added to 350 milliliters (ml.) of water from the coral tank and blended on high speed for five minutes. This reduced the algae to the size of plankton. The mixture was then distributed evenly in the coral tank, around 11:45 a.m. Later in the day, around 5:00 p.m., the corals were measured. This process was also completed July 2. On July 3 and 4, algae were added to the tank in the same manner, but the corals were not measured. A measurement was made around 4:00 p.m. on July 5. This was used as both a day-after measurement for the first algae trial and as a before-treatment measurement for the flake food trial.

On July 5 and 6, Wardley Total Tropical ™ flake food was added to the tank around 4:30 p.m.. Approximately 7 g. of flake food was blended with 350 ml. of water from the coral tank and added to the tank each day. The corals were measured immediately before and approximately 20 minutes after each addition of flake food. This trial was discontinued after only two days due to increasingly negative appearance of the corals. On July 7, the day after the last addition of flake food, the corals were again measured.

In early July, it was realized that the attempts to grow plankton in the greenhouse tanks had been unsuccessful. A decision was made to do one more trial in the 600-gallon tank using algae from the greenhouse tanks.

Due to the growth of red, filmy algae in the 20-gallon tank, only algae from the 40-gallon tank were used. It was scraped from the tank on July 16, osmotically shocked, and filtered overnight. This algal sample was not all green, but it contained more green than the previously used algae. Thus, the second algae trial will be referred to as the green algae trial. Approximately 7 g. of this algae were mixed with water from the coral tank, blended on high for 5 minutes, and added to the 600-gallon tank on July 19, 20, and 21 between 4:30 and 5:00 p.m. The corals were measured both before and after each feeding. A measurement was also taken around 1:00 p.m. on July 22.

Results

Simulated Algae Scrub

The Mushroom Polyp underwent a net increase in volume for two days after the simulated algae scrub. The Button Polyps, after a decrease in volume the day after the simulated scrub, increased to above their original volume on June 30. On the day after the simulated scrub, both the Bubble Coral and the Elegance had an increased volume. The next measurement, on June 30, showed that they had decreased in volume to below their original size. The remaining corals (Baby Leather, Separated Brain, Big Leather, Pearl, and Green *Goniopora*) showed a net decrease in volume from June 28 to June 30.

Qualitatively, the only corals that showed any change were the Big Leather and the Pearl. These both improved in appearance after the simulated algae scrub.

Addition of Foodstuffs

Immediate reactions to feeding. About 2 to 5 minutes after addition of food matter, the corals withdrew their tentacles and closed up (resulting in a decrease in volume). This may have been due to physical contact with the food particles. Typically, the volumes increased by the next day.

Brown Algae Trial

Addition of homogenized algae made the water very cloudy, much like an actual plankton bloom. Two corals, the Big Leather and Bubble Coral, qualitatively declined the day of the first feeding. The day after the last feeding of brown algae, they had both improved their appearance to what it had originally been. The Pearl and Green *Goniopora* slightly declined in appearance during the trial. The remaining corals showed qualitative improvement over the course of this trial.

The Big Leather, Bubble coral, Green *Goniopora*, and Baby Leather showed a large net increase in volume after this trial. The Separated Brain and Pearl showed a slight net increase, while the Button Polyps and Elegance showed a fair to large net decrease in volume. The mushroom polyp showed a large increase after the first feeding, but decreased after the other three. At the end of this trial it was approximately the same volume as it was at the beginning.

Flake Food Trial

Addition of homogenized flake food made the water even cloudier than the feeding with brown algae. Immediate qualitative effects were very negative for every coral except the Separated Brain, which had a slight improvement in appearance. The only coral that had a net improvement during and after this trial was the Green *Goniopora*. The others were shriveled and withdrawn, even the day after feeding was discontinued. The Separated Brain, Elegance, and Mushroom Polyp increased in volume after this trial.

The Button Polyps had no net change in volume, while the rest of the corals all decreased in volume. The big leather was withdrawn all of July 6 and opened slightly on July 7, but by the time it was measured on July 7, it had closed up again. Qualitatively, it was doing better during July 7, although measurements indicate that July 6 was the better day.

Green Algae Trial

This homogenate was much lighter in color than the previously used algae. It made the water cloudy, but not as cloudy as the brown algae had made it. The first measurement taken on July 21 was chosen to be the last measurement used in analysis because it was the last data taken 24 hours after addition of algae. The corals were measured on July 22 around 1:00 p.m., their peak time of day. These measurements could not be compared to measurements taken around 4:30 p.m., when the corals are different in regards to extension of tentacles and overall volume.

After the first day of algae addition, there was a dramatic rise in volume for all corals but the Green *Goniopora*. However, after the second feeding, many volumes fell below the original levels. The Bubble coral and Pearl showed a large net increase in volume after this trial. The Elegance and Separated Brain showed a slight to fair net increase. The other corals showed either no net change or a slight decrease in volume. Each coral's appearance did improve slightly over the course of this trial.

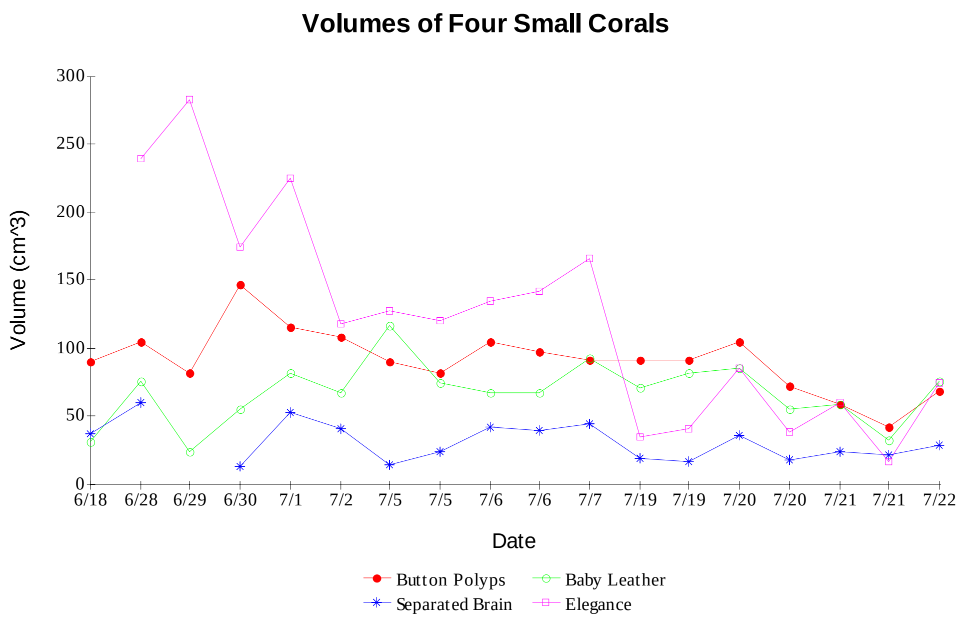

Figure 1. Approximate volumes of Button Polyps, Baby Leather, Separated Brain, and Elegance corals. The last measurement of each trial was taken approximately 24 hours after feeding, but corals were measured much earlier in the afternoon on 7/22, the first measurement of 7/21 is considered the end of the green algae trial.

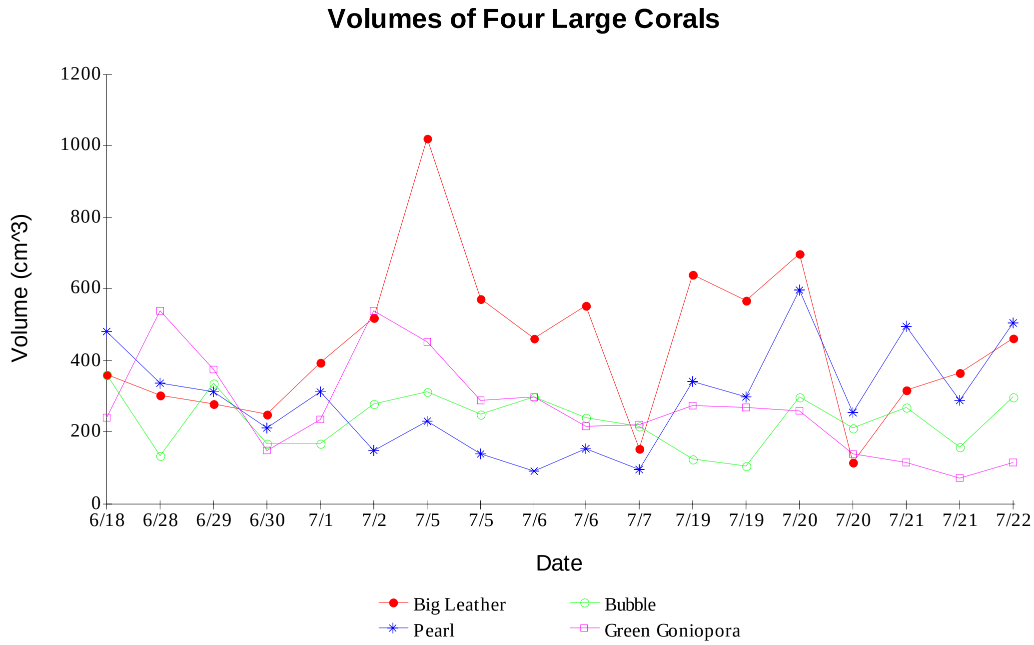

Figure 2. Approximate volumes of Big Leather, Bubble, Pearl, and Green Goniopora. *The last measurement of each trial was taken approximately 24 hours after feeding, but corals were measured much earlier in the afternoon on 7/22, the first measurement of 7/21 is considered the end of the green algae trial.*

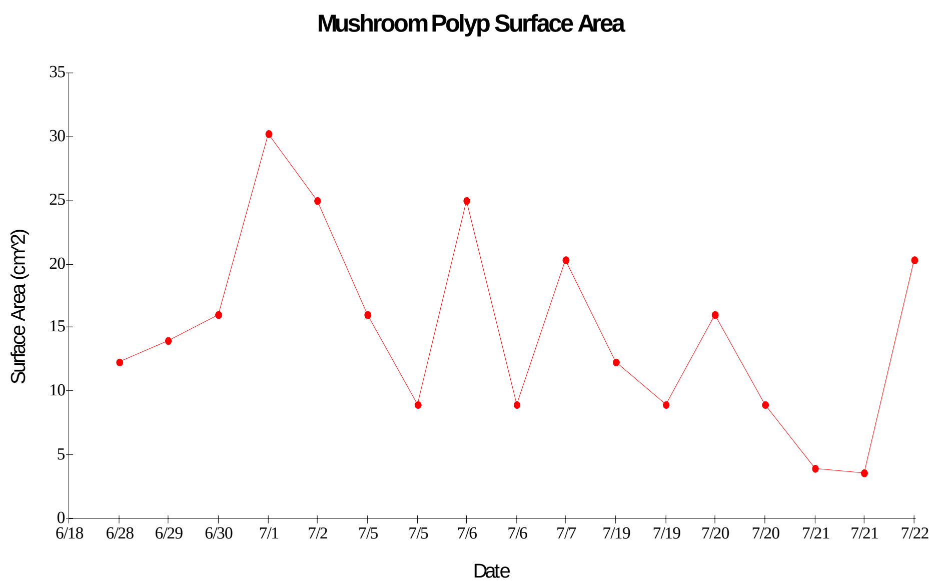

*Figure 3***.** *Approximate surface area of the representative Mushroom Polyp. The last measurement of each trial was taken approximately 24 hours after feeding, but corals were measured much earlier in the afternoon on 7/22, the first measurement of 7/21 is considered the end of the green algae trial.*

Discussion

The motion of the simulated algae scrub did not seem to benefit the corals in the tank. From this, it can be inferred that algae is beneficial to these animals. This conclusion seems to be supported by the brown algae trial. The results of the brown algae trial may not be reliable because plenum water (water from the bottom of the tank; underneath the gravel filters) was removed on July 1, the first day of adding algae. There was also a partial algae scrub on July 2. Both of these occurrences could have affected the measurements of the corals. Even so, the changes between July 1 and July 5 were large enough to suggest that, even after the removal of plenum and an algae scrub, the corals continued to benefit from the addition of algae.

The majority of corals responded negatively to the addition of flake food. It can thus be inferred that flake food is not a suitable plankton substitute.

The second algae run did not duplicate the first. This is probably due to different types of algae establishing themselves in the greenhouse tanks, which also explains the difference in color and cloudiness between the two trials. Curiously, corals benefited after the first addition of the green algae, but then experienced a large decrease in volume after the second. This type of algae may be beneficial to corals, but another study is needed to determine its value.

Preliminary conclusions from this experiment are that some types of algae benefit many corals in a closed system and that flake food has positive effects on only certain corals. Each trial showed some corals that improved and some that did not, suggesting that each coral species has its own diet. If more can be learned about the specific diet of each coral, or what benefits the majority of corals kept in a specific aquarium, they can be given the proper balance of organic and inorganic nutrients to maintain and promote coral health.

A long term study of the effects of algae on coral would prove useful, as would a project involving the growth of plankton in a closed environment. Plankton and algae could both be used in further studies of coral nutrition.

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RESOURCE MANAGEMENT AND REGULATION: CURRENT STATUS AND FUTURE TRENDS

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ABSTRACT

As recently as 10 to15 years ago, the prevailing mood between conservation organisations and the international ornamental aquatic industry in general, was one of considerable mutual suspicion. On the one hand, many industrialists believed that conservationists were, generally speaking, against all forms of trade, while, on the other, many conservationists deplored the fact that some industrialists were actually earning a living, directly or indirectly, from buying or selling livestock.

Today, despite the continued existence of occasional misunderstandings and misinformation, attitudes are, without doubt, much more enlightened all-round, with the result that collaborative ventures and constructive dialogue are now commonplace. Nevertheless, there is still widespread ignorance of, both this collaborative spirit, as well as some of the basic, but very important, facts regarding the resource management activities of the ornamental aquatic industry.

This paper aims to assist in disseminating this information by providing an overview of international resource management programmes. It will describe a number of aquatic-resource management strategies currently employed, place the industry in perspective in relation to other reef-associated activities and take a look at some developing trends which are likely to influence the future of both the marine hobby and industry in the new millennium.

Keywords: ornamental industry, conservation, management strategies, bio-piracy

The marine ornamental industry is a high-profile one, dealing - as it largely does - with organisms that live in and around coral reefs. It therefore tends to attract greater attention than its actual size would lead one to expect. There are many reasons for this, several of which revolve around its close association with such fragile habitats as the reefs themselves and the widespread destruction that they are subjected to.

In this latter respect, the aquarium industry has been (and still is) frequently accused of causing widespread damage through the use of unethical collecting methods such as cyanide spraying and dynamiting. These accusations are addressed below.

General Perspectives

However, before entering into a discussion of collecting techniques, it would seem appropriate to establish some basic facts regarding both the size and value of the industry, thus placing it in some form of perspective.

Table 1 presents some of the overall characteristics of the global ornamental aquatic industry and its major sectors. While a certain degree of caution needs to be exercised when considering such data, the overall trends and orders of magnitude can be regarded as being, at least, reasonably orientation; they must also be viewed as global, rather than national or regional, in nature. Thus, while some countries (or even the United States) may have been experiencing a period of little or no growth (or even decline) in recent times, the global trend for the industry is still one of growth. Equally, it is not clear whether the main supplier of oriental fish (Singapore) is being considered as a 'developed' or a 'developing' country. Anyone who has visited - or is familiar with - Singapore, will know just how advanced a nation it is. If it were to be regarded as such in the Table, the actual level of exports from 'developed countries' would be expected to be considerably higher than 37% of the global total.

Table 1. Ornamental Aquatic Industry: Some Global Figures for 1996 (FAO data and others).

	US$ Valuation
Approx. Export Value of Ornamental Fish	206,603,000
Approx. Import Value of Ornamental Fish	321,251,000
Approx. Import Value of Marine Species	24,000,000 - 34,000,000
Approx. Import Value of Freshwater Species	287,251,000 - 297,251,000
Entire Industry Worth About	15,000,000,000
Annual Growth Rate Since 1985	ca.14%
Exports from Developing Countries	ca. 63%
Exports from Developed Countries	ca. 37%
Captive-bred Freshwater Species/Varieties	90 - 95%
Captive-Bred Marine Species	5 - 10%

The low percentage of marine species that are currently bred in captivity (some estimates are even lower than 5%) may appear, at first sight, to give cause for concern. However, it is worth looking at some comparative data between the ornamental fish industry and its food fish counterpart to place the figures in perspective.

Certainly, the number of species that will be bred in captivity to supply marine hobby needs will increase over the coming decade, and this is to be welcomed. So will the actual quantities produced, but - at least for the foreseeable future - demand for wild-caught marine fish and invertebrates will remain.

Marine Food Fish - the world marine food fish industry accounts for around 100 million tonnes per year. Marine Ornamental Fish - the world marine ornamental fish hobby and industry account for 70-100 tonnes per year. In other words, the annual weight of ornamentals that supply the hobby is about one millionth the weight consumed by the food industry. Marine Food Fish Bycatch - i.e. the 'waste' fish that are discarded overboard - the annual figure for this is around 17 million tonnes. This represents a weight that is some 170,000-240,000 times the total annual weight of ornamentals.

Retail Values Compared. Marine Food Fish - although a world wide average is difficult to define accurately, an approximate retail value would be between US$14,500-16,500 per tonne. Marine Ornamental Fish - at a very approximate average weight of some 8gm per fish, the retail value of ornamentals works out at around US$1,800,000 per tonne. Taking all these figures into consideration, marine ornamentals can be seen to represent a globally low-volume, locally high-value industry, with the world's supply coming from some 150,000 sq. miles (ca. 400,000 sq. km.) of reef.

Table 2. Marine Food/Ornamental Fish: Comparative Weights Global Annual Catches/Harvest (tonnes).

	Harvest (mT)
Food Fish Harvest	100 million*
Food Fish Bycatch	17 million*
Ornamental Fish Harvest	70-100*

*Note: Figures indicated by * were obtained from calculations carried out by OATA (Ornamental Aquatic Trade Association). Weight of ornamentals excludes transportation water comparisons:*

The marine ornamental hobby and industry harvest represents 0.00007 to 0.0001% of the food fish harvest, i.e. a maximum of one ten thousandth of one percent (or one millionth) of the food fish harvest. The marine ornamental hobby and industry harvest represents 0.0004 to 0.0006% of the food fish bycatch or 'waste' which is discarded, i.e. a maximum of six ten thousandth of one percent (or a six hundred thousandth part) of the food fish bycatch

Table 3. Marine Food and Oranamental Fish: Comparative Values.

	US$/tonne
Average retail price of food fish	ca. 14,500-16,500
Average retail price of ornamental fish	ca. 1,800,000

About 3% of the weight of an ornamental fish consignment consists of fish. The remainder is water. For example from a one-tonne shipment, about 30 kilograms is fish and the remaining is about 970 kilograms of water. The 'average' marine ornamental fish weighs approximately 8 grams, i.e., 125 fish per kilogram. Thus, there is about 3,750 fish per 30 kilogram, giving 125,000 fish per tonne (wet weight).

Turning to hard corals, the overall picture is, basically, similar, with the marine ornamental industry harvesting very modest quantities when compared to other extractive activities. Some relevant comparisons are listed in Table 4.

Table 4. Some Coral Harvest Comparisons.

	Tonnes/y	Source
1997 Global Aquarium Harvest	687	Green & Shirley, 1999
Jakata Area (Mined for	15-37,500	Polunin, 1983
Construction Purposes)	5,000	Bentley, 1998
Maldives (Mined for Construction Purposes)	25,000	Brown & Dunne, 1988
Indonesia (Damage caused by Dynamiting)	15,000	Cesar, 1996; Spalding & Grenfell, 1998

West Lombok, Indonesia (Mined by 60 Families for Lime Extraction)	1,600	Cesar, 1996

	VALUE US$/Tonne
1997 Global Aquarium Harvest	7,000
Lime Produced from Coral	60

For comprehensive treatment of the international coral industry, see the Green and Shirley's 1999 report, 'The Global Trade in Coral.' This important document raises numerous issues which help place the collection of live corals for the ornamental aquatic industry in perspective. One of its significant conclusions is worth quoting at this point. After referring to survival of corals in aquaria and their sustainable/non-sustainable collection from the wild, the Executive Summary states: "However in comparison to other extractive and destructive impacts on coral reefs, such as mining and dynamite fishing, the effects of collecting live coral for the aquarium trade are very small."

Misinformation

Traditionally, reefs have been abused and misused for numerous purposes. Again, traditionally, the ornamental aquatic industry has been accused of wide-ranging destruction involving the use of sodium cyanide and dynamite to supply fish and invertebrates for the world hobby.

Undoubtedly, both cyanide spraying and dynamiting occur, but, as the following paragraphs will, hopefully, demonstrate, the use of the former with regard to the collection of marine ornamentals has, not only shown dramatic decreases in recent years, but will decrease even further and will (it is hoped) disappear entirely as a means of collecting for the aquarium industry. In the case of dynamiting, this practice is not employed by the ornamental aquatic industry, despite claims that are published regularly in hobby and 'learned' publications, or - in recent times - on the World Wide Web.

The two examples that follow are typical of the unsubstantiated accusations that are currently in circulation:

a) "The practice of dynamite fishing to stun fish and capture them for the aquarium trade has devastated reefs in parts of Asia, the South Pacific, and Africa."

   Second Lesson in 'Sea Connections', Ocean Planet, within the Smithsonian Institution's Education Section website (http://educate.si.edu/lessons/currhits/ocean/connect/essay.html)

b) "The tropical fish trade is killing the coral reefs of Southeast Asia, but one Texas Sea Grant researcher may have found a way to protect not only the fragile reefs, but also the $100 million marine tropical fish trade.

   "Scientists estimate that by the year 2020, many coral reefs in Southeast Asia will no longer exist because the practice used to collect tropical fish poisons coral. Divers squirt fish with sodium cyanide to stun them. But while the lucky ones are only temporarily paralyzed, others sink to the bottom and die as do an estimated 33 million coral heads annually."

   Part of Sea Grant Press Release Issued by: The Sea Grant Programme of Texas, Marine Science Institute, Port Aransas, 'Tropical Fish Aquaculture May Help Save Coral Reefs' 10 May '99

Note, in fairness to the Marine Science Institute at the University of Texas, it must be stressed that the above press release was published by an agency without the full knowledge of the scientists involved. Nevertheless, it was posted on the World Wide Web, thus constituting one more piece of damaging and inaccurate misinformation regarding the industry.

The issue of cyanide fishing is dealt with below. With regard to dynamiting, an extensive search mounted by our own organisation failed to identify any aquarium hobby/industry-related incidents, a finding which was further re-enforced by a statement from Dr. Don McAllister, President of Ocean Voice International - the Ottawa-based marine conservation organisation: "I hear this old chestnut from aquarists from time to time. Usually it is aquarists who have just heard it, not thought about it, or confuse capture of food fishes with explosives with collecting marine aquarium fishes.

"No one to my knowledge collects aquarium fishes with explosives. The Smithsonian should not be repeating this misinformation in regard to aquarium fishes. Yes, explosives are (mis)used around the world for getting food fishes."

Some Resource Management Strategies and their Regulation

Captive Breeding/Propagation

Over 100 species of marine fish have been bred in captivity in many countries. Of these, however, relatively few have been bred, or are, as yet, being bred in commercial quantities.

Clownfish (mainly *Amphiprion* species) are the best-known and most widely bred species, along with Neon Gobis (*Gobiosoma evelynae*), which are also bred in large numbers, but there are other species, as well, some of which may appear a little surprising - considering their reputation as hard-to-keep fish, e.g. *Hippocampus*. Other 'difficult' species which have recently come on stream include the Arabian Angel (*Pomacanthus asfur*) and the Yellow-banded Angel (*P. maculosus*). Invertebrates, too, are being propagated in captivity. *Tridacna* clams are probably the best-known, but even Stony (Hard) Corals, such as the Thorny Bush Coral (*Seriatopora hystrix*) are being produced.

Captive breeding will undoubtedly constitute an ever-growing component of international ornamental marine species management programmes, especially as aquarium technology, larval foods and knowledge continue to improve.

This move is to be welcomed and, while *ex situ* captive breeding and propagation/culture in hatcheries and elsewhere are providing ever-increasing numbers and an ever-widening range of species for the hobby, *in situ* programmes are also being developed. At the moment, though, there does not appear to be an overall coordinated development programme between the two. Over time, however, such coordination is expected to develop, and in a way that sees captive breeding/propagation/culture as complementary, but not alternative, to ethical and sustainable collections from the wild.

Ethical Collections

Ethical methods of collection have, without doubt, to be considered as the only methods that should be employed with regard to ornamental species. They may result in slightly more expensive fish and invertebrates than other methods (though this is not necessarily the case), but they are the only methods that are compatible with conservation policies. They are also the methods that are supported wholeheartedly by consumers and my own organisation.

Training is, however, crucial at every stage of the process, from instruction in safe diving methods, to the actual process of collecting, to holding and transportation. This all requires time, expertise and money. It is therefore hoped that relevant authorities will respond favourably to approaches that will, undoubtedly, have to be made for support.

There is also no doubt that a concerted effort by relevant parties produces results, as is vividly being illustrated in the Philippines. There, the OVI/Haribon project has resulted in over 800 collectors - out of an estimated total of around 2,500 - already being trained in the use of nets to collect fish. It would be wrong, however, to assume that the influence of the programme extends just to these 800 fishermen. In addition, the project has trained trainers located in several communities, thus extending the programme in a more indirect manner, especially since individual fishermen also 'unofficially' train other people. A further ramification is that some exporters are now supplying nets to fishermen and have installed their own training.

In total, therefore, probably as many as half the Filipino fishermen may have been influenced by the OVI/Haribon net-training programme. There is also the 'Cascade Effect' where trained Filipinos are now working elsewhere, such as in the Red Sea, or are 'exporting' their skills to other countries, such as Sri Lanka and, perhaps, Indonesia. The cross-fertilisation of ideas that this will create will, undoubtedly, produce further improvements.

A second major force in net training and sustainable resource management in the Philippines and other Indo-Pacific regions is the International Marinelife Alliance (IMA) via its wide-ranging 'Destructive Fishing Reform Initiative'. This organisation has also played a leading role in the establishment of a cyanide detection test and is continuing to develop its programme on numerous fronts.

Both OVI and IMA are strong supporters of the concept that ethical, sustainable harvesting of bio-resources constitute a powerful conservation tool with regard to reef health and diversity and as an important source of (often badly needed) income for local communities. These policies are strongly supported by the ornamental aquatic industry, both morally and in the form of ongoing grants.

Reef Management/Harvesting

Controlled supervision to ensure that collecting is kept within sustainable limits so that no individual species is over-exploited, or to ensure that destructive methods, including irresponsible tourism, are not employed, is crucial. In addition, at least, some of the management responsibilities can be placed in the hands of collectors themselves who, either individually or collectively, are entrusted with the sustainable harvesting of predetermined sections of reef. As a management concept, the basic ITQ (Individual Take/Transfer Quota) principle would seem well worth developing further in the context of the ornamental fisheries (as distinct from the food fisheries), since the acceptance of responsibility for one's continued survival usually acts as a particularly powerful incentive to protect a resource and maximise success on a long-term basis.

Although reef and river resource management of this type has actually already been implemented in some areas, e.g. parts of the Philippines, Australia and the Amazon, the practice is not as widely employed as it deserves to be. Where it is being implemented, it appears to be producing beneficial results all-round, but the global adoption of the ITQ principle for ornamental fisheries has not yet occurred. As a result, fisherfolk/collectors are not generally enjoying the benefits that their central - and vital - role in the supply chain warrants. Greater effort is therefore required in this direction. Linked to *in situ* captive-breeding/propagation programmes are manage- ment/harvesting projects, usually involving hard corals, aimed at producing a sustainable harvest in which local communities play a key role, while, at the same time, enhancing reef diversity. Counterpart International's Coral Gardens Initiative in Fiji and the Solomons is an excellent example of a win-win arrangement, which involves "island communities planting corals for management, conservation, and restoration of coral reefs" and which could act as a model for other, similar projects elsewhere.

Artificial Reefs/Living /Rock 'Seeding' and Harvesting. The use of tyres as 'nuclei' for artificial reefs is not an entirely new practice. There are, however, problems with using tyres, not just because they can disintegrate, but also because of the possibility of toxin release. A better, permanent, option is the use of artificial concrete reefs as employed in Bahraini waters, off Saudi Arabia. These reefs were lowered into place some 2 miles out to sea in February 1993 and, over the ensuing months, became colonised by a wide variety of organisms, from diatoms to groupers. From the earliest stages, they were visited by schooling fish, such as Jacks (e.g. *Alepes djedaba*) or more reef-associated species like Yellow-banded Angels (*Pomacanthus maculosus*). Within weeks, the encrustation process began and attracted further visitors and more-permanent residents. After six months, these residents included species such as Bannerfish (*Heniochus acuminatus*). At 48 weeks, more 'substantial' fish included groupers, such as *Epinephelus suillus*. By now the invertebrate and algal encrustation was also well established. Further work is required on the relative merits of artificial reefs and a project currently under way at the University of Florida, in Gainesville, should answer some fundamental questions regarding this conservation-based form of resource management.

A similar principle - but based on small lumps of natural rock or synthetic aggregate - is being applied in several regions, particularly Florida waters and Fijian reef flats, the synthetic aggregates being restricted to the former. The concept is simplicity itself in that it consists of the rocks being 'sown' on the seabed or reef flats, to be harvested several months later (usually after a minimum of six months) encrusted with coralline algae and colonised by invertebrates. In practice, the Florida projects, being located in deeper water areas, which are not always easily accessible owing to sea conditions, and which can be badly damaged by extreme weather, are considerably more expensive, labour-intensive and difficult to manage, with an increased in-built risk factor. Legislative factors relating to the actual status of the locations themselves, e.g. stage or federal, can also complicate matters.

Nevertheless, these projects are already producing excellent-quality material for aquaria at competitive prices and are likely to constitute a progressively more important sector of the industry. They also, of course, represent an alternative, non-extractive form of resource management.

Research and Education

Sustained progress cannot be maintained without research and education, both of which are essential components of any management programme. Whether we are talking about freshwater habitats or marine ones, the principles remain the same. Education must include programmes aimed at children so that they grow up appreciating the concepts involved. In the Rio Negro, for example, Project Piaba includes a school-based component that not only introduces children to the richness of their environment, but also to the need to preserve it. The importance of the sustainable harvesting policies being developed there is such, that Bio-Amazonia Conservation International - the organisation that runs the project - has coined the following slogan as the opening 'battle cry' of its Mission Statement: “Buy an Ornamental Fish: Help Save the Rainforest.” This highlights the possible destructive consequences of both a non-sustainable policy, or the cessation of collecting, following which the native communities would have to turn to the jungle for their survival, e.g. logging, etc. The association between this Amazonian conservation programme and the ornamental aquatic industry is now so strong that representatives of both meet from time to time, and are in contact with each other on an almost-weekly basis, thus ensuring that scientific/conservation research and commercial development work hard in hand, for the benefit of both.

Such a close relationship does not currently exist with reef protection projects, other than the OVI net training programme in the Philippines. However, it is a relationship that should be actively sought and developed wherever reef resource management includes a commercial component, i.e. sustainable harvesting for the marine aquarium hobby. Close relationships of the above type also serve the valuable purpose of educating all parties concerned with regard to each other's perspectives, their commonality of aims, the need for constructive liaison and co-operation. They also help dispel any elements of mistrust that might have existed before joining forces, help educate the world at large regarding the conservation/industry relationship and act as a dynamic source of new ideas. One of these is described briefly in the next section.

Conservation Fees/Levies/Taxes/Contributions. Over the past decade, as has been outlined above, the ornamental aquatic industry has contributed in several ways to conservation/sustainable use projects. One of these contributions has consisted of grants. However, although the industry will continue to support such projects, its funds are limited. Individual companies may well be able to m ake one-off substantial contributions, but industry-wise, these can only be effectively co-ordinated by an official non-profit-making organisation, such as OFI. Yet, our organisation is dependent, almost exclusively, on its income from members' subscriptions, a direct consequence of which is that funds are - by definition - limited.

Despite this apparent drawback, the industry can contribute to resource management/conservation programmes by assisting in the raising of funds in a different way. Just such an approach has recently begun bearing fruit after a period of several years' discussion between OFI, members of the Amazonian exporters' association (ACEPOAM), local government officials and Bio-Amazonia Conservation International.

At its simplest level, the arrangement consists of imposing a charge on every box of fish that is exported from Manaus, the Amazonian capital located at the confluence of the Rio Negro and Rio Solimoes, in Brazil. This fee/levy/tax/contribution (the label is immaterial) is of US$1.00 per box, with half this amount being paid by the exporter and half by the importer. The principle may be simple, but getting all the components into place is far from this. Nevertheless, it has been achieved. Within the first six months, US$30,000 had been raised and current estimates predict that, in a good year, this could rise up to as much as US$72,000, all of which will be ploughed back into research into both the biology of Amazonian fish and the establishment of sustainable harvesting levels for the Amazonian fishery. To date, no such resource management projects have been considered for marine fish and invertebrates...but they should, since they are capable of providing much-needed funds for essential research.

Grants/Subsidies/Monitoring/Certification. If governments or their ministries/agencies are genuinely interested in, and favourably disposed towards, the responsible development of an ornamental aquatic industry, it would seem reasonable to expect that this support be demonstrated in ways which will facilitate the envisaged development. Collaborative/supportive policies are, undoubtedly, extremely valuable, but financial support for relevant projects is also necessary. This could be in the form of grants or subsidies, or both.

For selected species or habitats, especially those under some form of threat, and for which this type of support is vital, it may also be worth considering the introduction of a certification system, such as that employed in Singapore for captive-bred specimens of the Dragon Fish (*Scleropages formosus*). *S. formosus* is currently listed under the CITES Appendix I, making trade in wild-caught specimens illegal. However, provisions exist under the regulations for the legal export of such species, if certain stringent CITES conditions can be met. Among these is proof that the species is being bred in captivity, at least, into the F2 generation. In order to establish this to CITES's satisfaction, the Singapore government, via its Primary Production Department (PPD), set up a collaborative captive breeding programme with a commercial Dragon Fish breeder, resulting after several years of meticulous monitoring, including micro-chipping of specimens, and considerable expense, in a successful outcome. Today, *S. formosus* is available for legal export from several Singaporean farms (plus a few in other Far Eastern countries), thus safeguarding the species' continued survival, both in the wild and on a commercial basis.

Each exported specimen carries its own government-issued certificate carrying a unique micro-chip code number that identifies - among other relevant data - the country of origin, the farm in which the fish was bred and its variety (green/silver, gold or red). The development of this certification/monitoring system is seen as a major breakthrough by the ornamental aquatic industry with regard to resource management and conservation.

The establishment of the Marine Aquarium Council, or - to be more specific - the establishment of MAC in its present format, is also seen by the industry as a major breakthrough. Its Certification System is seen as providing an excellent set of options for developing the future of the global marine ornamental aquatic industry on a monitored, sustainable basis. The current and future work of MAC is presented in other submissions to these Proceedings. I will therefore not dwell any further on this subject, other than to emphasise that MAC has the full support of my own organisation (OFI) and that, once the Certification System is developed and put into operation for the whole of the 'chain of custody', from collector to consumer, it will represent the best set of voluntary rules and checks that the marine ornamental industry has experienced to date.

Bio-Piracy

This is a relatively new phenomenon. Up to quite recently, the concept, while gradually gaining prominence, had not resulted in any major crises. More worryingly, though, as we as we enter a new century, we are also entering a new and far more serious phase that is resulting in arrests, deportations and confiscations...to say nothing of a growing air of tension, particularly between Brazil and what, according to its laws, are illegal collectors of its native fish resources.

When bio-piracy first begun being debated, the discussion centred mainly around the loss of potential revenue to producer countries for species, which had been taken from national waters and were subsequently bred in captivity in other regions. Discus, guppies and Malawi cichlids are the three types most commonly cited as examples. The argument goes that countries of origin, which ‘supply’ the hobby and industry with such species, should in some way benefit from this. Royalty payments, the issuing of breeding licences and other suggestions have been put forward at various times as possible mechanisms, which could be explored in this respect.

Although retrospective application of such measures would seem (at best) extremely difficult, if not impossible, to implement, or even agree upon, other protective safeguards designed at preventing the unlawful collection and export of native fish fauna offer more realistic possibilities, at least, with regard to the present and future. Brazil, in fact, now has a number of laws, most importantly, the new Law of Environmental Crime, that make it an offence to collect and take out of the country any of its native species without official approval from its environmental agency, IBAMA. Accordingly, import and/or export of Brazilian animals can now only be carried out by "juridical persons, public or private entities registered with IBAMA". Infringement of this law carries a fine of up to 1 million Reais (about US$500,000) per species!

Warnings have therefore been issued regarding the great importance that Brazil places on such matters, but, of course, the mere fact that a warning is issued, does not necessarily mean that it is either heeded or, as is more likely, that it reaches all the relevant people. Whatever the case may be, the fact is that, in recent months, no fewer than seven German nationals have been arrested and deported in connection with what the Brazilian authorities see as serious cases of bio-piracy.

It is, among other things, alleged that the testimony presented by one individual in his defence is false and is doing great harm to the hard-earned international reputation of Project Piaba - the Rio Negro-based sustainable ornamental fishery research programme led by Prof. Ning Labbish Chao. It has also been claimed (by IBAMA) that collecting licences which had been issued locally in Barcelos were illegal because the local mayor's office does not possess the authority to grant such licences. In another case, the collector in question was in possession of a letter of recommendation from a leading German university museum. However, such unilateral 'recommendation' are now insufficient, since, according to Brazilian law, all foreign institutions must first establish contact with the Brazilian Foreign Ministry and National Research Council, through whom application for the appropriate licences is subsequently made to IBAMA. Legal requirements go even further than this by stipulating that, even after a legal licence has been granted, foreign scientists/researchers, etc., must be accompanied by a researcher from a Brazilian institute.

Brazil, as can be seen, is taking strong action, in accordance with its laws, to tighten up on the ways that its fauna (and flora) are studied and exploited. Its arrest of the seven above-mentioned German nationals is therefore probably the first 'opening shot' in what could - if the warnings are ignored - develop into quite a hostile, complex and delicate international 'situation'. Brazil wishes it to be known that anyone visiting its rivers or jungles must obey its laws, or face the consequences. These include a permanent ban on re-entry into the country in those cases where the arrested/deported parties refuse to pay the imposed fines, which, at up to US$500,000 per species, can escalate into millions of dollars with alarming rapidity. The bio-piracy debate in Brazil is, clearly, fast gathering momentum and is sending out a powerful signal to the rest of the world. So much so, that the crisis was discussed at a workshop convened for the end of January/beginning of February 2000 in Barcelos, on the Rio Negro.

It is nevertheless heartening to learn that some improvement is (perhaps) being detected in the overall situation, with assurances being sent out from Brazil that fish collecting is perfectly legal in its waters and can be carried out, as long as the necessary steps are taken. There is also an indication that the current strict laws may need revising, but that - welcome and necessary though it may be - is still in the future. Whatever the outcome of future deliberations might be, Brazil is, obviously, taking important steps in managing its bio-resources. As yet, such crises have not affected the marine industry. . . but the possibility exists. It may therefore be prudent to examine existing national and international legislation, highlighting relevant preventive measures, thus, perhaps taking proactive steps to minimise the risks of bio-piracy ever affecting this sector.

Appropriate Infrastructure and Liaison

Without either of these factors, any resource management policies that may be developed will only, at best, experience moderate success. To ensure optimal success, the infrastructure must be right as well. In other words, it's little use training collectors in the use of hand nets if the collected fish cannot be housed in suitable holding facilities, or if packing techniques are not adequately developed, or if transportation /handling methods between collecting or holding facilities and export centres are inadequate, or if, having got the fish in good condition to an airport, the ensuing bureaucracy results in welfare-threatening delays.

For all of these, and other, factors to work well, liaison and consultation are necessary at all levels and on an ongoing basis. It is important, for example, for governments and the conservation community to communicate and consult with the ornamental aquatic industry regularly, particularly with regard to legislation. This did not use to happen in the past, but is now accepted practice in some countries and regions and, while the consultative process is sometimes imperfect and can result in inappropriate or unworkable policies from time to time, where input from the industry is actively sought and given due consideration, the resulting legislation is invariably fairer all-round.

The modern-day industry, for its part, is - owing to its commitment to conservation, welfare and to ethical/sustainable resource management policies - constantly taking steps to improve standards, from influencing the International Air Transport Association (IATA) Live Animals Regulations concerning the welfare of fish and aquatic invertebrates in transit, to installing a free 24-hour fish rescue service (shortly to be launched by my organisation) aimed - as its name implies - at rescuing stranded shipments, thus eliminating/minimising their distressing and unwelcome consequences.

In the future, resource management will, undoubtedly, be more stringently controlled and monitored, the Marine Ornamentals Information System currently being developed by MAC and the World Conservation Monitoring Centre being just one of the several important initiatives already under way. The industry welcomes and supports any move, which will result in win-win situations, where all parties benefit, from the industry itself, to the resources it depends on and the natural habitats in which these occur.

The future - while it will, undoubtedly, prove challenging - is seen by the industry as being full of exciting possibilities. Some 10-15 years ago, both the industry and the conservation/welfare communities had serious reservations about one another. While misunderstandings still occur, even after what can only be termed as a decade of major progress, there is, nevertheless, a general spirit of optimism today that augurs well for the future. . . always assuming that those entrusted with the responsibility for shaping that future, do so in an enlightened and courageous frame of mind.

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LIVE ROCK ALCHEMY

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ABSTRACT

Live rock harvest was banned in Florida waters in 1989 and collection from Federal waters ended by 1997. Beginning in 1993, several aquaculture projects were established around Florida, yet in 1999 most are still struggling. Insight is provided into what went wrong and what the prospects are for the future.

Keywords: live rock aquaculture, base rock, reef aquarium

Introduction

When the marine aquarium hobby embraced the miniature reef tanks in the middle 1980’s the live rock industry began. Live rock is considered to be the backbone of reef aquariums. Environmental concerns over the uncontrolled and rapidly expanding collection of rock to satisfy this market led to a collection ban in 1989 by the State of Florida. Collections still continued in Federal waters. In 1997 following a three-year phase-out the Federal ban took effect eliminating the last legal harvest off Florida. During this period a number of companies in Florida set up live rock aquaculture projects in the hopes of supplying this market once the expected ban took effect.

The concept of alchemy is to convert a low value item to a very high value product. Base rock cost as little as $0.0125 per pound while quality live rock sold wholesale for $2.00-4.00 per pound. This difference in value made live rock aquaculture appear lucrative. Two major misconceptions existed. First, collectors expected prices to hold steady or rise after the ban. Secondly, the actual cost of placing, retrieving and selling rock was grossly underestimated. This paper is a review of the methods used to culture live rock and an explanation of the misconceptions that have and will continue to prevent this fledgling industry from reaching success.

There has been little academic research on the feasibility of ocean-based live rock aquaculture. Currently in Tampa, Florida the Hillsborough Community College (HCC) Interdisciplinary Live Rock Project funded by the National Science Foundation is in its second year. The Year I Annual Report (Falls, et al., 1999) outlined the initial phase of the project, which is testing four types of base rock material at five live rock culture sites in Florida. One key bit of information from this preliminary report was to demonstrate the risk of storms. Major damage occurred on some of the sites following hurricanes.

Most of the information on this industry comes directly from the collectors who have attempted aquaculture. Frakes and Watts (1995) reviewed the various projects' set-up during their harvest phase-out period. In Florida there are two approaches. One can either get a State of Florida aquaculture lease in state waters or move out to Federal waters and get a permit issued jointly by the National Marine Fisheries Service and U.S. Army Corps of Engineers (CORPS).

The state lease application can take up to two years to complete. Sites can be up to 5 acres and can be located much closer to shore than federal sites. The extensive site survey and many steps involved have discouraged many applicants. One key advantage was that artificial reefs could be built by dropping the rocks by crane from a barge. New restrictive regulations may eliminate this traditional and economical method. The water is shallower in the Gulf of Mexico with sites generally in the 20 to 40 feet depths.

Federal permits for 1-acre sites can be issued in as little as two to three months now. On the Atlantic side of Florida and in the Keys the Federal waters start at 3 miles, while in the Gulf of Mexico the line is about nine miles from shore, which dramatically increases travel time and expense. Some aquaculturists in the Gulf of Mexico prefer the deeper water (40+ feet) of Federal sites. Rocks must be lowered to the bottom on these sites. Usually boxes, bags or baskets are loaded with rock and lowered to the bottom and tipped over. Projects in the Keys have generally been located just outside state waters on sand behind reef tracts. These are generally in 15 to 30 feet depths.

Site selection is very important. The preferred substrate is hard packed sand, because hard bottom areas are not allowed for development. In soft sand the rock can sink and be lost. Even on hard sand bottoms, storms can cause sand to bury the rock piles and in the Keys particularly, sand scouring of all visible life can occur. In the Gulf apparently due to the broad shallow shelf, storms have caused little or no damage over the past six years; however, several red tide events have killed many of the encrusting organisms. This has delayed maturation of the rock in some cases.

Weather and water conditions are also important considerations. In the Keys the water is clearer and warmer. More varieties of coral are available if storms don't damage the rock. Conditions in the Gulf of Mexico on one state site (Anclote Aquaculture) were monitored for the 1997/1998 season. At a depth of 20 feet, the water temperature ranged from 13 to18 degrees C. during winter months to 32 degrees C., during the summer. Salinity was 30 to 35 parts per thousand. Visibility, on calm days when diving was possible, ranged from 0.5 to 25 feet. The lowest visibilities were generally in the winter months when storms came through on a regular basis allowing little time for sedimentary settlement. Still with these conditions there are 4 or 5 species of coral that colonize the rock along with many species of sponge, algae, tunicates, worms, etc. One advantage of aquacultured rock is that it is the only legal source of live Caribbean coral.

Another key to success is starting with a good quality decorative seed rock. Rocks with attractive shapes and holes are always more popular. The rock material should also be porous and soft. Hard dense rocks are unattractive to both the aquarists and the encrusting organisms. Most of the 1994 placements utilized relatively dense Bahamian Coral rock costing $0.0125 per pound, which was about all that was available at the time. More recently, aragonitic rock from the Miami area has become available and is the rock of choice. It is lower in density, more decorative and rapidly colonized but costs over $0.09 per pound delivered to Tampa.

Placement costs are a major factor for live rock. The early state sites used barges and cranes to place rock similar to methods used for creating oyster bars. Loads of 500,000 to 3,000,000 pounds could be placed for about $20,000 a trip. Thus a million pound reef would cost about $0.02 per pound. Without providing specific reasons, the CORPS is trying to ban this economical method. The mandated lowering to the bottom dramatically increases cost. A barge could still be used but the crane time at over $300 per hour would go up dramatically. The principal alternative has been small boat placement delivering 1500 to 3000 pounds per trip. For Gulf sites this amounts to about $450 per trip thus a 2000-pound load costs

$0.225 per pound to deliver. Commercial rock collectors who tried to develop sites while still collecting rock used this approach. It is very expensive and time consuming to use this method alone. In the Keys where travel time is less; it is somewhat more attractive. A third approach is to hire idle commercial fishing boats that can haul up to 10,000 pounds per trip. This method still cost about $0.08 per pound.

Economic feasibility is a key consideration for anyone considering an aquaculture venture. Using the creation of a million-pound reef as an example and assuming the use of the Miami aragonite material, the cost of site development using the two methods are:

Barge Placement	Small Boat Placement
Rock - $105,000	Rock - $105,000
Barge - $20,000	500 trips - $225,000
Tota l- $125,000	Total - $330,000
Cost - $0.125 per pound	Cost - $0.33 per pound
Time - 1 to 2 months	Time - 2 to 5 years

For the small boat method a hidden problem is that there are only a limited number of good boating days per year and the collector/rock farmer has to make a living during this time and needs to be collecting when the weather is good.

The real issue however is the cost of rock sold. This takes into account not only the cost to place rock on the bottom but the cost of lost rock, collection, holding facilities, shipping and sales. All of these are real costs that are often overlooked. Recognizing that only about two-thirds of the rock can be harvested, the real cost of the rock will run about $0.20 to 0.50 per pound. Harvesting will add an additional $0.50 per pound for boat and diver expenses. The overhead and maintenance of a holding facility will add an additional $0.50 per pound unless the volume is very high. Finally the cost of packing, shipping and sales will add roughly $0.50 per pound. Thus the real cost of rock sold will actually total $1.70 to 2.00 per pound. This is quite different from the original $0.0125 per pound base rock cost. To make a reasonable profit the facility must sell the rock for at least $2.50 a pound.

This is where we encounter the second misconception. The market price logically should have gone up once the harvest of rock in Florida was banned. Instead a price war in Fiji between suppliers caused the cost of Fiji rock to drop in half. Shops can now buy rock from Fiji at under $2.00 per pound delivered. This low price has dramatically increased the volume of rock exported from Fiji in the last five years and is under scrutiny by environmental groups but at this time the Florida aquaculturists must face the reality of this inexpensive wild rock.

Aquaculture rock is actually quite different from South Pacific rock. Because of the long shipping times, Fiji rock should be cleaned of most encrusting organisms to avoid fouling. Florida rock is better known for the unusual encrusting organisms and greater diversity. It requires more careful handling; thus, there has been a shift to direct shop and consumer sales to avoid the damage that can occur when stacked in holding tubs or long periods out of water as is common at wholesale facilities. This also allows for a higher price. Thus aquaculture rock is currently surviving as a niche product sold at a higher price based on the more diverse assemblage of organism.

A ban of Fiji rock as suggested by some groups would not help the industry or the reefs. Currently, aquaculture facilities could not begin to supply the demand. The current consumption of live rock in the United States would quickly exhaust all of the marketable aquaculture rock currently under cultivation. Since it takes one to four years for rock to become marketable, the suppliers would not be able to supply the demand. Without live rock the reef aquarium industry could collapse. The best scenario would be for an end to the price war that is severely limiting profits for the collectors while increasing pressure on the resource. A modest price increase would maintain or even increase income to villagers and help aquaculture at the same time. Another approach could be a government mandated quota to limit harvests, which would drive prices up. Unless the market changes, the aquaculture of live rock will never reach its potential.

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MARINE AQUARIUM EQUIPMENT: FROM BIOLOGICAL TO MECHANICAL AND BACK AGAIN

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ABSTRACT

There is a dual meaning behind the title of this paper. For the majority of aquarium filtration systems the components of the system can be generally grouped into one of three categories: mechanical, chemical or biological. Thus the first meaning of the title, and the first part of this paper, reviews some of the key points in the design of aquarium equipment, from mechanical to biological, over the last 150 years. Furthermore, until recently, the design of most aquarium filtration systems had been done with an emphasis on the mechanical component of the filtration system. Biological processes such as nitrification, denitrification and photosynthesis were not given great importance. Even lighting systems for aquaria did not consider the biological needs of the aquarium organisms. Therefore, the second meaning of the title, and part of this review, is to discuss the evolution of aquarium equipment from an emphasis on brute mechanical filtration to more a sophisticated biological system, with greater consideration of the biogeochemistry of coral reefs. With equipment advances and a better understanding of the biological processes of coral reefs the success rate of coral reef aquaria has greatly increased. This trend should continue as further advances in research and equipment design are made.

Keywords: aquarium, natural, filtration, microbiology, wet/dry

The Beginning: 1850's to Early 1900's

The goal of this historical review on equipment for the marine aquarium is to provide more than just an equipment list. It is also to explain the evolution of the equipment along with the prevailing theory or method of filtration at certain key times in the development of equipment for the marine aquarium hobby.

As with any review there will be some items that I have left out that others may feel important; without a doubt I selected items from my own biased perspective and there will be others who would have chosen differently. However, I believe the major equipment areas will be covered in the space allotted.

First, I would like to explain the rational behind the title, "Biological to Mechanical and Back Again." As we start out on this historical review, one will see that the first type of marine aquarium filters were biological in function. However, as time passed and modern conveniences, such as electricity, became more common filtration systems took a more mechanical approach, which had certain benefits and negative consequences. Nowadays, filtration systems and support equipment for the marine aquarium have come back around to an emphasis on the biological filtration aspect, and thus the hobby has returned to its roots. My points about this will become clearer as we proceed.

The term Marine Aquarium (and for that matter the term Freshwater Aquarium) was first coined by Philip Henry Gosse in this book *The Aquarium: An unveiling of the Wonders of the Deep Sea* published in 1854.

In his book he states that he borrowed the word aquarium from botanists who used it to "designate tanks in which aquatic plants were reared." He considered the addition of fish to a planted aquarium "not an alternation, but only an extension" because plants were "still a most important and pleasing feature." He considered aquaria to be "interesting collections of aquatic animals and plants."

The inclusion of plants in the term, and more importantly, the actual aquarium was not an after-thought by Gosse. Plants were, in fact, the first filtration and aeration devices in an aquarium. Interestingly, while today grammar school-aged children are taught the basics of photosynthesis in which plants take in carbon dioxide and giving-off oxygen. Gosse writes for pages in the first part of his book presenting the results of experiments, which had only been published a few years earlier demonstrating photosynthesis and that the process produces oxygen. Concepts that were still not universally accepted at the time Gosse wrote his book.

From his experiences with aquaria, Gosse came to the conclusion that "the idea of maintaining the balance between animal and vegetable life on chemical principles is not quite so novel as I had first supposed." Thus, the first marine aquarium filtration principle was that the animal population needed to be counterbalanced by plant respiration. Therefore, the first marine aquarium filter was biological in nature. This, however, placed a natural limit on the biomass of animals that one could place in the aquarium. As there were only certain species of plants or algae that would successfully grow in a naturally illuminated aquarium there were limits to the numbers and kinds of fish that one could keep in the aquarium.

Some examples of early marine aquaria, and their equipment given by Gosse include the fountain aquarium. Since his time electric water pumps had not been invented, the water fountain was operated by placing a reservoir of water above the top of the fountain in the aquarium. The reservoir might be located on a floor above the aquarium, for instance. To operate the fountain, one filled the raised reservoir with water which, by gravity, flowed down to the fountain by way a hidden hose and sprayed out the top of the fountain.

Other described aquaria include the standard rectangular tank and octagon shaped tank. Gosse (1854) describes the tanks of this time as being constructed with plate glass, with a slate bottom and birch-wood pillars in the corners. A framework of iron was also available. Equipment was limited by today's standards. One must remember that there was no electricity or indoor plumbing. Thus, there were no artificial lights, no power filters or other electro-mechanical devices. Maintenance was still done. However, there was no flake or frozen food, not that it mattered because Gosse (1854) notes that he did not feed his fish. Instead he allowed infusoria and entomostracans to grow on their own. A novel way to clear up cloudy water was to use oysters or other bivalve mollusks. Artificial aeration was done with a drip glass and Gosse mentions using charcoal to clear the water or tannic substances. The problems common to aquaria during this period were cloudy and milky water, temperature control (too hot in the summer, too cold in the winter), and providing enough light for the plants in the winter.

As we leave Gosse and the beginnings of our hobby, I think is appropriate to also acknowledge that Gosse (1854) was also the first to warn against overcrowding. "Do not overcrowd your tank. It is far better to have it half occupied at first . . . then by too eager a desire to see it filled, make it a Black Hole of Calcutta, and mourn over a host of corpses."

A Paradigm Lost: 1930's to 1980's

Moving forward into the early part of this century, the 1930's and 1940's, one finds that electricity is now more widely available in homes and there are newer materials for use in building aquaria and related equipment. Furthermore, the wide spread use of plastic is just around the corner. Water pumps have become more common, along with other electro-mechanical devices.

At this point in time, some types of equipment that would become standards were introduced to the hobby. These include disposal air diffusers for aeration, air pumps to power the diffusers and to use for lifting water through an outside filter. Aquarium heaters also became available which allowed tropical species of marine fish to be kept more successfully. Some test kits (i. e., for pH) also became available for the marine hobbyist.

Electricity and the resulting availability of water pumps, filters and aeration devices allowed the aquarist to increase the biomass in the tanks to unnatural levels. Thus, relaying on plants became obsolete and as they were not needed as aquarium filters. The paradigm of balancing animal and vegetable life was no longer valid.

The Mechanical Age

Marine aquarium keeping now entered what I consider a new age of filtration - one that I have termed the mechanical age. With bigger filters and larger air pumps, more biomass could be put into a given volume of water. Bigger has come to mean better.

Perhaps the greatest effect on marine aquarium-keeping takes place in the 1950's, with the introduction of the undergravel filter. One early version of the undergravel filter was a brand called the Miracle Filter. The inventor of the Miracle Filter even wrote a book about the filter and proclaimed himself to be the "discoverer of biological filtration in aquariums" (Hovlid 1956). However, this author never mentions nitrifying bacteria or the chemical oxidation of ammonia and nitrite. Thus, it is doubtful whether biological filtration as defined by Hovlid (1956) has the same meaning as it does today.

In any case, the undergravel filter by its mechanical filtering ability to a great extent solved many of the problems, which had plagued aquarist since the time of Gosse. The undergravel filter quickly cleared-up a cloudy tank and, generally, kept it clear. It also aerated the water. For at least a period of time, an undergravel filter would provide a well-aerated area for the growth of nitrifying bacteria. However, the undergravel also acts as an efficient mechanical filter and becomes clogged with debris just as any other mechanical filter does. Therefore, undergravel filter were not maintenance-free as some claimed.

There can be no doubt, however, that undergravel filter increased the potential for establishing a successful marine aquarium. In fact, when influential marine hobbyist Robert Straughan published the first edition of his book *The Salt-Water Aquarium in the Home* in 1959 he claimed on the jacket of the book that the "sub-sand filter was invented by the author". He also writes that sub-sand filter (which we now call the undergravel filter) is "the next most important item besides the aquarium" and "this ingenious device should be used with every marine aquarium" (Straughan, 1959).

The undergravel filter became the most popular and commonly used aquarium filter in the United States. In fact, by the late 1960's few people would dare to set up a marine aquarium without an undergravel filter. Undergravel filters run by air pumps and airstones, and eventually powerheads, were manufactured to fit aquaria of all shapes and sizes.

I term the period from 1960 to the mid 1980's as the brute mechanical filtration period. One is not sure which is the cart and which is the horse, but as manufacturers built bigger filters, more powerful water pumps, and larger air pumps, the hobbyists continued to call for even larger devices. It seemed to be a horsepower race with little consideration given to the needs of the marine fish and invertebrates. Thus, even more aquatic biomass was loaded in the relatively small volume of the typical marine aquarium. This resulted in new problems facing the hobbyist. But this is not to say that all was bad or wrong during this period. There were significant advances made in the equipment available to the hobbyist. Modifications of these basic equipment categories continue to this day.

For instance, more convenient filters, such as self-starting hang-on-the-tank filters, were built. More effective mechanical filters such as canister filters were invented. The manufacturing of sea salts became commonplace and with good distribution even hobbyists hundreds or thousands of miles away from an ocean could keep marine specimens. Aquarium construction also greatly improved with 100% glass aquaria available made with silicone sealant. Plexiglas aquaria, clearer and lighter in weight than 100% glass aquaria, became popular in some areas.

Most importantly, it was during this period that there was also a significant growth in the understanding of the biological and chemical processes occurring in marine aquaria. Much of this knowledge came from the wastewater treatment field, with its extensive use of massive trickle filters and spray bar distribution system, and rotating biological contactors. Combined with studies from the field of aquaculture the basics of nitrification were formulated and it became understood why one had problems with newly set-up aquaria; that maintaining low ammonia and nitrite concentrations in an aquarium were critical; and, that bacteria were responsible for many important processes occurring in the aquarium.

Further studies showed that there were critical levels of pH and dissolved oxygen that one had to maintain to be successful and that pH was affected by nitrification. The beneficial role of activated carbon was also detailed. While still surrounded by many myths, and not universally accepted for aquarium filtration, activated carbon, which can be made from a number of base materials, has been demonstrated to be effective for aquarium filtration by removing certain substances (for a review of activated carbon in aquaria see Hovanec 1993 and 1998).

Unfortunately, aquarium lighting was an area of equipment design and advancement that progressed little during this time. While fluorescent tubes became the standard there was little consideration given to the proper light intensity or spectral output. Rather, lights were designed to best show-off the fish and little thought was given to how lighting could help with aquarium filtration.

One of the worst problems for the marine hobbyist was the rampant growth of algae. Diatoms and green algae were for all appearances universal. Thick mats of cyanobacteria seemed to be endemic to marine aquaria, covering the substrate, decorations and sides of the aquarium. Of course, it is easy to understand why. The combination of a heavy biological load, which was fed a high protein diet several times a day resulted in high concentrations of phosphorous and nitrate. Depending on the wavelength and intensity of the light one type or another of algae would grow unchecked in the typical marine aquarium.

I believe most manufacturers would agree with the statement that growth in the marine hobby was stagnant in the mid 1980's. The reasons for this are many but the fact is that marine aquaria at this time were basically fish-only tanks and they had the reputation, in some ways deserved, of being hard to keep and, for sure, a lot of work to maintain because one constantly had to battle algae.

Of course, the underlying problem with aquarium filtration at this time was that the role of the primary producer (the vegetable forms in Gosse's terminology) had been seemingly forgotten. It did not matter how big a filter or air pump one had, eventually nutrient levels in marine aquaria increased to concentrations that promoted the uncontrolled growth of algae in one form or another. However, the situation changed, for the better, virtually overnight in the United States.

The Enlightenment

The change was due to a 7 part series of articles written in *Freshwater and Marine Aquarium Magazine* by George Smit starting in January of 1986 (Smit 1986). In this series of articles, Smit provided the details for building and maintaining a “mini-reef” marine aquarium complete with plants, corals and fish.

The filtration methods that encompassed the mini-reef system were very different from those of the typical marine aquarium in the United States, which used the undergravel filter. The key components to the mini-reef were: 1) a separate biological filter (the Dry-Wet filter) and no undergravel filter, 2) surface skimming of the aquarium water, 3) use of a protein skimmer, and 4) proper lighting, both quality and quantity.

In the Smit series of articles many concepts were put forth that became the basis for the state of the industry, as we know it today. Live rock was the most important of these components because “live rock is not just a decorative alternative to coral skeletons, but as necessary to the long-term survival of the miniature reef as the correct quantity and quality of light” (Smit, 1986). Live rock is critical because it contains a mixture of plants and microorganisms, which chemically balance the animal life in the aquarium, therefore, filtration in the marine aquarium hobby had come back around to the natural biological filtration methods with which it began. Natural meaning maintaining a balance between animal and vegetable life based on chemical and biological principles which are provided by natural substances (live rock) instead of artificial filtration devices (e.g., undergravel filters).

Soon after the publication of the Smit series there were many start-up companies promoting their version of a mini-reef system and associated equipment. Much of this equipment was not tested or well made. Some exaggerated claims were made regarding what the equipment could do. In fact, some companies went so far as to virtually guarantee success if one bought and used solely all of their products. Of course, this did not turn out to be the case and today many of those companies are no longer in business.

Marketed along with these early systems were all sorts of water quality monitoring devices with probes and controllers. So while the hobby started back towards an emphasis on biological filtration over brute mechanical filtration there was a huge jump in the technical devices that one supposedly needed to have a successful tank. As time passed, it became apparent that most of this electronic gear was not necessary for the success of a mini-reef aquarium. Instead, there were a few basic pieces of equipment that one needed to have a successful mini-reef aquarium. These included a good lighting system, a protein skimmer, providing sufficient water movement in the aquaria, activated carbon, and the addition of some chemicals on a regular basis.

However, this is not to say that the development of equipment for the mini-reef has ended because everyone was satisfied with the current state of affairs. In fact, some might disagree with the recommended basic equipment list in the preceding paragraph. There has been a succession of mini-reef filtration types from the beginning and new ones continue to be introduced today. One can assemble the systems and concepts for filtering a marine aquarium into a few groups, some of which are common, others that are not. These include 1) traditional trickle filter or wet-dry systems; 2) algal scrubbers which have a separate compartment of algal mats attached to the aquarium for the removal of nutrients; 3) the Berlin filtration method which uses live rock and a protein skimmer but no dedicated biological filter; 4) the Jaubert filtration method, which uses a plenum and the creation of an anaerobic area for processes such as denitrification; and 5) the Leng Sy miracle mud method which also uses natural mixtures of microorganisms for aerobic and anaerobic filtration processes.

There is still debate as to which system is the best or whether dedicated biological filters are really needed. Some authors go as far as to state that trickle filter are detrimental to hard coral mini-reef aquaria because a dedicated biological filter is a nitrate factory that will result in a high nitrate concentration in the aquarium (Delbeek and Sprung, 1994; Paletta, 1999). However, recent research has show that this is not the case (Hovanec et al., in this volume).

The mini-reef system also showed the importance of other areas of marine aquarium equipment that are still evolving today. These include the use of chemical additives, such as iodine and strontium to replace those utilized by coral and other animals in the mini-reef; water chilling systems to maintain water temperature and decrease the chance of coral bleaching, which can occur in mini-reef aquaria when the water temperature gets too high; plus, more efficient and easier to use protein skimmers and lighting systems.

This is not to say that the hobby is without controversy and that everyone agrees as to what is the best way to set-up and maintain a mini-reef aquarium over the long-term. This is not the case. However, more and more scientifically controlled studies are being done with the express desire to answer what is best for the growth and reproduction of corals and fish for the marine aquarium.

The Future

I believe that the future holds great promise for the marine tropical fish and coral reef hobby. Progressive manufacturers are spending money on serious, scientific research and development, both basic and applied (Hovanec and DeLong, 1996; Hovanec et al., 1998). Research efforts include: a) a better understanding of the biogeochemical pathways in marine aquaria; b) determining the role bacteria and other microorganisms have in filtering marine aquaria; and, c) which chemical additives and their forms are more beneficial to marine aquaria.

Funds are being spent on basic research in modern laboratories, which combine water chemistry analyses with microbiological studies, which use modern molecular methods such as PCR and DNA sequencing. This research will help determine, which microorganisms inhabit the aquarium environment, and start the development of new methods and equipment for the important filtration processes needed for the long-term success of marine aquaria and the hobby itself.

In the near future, manufacturers will provide incremental improvements in the main components for marine aquaria. Successful manufacturers and products will be ones, which accentuate natural processes instead of fighting them. One can expect equipment that provides more efficient lighting, results in better organic removal, and contains controlled use of biologics, microorganisms, and more effective chemical additives

In conclusion, I believe we all have a greater respect and understanding for balancing the animal and vegetable life in a marine aquarium which means that never has the chance for successfully setting-up and maintaining a marine aquarium been so great.

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A COMPARISON OF FOUR TYPES OF CORAL REEF FILTRATION SYSTEMS: PRELIMINARY RESULTS

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ABSTRACT

Four 284 l. mini-reef aquaria were set-up with either a trickle, "BioWheel”, Berlin or Jaubert style filtration system and compared for numerous water quality characteristics. After 156 days of operation there were almost no differences in the ammonia-nitrogen (<0.01 mg./l.), nitrite-nitrogen (<0.03 mg./l.), orthophosphorous (<0.05 mg./l.-P), pH, alkalinity or total inorganic carbon trends in the four systems. The two systems with dedicated biological filters, the trickle and "BioWheel” aquaria, had lower nitrate-nitrogen concentrations (<0.2 mg./l.) than the other two systems. After Day 114, nitrate-nitrogen increased to 1.0 mg./l. in the Jaubert system, with the Berlin system at about 0.3 mg./l. The total organic carbon concentration (TOC) in the Jaubert system was 3.5 mg./l. carbon, which was considerably higher than the other three systems which had TOC values of less than 1 mg/L-C. Nuisance algae growth was greatest over the term of this test in the Jaubert system. The results of this test demonstrate that claims by well-known authors that dedicated biological filters should not be used on mini-reef filtration systems because they result in high nitrate concentrations are incorrect. There was no evidence of poor coral health or other negative aspects in aquaria filtered with dedicated biological filters.

Keywords: trickle filters, "BioWheel,” Jaubert, Berlin, biological filtration, coral reef aquarium

Introduction

The trickle filter was first introduced to the marine aquarium hobby in the United States by a series of articles by Smit (1986). The trickle filter, a type of fixed bed biological filter, uses a stationary bed of plastic filtration medium to provide a substratum for the attachment of nitrifying bacteria. There are various shapes and sizes of the filtration media but all have a few basic properties, which include a high void space, so that water can easily pass over and through the media without a chance of clogging, and the media sitting above the water, rather than submerged underwater.

The basic design of the trickle filter is in sharp contrast to the undergravel filter which was the most popular type of biological filter used in the marine aquarium hobby at the time the trickle filter was introduced. The undergravel filter consists of a perforated or slotted plastic plate, which sits on the bottom of the aquaria. An aeration system is used to move the aquarium water through the undergravel filter and to recirculate it back into the aquarium. Once the aeration system has been assembled, the plastic plate of the undergravel filter is covered with 2.5 to 7.6 centimeters of fine grain coral sand and the aquarium filled with seawater. The action of the aeration system causes water to pass though the coral sand which becomes the attachment site for the nitrifying bacteria.

From these short descriptions it is evident for the trickle filter that the biological filtration medium is in the atmosphere, while for the undergravel filter, the biofilter medium is underwater. This means that the nitrifying bacteria on the coral substrate of the undergravel filter are exposed to much less oxygen than the nitrifying bacteria attached to the trickle filter media. Furthermore, the undergravel filter, without regular cleaning, will eventually clog with detritus because of the small grain size of the coral sand. Trickle filters, along with live rock and a protein skimmer, quickly became the preferred method of filtering a marine coral reef aquarium and ignited the rapid growth of the “mini-reef” portion of the marine aquarium hobby that continues today.

Another type of fixed bed biological filter for use in coral reef aquaria was also introduced in the last 10 years. This system is called the “BioWheel” (Marineland Aquarium Products) and differs from the trickle filter in that the filtration medium sits half submerged in the water and continuously rotates. The constant turning of the “BioWheel” in the water ensures that all the filtration media is wet and available for colonization by the nitrifying bacteria.

Two other types of filtration systems, which expressly do not use a dedicated biological filter, were introduced to the marine aquarium hobby in the mid-1990s. These systems belong to a class of filters which are called “natural”. The idea being that the filtration in a natural filtered aquarium is performed without man-made mechanical and biological filters. Instead, the liberal use of live rock and coral sand on the bottom of the aquaria is employed as the filtration. Delbeek and Sprung (1994) provide details on assorted natural systems as well as the trickle and “BioWheel” systems. The two main natural systems are the Berlin method, so called because it originated in the city of Berlin, Germany, and the Jaubert System, which was developed by Dr. J. M. Jaubert of the University of Nice, France.

The basis of the Berlin system is the use of a large amount of live rock, good water circulation and a large protein skimmer for organic removal. For the Jaubert system, a void area is constructed underneath a bed of coral sand inside the aquarium. The void area becomes filled with water and over time a zone of changing redox potential develops through the sand and pore water where different microbial processes (i.e., nitrification, denitrification) occur and provide the necessary filtration.

In the last several years, the use of the trickle filter, however, has fallen out of favor among the cognoscenti of mini-reef aquaria because it is believed that the use of a dedicated biological filter will cause high concentrations of nitrate in the aquaria. Paletta (1999) states, “a major downside of most trickle filters, as well as undergravel filters, is that they tend to produce nitrate as an end-product.” Delbeek and Sprung (1994) write “our experience has shown that trickle filters are not only unnecessary for coral reef aquariums with adequate amounts of live rock, in fact, they can be detrimental in hard coral aquariums.” But to date there have been no published studies which compare the different types of filtration methods for mini-reef aquaria with long term water quality data and observations of coral health.

The goal of this pilot study was to set-up and run the four mini reef aquarium/filtration types for a minimum of 2 years and determine: a) if there were any meaningful differences in the water chemistry of the four systems, b) if the systems with dedicated biological filters (the trickle and “BioWheel” aquaria) had higher nitrate concentrations, as some would predict, and c) if coral health and growth is different in any of the systems.

Materials and Methods

Four identical 284 l. all-glass aquaria were set-up in a temperature-controlled room in which the air temperature was a constant 26 ± 1 degrees C. Each unit had a lighting system which consisted of two 10,000K “Euro” style metal halide fixtures and two 40 watt actinic tubes (Hamilton Technology Corp., Gardena CA). To counteract the heat radiated by the lighting system a water chilling unit (Marineland Commercial Aquariums, Moorpark, CA) was installed on each aquarium to insure that the water temperature did not go above 26.5 ± 1 degrees C. All aquaria received 32 kilograms (kg) of cured Fiji live rock and had weekly additions of Kalkwasser except for the Jaubert style tank. Table 1 presents further details of the system set-ups. The set-ups differed in the following aspects: Tank 1 (trickle filter) had an Amiracle™ trickle filter, Knop protein skimmer (Model ss100), 9 kg of crushed coral, and used activated carbon; Tank 2 ("BioWheel") had a Tidepool filter with a "BioWheel," Knop protein skimmer (Model ss100), 20 kg of crushed coral, and used activated carbon; Tank 3 (Berlin) was a Berlin style system with no dedicated biological filter, with a Knop protein skimmer (Model ss100), 20 kg of crushed coral, and used activated carbon; Tank 4 (Jaubert) was a Jaubert style system with a plenum using 50 kg of crushed coral but no protein skimmer or activated carbon. The salinity of all the aquaria was maintained at 30 parts per thousand salinity with Tropic Marin sea salts.

Fish and Corals. Care was taken to try and purchase each species of animal in groups of four (of similar size) from the same wholesaler. When groups of 4 were not obtainable similar types of animals were used as substitutes with the test aquaria divided into two groups for animal stocking. The "BioWheel" and Berlin systems were a group while the trickle and Jaubert systems formed the second group. All animals were purchased from wholesalers in the Los Angeles area. Initially all aquaria were stocked with three medium-sized *Zebrasoma flavescens* (Yellow Tang) and three large-sized *Pterapogon kauderni* (Bangaii Cardinal). Further, the Jaubert and trickle systems were each stocked with one rock each (covered with 6 to 8 medium-sized polyps) of the red and green varieties of mushroom anemones (*Actinodiscus* sp.), one *Pachyclavularia viridis* (Green Star Polyp) and one *Lobophytum pauciflorum* (Devil's Hand). The "BioWheel" and Berlin systems received one rock each (covered with 6 to 8 medium-sized polyps) of the green striped and blue-violet varieties of mushroom anemones (*Actinodiscus* sp.), one *Sarcophyton* sp**.** (Leather Coral) and one Colt Coral.

On Day 57 of the test additional animals were added. These were one each of *Pseudocheilinus hexataenia* (Six Line Wrasse), *Parupeneus multifasciatus* (Multibarred Goatfish), *Opistognathus aurifrons* (Yellowheaded Jawfish) and *Valenciennae puellaris* (Diamond Goby). Plus one each of *Wellsophyllia* sp. (Red Brain), *Catalaphyllia* sp. (Elegant coral), *Sarcophyton* sp**.** (Leather coral), *Acropora* sp. (Staghorn coral), *Tridacna derasa*, *Tridacna maxima*, *Caulastrea furcata* (Trumpet coral), *Sarcophyton sp.* (Yellow Leather coral), *Euphyllia ancora* (Hammer coral), one Red Sea *Xenia* sp. , *Mespilia globulus* (Royal Urchin), *Stylophora* sp. brown, and two rocks with 5 to 6 polyps each of mushroom anemones (*Actinodiscus* sp.).

Each aquarium was fed twice a day (8:30 a.m. and 4:00 p.m.). They received a small portion of live black worms, 2 cubes of frozen brine shrimp and a pinch of *Spirulina* flake food. Periodically, live brine is substituted for frozen brine shrimp.

Total ammonia-nitrogen was measured using the salicylate-hypochlorite method (Bower and Holm-Hansen, 1980). Nitrite-nitrogen was measured using the azo dye technique (Strickland and Parsons, 1972). Flow injection analysis (FIA), using a Tector FIAStar 5010 system, was employed to measure nitrate-nitrogen and orthophosphorous. pH and ORP were determined with an Orion pH meter and specific probes. Alkalinity was measured by titration (Strickland and Parsons, 1972). Dissolved oxygen was measured with a YSI Model 51B dissolved oxygen meter. Turbidity was measured with a Micro 100 turbidimeter (HF Scientific). Total inorganic carbon was determined, after acidification with concentrated phosphoric acid, with a Shimadzu TOC 5000 analyzer. Total organic carbon was determined by direct injection high temperature combustion using a Shimadzu TOC 5000 analyzer.

The aquaria were observed daily, and digital pictures taken every 7 days, to assess the extent of algal growth, coral health and other subjective measures of filtration system performance. The inside front glass of each aquarium was wiped clean after the photographs were taken. A 70 l. water change was performed on each aquarium 101 days into the test.

Results

We present the results for the first 156 days of operation of the aquaria. The mean ammonia-nitrogen and mean nitrite-nitrogen trends for the four filtration systems are presented in Figure 1. The data show that there are no differences in these two water quality measurements between the filtration systems. The highest ammonia and nitrite concentrations were recorded during the first 10 days of the test. However, these values were below 0.20 mg/l-N. For the rest of the testing period ammonia remained below 0.01 mg/l N, with only three exceptions. The nitrite concentrations have remained low (< 0.03 mg/l) for a majority of the testing period but have fluctuated more than the ammonia values (Figure 1). It should be noted that none of the systems experienced ‘new tank syndrome’ (NTS). NTS is the name given to the common occurrence of high ammonia and nitrite concentrations during the first 30 to 45 days after setting up a new aquarium. Generally this is due to a lack of sufficient numbers of nitrifying bacteria.

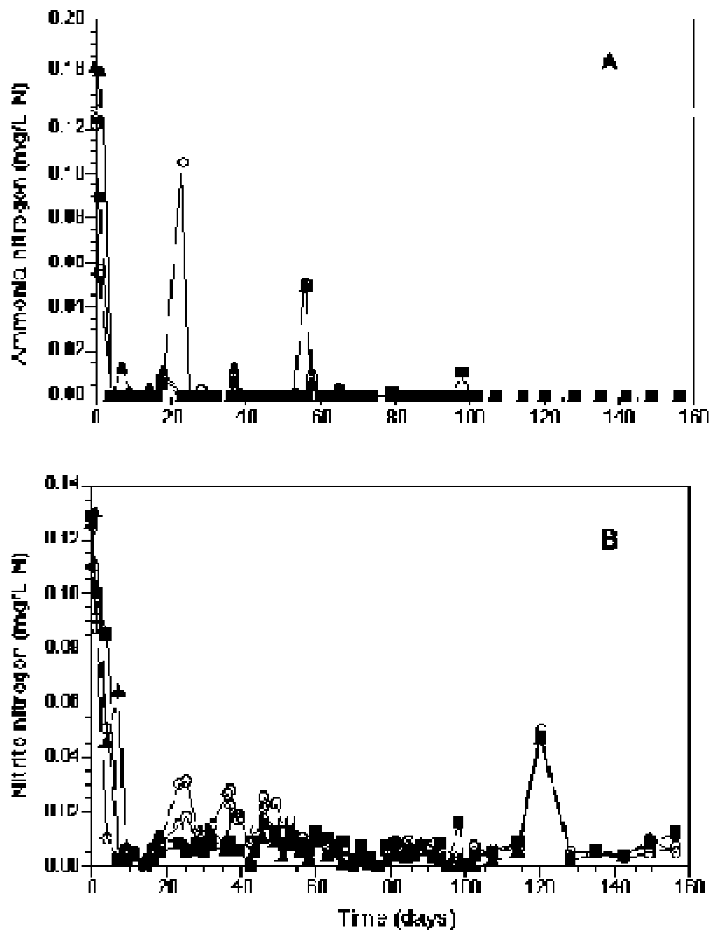

Figure 1. The ammonia (A) and nitrite (B) trends over 156 days for aquaria filtered with a trickle filter (B), a Tidepool “BioWheel” system (E), a Berlin system (A) and a Jaubert system (H). Note break in the ammonia plot between 0.12 and 0.18 mg/L NH3-N.

A comparison of the mean nitrate-nitrogen concentration for the four filtration systems shows that there were no differences among the systems for the first 100 days (Figure 2). However, at Day 114 the nitrate concentrations increased in both the Berlin and Jaubert aquaria (Figure 2). In the Berlin system the nitrate concentration increased to 0.35 mg/l NO3-N but dropped to less than 0.1 mg/l N03-N by day 149 (Figure 2). The nitrate concentration of the Jaubert system increased to 1.04 mg/l NO3-N (Day 149) before dropping back to 0.08 mg/l NO3-N (Day 156) (Figure 2). The two systems with dedicated biological filters, the trickle and "BioWheel" aquaria, have maintained nitrate concentrations of less than 0.2 mg/l since the 10th day of the test (Figure 2). There is no evidence of elevated nitrate concentrations in the aquaria filtered by either the trickle or "BioWheel" systems.

The pH, alkalinity and total inorganic carbon trends are presented in Figure 3. There are no major differences between the filtration types. The Jaubert filtered aquaria has had a slightly lower pH than the other three systems since day 100, and this same system has also had slightly greater alkalinity and total inorganic carbon values (Figure 3). The differences, however, are not notable.

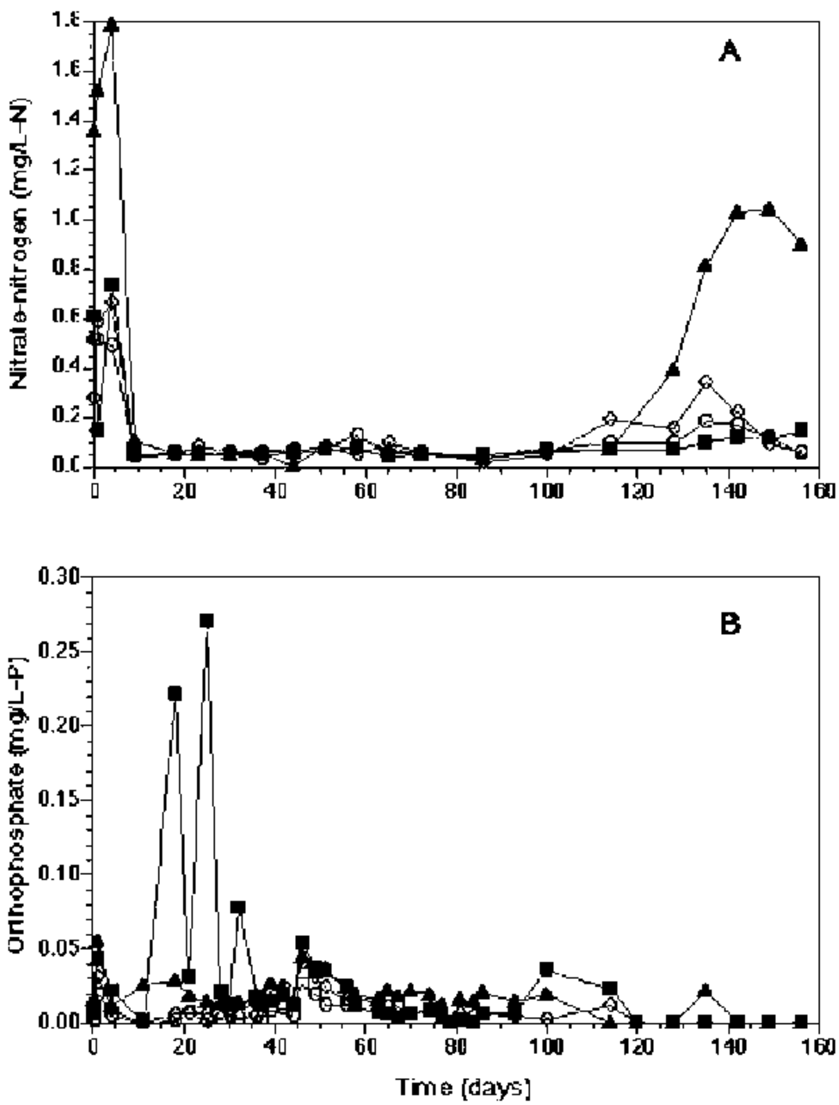

Figure 2. The nitrate (A) and orthophosphorous (B) trends over 156 days for aquaria filtered with a trickle filter (B), a Tidepool "BioWheel" system (E), a Berlin system (A) and a Jaubert system (H).

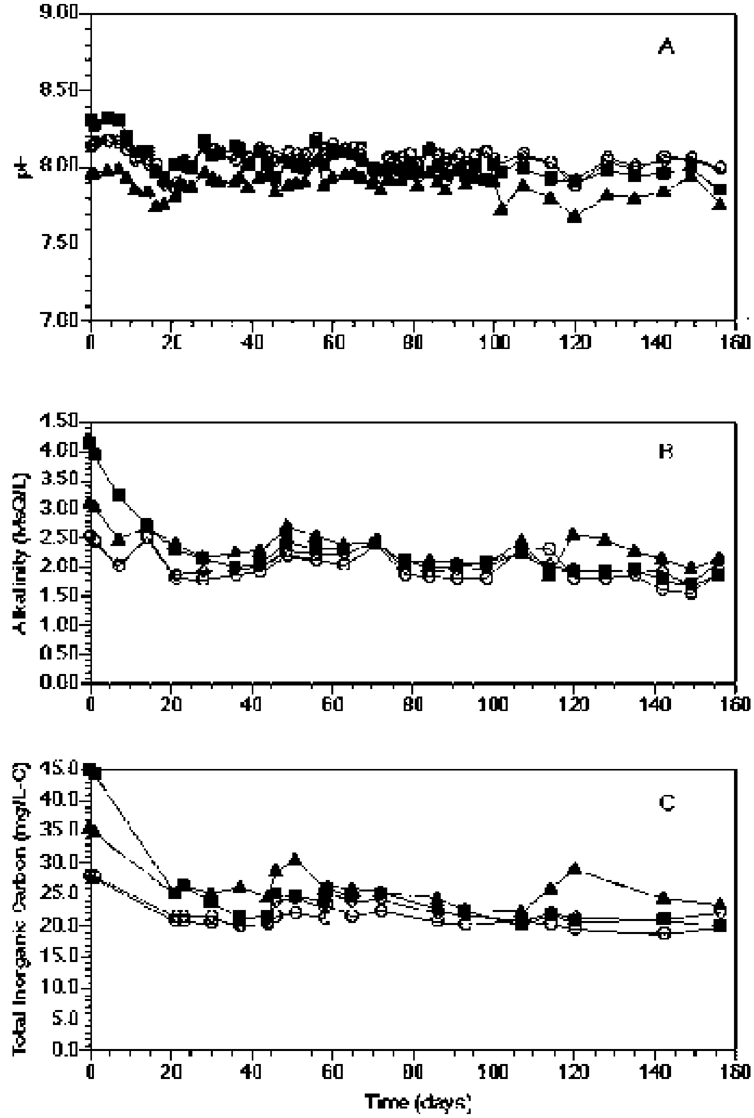

Figure 3. The pH (A), alkalinity (B) and total inorganic carbon (C) trends over 156 days for aquaria filtered with a trickle filter (B), a Tidepool "BioWheel" system (E), a Berlin system (A) and a Jaubert system (H).

The greatest difference in water quality between the four filtration systems is that the Jaubert filtered aquarium has a considerably greater concentration of total organic carbon (TOC) (Figure 4). The trickle, "BioWheel" and Berlin systems have had TOC values of less than 1 mg/L-C. However, the TOC in the Jaubert system has never dropped below 2 mg/L-C. The water change on Day 101 resulted in a temporary drop in the TOC concentration, from 3.4 to 2.4 mg/l-C, but this was short-lived and the TOC concentration was soon back up to 3.5 mg/l-C (Figure 4).

In terms of coral health, each tank had some mortality right after the addition of the corals. These organisms were probably damaged in collection and shipping which led to their death within a week of being added to the aquaria. The corals in the Jaubert system have not done well and this seemed to be linked to the increasing TOC concentration. This was the only overt problem with coral health experienced with any of the systems. The water in the Jaubert aquaria has been much more colored (a brownish-green tint) than the others and the bottom substrate blanketed by a film of green algae. The water change on Day 101 was done because the organisms in the Jaubert system did not look healthy. The other three systems did not need a water change but in an effort to treat all the systems equally they were given the same volume water change as the Jaubert system.

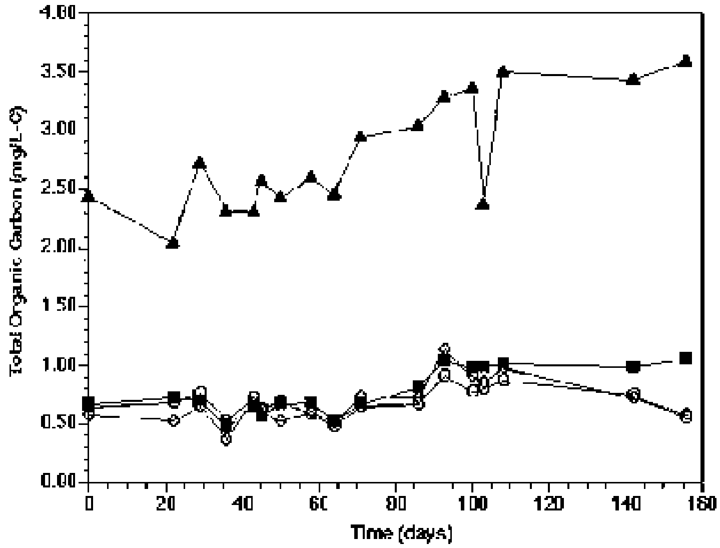

Figure 4. The trend of total organic carbon (TOC) over 156 days for aquaria filtered with a trickle filter (B), a Tidepool "BioWheel" system (E), a Berlin system (A) and a Jaubert system (H).

Algae growth in the four aquaria has varied by aquaria and time. Two weeks after set-up, the Jaubert system had the least amount of algae growth, followed in order by Berlin, trickle, and "BioWheel" systems. All aquaria during this time had algal populations consisting mainly of diatoms. After the third week, the Jaubert system started to grow much more algae than the other 3 systems, a trend which continues to date. From the third week until Week 7 or 8, the trickle system seemed to have the least amount of nuisance algae growth on the glass, rocks and gravel. While the Berlin and "BioWheel" seemed to have a little more algal growth than the trickle, but about the same relative to each other. After 9 weeks, the Berlin and "BioWheel" systems seemed to have fewer algae than the other two systems with the Jaubert system continuing to have, by far, the worst algae problem.

For a month or so starting at Week 11, the Berlin system seemed to have slightly less algae than the "BioWheel" system. However, when comparing all four systems, the Berlin and "BioWheel" systems were nearly the same, with the trickle system having much more algal growth and the Jaubert system substantially worse than the others. Starting about Week 14, the "BioWheel" system started to have the least amount of algae, followed by the Berlin system, the trickle system, with the Jaubert systems still considerably worse more than the other three aquaria. From the viewpoint of the casual hobbyist the "BioWheel" system would be more desirable at this time because most of the algae is growing on the back wall, where no scrubbing has ever occurred. There are some diatom mats on the gravel, but virtually none on the live rock and the front glass. The Berlin system has an even coat of algae on all sides of glass and gravel. The Trickle system has more algae growth on the front glass. The Jaubert systems, with substantially more algae growth than the other three systems, has a lot of algae on all surfaces.

Discussion

The results of this experiment show that mini-reef aquaria with dedicated biological filters do not exhibit higher nitrate-nitrogen concentrations when compared to other types of filtration methods. There were daily inputs of ammonia into each aquaria via the resident fish population as ammonia is the chief nitrogenous waste product of the fish. There are two possible fates for the excreted ammonia: a) the ammonia could be oxidized, via bacterial nitrification, to nitrate or b) the ammonia could be utilized by algae, including the symbiotic algae in the coral, for growth. For the first choice to be correct denitrification must be occurring at virtually the same rate of nitrification as there is no net increase in nitrate, the end product of nitrification. While this scenario cannot be dismissed it seems unlikely that a newly set-up aquaria would be able to establish the conditions for denitrification so quickly. The most likely explanation for the low nitrate concentrations seen in the four aquaria is the ammonia produced by the fish is utilized by primary consumers, which live on the live rock and are part of the coral community.

While it is beyond the scope of the present study to definitively answer the question of the fate of the ammonia produced in the aquaria, one can look for common factors among the test aquaria in an effort to find the possible location of the ammonia consumers; be they autotrophic nitrifiers, working in close conjunction with denitrifying bacteria, or primary consumers. The common component of the four systems is the live rock. Thus, a strong correlation can be drawn between the presence of an adequate amount of live rock and the stable water chemistry exhibited in the aquaria. Live rock is the main filter device for nitrogen and phosphorus via the action of microorganisms. However, there does not seem to be a process associated with live rock to remove organic carbon from the water which is why the Jaubert system, without a protein skimmer or activated carbon, has such high a TOC concentration.

The most often asked question, in terms of setting-up a mini-reef aquarium, is what filtration system should one use? The results of this test show that the filter system most likely plays a secondary role. To be successful, over the long term, one needs a large amount of live rock, a good lighting system, and an organic carbon removal system. Having a dedicated biological filter may be an added plus but it is certainly not a detriment to the goal of setting-up and maintaining a healthy mini-reef aquarium.

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MARINE ORNAMENTALS: THE INDUSTRY AND THE HOBBY

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ABSTRACT

The structure of the marine ornamental trade is analyzed in terms of the number and distribution of the species that comprise the market. A snapshot of the number of species of fish and invertebrates that are offered to hobbyists were developed from the price lists of wholesalers. The percentage rank of the most abundant fish species in the trade were developed from actual recent sales of a major wholesaler, Quality Marine. Currently, the trade consists of 500 to 700 species of marine fish and at least 300 species of identified marine invertebrates. Sales of 206,215 fish representing 705 species were analyzed. Seventy-seven species represented 78% of all fish sold. Cultured fish represent only about 2% of fish in the trade.

A brief history of the development of aquaculture of marine ornamental fish is presented with a discussion of the major breakthroughs in the culture of marine tropical fish.

Key words: marine ornamentals, marine ornamental trade, marine fish aquaculture

Introduction

This paper was the plenary presentation at the Marine Ornamentals ‘99 Conference in Hawaii. Its purpose was to provide an introduction to the problems the industry currently faces, an analysis of numbers and distribution of the species that make up the current trade of marine ornamental species, and to present a brief history of the technical breakthroughs in the culture of marine tropical fish. A major point of the presentation was to demonstrate that the marine ornamental industry is dependent on a very broad constellation of species, distributed so widely that aquaculture efforts simply cannot supply the number of species required to maintain a vital and healthy hobby and industry. Therefore, although aquaculture can and will increase in scope and importance to the commercial industry, the industry must continue and increase it's efforts to develop sustainable and properly managed fisheries to provide the product for the marine ornamental industry and hobby. Commercial marine ornamental aquaculture companies are usually small and struggle with many technical and economic challenges. It is usually not economically possible to conduct controlled scientific trials to solve technical problems. Thus many innovations are developed only through the instincts and experience of dedicated and driven individuals. In my career as a marine fish farmer I have had six major breakthroughs or “eurekas” that in a small way, document the history of marine fish aquaculture. These are briefly described in this paper.

The Industry and the Hobby

I think that there are two reasons why we are here today.

1. We are concerned about the future of the marine ornamental industry and hobby and we want to contribute and help create a dynamic and successful structure that will carry the hobby, and the industry that serves it, into the next century.

2. We want to learn and to teach. We want to gain knowledge that will better our endeavors in the science and business of marine "aquaristics."

I hope to contribute to both reasons this morning.

> The current status of the marine ornamentals industry and hobby was well summarized by Charles Dickens (Dickens, 1859) about 150 years ago in his novel, "A Tale of Two Cities. "
>
> "It was the best of times, it was the worst of times, - it was the age of wisdom, it was the age of foolishness, - it was the season of light, it was the season of darkness."

And so it is with marine ornamentals. It is frustrating, that just as we are learning some of Neptune's deepest secrets and solving many of the critical problems that have severely limited culture and maintenance of captive marine life, that we are harnessed and harassed by current and potential environmental and political regulations. At this point, the future of the marine ornamental industry depends more on the external controls of environmental and political regulation than on the internal development of technological and aquarium science advances. This is not to say that the marine ornamental industry does not need improvement and regulation, in fact, the future of the industry depends on development of constructive regulation that will create sustainable fisheries for ornamentals.

It is also very important to realize that the marine ornamental fishery is not like a typical single species, specific area fishery. It is actually hundreds of small fisheries dealing with about a thousand species in hundreds of tropical areas throughout the world. The opportunities, problems, and solutions of each fishery in each area are unique to a lesser or greater degree. The fact that simple solutions, sweeping reforms and generalized regulations will not work in every situation should always be a consideration.

It is well documented that coral reef environments throughout the world are suffering decline and damage from human impact and environmental changes. We will hear much more about this during this conference. While it is true that the marine ornamental industry has contributed to the human impact on coral reefs, it is unfortunate that this industry often undeservedly takes the lion's share of the blame. For example, in many tropical areas, fish species typically identified as "aquarium fish" are exploited much more actively as food fish than as aquarium fish yet the marine ornamental industry is often cited as the sole cause of declines in fish populations.

We know that there is a very great difference between collection and processing of coral for roadways, animal feed, and curios, and the collection of coral fragments for aquarium culture.

And that there is also a very great difference between fishing for food fish with cyanide and explosives, and responsible, managed collection of live tropical fish for the aquarium trade.

Yet, because of the high public profile of marine aquariums, and the visual and emotional impact of keeping a coral or a fish alive rather than processing a dead product, the marine ornamental industry is often the “nail that sticks up” in the public mind, and thus we receive blows from the hype hammers of the media that are far out of proportion to the real impact of the industry on the coral reefs.

For example, and I mention only one of a great many, CNN.com on the internet (http://cnn.com/NATURE/9911/01/aquarium.threat.ap/index.html) reported on the recent meeting of the Coral Reef Task Force in the Virgin Islands earlier this month. The report consisted of two pages of accusations of environmental destruction under the title “Home Aquariums Pose Growing Threat to Reefs, Experts Say.” Casual readers of that “news release” are left with the perception that collection of marine ornamentals is the major cause of coral reef decline.

Yet the report of the working group, “The National Action Plan to Conserve Coral Reefs” (CRTF Working Groups, Nov. 2, 1999) presented at the U.S. Coral Reef Task Force meeting, in the R.S. Virgin Islands on November 2, 1999, presented a much different picture indicting the factors of pollution, over-fishing of food fish, dredging and shore line modification, disease and global warming as among the most severe threats.

However, it is very important to realize that, whenever perception and reality collide in the public mind, perception always wins.

It is imperative that if there is one thing that all sectors of the industry and the hobby must do together, it is to educate, and to do everything possible make the public perception of the marine ornamental industry reflect reality.

Species Analysis

At this point, I want to look at the structure of the industry from a very basic viewpoint, the organisms that make up the hobby. In order to do this we have to look to the wholesalers.

The wholesalers, incidentally, are the heart of the industry for everything that makes up the hobby passes through the wholesaler. The retailers are the mind of the industry, for it is from them that the hobbyists gain most of their information. The manufacturers are the body of the industry for they create the structure of the hobby. And the hobbyists are the soul of the industry for they are passion that drives the hobby. As for those that supply and encourage collectors to use cyanide to take fish, well, I'm sure that you can come up with an appropriate body part for this analogy.

I analyzed the price lists of 7 wholesalers, large and small, just to get an idea as to how many fish, invertebrates and plants are typically available to the hobby. The results, Table 1, were interesting. The number of fish species offered varied from 86 to 741. As would be expected, small regional wholesalers offer fewer species than large wholesalers that import from collectors all over the world. Invertebrate species followed the same pattern and varied from a low of 19 to a high of 340. Tank bred fish made up a very low percentage of the species offered, 1 to 5%. Only Inland Aquatics, a more retail than wholesale operation, and atypically strongly oriented toward aquaculture, had a relatively high percent of tank bred species, 35%.

Table 1. Wholesale Price List Data, number of species, fish and Invertebrates.

Wholesaler	Fish Species			Invertebrate Species			Plants
	Total	Tank Bred	%	Total	Tank Bred	%	
Golden Gate	741	--	--	340	--	--	5
High Bright	130	--	--	97	--	--	--
Inland Aquatic (retail)	141	35	24.8	131	83	63.3	28
Quality Marine	320	3	0.9	165	--	--	10
Red Sea	86	--	--	19	--	--	--
Sea Critters	224	12	5.4	264	17	6.4	20
Tropical Marine Centre	477	9	1.8	223	--	--	13

The point I want to make here is that the hobby as it is now structured works with about 500 to 700 species of fish and at least 300 species of identified invertebrates.

Secondly, through the kindness of Phil Shane at Quality Marine, 5420 W. 104th St., Bldg. 2E, Los Angeles, CA 90045, I got a look at the numbers of fish, by species, that actually moved through the tanks of a major wholesaler. I did an analysis of these fish, which I will present briefly. There were a total of 206,215 fish representing 705 species that recently passed through the tanks of Quality Marine in this analysis. I took Phil's raw data, which was recorded in numbers of fish sold and listed by common name, sometimes from different areas and sometimes broken up into juvenile and adults listings, and reduced it to a single entry by consolidating all entries that represented a single species. I then identified the common name of each species with the scientific name. Many scientific and popular texts were used to determine the correct scientific name. Only those species (77) that represented more than 0.02% of sales were included in these tables.

Table 2 shows the distribution of numbers of fish in the top 25, second 25 and third 27 of the fish species in this universe. Note that the top 25 species represented 55 percent of all the fish and the top 77 species represented 78 percent of all fish sold.

Table 2. Distribution of wild collected fish by percentage of species and by number of fish in recent sales by Quality Marine. Data courtesy of Phil Shane.

Species Group	% Species	% Number
Top 25 species (1 through 25)	3.5	55.3
Second 25 species (25 to 50)	3.5	14.9
Third 27 species (50 to 77)	3.8	8.4
Top 50 species (1 through 50)	7.1	70.3
Top 77 species (1 through 77)	10.1	78.7
Total number of species	705	
Total number of fish	206,215	

Table 3 illustrates the relationship between tank bred (aquacultured fish) and wild collected fish. Note that in both species and numbers, tank bred fish represent only about 2% of the total fish sold.

Table 3. Comparison of wild collected fish with tank bred fish in recent sales of Quality Marine. Data courtesy of Phil Shane.

Number of Fish Species		%	Total Number of Fish	%
Collected	705	98.1	206,215	98.0
Tank bred	14	1.9	4,270	2.0
Total	719		210,485	

Table 4 shows the distribution of wild collected invertebrates. Tank bred invertebrates, if present, were not identified as such. Anemones were by far the most numerous, 81%, of the four categories of invertebrates. Invertebrates were listed by broad category and not by specific species in the Quality Marine lists and also in the price lists from other wholesalers.

Table 4. Distribution of wild collected invertebrates in recent sales from Quality Marine. Data courtesy of Phil Shane.

Type Species	Number of	% Species Individuals	Number of	% Number
Anemones	19	32.2	11,742	81.0
Cephalopods	5	8.5	217	1.5
Soft Corals	16	27.1	1,076	7.4
Hard Corals	19	32.2	1,489	10.3
Total	59		14,4524	

Tables 5, 6, and 7 show the rankings of the individual species of the top 77 species (10% of all species, 79% of all fish) in individual numbers. The data are most interesting and I wish I had time to explore all the insights that are exposed in these tables. Note, however, that the top 25 species account for 55% of all the fish in the sample. Note also that damsels are the most common species in the top 25. Note also that only 6 species account for more than 2% each in sales and the most abundant species, the blue devil, accounts for only 8.5% of sales. All the rest of the top selling fish, 71 separate species, is between only 2 and 0.2% each of sales.

Table 5. Species distribution by percentage of the top 25 species (1 through 25) in total recent sales of collected fish by Quality Marine. Data courtesy of Phil Shane.

First Rank, Top 25 Species, 1 through 25		% of Total Collected Fish
1. Blue devil damselfish, *Chrysiptera cyanea*		8.5
2. Blackaxil chromis (green chromis) *Chromis atripectoralis*		6.5
3. Yellowtail damsel, *Chrysiptera parasema*		5.8
4. Three spot dascyllus (domino), *Dascyllus trimaculatus*		3.8
5. Yellow tang, *Zebrasoma flavescens*		3.6
6. Blacktail damsel (4 stripe) *Dascyllus melanurus*		2.6
7. Blue tang, *Paracanthurus hepatus*		2.0
8. Humbug (3 stripe damsel), *Dascyllus aruanus*		2.0
9. Bluestreak cleaner wrasse, *Labroides dimidatus*		1.9
10. Royal gramma, *Gramma loreto*		1.7
11. Clownfish, tank bred, *Amphiprion* sp. (4 species)		1.7
12. Green mandarinfish, *Synchiropus splendidus*		1.6
13. Catalina goby, *Lythrypnus dalli*		1.3
14. Ocellaris clownfish, *Amphiprion ocellaris*		1.3
15. Banggai cardinalfish, *Pterapogon kauderni*		1.3
16. Ocellated (scooter) dragonet, *Synchiropus ocellatus*		1.2
17. Flame hawkfish, *Neocirrhites armatus*		1.1
18. Purple (magenta) dottyback, *Pseudochromis porphyreus*		1.1
19. Firefish, fire dartfish, *Nemateleotris magnifica*		1.0
20. Reticulate dascyllus (2 stripe) *Dascyllus reticulatus*		1.0
21. South Seas devil damsel, *Chrysiptera taupou*		0.9
22. Sailfin blenny, *Emblemaria pandionis*		0.9
23. Percula clownfish, *Amphiprion percula*		0.9
24. Saddle damsel, Indian Ocean		0.8
25. Coral Beauty, *Centropyge bispinosus*		0.8
Number of Fish in First Rank:	114,129	55.4

Table 6. Species distribution by percentage of the second 25 species (26 through 50) in total recent sales of collected fish by Quality Marine. Data courtesy of Phil Shane.

Second Rank, Second 25 Species, 26 through 50		% of Total Collected Fish
26. Smith's pink damsel, *Pomacentrus smithi*		0.8
27. Goldring surgeonfish, *Ctenochaetus strigosus*		0.7
28. Flame angel, *Centropyge loriculus*		0.7
29. Tomato clownfish, *Amphripion* sp. (3 species)		0.7
30. Bannerfish, *Heniochus* sp.		0.7
31. Sixline wrasse, *Pseudocheilinus hexataenia*		0.7
32. Volitans lionfish, *Pterois volitans*		0.7
33. Lyretail Anthias, *Pseudanthias squamipinnis*		0.7
34. Bicolor, Centropyge bicolor		0.6
35. Sargent major, *Abudefduf saxatilis*		0.6
36. Lemon peel, *Centropyge flavissima*		0.6
37. Diamond watchman goby, *Valenciennea puellaris*		0.6
38. Naso tang, *Naso lituratus*		0.6
39. Foxface rabbitfish, *Siganus vulpinus*		0.6
40. Lemon damsel, *Pomacentrus sulfureus*		0.6
41. Blue chromis, Atlantic, *Chromis cyanea*		0.5
42. Powder blue surgeonfish, *Acanthurus leucosternon*		0.5
43. Porcupine puffer, *Diodon holocantus*		0.5
44. Yellow chromis, *Chromis analis*		0.5
45. Picasso Triggerfish, *Rhinecanthus aculeatus*		0.5
46. Neon goby, *Gobiosoma oceanops*		0.5
47. Yellowhead jawfish, *Opistognathus aurifrons*		0.5
48. Sailfin tang, *Zebrasoma veliferum*		0.5
49. Clown Trigger, *Balistoides conspicillum*		0.5
50. Snowflake moray, *Echidna nebulosa*		0.5
Number of Fish in Second Rank	30,754	14.9
Number of Fish, Top 50 Species	14,4883	70.3

Table 7. Species distribution by percentage of the third 27 species (51 through 77) in total recent sales of collected fish by Quality Marine. Data courtesy of Phil Shane.

Third Rank, Next 27 Species, 51 through 77		% of Total Collected Fish
51. Clown gobies, *Gobiodon* sp.		0.4
52. White damsel, *Dischistodus perspicillatus*		0.4
53. Maroon clownfish, *Premnas biaculeatus*		0.4
54. Niger triggerfish, *Odonus niger*		0.4
55. Lyretail chromis, *Chromis* sp.		0.4
56. Copperbanded butterflyfish, *Chelmon rostratus*		0.4
57. Zebra lionfish, *Dendrochirus zebra*		0.4
58. Purple flame dartfish, *Nemateleotris decora*		0.4
59. Bicolor chromis, *Chromis bicolor*		0.3
60. Clarkii clownfish, *Amphiprion clarkii*		0.3
61. Christmas wrasse, *Thalasoma lunare*		0.3
62. Koran angel, *Pomacanthus semicirculatus*		0.3
63. Engineer goby, *Pholidichthys leucotaenia*		0.3
64. Orbiculate cardinalfish, *Sphaeramia orbicularis*		0.3
65. Bird wrasse, *Gomphosus varius*		0.3
66. Diadem dottyback, *Pseudochromis diadema*		0.3
67. Beaugregory, *Stegastes* sp.		0.3
68. Longhorn cowfish, *Lactoria cornuta*		0.3
69. Blue velvet damsel, *Neoglyphidoden oxyodon*		0.3
70. Raccoon butterflyfish, *Chaetodon lunula*		0.3
71. Black-bar chromis, *Chromis retrofasciata*		0.3
72. Longnose butterfly, *Forcipiger* sp.		0.2
73. Spotted mandarinfish, *Synchiropus picturatus*		0.2
74. Banded sleeper goby, *Valenciennea* sp.		0.2
75. Harlequin tuskfish wrasse, *Choerodon fasciatus*		0.2
76. Dragon wrasse, *Novaculichthys taeniourus*		0.2
77. Pearlscale butterfly, *Chaetodon xanthurus*		0.2
Number of Fish in Third Rank	17,408	8.4
Number of Fish, Top 77 Species	162,291	78.7

These data well illustrate the very broad species base of the marine ornamental industry, which is quite obvious to those in the business, but now there are some numbers to back up the empirical observation.

My major point is that collected species are the very basis of the industry and that aquaculture, now and in the foreseeable future, can supply only a very small percentage of the species that make up the hobby and that even large aquaculture operations can not and will not "save the coral reefs". We have to look to sustainable, well-managed collection to provide the variety of species that the hobby requires. Aquaculture will relieve collection pressure on certain species and advance our knowledge of the biology of these organisms, but it cannot completely, or even marginally, substitute for wild sources of the great variety and number of organisms that make up the hobby. Those that use the promise of aquaculture to advance their own agenda at the expense of the public image of the industry do a disservice to the hobby. The promise and benefits of aquaculture to the environment and to the hobby can be told without false denigration of the fisheries that sustain the hobby.

It would not be wise for the industry to abandon collection, or even negotiate restriction in favor of aquaculture when aquaculture, with the notable exception of a few species, can not even begin to carry the load. All invested interests in the industry and the hobby should work toward long term, well managed, sustainable collection as the foundation of the hobby.

To draw a biological analogy, in nature, an anemone, a facultative symbiont, does not need a clownfish to survive, but a clownfish, an obligate symbiont, must have an anemone in order to survive. The industry needs both collection and culture, and culture will become increasingly important, but at this point, collection is the anemone and culture is the clownfish.

Marine Fish Aquaculture

The second part of my talk deals with aquaculture of marine fish, since that is my area of endeavor. This is my effort to provide some information that may be of help to you in the science and technology of marine aquaristics.

Aquaculturists occasionally have “eurekas”. Minor eurekas are not particularly unusual, but major eurekas are very rare. A eureka is an insight or discovery that makes an important difference in a particular project or process. For aquaculturists, a minor eureka may be the addition of something in the food that produces faster growth or better color, or the addition of a structure that makes control of spawning easier or produces more larvae. But a major eureka, that is something that turns night into day, total disaster into triumph, a morgue into a nursery. I have been fortunate to have six major eurekas over the years and I thought it would be interesting to share the details of some of these with you. In a small way, my history of these “eurekas” is also the history of the early years of marine ornamental fish aquaculture.

My first eureka occurred in the fall of 1969. I was working for a private company in West Palm Beach, Florida, trying to develop the technology for spawning and rearing pompano, a subtropical food fish. The spawning part went well but we were hung up on rearing the larvae. I learned about a small organism, a rotifer, *Brachionus plicatus*, that was being used at Scripps Institute of Oceanography, LaJolla, CA, USA, to rear anchovies. We acquired a culture of these little animalcules, and suddenly the tanks were alive with well-fed larvae and, for the first time, postlarval pompano, *Trachinotus carolinus*.

The second eureka concerned postlarval clownfish. In the late winter, early spring of 1973, we had formed Aqualife Research in St. Petersburg, Florida, and we were well into the commercial culture of clownfish, *Amphiprion* sp., using rotifers, *B. Pilicatus*, and brine shrimp, *Artemia salina*, in small closed systems. We were plagued, however, by a lethal syndrome that came on very rapidly and killed every small clown in the system within 24 to 48 hours. We dubbed this phenomenon the “toxic tank syndrome” and it threatened to completely demolish our fledgling marine fish culture operation. We experimented and found that if we moved the fish to a new system as soon as the first signs of the toxic tank syndrome appeared, we lost few, if any, fish. The move to bare tanks without biological filtration and subsequently to open systems for grow out was predicated by avoidance of the toxic tank syndrome. Since then, we also found that use of relatively large volumes of activated carbon seems to remove the toxin and also allows survival.

The third eureka concerned rearing larval Atlantic angelfish, *Pomacanthus* sp. We moved the hatchery to the Florida Keys in 1975 primarily to work with propagation of angelfish.

No matter what we did, various foods, various tank shapes and volumes, lighting, water color, temperatures, various antibiotics, and assorted fish culture chemicals, the very best we could do was to rear perhaps a dozen larvae out of 20,000 eggs through to postlarvae. This was the situation over a number of years of experimentation. Then one day, based on a paper about the culture of lugworms, *Arenicola cristate*, (D'asaro, C.N. and H.C.K. Chen, 1976) we added streptomycin at about 13 mg./l to the larval tank. Immediate Triumph!

After that breakthrough, we were able to rear up to about 2000 larvae in one tank to postlarvae within 21 to 30 days.

The fourth eureka occurred in the Bahamas after Aqualife Research moved to Walker's Cay. And this is a weird one. Although I had extensively tested the well water that we were to use on postlarval clownfish before the move, I did not do preliminary work with larval fish. To my surprise, once the hatchery was established, mortality of larvae within the first 2 or 3 days of hatch was almost total. Every species, every pair, every time - almost total mortality. Nothing we did seemed to make any difference. Examination of the moribund larvae under the compound microscope revealed something most interesting. There were numerous strange elongate structures moving through the blood vessels of all the larvae. We went through extensive efforts to identify these objects and finally, Dr. Louis Leibovitz, at the time the Director of the Laboratory for Marine Animal Health at Woods Hole Marine Biological Laboratory, Woods Hole, MA, identified these structures through electron photomicrographs as red blood cells with an extreme "sickle cell" condition, a phenomenon he had never seen before in larval fish.

We went through extensive efforts to determine what was causing the sickling of the larval red blood cells. We suspected something in the saline well water, although all measurable parameters were normal when larva were introduced to the tanks, and ran a seawater line from the Atlantic ocean that washed the shores of Walker's Cay. Even natural Bahamian seawater made no difference in the condition of the larvae. Finally, thinking that perhaps if we diluted whatever was in the water, "Factor X", with freshwater, it might make a difference, we added about 20% fresh water to the larval tanks, bringing the salinity down to about 23 ppt. Suddenly there was life where only death occurred before.

I still don't know what caused this condition to occur at Walker's Cay, and I saw no clues in analysis of the water supply, but since that time, every larval tank was given this dilution factor and when this was done, the red blood cells were normal and the larval survived. After 10 to 15 days, the salinity was brought up to that of normal seawater through trickle exchange and the fish suffered no ill effects.

The fifth eureka consisted of adding wild plankton, mostly copepod nauplii, to the diet of 10-day-old orchid dottyback, *Pseudochromis fridmani*, larvae. In my relatively recent rearing work with these dottybacks (Moe, 1997), a diet of just enriched rotifers and brine shrimp resulted in total mortality of all larvae by day 16 to 18. Addition of wild plankton to the diet allowed me to rear 351 individuals to the juvenile stage in one rearing run in a 20-gallon tank.

The sixth eureka concerns flame angels, *Centropyge loriculus*. I don't have time to go into the details and there is much more work to do with this species, so I can only say that I have succeeded in turning the near total mortality of the early stages into total survival. Resolving the remaining problems with culture of these species that have the smallest pelagic eggs and larval stages will be one of the major steps in expanding the economic feasibility of marine tropical fish culture.

The Future of the Industry

The future of the marine ornamental industry and aquaculture of marine ornamentals rests on a three-legged stool. The legs are ethics, economics, and education.

The ethics of people in this industry, the way we treat our livelihood, the fish and invertebrates, our dealings with one another, and the presentation of our industry and hobby to the public, must be above reproach. A sleazy industry that allows unconscionable mortality and contributes to the decline of the coral reef environment will not long survive.

Too many of us in this industry have been tarred with the brush of “make a quick buck” to the detriment of the animals, the environment and the hobbyist. The industry is large enough now, and strong enough economically, to support efforts like the Marine Aquarium Council, The Breeders Registry, and the American Marinelife Dealers Association, and others, that are working to improve collection, transport, culture, and maintenance of our aquatic friends, and repair the public image of the industry and the hobby.

Economics are a reality of commercial life. No business that does not make a profit will survive long. A hobbyist, however, can follow a dream and create wonders without concern for the bottom line, but the collector, breeder, wholesaler, and shop owner must, eventually, either operate profitably or find another source of income. It is very important that hobbyists realize that the marine ornamental industry is a business, and that the future of this industry depends on high quality animals and the knowledge and regulation to sustain that quality throughout the chain that ends with the hobbyist. The hobbyist must support the industry by accepting the costs of high quality products and by gaining the knowledge that will yield a wise purchase.

Thus education is the cornerstone of the hobby, and of the industry as well. The future of the industry may depend on how well we can educate the public on the reality that is represented in the corner aquarium shop and in the spectacular display of aquatic life that composes a modern reef aquarium.

It is up to us, at this conference, to nurture the seeds that are already planted that will grow into the marine ornamental industry of the future. Some may think that this slide of a sunset (my backyard at our new home in the Florida Keys) represents the current status of the marine ornamental industry, but according to little known theory, if you reverse the slide as you insert into the projector, as I did, it becomes a sunrise. And I think that with a little effort, we will find that the marine ornamentals industry is at a new sunrise and not a sunset, and that the best is yet to come.

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ECONOMIC AND SCIENTIFIC DEVELOPMENT OF FLORIDA’S MARINE ORNAMENTAL AQUARIUM SPECIES SECTOR

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ABSTRACT

The Florida Sea Grant College Program aims to foster sustainable marine aquarium species aquaculture. It seeks to emulate the success of the state’s freshwater ornamental species culture sector, the largest in the United States. Its partnership with university scientists, businesses and non-profit interests includes research on fish and invertebrate life history and economics, education, and application of findings to commercial and conservation issues.

Keywords: aquarium species, economics, Florida, marine ornamentals, life history

Introduction

This paper describes the effort of a Sea Grant-Land Grant university partnership with commercial interests to further the development of Florida’s marine ornamental aquarium species production, research and technology sector. The effort seeks to emulate the success of the freshwater tropical fish business and its allied research and education interests in Florida, the largest endeavor of its kind in the nation. The work described has been undertaken by Florida Sea Grant (FSG) as a means of complementing ongoing activity by commercial, academic and public interests.

Rationale and Planning

Marine ornamental species culture has been a formal priority of the Florida Sea Grant College Program since its establishment as an element of the program’s long-range plan in 1996. Here we describe the basis for that decision.

The ornamental aquarium species industry of Florida is the largest of any state in America. Most of this trade is derived from a well-developed freshwater species culture, trade and sales sectors, which are centered east of the Tampa Bay area and in southeast Florida. Ornamental fishes for the home aquarium accounted for 56% of total Florida aquaculture sales in 1997, accounting for farm gate sales of $57,200,000 by 203 producers (Bureau of Seafood and Aquaculture, 1999). The principal groups of fishes produced include livebearers and egg layers.

Success with freshwater species aquaculture clearly offers a foundation for the industry to expand into and include more marine organisms. The existing expertise in production, marketing and distribution gives Florida a great advantage over other domestic and overseas producers. As noted by the 1999 Florida Aquaculture Plan of the Florida Department of Agriculture and Consumer Services (Bureau of Seafood and Aquaculture, 1999), marine ornamentals offer high prices and good market potential, making them competitive. The same agency calculated that over a 50-year period production of ornamental fishes in one rural area yields $11.4 million per acre, versus $1.0 million for residential construction and resale. Finally, growing academic capability to assist this industry is reflected in expanded research, diagnostic, demonstration and training activities by organizations such as the University of Florida Tropical Aquaculture Laboratory and Harbor Branch Oceanographic Institution.

At a 1996 statewide meeting of Florida aquaculture industry, academic and government agency experts, 13 major groups of organisms were reviewed for potential Florida Sea Grant (FSG) involvement through research, extension, technology transfer and communications. For each group, opportunities, issues and needs were reviewed (Seaman and Adams, 1998). Based on that analysis, priority topics (in equal order of importance) for ornamental marine species research were identified as:

- Closing a species' lifecycle and larviculture;
- Broodstock management;
- Diet;
- Disease diagnosis, treatment and prevention;
- Economic feasibility analysis;
- Market description;
- Production technology for intensive, land-based systems;
- Siting and appropriate locations;
- Documentation of natural colonization and ecology; and,
- Conservation of wild populations.

Subsequently, an initial group of research projects (described below) was supported, based on competitive, peer-reviewed proposals. With this initial core of research in place, FSG felt comfortable in developing stronger ties with industry. In early 1999, an advisory committee of six users representing commercial and non-profit interests was established. This group has met twice; the latter time in a workshop setting to receive reports of FSG-funded research. It will work to guide priorities for the 2002-2003 biennial research funding competition, and assist developing other aspects of the program such as outreach.

Florida Sea Grant priorities for marine aquaculture in 1997-2002, as related to ornamental species, include:

1. Communication and education to promote overall public awareness;
2. Determination of financial feasibility and market characteristics for species of greatest technical potential;
3. Development of culture techniques, including broodstock management, nutrition and health, for invertebrate and fish species of reasonably demonstrated economic viability; and,
4. Demonstration and technology transfer from recent and current Sea Grant projects.

Research and Extension Foundations

Based on its long-range plan, FSG has advertised for new research on ornamental species in its two most recent statewide advertisements for proposals. Priority for this "commodity" will continue, with the intent of adding outreach/extension capability.

Of 17 research projects in its 1998-2000 "core program," which includes other areas such as seafood quality, biotechnology, engineering and policy, FSG is conducting three projects related to ornamental species. A brief description of each follows:

Project R/LR-A-23, Structure and Competitiveness of Florida's Tropical Ornamental Marine Species Industry. Approximately 300 different species of marine life are collected in Florida each year for sale by the marine aquarium industry. These species are valued at $4 million annually to Florida collectors, with a much higher value to the wholesale and retail sectors. Although this is obviously a thriving industry, little is known about its structure. This project takes a thorough look at the demand for Florida's marine life products. It is identifying the product value for individual species, market channels, substitutes, and future trends; and assessing the competitiveness and the future economic potential of Florida's marine life industry.

Project R/LR-A-22, Culture Techniques for Marine Ornamental and Consumable Fish: A Better Larval Diet? Copepods are the natural food of many fish larvae. However, difficulties in getting copepods from the wild or growing them in controlled conditions have prevented their use as a food for aquacultured fish. This project, conducted in cooperation with Texas Sea Grant, is determining (1) if the growth and development of ornamental fishes can be improved by feeding them copepods; (2) if the survival and growth of marine fish grown commercially, such as red drum, can be improved by using copepods as a food for them; and (3) the food quality of copepod nauplii obtained from adults raised on different diets in the laboratory and from the field.

Project R/LR-A-24, Atlantic Surgeonfish as a Model for Description of Normal Anatomy, Histology and Natural Diet of Herbivorous Ornamental Reef Fish. Atlantic surgeonfish are routinely captured off the Florida coast for sale through the aquarium trade and for display in oceanaria. Unfortunately, captured reef fish often suffer from two important illnesses that probably result from improper nutrition. This project uses Atlantic surgeonfish as a model for finding ways to improve the nutritional management of captive reef fish and to hopefully improve their health, longevity, and ability to reproduce in captivity.

The first major ornamental species research project sponsored by FSG ran from 1995-1997, and was entitled Cultivation of Ornamental Marine Shrimp for the Saltwater Aquarium Industry. It proposed to develop culture techniques for six species of shrimp. The study further refined the larviculture protocols for three species of ornamental marine shrimp. Feed types, density and related growth and survival information was documented. One species, *Lysmata wurdemanni*, was cultured with sufficient success to justify pilot-scale commercial production. Refinement of techniques for the golden coral shrimp, *Stenopus scutellatus*, suggests that this species can be cultured commercially in the near future. Although mating behavior and larviculture techniques were described in this study, successful commercial culture may be curtailed based on the sensitivity of the larvae and their protracted larval period. As a result of this research, a private company has begun commercial production of the peppermint shrimp, *L. wurdemanni*, and selling them as part of their product line of tank-reared ornamental fishes. This same company is engaged in pilot-scale production of *S. scutellatus* and *L. amboinensis*. The company attributes much of their success to information provided by the project, as contained in journal publications (e.g., Lin et al., 1999) and a graduate thesis.

Planned for 2000-2001 are three FSG new projects, selected on the basis of peer-reviewed technical merit and as part of a package of 17 total projects in the biennium: Project R/LR-A-29, Market Preferences, Wholesale Demand, and Breakeven Prices for Ornamental Fish Cultured and Collected in Florida; Project R/LR-A-30, Captive Nutritional Management of Herbivorous Reef Fish Using Atlantic Surgeonfish as a Model; and Project R/LR-A-31, Effects of Broodstock Diet on Fecundity, Egg Quality, and Production of Marine Ornamental Shrimps.

With a research component established, technology transfer will receive emphasis in the immediate future. Especially FSG seeks to establish an extension position for marine aquaculture, including ornamental species.

Outlook

While sponsorship of a small number of research projects about ornamental species annually is important, clearly there is opportunity and need for a more comprehensive Florida research program. Hence, FSG subscribes to the National Sea Grant "Initiative in Marine Aquaculture" (Aquaculture Task Group, 1999) which calls for a multi-million dollar investment in research, education, outreach and technology transfer. Included with topics such as culture systems, nutrition, genetics, biotechnology, public policy and stock enhancement, "marine ornamental fishes and invertebrates" are a priority. The worldwide market for marine ornamentals is estimated by that report to exceed $100 million. Thus, opportunities include identification of candidate species, definition of culture requirements, enhancement of growth and reproduction, examining market potential, reducing shipping losses, and fostering of conservation. As increased funding becomes available, FSG will facilitate competitive proposals from faculty statewide.

The Florida Sea Grant theme area for ornamental aquarium species culture and conservation, and industry development is arguably one of the largest of any Sea Grant program in the U.S. Sponsorship of a 15-person delegation to the Marine Ornamentals '99 conference by FSG provided a way to exchange technical information and continue development of future Florida efforts. The aim is to foster international leadership commensurate with the potential of this sector, both economically and scientifically. It is likely that Florida will host the next (second) international Marine Ornamentals conference.

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HOW TO MAKE MONEY FROM THE REEF TO THE PET SHOP

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ABSTRACT

The author shares his viewpoint on the commercial marine ornamental fish business. He discusses his principles of maintaining a successful business and his concerns for sustainable collection.

Keywords: use not abuse, net caught

I want to thank the organizers. This conference has been needed for a long time. I hope this event becomes a regular occurrence. All concerned -- the hobbyist, government, academia, environmental groups, and industry -- need to exchange views on regular basis.

What you will hear from me is a 100% commercial viewpoint. I have no formal training in this area. Actually I have a master’s degree in psychology. I am not an expert in anything. I started in this as a hobby. I have been in the ornamental fish business since 1961. Segrest farms started with 16 aquariums. Today we either own or manage facilities in five cities in the U.S. and have another site under construction

Overseas we own, or have built for our suppliers' facilities in ten countries. We have permits for other countries. These facilities cost between $100,000 and $300,000 each. About one half fail because of partners, war, change in governments. In one case the facility would not produce the quality we need.

Over the years we have survived the ups and downs of business: government regulations that went far beyond the intent, do-gooders that have great intentions but do not know what they are doing, and animal rights extremists who disdain any pet ownership. We have been helped by good government regulations that regulate or eliminate those who operate with little or no consideration of the future of this industry.

We have been helped by environmental organizations that work toward the protection of the ecosystem and our product while helping our industry to become better stewards of Mother Nature. The newly formed MAC may be one of the best things to happen for our industry. I will never see eye to eye with animal rights activists because I believe the Bible tells us that all was put here for man's use. However it also tells us that all was put here in man's care. To me this simply means, “use not abuse”.

I have been in this business for 38 years, my children are in this business and I hope my grandchildren will have the good fortune of continuing this business. For this to happen we in industry with the help of academia, environmental organizations, government, and hobby must make sure our product is always a renewable resource. We must use not abuse.

Here is the secret formula Segrest Farms has used for a successful and long term livestock operation: It is very simple and easy, expensive but good return.

Secret 1	We must protect the habitat and the propagation of our product.
Secret 2	We must provide conditions that stress the product as little as possible while it is in our care.
Secret 3	We must distribute this product to pet shops in a condition that it can establish itself in a home aquarium.
Secret 4	We must accomplish all the above and make a profit.
Secret 5	We must provide quality products.

Secret Number 1 - Protect habitat, propagation

If our industry does not have a renewable resource, environmental organizations and governments will put us out of business, and rightly so. However economics also determines we have a renewable resource.

We have found that to get the very best product that satisfies us, satisfies our customer, and satisfies our customer's customer, we have to control the product from the reef to the pet shop. Our method is to establish our own collection stations around the world or build facilities for our suppliers. We then send trained managers to operate the station and divers trained in net capture.

It is very expensive to do this. We cannot afford to use up the product in the area and have to move and rebuild. Each station must make a profit and conservation is the only way for long-term profit.

In Saudi on the Red Sea we have been collecting from a six mile area for seven years. There were just as many fish in the area last year as when I first dove there. This is so easy to accomplish. Three things assure a continuous supply. First do not destroy the habitat. Second, do not collect small fish, and third do not collect breeders.

The purple tang is the most known fish out of the Red Sea. We sell regular and medium sizes only. Economics dictates this. By far the largest cost of most imported fish is airfreight, boxes charges, customs, and wildlife clearance.

Small fish cannot handle the stress of capture, holding, packing, shipping and adjusting to three or more environments. They die. All the expenses just mentioned are the same on dead fish as well as live arrivals. We have never found a way to be profitable dealing with dead fish.

Large fish require more space in a box and more water. Because of the just mentioned expenses it makes these fish too expensive to sell. For our secret 1, controlling the fish from the reef to the pet shop to be profitable we must use not abuse.

Secret Number 2 - Stress as little as possible

First we use divers and personnel trained to handle the fish without damaging the product. Then we must provide facilities that eliminate as much stress as possible. We make all our own filtration equipment. Generally, we follow what Martin Moe has described. Chiller, fluid bed, foam fractionater with ozone and UV light. The difference is we build four to six times the filtration of what anyone recommends.

There is a huge difference in filtration for a pet shop or a home aquarium and a large collection station. In our operations a system may be 80% full and make a shipment and immediately be 10% full. Then in two or three days of collection and 90% full again. These new fish are full and dump huge amounts of waste. This puts a tremendous amount of pressure on a filtration system that few have experienced.

These pictures show: six storage tanks, a chiller, two fluid beds of two feet diameter and eight feet high, a four feet diameter fractionater with ozone, and a twelve bulb UV light. Everyone who has seen our systems has said they are much too large. We are not expert in filtration, but we are betting a large amount of money that there will never be an ammonia, nitrite, bacteria, virus or temperature spike in any of these systems scattered around the world. We cannot afford for that to happen.

Secret Number 3 - Distribution

We use methods that we have developed over the years. We have a laboratory and a full time fish veterinarian, Dr. Denise Petty. She and two assistants continuously run experiments on the handling and shipping of our products. These are true trade secrets that we do not disclose. These methods must be successful because our organization ships to more that 1000 pet shops each week and that number is growing. My advise to the industry is that you must put back a large portion of profits into your business. The addition of qualified personnel and a lab definitely pays for itself.

Secret Number 4 - Profit

Obviously if we do not make a profit, we will not be around. How well we do the first three secrets and how well we eliminate unnecessary expenses determines our profit.

Secret Number 5 – Quality

This is a hobby and for the long term the best quality will attract the most business.

Those are the secrets Segrest Farms has used to build the largest ornamental fish organization in the world.

I have always been a hobbyist but I am in this business for profit and as much profit as possible while keeping the future of Segrest Farms bright. What I have learned in 38 years is the only way for long term profit is “use not abuse.”

You have and will hear me repeat “long term” many times. Segrest Farms does not conduct business for tomorrow. Everything we do is toward 5 -10, even 20 years from now. That is probably secret 6.

Now that I have let you in on how to survive in the fish business I would like to comment on some issues:

Dynamite: To my knowledge not one stick has ever been dropped into water to collect ornamental fish. We do deal in a live product. There are unbelievable amounts of dynamiting done to harvest food fish. I have heard of ornamental collectors working around the outskirts of a dynamited area collecting stunned fish.

Cyanide: Not but a few years ago no one knew cyanide killed reefs. The only question was did it kill fish. To answer this question I have watched cyanide divers work and kept some fish they caught for years. An overdose does kill fish. These fish die on the collector, at the station, in shipping or at the wholesaler, all of which is an extra expense for those dealing in cyanide collected fish. Cyanide does kill the habitat of the ornamental fish and also the habitat of the food fish for the villagers. Most villages now know this. Another big influence is there are very few old cyanide divers. Cyanide is absorbed by divers just as it is by fish. The use of cyanide is not profitable for anyone, except uninformed collectors who do not know that his fishing grounds will die and his life will not be long. He needs to be educated.

Misinformation: The distribution of inaccurate information, whether from ignorance or intentionally emotion stirring to advance one’s agenda, does little good.

I read an article on ABC News on dying reefs:

"Cyanide paralyzed fish drift to the surface where they are collected by the hundreds. There are no recognizable organs and they explode when opened."

If this is true, no one has ever gotten a fish exposed to cyanide in their aquarium. An animal with dissolved organs cannot live. However this has not been my experience. All fish I have seen hit with cyanide sink to the bottom or lose their balance. I have never seen or heard of cyanide collected ornamental fish floating. I have opened fish I know were exposed to cyanide and their organs looked like any other fish. I have read that a cyanide detection test is difficult because after two days there is little difference. The only fish i have seen float, pop from gas when opened, and their organs be dissolved have been dead one or two days.

Another article stated: “...by the year 2020 the tropical fish trade will kill the reefs of Southeast Asia.”

The tropical fish trade is small in comparison to food fish, gold mining dumping thousands of pounds of cyanide, deforestation sending mud, nutrients from farming, sewage. etc.

Yes, ornamental collection is responsible for its share. I have just explained that conservation is the only means of long-term profits. We need all the help we can get to be better stewards of the environment. But emotional stirring scare tactics and misinformation does not help.

Coral: Coral can be collected and be a renewable resource. However, the future of coral used in aquariums is to be cultured in greenhouses. This is a growing industry. Economics dictate this to happen.

Live rock: The future of live rock is also to be cultured in greenhouses, even the rock will not come from nature. It will be made in any shape or color desired and lighter that natural rock. The coral and rock cultured in green houses adjust to the home aquarium much quicker than collected.

Fish: I wish my crystal ball saw the same picture for fish, but it will be many years before a majority of saltwater fish is cultured commercially. The industry needs the help of the hobby and organizations such as Sea Grant to accomplish these goals. On a sad note, one thing we all need to remember. As we culture these items, we are taking away the livelihood of thousands of very good people that have no other way to make a living in third world countries.

I want to leave you with three final thoughts: One, education and training is the answer to cyanide, and many other problems we face today. Two, any wholesaler would rather have a cultured product as long as it is equal in quality, color, size, and economically feasible. Three, my last thought for all of us in the collection of natural resources is “use not abuse.”

HOBBYIST PERSPECTIVES, UNINFORMED OR BLISSFULLY NAÏVE?

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ABSTRACT

The aquarium hobby is the third largest segment of the pet industry in the United States, and yet there is misinformation, mystique, and lack of understanding. With significant restrictions on collection and importation of marine fish and invertebrates in the future, maricultured, and tank-raised specimens are a subject that needs to be explored now. I will address two issues: one, the frustration for lack of information; the other, improving the current process of distributing that information.

I queried pet show attendees, members of marine aquarium societies, and CompuServe’s Fish Forum members with a simple survey. Seventy-five percent of the hobbyists were aware of future restrictions on wild caught livestock. Seventy-three percent said they would pay slightly more for tank-raised livestock if the wild caught livestock was limited. Forty-seven percent said that their local tropical fish shop carried tank-raised livestock.

Providing more information will cost the mariculturist more time and money, however, the result will be a more informed customer. At the moment, the market may not be receptive to tank-raised product, but if one starts now, when wild caught livestock becomes less accessible, the wholesalers, retailers and hobbyists that are familiar with the tank-cultured products will seek out the mariculturist.

Keywords: mariculture, tank-raised, information, survey, marketing, consumer

Introduction and Perspectives

The origins of aquaculture most likely originated when fish were trapped in some type of enclosure after monsoon floods receded. Earliest records of fish farming come from China, where hatching of carp was practiced in 2,000 BC.

The origins of aquarium keeping have been around for about as long as keeping food fishes, although the methodology and understanding of aquarium filtration has varied considerably. During the mid-1800’s, the “balanced aquarium” approach was considered the only method for keeping aquarium fish, consisted of “a tank in which the air surface of the water, aided by plants would supply sufficient oxygen” and “most of the waste from the fish was consumed by the plants and scavengers”. During the early 1900’s, aeration, particulate and charcoal filtration was touted as the state-of-the-art, but it wasn’t until the 1950’s that the under-gravel filter was introduced. Ironically even though it was promoted as a biological filter its true role in filtration was still misunderstood, and yet the under-gravel filter has been the greatest advancement to the aquarium industry.

It wasn't until 1974 that successful commercial attempts to spawn and rear marine ornamental fish began to occur and by 1975, Martin Moe and Chris Turk of Aqualife Research and Frank Hoff and Tom Frakes of Instant Ocean Hatcheries were raising three species of clownfish, *Oscellaris (Amphiprion ocellaris,),* the tomato *(A. frenatus* and the *Clarkii* clownfish *(A. clarkii).* By 1976, five more species of clownfish had been added to the list, and as of today there are about 15 species of clownfish that have been successfully bred.

In 1984, the second greatest advancement occurred in the aquarium industry, the introduction to the US of the European wet-dry filter. Now, hobbyists could keep fish as well as corals and invertebrates successfully. The majority of corals kept at that time were large polyped stony corals, soft and leather corals, xenia, as well as zooanthids and actinians.

By 1990, a greater number of *Acropora* species became available. Many hobbyists became entranced with these fast growing small polyped stony (SPS) corals. Today SPS corals hold a greater appeal than the other corals and the reason for it may be that they are much easier to fragment and grow. Today many hobbyists are beginning to propagate a wide variety of corals, and a number of hobbyists are becoming successful at raising some marine fish. This has lead to the beginnings of a new industry in mariculture, and yet there are less than a dozen commercial businesses and a scattering of hobbyists currently involved in it.

Future Problems

So why is mariculture becoming a topic of interest these days? Is this the next step in marine aquarium keeping? Is it due to articles such as "Raiders of the Reefs" in *Audubon Magazine*, or "Corals in Peril" in *National Geographic*, or "Reef Alert" in *Aquarium Fish Magazine*? Or is it the results of the June 11, 1998 Coral Reef Protection Executive Order signed by President Clinton?

It is most likely a combination of all of these. The sad truth is that reports indicate that in 1998 sixty countries recorded coral bleaching events due to global warming, over- fishing and an assortment various pollution factors. The results of these environmental and commercial conditions on coral reefs have caused numerous environmental agencies to take notice and to begin to question why and what can be done to minimize these effects. At a recent meeting of the Coral Reef Task Force, the International Working Group, "identified several key issues", and at "the top of their list was the international trade in coral and coral reef specimens" (Charles Delbeek, personal communications).

So where does this leave the marine aquarium hobby? With potential restrictions on collection and importing of marine fish and invertebrates, mariculture or tank-raised specimens are a subject that needs to be explored, if wild caught aquarium habitants are going to decrease and the aquarium hobby is to survive. Currently there are approximately less than 60 species of marine aquarium fishes being tank bred, most of which are the clownfish species, and less than 200 marine aquarium corals and invertebrates, most of which are the *Acropora* and soft coral species, are being tank raised.

In a recent simple survey I conducted, consisting of pet show attendees, members of two marine aquarium societies, and a posting within CompuServe's Fish Forum, I questioned a number of hobbyists as to how many species of tank-raised fish they thought were available. Fifty-eight percent had no idea. Those that did answer the question came up with an average of forty. Of those 40, clownfish, *Bangaii* cardinalfish, and a few species of *Psuedochromis* were the ones most often reported.

What does this say about the distribution and promotion of tank raised fishes? Of those same four groups of individuals I asked, “Does your retail store carry tank-raised fish? Twenty-nine percent had no idea, twenty-six percent said no and forty-seven percent said yes. Clownfish being the most commonly available retail tank-raised fish.

When asked if, other than retail shops from “where can you get tank-raised fish?” only thirty-eight percent had any idea of where tank-raised livestock was available beyond their retail store.

The Hobbyist and His Information Dilemma

So who are marine hobbyists? Hobbyists around the country seem to vary quite a bit. They range from the teenager to semi-retired individuals. The average is about 25 years old.

There are two different types of marine aquariums kept, the fish only and the coral reef tank. With reef aquariums being the more involved and costly to set up, the fish only system is generally where the hobbyist starts. Each of those groups has three levels: beginner, intermediate and advanced. The beginning and intermediate hobbyist are the ones who are the least knowledgeable. They are the ones who will go all the shops in town, or ask each sales clerk in each store what they think. Unfortunately the hobbyist ends up totally confused as he now has numerous different versions as to how to set up his tank. Sadly they are easy targets for over zealous sales clerks who, are not selling what the hobbyist needs, but what the sales person has in stock. The advanced hobbyist, having the advantage of past experience, may spend more money overall, but chances are that he does not spend it in the same places as the other two levels of hobbyists.

There is a fourth group of hobbyist. That person is the one who hires an aquarium service company to set-up, stock, and or maintain the aquarium. One may not actually consider this person a hobbyist but more of a viewer of living furniture. Other than making the payments, his only real involvement is feeding the tank. By the way, aquarium service companies are an untapped and unidentified market, and as retail store sales are slumping, aquarium service companies are doing quite well. This is most likely due to two factors: the economy is doing quite well at the moment; and those that can afford to have their tank maintained, don’t have the time to do it themselves.

As expected, most beginning marine hobbyists have no real idea as to what it takes physically, biologically or financially to start a marine aquarium. Most assume that it is a simple three-stepwise process. A larger portion assume that its similar to owning a cat or a dog, they just simply add water, add some food, and sit back to watch.

The aquarium hobby is the third largest segment of pet industry in the United States. So why is there so much misinformation, mystique, and lack of understanding? Granted there are books, videotapes, magazines and web sites. The sad truth is that most of this information is never used by the hobbyists. Why? I suspect it’s partly due to the additional cost and to the thought that operating an aquarium should be as simple as owning a dog or a cat. Ironically the number of books on dog and cat care is even less in the homes of pet owners. Think about it, how many of you own a cat or a dog? How many of you actually have information at home on its care and keeping?

How much money does the average hobbyist spend monthly on livestock? Excluding the beginning hobbyist, the average was $65.00 per month.

How many hobbyists were aware that there could be future restriction on wild caught livestock? 75% were aware.

Are they concerned about the possible restrictions on wild caught livestock? 95% said yes.

Would they pay more (30%) for tank-raised livestock, if wild caught was limited? 73% said yes.

What is the greatest frustration that hobbyists have with livestock? Unexplained deaths; quality; availability; information; and lack of knowledge on the seller's part are highest among the list of frustrations. I do want to take a moment and discus the title of my presentation for a moment, "Uninformed or Blissfully Naïve." This will address two issues, one being some of the frustration expressed by the hobbyist; the other, ways of improving on the current process and the quality of the livestock.

Ask the majority of the aquarium hobbyist as to how their fish are collected and they will most likely answer "a native boy uses either a net or some chemical" and "then they are shipped to a local wholesaler who sells them to the fish store." Most hobbyists have absolutely no idea as to what their livestock goes through before it ends up in their tanks. Only recently has some of this information begun to come to light, and that information is either purposely or unintentionally skipped over. Take for example, what does the "native boy" do with the fish he collects each day? Does he make a run into the local village to deliver his product to the local distributor? If not, what does he do with his catch at the end of the day? How often does he take a batch of fish to this distributor?

As hobbyists, we have heard a little about the quality of the systems that these local distributors have. Some have concrete or wooden vats. How large are these systems and how many fish do these systems hold at one time? How often do these distributors ship out product? How long is the fish held in their system? Some have adequate filtration; some do not. Where are these distributors located in relationship to the ocean? Are they a mile or two inland, or are they next to the water, or bay? What is the quality of the water, how frequently is it changed? Are the fish acclimated to the distributor's water, or just dumped in?

Lets talk about how the fish are shipped. How are they packaged? What is the source of the water they are shipped out in? How many fish are placed in a bag? Due to freight costs how much water to a bag? Once in the bag, how long a time will pass, before they are sent to the airport? How long does it take to get to the airport? How long do they sit at the airport before they are loaded onto the plane? How long is the flight? By the way, the average pH of the bag water once a fish arrives to the wholesaler is 6.5 units.

How are the fish acclimated to the local wholesaler once they get into the US? What is the condition of the fish once it makes it to the States? If there is a problem with the shipment, is there an adjustment made for future shipments?

One of the greatest frustrations of the importer is the airline. Livestock seems to not be their priority. Even if a box is marked Live Animals, it just does not gain the same importance as other cargo, and many times its departure is delayed. Recently I had the opportunity to visit a wholesaler, who had just received about 300 flame angels and lemon peel angels. I was shocked to see about 50% of these fish, which had just been introduced into the holding system, were lying on the bottom of the tanks gasping. Whatever the reason, I am very sure that this situation definitely contributed to some form of stress to the animal. In speaking with this wholesaler, he informed that it's quite common for these fishes to be collected and held in small containers, grouped together by a net, in a lagoon, for up to a week before they are brought to the local collection facility on that island. A friend of mine recently witnessed a situation at another wholesaler. An individual was pulling yellow seahorses out of a cubical and tossing them into a dry styrofoam container and then placing then into another cubical system, all without acclimating them to the new water. Speaking of acclimation, I have only seen a couple of wholesalers, who have a dedicated acclimation area. Let me go a step further, too often the retail store's version of acclimation consists of floating the bag in a tank, dumping its contents directly into the tank, and only after aggression has occurred is that animal moved to another location.

It just seems to me that too often the hobbyist is blamed for the lack of quality introduction or health care, but in fact, the problem leading to poor quality fish may occur prior to the hobbyist even receiving the fish. My reason for diverting towards the wild caught industry is not intentionally to criticize, but to make a suggestion on what to avoid or better yet, point out an area that needs significant improvement and renewed training, at all levels, on how to properly handle the product.

Information Distribution

How can the maricuturist market their product, and how can he get more quality information to the end user? The current distribution chain is the collector to the wholesaler, to the retailer, and finally, to the consumer. The collectors acquire the product; the wholesaler, provides the distribution network; and the retailer, presents the product to the consumer. The hobbyist is the consumer and the first place they are going to go to is the retailer.

Now substitute the collector with the mariculturist. He has two choices to marketing his product. First he can market his product directly to the end user, generate greater profit margins but a lower volume, and expect to incur greater expenses in promoting this new marketing path. Or, he can work within the established marketing path, expect lower profit margins but greater volume and decrease substantially promotional costs. Since the current distribution path is so well established there is no point in re-inventing this process.

Having decided on the path that the mariculurist will use to market his product, the next steps are providing information and promotion. The most important types of information should consist of handling and acclimation! No matter how high a quality your livestock is, if it is not handled correctly or introduced properly into the aquarium, the chances that it will do as well as it was intended to will decrease. Provide information on how to acclimate, how long to acclimate, and what to acclimate for. How was it grown, breed or raised? Where was it grown? When was it born? You do not need to give away all your secrets, but give the hobbyist an idea as to the work that was involved in making this product available to them.

How to promote yourself to the hobbyist? There are three paths:

1 - Provide packets of written information to the wholesaler to distribute to the retailer. This will require the aid of the wholesaler to actively promote this information with hopes that the retailer does more with it than just placing it on his sales counter.

2 - Reach out to the retail stores directly. This can result in the stores requesting that their local wholesaler carry the product and odds are that that same information will be passed along to the consumer resulting in greater requests for the product. One small note, you will most likely be asked if the store can purchase direct from you. If you decide to make this an option to the retailer be sure that you have created a multi-stepped price list, otherwise you will alienate the local wholesaler.

3 - Attempt to promote your product information directly to the consumer. This can be done through a number of different avenues. Hobby magazines, books, conferences and society meetings, as well as Internet web sites, on-line forums and trade shows were the ones most often stated as alternative sources to the retail store by the participants of the survey that I took.

Each one of these promotional steps will progressively cost more money and time, but providing the hobbyists with more insight will result in a more informed customer.

If there is one thing that I can provide you, it is that hobbyists thrive off information. At the moment, the market may not be 100% receptive to higher priced tank-raised product, but if one starts now when the day comes that wild caught livestock begins to become less accessible and its your name, your quality, and you that provided the hobbyists with information, then it will be your product that they will seek out.

PRACTICAL MASS CULTURE OF MICROALGAE

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ABSTRACT

Microalgae produce live plankton feeds of optimal composition for marine fish larvae; mass culture is more approachable than literature suggests. "Green-water" is inexpensive and convenient. Monoculture provides control of algal cell size and composition. Requirements include maintenance of inoculums; avoidance of senescence, contamination, and nutrient and light limitation; and active mixing. Agricultural materials are adequate inexpensive inputs.

A Review

As captive spawning techniques are developed for greater numbers of marine ornamental fish species, demand for cultured microalgae and appropriate culture techniques will increase. Marine fish larvae are generally smaller than those of freshwater fishes, and more likely to require live food items at first feeding. Live feeds are best cultured on microalgae because algae produced feeds have the most favorable nutritional composition (Watanabe et al., 1983; Ben-Amotz et al., 1987) at costs that can be smaller than with use of highly enriched artificial particles. If marine ornamental fishes prove to resemble marine food fishes in their requirements for dietary essential fatty acids, composition of feeds will be important for culture success.

There is extensive knowledge of requirements and techniques for algal mass culture, including comprehensive reviews and summaries (e.g., Guillard, 1975; Fox, 1983) as well as detailed practical instructions (Lavens and Sorgeloos, 1996; Hoff and Snell, 1998). The comprehensive and detailed nature of these sources makes them both essential for the uninitiated and potentially discouraging in raising the prospect of high cost or technical difficulty. In fact, it can be costly and technically difficult to bring new microalgal species into culture or to expand the culture of common species to an industrial scale with reliability and efficiency. For common species on a modest mass-culture scale, however, experience suggests numerous cost- and effort-saving practices, though it must be noted that successful microalgal culture typically involves elements of good and bad fortune, and that in times of difficulty it is necessary to revisit the basics with their details.

This communication aims to encourage the practice of mass microalgal culture for production of live feeds for fish larvae, by pointing out for evaluation a list of practical necessities and practical approaches to satisfying them.

The most convenient and least costly source of a dense microalgal stock is a body of water that produces its own "green water" bloom, which results from the dominance of one or a few species under conditions of high nutrient concentration. Such blooms may be found in fed tanks or ponds containing fishes and shrimps, or may be encouraged by adding fertilizers to "uninhabited" tanks or ponds. It is generally beneficial to manage the culture actively, for example by maintaining vertical mixing by means of aeration, or removing clumped and settled material from the bottom. Blooms may persist for extended periods (weeks and longer) under conditions of good light and steady fertilizer inputs, and are generally propagated by inoculation of new water bodies with healthy culture water, though they often re-inoculate themselves from fish wastes or resting benthic cell forms. Such stocks can often support mass-culture production of live feeds including rotifers and brine shrimp, relatively inexpensively. Disadvantages of this strategy include limited control of algal nutritional quality, little control of the associated microbial community, and the application of management effort that may constitute a significant fraction of that needed for a monospecific algal culture.

Monoculture (purposeful cultivation of a single microalgal species) is practiced for the advantages of repeatability, control, and known nutritional value of the product. There are several major requirements different from and in addition to those of green water culture. First, it is necessary to maintain a ready inoculum for the largest scale or container in use. Because it is advisable to inoculate new containers with 10-20% of their projected final stock, it may be necessary to maintain replicated sets of containers of various sizes, ranging down to the container size, in which laboratory-level purity of the stock is maintained. Such a system is necessary because it is not advisable, often not possible, to maintain the largest containers indefinitely by splitting their products. At the smallest size scale, it is now convenient and relatively inexpensive to acquire starter stocks, with the caution that there may be governmental control on imports.

On all container size scales, it is necessary to avoid or prevent senescence of monocultures. Senescent inocula may exhibit undue lag or fail entirely to grow in the new medium and container. A senescent production culture exhibits slow growth, and may exhibit compositional changes that are undesirable, though some research results show enhanced lipid production. Senescence is prevented in "batch" culture strategies by complete harvest of stocks, and cleaning and re-inoculation of the container with culture in log-phase growth, using at least 10-20% of the final target stock level. Larger fractions of log-phase inocula work as well, but are not efficient in terms of facilities use. Production containers may be harvested repeatedly in many situations, and topped up with fresh medium for resumption of production. Such partial harvests should constitute substantial fractions of the stock, leaving less than or about 33% behind (with no hesitation in discarding excess product), and should only be done from stocks still in log-phase growth. Smaller harvests are inefficient use of capacity, and senescent stocks, as noted above, may not produce or persist. There is a limit to the number of partial harvests that can be made before the container requires emptying and sanitation if it is to support productive cultures. At some point, it is tempting to try small frequent partial harvests and additions of medium, approaching or attaining continuous input and removal. Though "continuous" culture is routinely practiced in research laboratories, the strategy is limited in mass culture by the instability of the associated microbial community, vagaries of weather, and sometimes insufficient attention to maintenance of log-phase growth in the algal population. It requires a relatively high level of experience in management, and may involve more effort than anticipated.

Resource-limitation of cultures will lead to senescence or precipitous loss (crashes), and so must be avoided. Management of depth in relation to density of the culture can modify exposure of cultures to natural light. Because dense cultures are self-shading, low natural light conditions (cloudy days) indicate a need for shallower depth to permit all parts of the culture to be exposed to sufficient light. However, research has shown that one cloudy day need not harm a dense culture irreparably. Thin cultures may require shading to prevent damage by UV or high intensity visible light. Stirring facilitates even exposure of all parts of a culture to light. Healthy cells tend not to sink, but high density and stress (inoculation, weather changes) can cause clumping and sinking. Aeration is an efficient means of stirring, with the understanding that a bubble stream rising vertically creates a circulation cell with horizontal diameter approximating its own depth, that is, a column of bubbles in a tank of 1 m depth creates a cylindrical cell about 1 m in diameter. This guideline should direct design of air stone deployment patterns and bottom-situated pipe systems. Pipe system designs should take account of the guideline that the area of the air holes in a pipe should be in total no greater than the pipe's cross-sectional area if unworkable pressure drops are to be avoided.

Nutrient limitation can be avoided by straightforward attention to known requirements, but growth in log-phase cultures can outpace attention by the inexperienced. If a batch culture is growing in a medium with sufficient dissolved nitrogen compounds to support the target crop, it is noteworthy that the last half of the nitrogen is taken up during the last doubling time, which can often be as little as one day. Therefore, nutrient analyses showing that 1/2 to 3/4 of the nutrient stock remains do not indicate a long future of sufficiency.

The term monoculture refers only to the intent to foster a single microalgal species. Other microbes including bacteria and possibly other algal cells will inhabit all but the most stringently maintained laboratory cultures. Successful production culture involves managing conditions in favor of the target species. Containers are sanitized between uses, with muriatic or purer hydrochloric acids in the case of small and modest sizes, or with chlorine for larger containers other than ponds. Ponds may be drained, dried, and limed according to standard guidelines. Sterilizing water sources is laborious and expensive, though necessary in some cases. This is typically done by addition of chlorine and its later neutralization with thiosulfate. It is less expensive and highly desirable to filter source water at a practical expense level if this practice is sufficient for a given purpose. Mesh bags that filter at the 5-micrometer (micron) level are relatively inexpensive. Finer filtration may be affordable, but frequent examination of fine filters for flocculent precipitates is advisable. Such precipitates not only clog filters, but may also scavenge materials such as trace metals from media. Covering cultures to eliminate inoculation of competitors through the aerosol can be helpful in some environments, such as shorelines of natural and large artificial water bodies. Microbial competition is minimized not only by reducing initial levels of competitors, but at least as importantly by observing the guidelines for sufficient inoculum of log-phase culture noted above.

Fertilizers may be a substantial cost item in mass microalgal culture. Practical mass cultures can be well supported by relatively inexpensive materials. Garden fertilizers and agricultural urea and bicarbonate can be used to approximate research-developed media. For example, the widely used and referenced F/2 medium (Guillard, 1975) has an inorganic nitrogen (N) concentration of 883 μM. This concentration in 1000 l of water could be obtained from, for example, about 82 g of Miracle Gro (R), at a worst-case cost of about $0.55. This would, however, waste most of the phosphorus (P), as the fertilizer is rated 15-30-15. A less expensive strategy would be to use urea (about 47% N) as the source of 90% of the N, reducing the cost of the 1000 l batch to about $0.20, and still providing the 5 most abundant trace metals found in F/2: Fe, Zn, Cu, Mn, and Mo. Vitamins (only a few B vitamins are widely required) could be obtained from a ground B-complex tablet. Carbon is another matter. Seawater at 35 ppt salinity has less than half the C required to match the N and P concentrations of F/2 medium. Industrially, gaseous carbon dioxide is applied in some excess to cultures, often controlled automatically through pH sensors. On a smaller scale, agricultural grade sodium bicarbonate can be added relatively inexpensively as required. Silicon is required for diatoms, and is relatively scarce in most marine surface water. Ground water is richer in some places, but may not fully match requirements, which are of similar magnitude to phosphorus.

In summary, practical mass algal culture may be less expensive and more approachable than standard information sources may suggest. The requirements detailed in these sources must, however, be met if cultures are to be productive.

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COMMUNITY-BASED MANAGEMENT OF A HAWAI`I AQUARIUM FISHERY

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ABSTRACT

Commercial marine aquarium collecting is controversial in West Hawai`i. Competing uses and reports of declining reef fish populations prompted several attempts to regulate the fishery. Management efforts led to a community-based legislative mandate establishing a minimum of 30% of the West Hawai`i Coastline as no aquarium collecting "Fish Replenishment Areas."

Keywords: aquarium collecting, community-based management, marine protected mreas, fish replenishment areas, West Hawai`i Fisheries Council

A Review

Aquarium collecting in Hawai`i has a long contentious history. As early as 1973, public concern over collecting activities prompted the Division of Fish and Game to suspend the issuance of Aquarium Fish Permits. Regulation of fine mesh aquarium nets and permit issuance began twenty years earlier. The suspension was lifted one week later to enable Fish and Game to investigate alleged reef fish declines without disrupting the activities of tropical fish aquarists. Aquarium permittees were also required at this time to submit monthly fish catch reports.

Shortly after the suspension was lifted, the State Animal Species Advisory Commission recommended restricting issuance of aquarium fish permits pending full and extensive study. University marine scientists further recommended the establishment of sanctuaries to prohibit collecting within their confines. No studies were conducted and no sanctuary areas were established.

Five years later a Hawai`i Sea Grant conference on tropical reef fish was held in Kona, Hawai`i, where a state Fish and Game biologist noted there had been a dramatic increase in the number of aquarium fish permits issued in recent years. He stated the Division had been compiling aquarium fish catch data since 1973 but the reliability of these data depended upon the sincerity of the permittees. The biggest problem was the analysis of the data. "Only adequate funding will allow us to make a complete evaluation of these data" (Katekaru, 1978).

Fish and Game paid little attention to aquarium collecting for almost 10 years. Meanwhile the number of collectors in West Hawai`i continued to increase, and conflict escalated particularly between dive tour operators and collectors. This conflict led to a meeting of the two groups in 1987. Encouraged by Sea Grant and the Division of Aquatic Resources (DAR), formerly the Division of Fish and Game, an informal year-to-year "Gentleperson's Agreement" was negotiated. Aquarium collectors agreed to refrain from collecting in certain areas, and charter operators agreed not to initiate legislation to restrict collecting and to cease harassment. Four areas totaling approximately 6.4 km were agreed upon. According to tour operators the agreement worked reasonably well for about six months in spite of a small number of collectors refusing to abide by its terms.

When the agreement expired the next year, collectors reportedly resumed collecting in the previously closed areas. Meetings were held in 1988 to reinstate the agreement and to permanently close previously closed areas. No agreement was reached on additional closed areas, nor for further controls on collectors. The Gentleperson's Agreement areas were formalized as the Kona Coast Fisheries Management Area (FMA) zones which became effective October 1991. The following year an independent initiative established a 2.1 km Marine Life Conservation District (MLCD) in Kona. MLCDs generally prohibit any taking of marine life.

Controversy and conflict over aquarium collecting continued unabated, however. Various meetings and legislative resolutions and bills attempted to address the issue. A 1996 resolution directed DAR, in conjunction with a task force convened to assist them, to develop a comprehensive management plan to regulate the collection of aquarium fish.

Thus was born the **West Hawai`i Reef Fish Working Group** (WHRFWG) which held its first meeting May 1996. Individuals from various West Hawai`i constituency groups were invited to participate. DAR and Sea Grant made a determined effort to have representation from each reef resource user group. Others who became aware of the group by word of mouth or through the newspaper were also welcomed to participate. At least 70 members of the West Hawai`i community were involved. The group, led by a trained facilitator, held nine meetings over a 15-month period. Information to assist decision-making was presented by scientists, resource management experts, and Hawaiian community members

The WHRFWG accomplished a number of objectives. It opened dialog between user groups and community members. It provided a forum for the education of its members on a wide range of biological and social issues involved in resource management including aquarium collecting. The group identified coastal "hot spots" where conflicts over ocean resources were especially intense and proposed management recommendations. With the assistance of a DAR biologist, two local communities proposed more comprehensive management rules for their communities. DAR commenced a joint research project with the University of Hawai`i Hilo (UHH) to finally investigate the biological impact of collecting.

Unfortunately, due in part to legislative inertia and to opposition by aquarium collectors outside of West Hawai`i, only one WHRFWG legislative recommendation passed, i.e., establishing licenses for aquarium exporters. Similarly, management initiatives for the local communities languished.

In response to the perceived lack of adequately dealing with aquarium collecting, a number of citizens, including several members of the WHRFWG formed a grassroots organization, the **Lost Fish Coalition** (LFC), to push for a ban on aquarium collecting in West Hawai`i. They collected almost 4000 signatures on a petition to ban collecting. In January 1997 a bill was introduced in the State Legislature to accomplish this objective. Shortly thereafter another bill was introduced to establish a West Hawai`i Regional Fishery Management Area along the entire West Hawai`i coast of 235 km. Among several provisions of this bill was a requirement to set aside 50% of the FMA as Fish Replenishment Areas (FRAs) where aquarium collecting would be prohibited. In February 1998 the bill calling for a total ban was killed. During committee hearings of the other bill, the 50% provision for FRAs was reduced to "a minimum of 30%." Aquarium collectors and other user groups endorsed this bill. It was approved by the legislature and ultimately became Act 306, effective 13 July 1998.

The purposes of Act 306 include (1) effectively managing fishery activities to ensure sustainability; (2) enhancing nearshore resources; and (3) minimizing conflicts of use in this coastal area. It also mandated the designation of "a minimum of 30%" of West Hawai`i coastal waters as FRAs. The Act directed DAR to identify these areas "after close consultation and facilitated dialogue with working groups of community members and resource users." A review every five years of the effectiveness of the West Hawai`i Regional Fishery Management Areas was also mandated.

The specific wording of "a minimum of 30%" was based upon studies by Dr. James Bohnsack and the South Atlantic Fishery Management Council. With regard to Marine Fishery Reserves (MFR) they recommended "fishery reserves be established for 20% of the habitat while other traditional fishery management practices be applied to the other 80% of the habitat. Without adequate management in fished areas, we recommend that MRFs be increased to include *at least* (emphasis added) 30% of the shelf" (Bohnsack, 1990). In testimony in support of the bill, noted Hawai`i ichthyologist Dr. Jack Randall supported this minimum percentage by stating "Studies on coral reef management have shown that 30% is the minimum to set aside as reserves" (Randall, 1998).

In order to accomplish the mandates of Act 306 with substantive community input, a council approach was decided upon. As a starting point, an organizing group from DAR and Sea Grant reviewed the roster of the earlier West Hawai`i Reef Fish Working Group. They attempted to assemble a council with broad geographic representation and which represented the various stakeholder, community and user groups in West Hawai`i. It was believed the efforts of this earlier group would prove highly beneficial to the task. A working document of Operational Practices & Procedures was developed to serve as a vehicle for decision-making.

The West Hawai`i Fisheries Council (WHFC-initially called the West Hawai`i Fishery Management Council) was convened June 1998. It consisted of 24 voting members and six ex-officio Agency representatives (DAR, Boating, Enforcement, Sea Grant, and the Governor's Office). There were four aquarium representatives (three collectors, one aquarium shop owner), three commercial dive tour operators, and one Hotelier. The rest of the Council consisted of a variety of overlapping and not easily definable interests. There were commercial and recreational fishermen (at least ten), shoreline gatherers, recreational divers, a LFC representative and several community representatives. Two community members had degrees in marine or fishery science. Forty percent of the council was Hawaiians, one being on the board of the Office of Hawaiian Affairs (OHA). Seven of the 30 Council members were not on the WHRFWG but were added to expand expertise and representation.

Prior to the beginning of the Council's decision-making, pertinent literature on marine protected areas, community-based resource management and scientific studies dealing with Hawai`i's reefs and aquarium fish collecting was distilled for the Council into specific site selection criteria. The group discussed aspects of reserve design and function including minimum size, shape (e.g. single large or several small reserves), location, enforceability and conflict reduction.

After site selection criteria were established each Council member was given a set of coastal maps. They were asked to gather information from their respective communities or user groups and then designate specific FRA locations. The importance of Council members conveying information during this process to their respective "constituents" was stressed repeatedly with emphasis on representing not only themselves but also more importantly, a particular user group or community. In several instances community meetings were called by residents to request clarification on the provisions of Act 306.

The designations on each map were compiled on master maps of the coast to provide a clear graphical indication of the group's choices. Consensus on certain areas was readily apparent. Collectors were directed to indicate areas considered critical to their fishery. One of the four aquarium representatives provided such information. The others provided only a single brief outline of their combined FRA choices, which totaled less than the minimum 30%. They provided no specific information on areas they considered critical to their fishery. Nevertheless, areas designated by the collectors showed a remarkable congruence with those ultimately selected by the Council as a whole.

The Council was repeatedly tasked to keep the combined size of the FRAs as close to 30% as possible. This strategy was adopted, despite considerable pressure from within the Council and the public at large to close a significantly larger portion of the coast. It was made very clear to the Council that they were to manage the fishery by ensuring sustainability and reducing conflict, and not to shut it down. Though the language of Act 306 was clear and written with full knowledge of the collectors, the percentage aspect was a source of much rancor and discord. Repeatedly throughout the FRA designation process, aquarium collectors asserted that the bill was written to set aside no more than 30% of the coast (as FRAs). When the site selection process exceeded 30%, they stated they had been betrayed and exploited. They rallied behind this to justify opposition to the FRA plan and non-participation in the process.

During the time of the WHRFWG and when the WHFC was first formed, there was little scientific information regarding the impact of aquarium collecting in Hawai`i or elsewhere. This fact had been held up time and again by collectors throughout the years whenever there were calls for increased management. Only a single Hawai`i study (Nolan, 1978) had specifically addressed the issue but it was fraught with methodological problems and was not peer reviewed nor published in any scientific journal. As the initial results of the joint UHH/DAR aquarium reef fish study became available (Tissot and Hallacher, 1999) they were presented to the Council and reported in public lectures. Additionally, preliminary results of two other DAR studies (Walsh, unpublished data) that examined changes in reef fish communities over 20-year periods were also presented. All three of these studies indicated substantial effects on fish populations due to aquarium collecting.

Aquarium collectors on the Council responded to these findings by ceasing their active participation. All attended the initial meetings (one by proxy), but subsequently their attendance became sporadic. They either failed to show up or sent proxies whose presence was often not constructive. Absenteeism at Council meetings was not limited to the collectors and a number of members were dropped from the Council due to nonattendance. Maintaining peoples' commitment to such a group has proven to be a difficult undertaking given the differences of interests and the often contentious and emotionally charged atmosphere of decision-making meetings.

Nevertheless, the Council as a whole persevered and by consensus, vote and determination worked out a biologically sound, enforceable, and conflict-resolving FRA Rule. Nine separate areas along the coast were selected ranging in size from 1.4 km to 9.6 km comprising a total of 35.2% of the West Hawai`i Coastline (including already protected areas). Seaward boundaries were set at 100 fathoms to anticipate future use of deep-water rebreather technology.

To enhance enforceability and stabilize the fishery other provisions included GPS boundary coordinates, prohibition of aquarium collecting gear or collected animals within FRAs, an aquarium vessel registration/identification system, and a control date for possible future use in a limited entry program.

The FRA Rule was presented at a public hearing held in April 1998. The hearing was the largest ever conducted by DAR. The Rule received overwhelming support (93.5% of 876 testimonies) from a wide range of community sectors. Several months later it was unanimously approved by the Board of Land and Natural Resources (BLNR, the parent agency of DAR) with all its provisions except for the prohibition on aquarium collecting gear within FRAs, which was inexplicably omitted.

The Attorney General's office then reviewed the Rule in preparation for the Governor's signature. A Deputy Attorney General issued an opinion that due to an administrative technicality, several of the provisions (animal possession, vessel identification, and control date) could not be lawfully adopted until they went through another complete public hearing process. DAR questioned the soundness and validity of the opinion but decided to bring the Rule back to the BLNR for re-approval without the provisions objected to by the Deputy Attorney General.

The amended Rule was approved shortly thereafter by the BLNR and on 17 December 1999 the Rule was signed by the Governor, effective 31 December 1999. DAR is in the process of restoring the eliminated provisions to the Rule.

To evaluate the effectiveness of the FRAs and to better understand the ecological dynamics of our nearshore reef environment, a long-term collaborative effort is currently underway by University scientists and DAR. This study is the West Hawai`i Aquarium Project - WHAP.

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Papers by The Oceanic Institute

Marine Ornamentals '99

Hawaii

Collection, Culture, Conservation

OVERVIEW OF INTEGRATED RESEARCH AT THE OCEANIC INSTITUTE

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Introduction

Solving problems successfully in marine ornamental culture and protection could be accelerated through an integrated and focused approach.

The Oceanic Institute (OI) is a private, nonprofit research and development organization founded in 1960. Its mission is to develop and transfer economically viable and environmentally responsible technologies to increase aquatic food production, while promoting the sustainable use of ocean resources. Although not food-related, marine ornamental research is a logical area for our attention. The technologies which apply to marine foodfish aquaculture and shrimp farming may have application to ornamental issues, which are framed in the context of reef conservation or sustainability of ocean resources, as well as economically.

OI develops and transfers technologies to the public and private sector. Funding is through federal, state, foundation and corporate sources, as well as generous support from individual donors. All of these sources have interest in environmental protection or economic development, both of which are central themes in marine ornamental research.

A scientific team approach, when applied, could influence progress of the culture of various marine ornamental species, both to support a market, and to restore and preserve wild marine populations and habitats. The team approach integrates research in complete life cycle technologies for the culture of marine finfish; aquatic feeds and nutrition from larval stages through maturation; total production system design including biosecurity; animal health, genetic selection and behavior studies; and stock restoration and enhancement and essential habitat conservation and preservation (Figure 1). OI’s history of advancements in each of these areas positions it for seminal research by an integrated research team focusing on all ramifications of the marine ornamental issue.

OI researchers have prepared a series of papers describing the tested approaches to aquaculture of marine foodfish organisms and technologies, which may have direct relevance as the Institute turns its attention to marine ornamentals. The cumulative experience of integrating the component technologies involved in finfish and crustacean aquaculture has suggested efficient methods of addressing the constraints of marine ornamental aquaculture.

An Integrated Approach to Research

The Oceanic Institute stresses a unique, focused, integrated team approach to solving problems associated with the culture of marine species (Figure 1). In the past, research priorities of the Institute and its funding sources have emphasized foodfish, marine shrimp farming and stock enhancement. Today, concern for the environment and a considerable market potential is stimulating research into the scientific investigation of high-value ornamental species. Considerable research hurdles are yet to be surmounted, particularly regarding species-specific issues such as spawning in captivity, first-feeding, growout and survival, as well as the unknowns in habitat restoration and stock enhancement. OI has tested research methodologies and technologies through its 40-year history in working with marine finfish and shellfish for food production. Research results and procedures are being rescoped for application to new species and purposes.

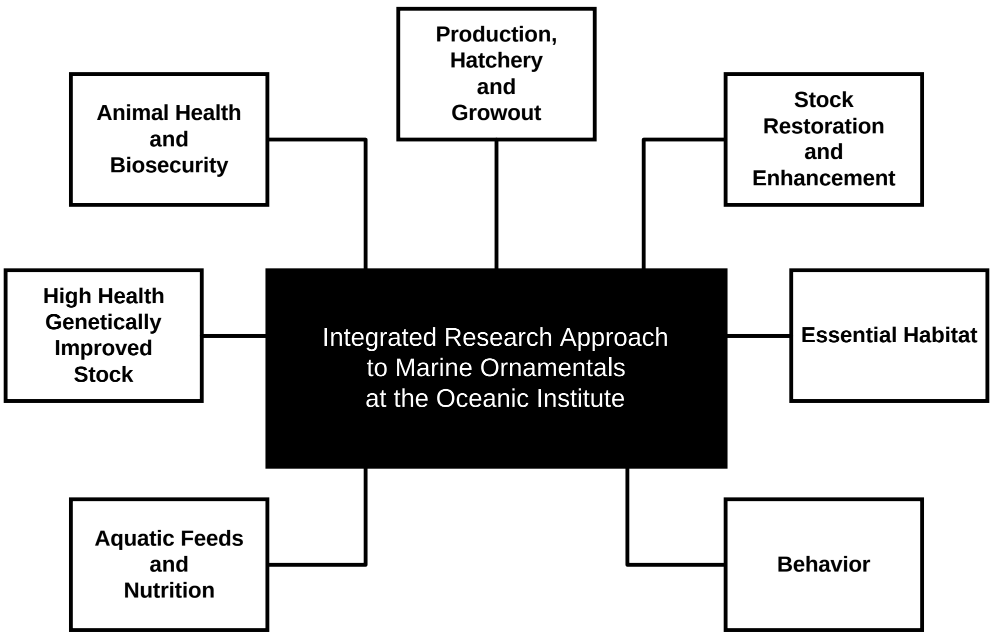

Figure 1. OI's Integrated Approach to Research.

The following papers describe our related research efforts, and as a group, represent the integrated approach the Institute takes in its research. We offer this background as lessons learned in hopes that it may provide applicable information for others whom are working in this area. We would certainly appreciate any feedback through comments or dialogue as we all move forward in this crucial and exciting work.

PRODUCTION, HATCHERY AND GROWOUT *(see Application of Marine Foodfish Techniques in Marine Ornamental Aquaculture: Reproduction and Larval First Feeding, Anthony C. Ostrowski)*

Experience in reproduction, maturation, larval rearing and growout of marine fish is paving the way for developments with economically and environmentally important species such as snappers and coral reef fish. The lifecycle for more than eight species have been closed, and the on-site hatchery produces more than one million fingerlings per year for farmers and for stock enhancement. The finfish program has led to new initiatives such as an open-ocean cage culture project and environmental research through enhancement technologies. OI is using its experience to solve problems of first-feeding and reproduction.

AQUATIC FEEDS AND NUTRITION *(see Application and Transfer of OI Technologies on Aquatic Feeds and Nutrition to Marine Ornamentals, Albert G.J. Tacon and Michael Haring, in this volume)*

Innovative feeds technology provides specifically tailored products that aim to provide plant substitutes for fishmeal, as well as, to make the best use of byproducts from fishing and other sources. Capabilities of feeds formulation and processing for fish and shrimp are complemented by research in live feed items. The Institute expects the nation's first dedicated aquatic feeds research laboratory to come on line in 2001. This capability will enhance efforts in determining and meeting the feed needs of cultured ornamentals.

STOCK RESTORATION AND ENHANCEMENT *(see The Potential for the Restoration of Marine Ornamental Fish Populations through Hatchery Releases, David A. Ziemann)*

Our research is exploring the advanced techniques for getting stocks to reproduce and restore depleted fisheries more rapidly. Nearly 500,000 Pacific threadfin (*Polydactylus sexfilis)* have been released in waters around Oahu for stock enhancement studies, and is doing similar work using cultured fish in the wild environment to measure pollution as a part of remediation efforts. Also, OI is part of a consortium effort to implement fisheries enhancement in the Gulf of Mexico. Such experience will likely come to bear as efforts are made to replenish wild ornamental populations. Our researchers are involved in studies of reef environments around the world, adding to the understanding of how reef fishes interact in various environments.

HIGH HEALTH, GENETICALLY IMPROVED STOCK *(see Biosecurity and Genetic Improvement of Penaeid Shrimp: Applications to the Marine Ornamental Industry, Shaun M. Moss and Brad J. Argue)*

Genetic breeding and biotechnology are leading to the development of healthier and faster growing animals. Selective breeding and genetic studies are helping develop healthier, more profitable animals for the U.S. shrimp farming industry. Our breeding program for Pacific white shrimp (*Litopenaeus vannamei*) has produced the world's most genetically diverse population of this species. This foreshadows work that is envisioned for cultured ornamentals.

ANIMAL HEALTH AND BIOSECURITY *(see Aquatic Animal Health and Biosecurity for Marine Ornamental Fish, Robert A. Bullis, in this volume)*

Research in closed recirculating production systems for shrimp shows immense promise for preventing disease outbreaks and eliminating discharges into coast waters. The culmination of integration of aquaculture technologies, well-defined health protocols and biosecure systems, is a model for successful culture of ornamentals, to obviate disease and pollution problems.

ESSENTIAL HABITAT *(see Essential Fish Habitat and the Effective Design of Marine Reserves: Applications for Marine Ornamental Fishes, Alan M. Friedlander)*

Wild collection of ornamentals can be devastating to fragile reef ecosystems. The creation of marine reserves is known to afford protection of species. Decisions about the creation of these reserves can be informed through scientific research on the fish as well as the habitats. OI researchers are already involved in studies on essential habitat requirements, a key element to consider in ornamental programs and policy.

BEHAVIOR *(see Behavioral Approaches for Aquaculture and Stock Enhancement in Pacific Threadfin, Reiji Masuda and David A. Ziemann, in this volume)*

Behavioral studies on Pacific threadfin (*P. sexfilis*) concerning diet and environmental rhythms (daily, annual, lunar) suggest that similar studies on reef fish will be beneficial both in culture programs as well as restoration and preservation efforts. Understanding of the myriad variables in diet, habits, predators, and behavioral development of each species will be essential to culture of exotic fish. Studies like the behavioral approaches for aquaculture and stock enhancement of the Pacific threadfin (*P. sexfilis)* provide not only scientific data, but also models for experiments focused on ornamentals.

CTSA *(see CTSA Vision for Marine Ornamentals: Planning and Support, Jensen Lee, in this volume)*

OI shares administration of the Center for Tropical and Subtropical Aquaculture (CTSA). This relationship extends OI's reach into the Pacific, areas where ornamental culture, and reef preservation and restoration is a serious matter for future planning. CTSA has helped fund significant research in culture and conservation, both at OI and other institutions in the Pacific Region. The collaboration has yielded far-reaching results and will certainly continue to provide support and direction.

Conclusion

Our experience in marine foodfish and shrimp suggests that a fully integrated, team approach promises the best results in marine ornamental culture. We project a "map" that may prove useful to solve problems and direct research efforts.

AQUATIC ANIMAL HEALTH AND BIOSECURITY FOR MARINE ORNAMENTAL FISH

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ABSTRACT

The catastrophic loss of animals due to infectious and non-infectious diseases is one of the largest contributors to profit loss in every animal industry. At the Oceanic Institute, aquatic animal health management provides a “biosecure blanket” that protects the institution from the damaging effects of disease on our research programs. The term “biosecurity” is used to describe the integrated components of the health management system. Biosecurity protocols are put in place not only to protect OI from becoming contaminated from outside facilities or wild-fish introductions, but also to protect outside facilities from becoming contaminated by OI. Such a combination of inward and outward perspectives is not only environmentally responsible, but economically rewarding. And it is absolutely critical to the success of our biosecurity program. The Aquatic Animal Health Program at OI focuses on four major areas: Preventive Medicine, Diagnosis, Treatment, and Regulatory Oversight. This paper discusses the integration of the four major components and their applicability to ornamental marine fish culture at the Oceanic Institute.

Keywords: animal health, biosecurity, diseases, preventive medicine, treatment, regulatory oversight.

Introduction

The catastrophic loss of animals due to infectious and non-infectious diseases is one of the largest contributors to profit loss in every animal industry. This is no less true for the small aquafarmer than it is for a multinational agribusiness or the Oceanic Institute Center of Applied Aquaculture. At the Oceanic Institute, aquatic animal health management provides a “biosecure blanket” that protects the institution from the damaging effects of disease on our research programs. The term “biosecurity” is used to describe the integrated components of the health management system. Biosecurity protocols are put in place to protect not only OI from becoming contaminated from outside facilities or wild-fish introductions, but also to protect outside facilities from becoming contaminated by OI. Such a combination of inward and outward perspectives is not only environmentally responsible, but economically rewarding. And it is absolutely critical to the success of our biosecurity program.

Significance of Health Management

Proper animal health will ensure vigorous animals, maximal reproductive yield, and minimal animal loss due to disease. Aquatic animal health is dependent not only on proper nutrition and animal selection, but also on proper water quality, water system/life support maintenance, and water system design. Operating closely monitored and well-maintained water systems, and implementing a preventive medicine program can maintain fish hygiene at a high level, which will minimize losses in valuable animals, research time, and money due to water system failure or infectious disease.

Disease is the result of a complex interaction of host, environment, and pathogen. All three factors may be out of balance in the highly artificial world of aquaculture facilities. A primary goal of the health management program is to maintain our aquatic systems in a naturally balanced state where host, beneficial microbes, and potential pathogens coexist in an environment controlled by man.

Because aquatic systems are very complex, controlling disease outbreaks is a difficult endeavor. Consequently, pathogen-host relationships are difficult to assess in the laboratory environment especially when a candidate species is first cultured and little is known about its diseases. Since primary pathogens can induce disease when other environmental factors are balanced, they must be distinguished from secondary or opportunistic pathogens, which cause disease, when other metabolic or environmental factors are not optimal (Noga, 1996). Poor health is often a reflection of one or more marginal environmental variables such as temperature, pH, hardness/alkalinity, water chemistry, nutrition, bacterial build-up, or overstocking. Disease usually results when stresses within a marginal environment tip the balance in favor of the pathogen (Figure 1).

Simply put, disease diagnosis is the recognition of imbalance within the system. Prevention acts as a buffer to extend the limits of the balanced system. The aim of treatment is the restoration of balance to a disrupted system. Proper health management of the aquaculture facility and subsequent disease control depends on an interdependent action of the above mentioned practices: preventive medicine, diagnosis, and treatment.

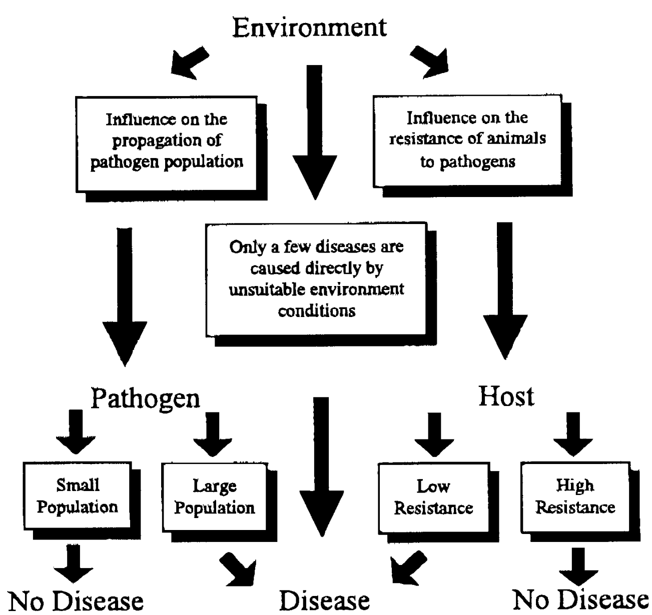

Figure 1. Host-Pathogen-Environment Interaction. The aquatic ecosystem maintains a delicate balance between fish, potential pathogens, and environmental parameters. While relatively few diseases are the result of environmental imbalances (temperature shock, gas bubble disease), the environment has a direct

influence on potential populations and the hosts resistance to disease. Routine monitoring of environmental parameters are, therefore, an important part of an integrated animal health program.

The Animal Health Program

The foundation of the Animal Health Program at the Oceanic Institute is preventive medicine, which provides us with basic protection and promotes best management practices (BMPs). Standard operating procedures (SOPs) are set up for each species and all of its life stages, which specify such things as how the animal is to be fed and cared for, the methods and frequency of sanitation and disinfections, the preferred environmental conditions which promote good health, and how and why diseases and environmental conditions which are detrimental to that species become established. Procedures are then put in place that eliminates practices or conditions that promote ill health. Training and educational programs are initiated to make sure all personnel are aware of any recent procedural changes. Measures are then enacted and diagnostic methods are developed which ensure that specific pathogens, infected animals, animal care personnel or visitors to OI are prevented from ever reintroducing a disease once it has been eliminated.

Diagnostic screening for important disease agents therefore becomes a regular and important part of routine operations (Noga, 1996). Careful screening not only identifies an infectious agent before an outbreak becomes catastrophic, but also allows for the screening of incoming animals and of those scheduled for export. Thus, consistently negative reports from routine diagnostic checks become proof of compliance with the SOPs and provide additional evidence of the animals' disease-free status. A key component to the preventative medicine program is the maintenance of "sentinel" animals within each culture system. These animals occupy one tank within each separate water system. For disease status monitoring purposes, these animals may be routinely evaluated for various potential pathogens, to which the fish within the system may have been exposed. Since these sentinel animals have been exposed to the same environmental conditions as the study fish, the use of valuable animals for routine disease surveillance and diagnostic work-up in the event of a disease outbreak is eliminated. Sentinel animals are placed within a water system with routine culling for diagnostic purposes performed according to an established schedule. Some sentinel animals are subjected to the water system environment for extended time periods to ensure the adequate exposure to potential pathogens with a chronic, subclinical, or insidious onset of disease (e.g. *Mycobacteria* sp.).

A concerted effort is undertaken to limit the introduction of new fish from outside sources. The introduction of new animals always constitutes a source of pathogen introduction into an established culture facility. However, wild fish can be introduced into a facility safely by utilizing stringent quarantine/surveillance programs and by obtaining animals from reputable local suppliers or from the facilities of research colleagues that also implement comprehensive health management protocols.

But even with the best of intentions, poor health and disease can still occur. In such cases, protocols are already in place under the SOPs that specify the diseases of importance, how to diagnose their presence, and how to eliminate them. Treatment protocols can therefore be implemented rapidly, effectively, and in an environmentally responsible fashion without resorting to guesswork.

Animal Health Monitoring

In assessing the health of a colony, it is important to evaluate the appearance and behavior of the animals on a daily basis. Several nonspecific signs in abnormal appearance or behavior can be useful in the initial diagnostic work-up to help determine the causative agent or event (Table 1). It is important to remember that these are only nonspecific clinical signs of disease and are only useful in forming an initial list of rule-outs. More specific diagnostic tests are then implemented for accurate identification of the causative agent (Astrofsky et al., 2000).

Animal Health and Nutrition

Although nutrient requirements have been determined for commonly cultured fishes such as catfish or salmonids, little is known about the nutrients required for balanced nutrition in marine ornamentals (Tacon, 1992). Confounding our lack of knowledge is the differing requirements for the various larval stages of candidate species. Providing adequate calories is of primary concern until complete formulated diets replace any live feeds required for culture. During the research phase of bringing a candidate wild species into culture, costs are rarely figured on a cost basis as for commercial food species, but rather on the availability and palatability of feed. Initially, calorie provision is almost invariably evaluated by the visual appearance of the fish and its apparent growth rate. Later, calorie provision can be figured on a cost basis once feed conversion ratios and minimal daily requirements have been established. The exact amounts of feed for a given species and a daily assessment of nutritional status is therefore a part of the daily animal care plan in the SOP for a given species.

Table 1. Generalized clinical signs important to assessing heath in marine ornamental fish.

Generalized Clinical Signs	Differential Diagnosis
Opercular flaring	Respiratory distress, Parasites, Bacterial infection
Sloughed mucus	Chemical irritation, Parasites
Clamped fins	Parasites
Petechiation or hemorrhage	Bacterial & viral infections, Parasites
Changes in body color	Bacterial & viral infection, Hormonal influences
Scale loss	Parasites, Mechanical trauma
Improper buoyancy	Baroregulatory failure, Parasites
Lethargy	Disease, Stress, Starvation
Surface breathing	Oxygen depletion
Emaciation	Starvation, Parasites

Overfeeding is a more frequent problem than under feeding and leads to a number of potentially serious problems for the fish (e.g. obesity) and the culture environment (e.g. ammonia loading, bacterial blooms). Underfeeding is usually a more serious problem with larval and juvenile stages in most species. Emaciated fish develop sunken bellies as a result of the loss of dorsal musculature (e.g. starvation). In many cases, live larval feeds of appropriate size ranges (see Ostrowski, A.C., this issue) offer a selection of food sources for young fish and provide an appropriately balanced diet until defined formulated diets are developed. In a similar fashion, defined diets are also developed for the enhanced nutritional needs of broodstock. The most common cause of inadequate calories is competition in the tank from more aggressive fish. Nutritional assessment is, therefore, an important factor in determining rational stocking densities as well. Conversely, parasitism can increase the energy requirements of a fish, making otherwise acceptable feeding levels deficient in energy requirements and manifesting as slow growth or emaciation without an observable decrease in appetite. The Animal Health Program delivers its findings of nutritional deficiencies or pathology to the Aquatic Feeds and Nutrition Program (AQUAFAN) for incorporation into the nutritional research plan for a candidate species (see Tacon, A.G.J., this issue).

Environmental Health Monitoring

Water quality monitoring is a vital complement to the Animal Health Program. The degree of monitoring any system is dictated by necessity and economic reality since it may become quite labor intensive and expensive. No matter how many tests are run, they are of no value unless they are interpreted as part of the integrated health plan for a given species. Good water quality is an important key to the successful culture of marine ornamental fish. Water quality includes all physical, chemical, and biological factors inherent in the maintenance of health. Any characteristic of water that influences the reproduction, growth, management, or survival of an animal is a variable that becomes routinely scrutinized under the SOPs for that species. Some of the most important variables are temperature, dissolved oxygen, salinity, and pH. Routine scrutiny of these important variables provides important evidence in determining the cause of poor health. At OI, the Animal Health Program relies on the advice and assistance of the Program in Fisheries and Environmental Science to calibrate and monitor the accuracy of water quality testing equipment (see Ziemann, D.A., this issue).

Temperature

Temperature is critically important in the survival, growth, and successful reproduction of marine fish. The temperature of the water in each system is monitored and recorded daily by animal care staff. Small shifts in the temperature either above or below the optimal range are usually not detrimental but when the water temperature is abruptly raised or lowered, most marine tropicals show an internal shock reaction. Sudden, large shifts can quickly incapacitate resident fish. The magnitude of this effect depends on the strain, its recent thermal history, and the magnitude of the temperature change. Even small temperature changes, for example, can influence the induction of deformities in larval fish (Brown and Nunez, 1998). Small fluctuations in temperature in either direction can be enough additional physiologic stress on fish maintained in otherwise marginal environmental conditions to precipitate disease outbreaks a few days later. This is especially true for the larval stages of marine ornamentals, which are less temperature tolerant than their respective adult forms. As a general rule, we limit changes in temperature to +/- 1.5 degrees C/day although many species can tolerate larger shifts in temperature quite well after an initial minor shock and a brief period of acclimation. A change in temperature also affects the fish's tolerance to other factors. Increased temperature (within the tolerance range) speeds up metabolism and increases oxygen demand (and feed consumption). Temperature change (usually increases) is often a factor in the initiation of reproductive activity or other hormonal induced activity. Accurate temperature data is obviously extremely important in interpreting animal and environmental health.

Dissolved Oxygen

In water, a fish will asphyxiate when the oxygen content drops below a critical level. This level is species specific, subject to adaptation, and temperature dependent. When a fish is taken out of water, the gill lamellae stick together because they lack internal skeletal support. Since this dramatically reduces the surface area available for oxygen diffusion, the fish will ultimately die of asphyxiation unless returned to the water. Therefore, the length of time out of water due to periodic sampling for experiments or when transferring animals, should be as brief as possible. Experimental determinations of environmental oxygen requirements (among other values) are used to develop rational and safe shipping and transport protocols for each species.

Fish avoid areas where oxygen depletion develops. This can be an aid in the identification of oxygen deficient areas within culture systems. Likewise, large numbers of fish gathered around aerators, air stones, or other points of air supply indicates serious oxygen depletion within the system. In the same manner, fish gathered at the water surface also indicate oxygen deprivation.

Although adequate oxygenation is essential, too much dissolved oxygen can be detrimental and even fatal if not corrected quickly. Massive aeration can produce clouds of very fine bubbles. Also, improperly maintained equipment (water pumps) or air stones placed too close to the water pump inflow lines can compress room air to the point where the water becomes supersaturated with dissolved gas (usually oxygen and nitrogen). Under the high pressure of the pump, the compressed gas tends to remain in solution. Once expelled into the circulating water system, the compressed gas comes out of solution at lower pressure in the respiring fish. This results in a phenomenon known as "gas bubble disease," similar to the "bends" in humans. It frequently manifests as fish demonstrating difficulty in breathing (open mouth), hemorrhage around the gills, exophthalmos, small air bubbles associated with the scales or cornea, and sudden death.

Dissolved oxygen (DO) concentration can be affected by system flow, filtration, and temperature fluctuations. DO fluctuations contribute to many culture problems that are associated with the sudden or gradual loss of dissolved oxygen. Routine DO monitoring is therefore an important part of the SOP for every candidate species.

pH

The pH, or hydrogen ion concentration, is vital to the survival of fish. This parameter is particularly important in recirculating systems where, after a period of time, the buffering capacity of the water is diminished and the pH will begin to fall as a result of the constant addition of acidic waste products of the fish and biofilters. Unfortunately, at the normal pH of marine waters (8.0 -8.3) the carbonate buffering system is not particularly efficient, so the addition of sodium bicarbonate to increase buffering capacity is of limited usefulness. For this reason eventual water changes are needed and the routine replacement of a portion of culture water also becomes part of the SOP which governs the care of that species.

Salinity

Reef fishes are often quite tolerant of relatively rapid salinity changes in nature, particularly after rainstorms or long dry spells. Pelagic fishes are very much less tolerant of these rapid changes as are the larval stages of all marine fish. Salinity measurements are needed for readjusting salinities after osmotic treatments as well as in routine tank monitoring as part of the SOP.

Administration, Records and Regulatory Oversight

The aquatic animal health program at OI also provides for regulatory oversight, an important and critical part of the integrated management plan. Records are kept of all husbandry practices, water quality parameters, and health examinations. These records are interpreted by the veterinary staff for compliance with established protocols and in the identification of changes within the animals or the system itself which will contribute to poor health. These records are made available to the Institutional Animal Care and Use Committee (IACUC) which oversees the animal research program at OI and monitors the Animal Health Program for compliance with all applicable laws and regulations.

Getting permission to transport most animals nationally and internationally is becoming an increasingly difficult task, but one that is nonetheless important and necessary to compete profitably in the modern global economy. As the spread of economically important aquatic diseases becomes better understood and the diagnostic tools to identify new and emerging diseases more refined, it is only natural that regions and countries wish to protect their domestic animal industries from external risk by specifying that animals to be imported show proof of specific disease-free status. Today, this usually means an official health certificate signed by an accredited veterinarian. The veterinarian must show, through past history and the most recent diagnostic tests, that the suspect animals do not pose a risk to the importing country. It isn't hard to realize why such assurances are most readily given when a producer has an integrated health management system already in place.

OI is currently developing integrated health management plans for a number of candidate ornamental species being considered for Hawaiian aquaculture.

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CTSA VISION FOR MARINE ORNAMENTALS: PLANNING AND SUPPORT

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ABSTRACT

Aquaculture of marine ornamental fishes and invertebrates has attracted increased interest in the Pacific Islands. The USDA’s Center for Tropical and Subtropical Aquaculture (CTSA) funds research that addresses bottlenecks in the culture of various marine ornamental fishes and invertebrates. The plans and support for development of the marine ornamental industry through CTSA funding, with particular consideration of regional conditions affecting aquaculture, are discussed.

Keywords: CTSA, ornamental, Pacific Islands, Hawaii, aquaculture, planning

Introduction

Seafood is a major import item in the U.S. and is the second largest deficit item after petroleum. In 1997, the U.S. imported more than 14.6 billion tons of seafood resulting in a trade deficit of $5.3 billion. In order to reduce this deficit, the U.S. must produce more seafood for its local markets. To assist in this effort, in 1987 the U.S. Congress authorized $7.5 million for the U.S. Department of Agriculture (USDA) to create five regional aquaculture research, development, and demonstration centers. The mission of these five regional aquaculture centers is to support aquaculture research, development, demonstration and extension education to enhance viable and profitable U.S. aquaculture. The Center for Tropical and Subtropical Aquaculture (CTSA) is one of these five regional aquaculture centers (RACs). Its region extends from the islands of Hawaii, south to American Samoa, west and southwest to the Commonwealth of the Northern Mariana Islands (CNMI), the Republic of the Marshall Islands, the Federated States of Micronesia, Guam, and the Republic of Belau. This region extends more than 4,600 miles from Hawaii to the Republic of Belau and is scattered over an area as large as the continental U.S. (Fig. 1). While the areas are similar in size, their obvious difference is the latter is a large mass of land, while the former consists of many tiny islands scattered over a large body of water. Because of abundant seawater, aquaculture presents a potential opportunity for economic revitalization in the region. While there are several advantages, some obstacles are also found in the region (Lee, 1999). Can aquaculture be a profitable and sustainable industry in the region? Until now, a vital aquaculture activity has yet to be identified and implemented. One activity that holds some potential is the development of an ornamental industry. This report discusses the rationale behind CTSA’s support of this development and provides an overview of related activities.

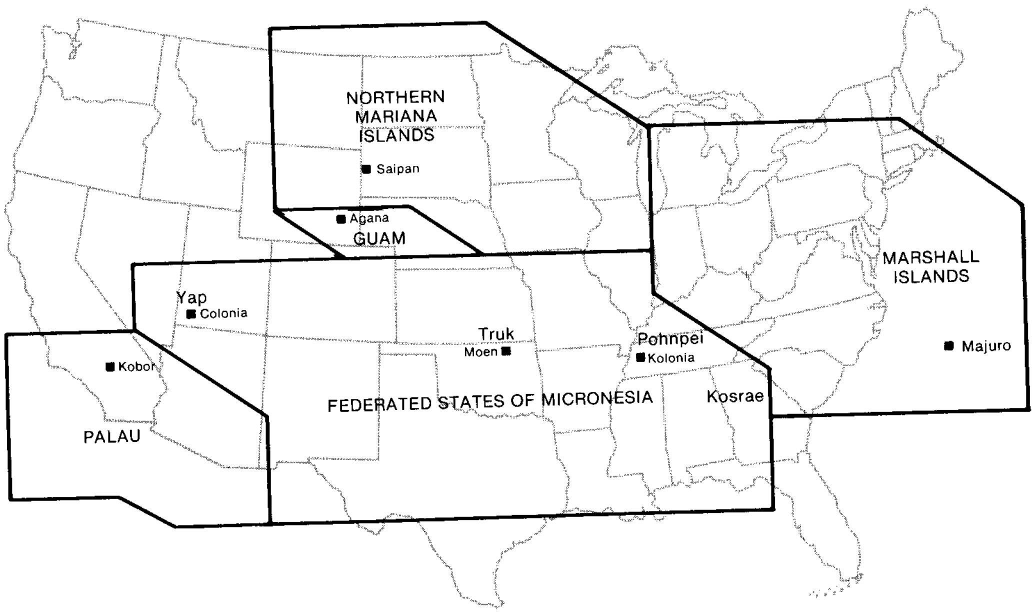

Fig. 1. Area comparison of Micronesia and the continental U.S.A. (U.S. Congress, Office of Technology Assessment, 1987).

In general, the following conditions in the region affect aquaculture development.

1. Small landmass – The total land area of 16,641 km^2 (Table 1) is less than the state of New Jersey. Because of the small land area, land-based aquaculture is not practical or ideal.

2. Small population – According to a 1998 survey, the total population in the region is about 1,608,514 (Table 1) with more than 70% residing in Hawaii. This small population means a small local market for any products and less available manpower for any industrial development. Export markets and a means of transportation must be identified in order to develop a successful industry.

3. High population density – While total population size is small, the population density is quite high, ranging from 39 to 348 per square Km (Table 1). High population density results in increased competition for limited living area and other common resources. This again implies the ideal type of farming practice cannot be on land and should avoid the use of other limited common resources.

4. Land tenure system – The different cultural backgrounds have different practices in certain social activities such as land tenure systems. The ownership of land may not be as well defined as in other countries and may not be protected by a legal system. Natural resources are often considered property belonging to everyone. As discussed by Fairbairn (1992) and Iwakiri (1992), marine property rights and land tenure have always been based on the customary rights of tribal communities. This complex land tenure system may discourage investors from engaging in any business related to this issue.

5. Shortage of freshwater – Although it is not a universal situation throughout the region, freshwater sources on islands are generally not as abundant as on continents. Rainfall has been the major source of freshwater and varies significantly between islands. It is not practical to

conduct aquaculture activities that require the same scarce resource that other community activities need.

6. Abundant seawater – Contrary to the freshwater situation, there is easy access to seawater. Farming using seawater will not conflict with other usages and is recommended.

7. Island environment – The isolated environment of an island is ideal for holding disease-free stocks, as it is easier to avoid contamination with potential pathogens.

8. Distant markets for import and export – Isolation also means distance from the marketplaces for both exports and imports that are important to economic activities. The situation is not so severe for some locations such as Hawaii, Guam, Palau, and CNMI. However, it does create a disadvantage when competition with other producers is unavoidable.

9. Transportation system – Distance is not a problem if there is a well-established transportation system offering sufficient cargo space. Unfortunately, this is not the case for the region except in Hawaii and Guam. The infrequent transportation service and limited cargo space common in the rest of the region creates obstacles for both importing supplies and exporting local products. This is particularly a problem when transporting the perishable goods and live products common in the aquaculture industry.

10. Year-round warm water – The Micronesian island groups are located between the Tropics of Cancer and the equator, in the tropic area. A year-round warm ambient air temperature (average 26-27^{0}C) as well as warm water temperature is typical in the region. The warm and pristine seawater surrounding each island is not found in many other locations throughout the world. However, human pollution is a growing problem in comparatively enclosed lagoon areas. Steps for preventing further pollution must be taken to ensure the Pacific Islands can enjoy the natural resources from the surrounding ocean for years to come.

Table 1. Land and population statistics within the CTSA region.

	Land Area (KM^2)	EEZ * (x1000 KM^2)	Population in 1998	Population Density (KM^2)
Federated States of Micronesia	702	2,978	129,658	185
Guam	541	218	148,060	274
Marshall Islands	181	2,131	63,031	348
CNMI	477	777	66,561	139
Palau	458	629	18,110	39
American Samoa	199	390	62,093	312
Hawaii	16,641	2,148	1,193,001	72

* Exclusive Economic Zone

Successful aquaculture consists of identifying an appropriate species, culturing it, and marketing it to make a profit. The special conditions in the region result in an emphasis on products of high value and low volume. CTSA and the other RACs are among the few funding agencies that depend on input from industry representatives to identify their annual funding priorities. Each year, CTSA invites industry representatives to identify the problem areas impeding aquaculture industry development in the region and determine the funding priorities. Researchers on the technical committee address these issues and identify the best approach and research team (project work group) to solve the problem. Based on their recommendation, CTSA solicits proposals from the suggested working groups. After the proposal is reviewed by internal and external experts and approved by the USDA, funding is provided to the project work group to conduct the proposed research. Utilizing this process, CTSA has identified the farming of aquatic ornamentals as a priority in the region and has funded several projects that directly or indirectly relate to the development of this promising area. Of the 123 projects supported by CTSA since its inception, the following have provided indirect benefits to the ornamental industry.

1. Giant clam training and demonstration project – The initial objectives of this project were to provide training in giant clam culture techniques, to restore the natural population, and to grow products for traditional food markets. Interest in producing clams for ornamental purposes was stimulated when particularly colorful giant clam species began to command a high price in the aquarium trade. Consequently, several private and government farms in the region are actively engaged in producing giant clams for ornamental purposes.

2. Pacific Islands extension and training project – This project is also engaged in promoting the culture of giant clams. Many training workshops and information sheets have been produced to facilitate technology transfer. Besides the giant clam, the project also provides education, training and transfer of available technology for freshwater and marine ornamentals, black pearls, soft and hard corals, sponge cultures, and other marine species.

3. Sponge culture project – This project developed the culture technique for bath sponges. While no efforts were invested in the culture of ornamental sponges, it is believed that the technology and public interest in sponge farming generated by this project will have positive impacts on the future development of ornamental sponge culture.

4. Library aquaculture workstation project – Communication difficulties have been one of the major obstacles for industry development in this region, particularly for remote Pacific islands. This project uses today's Internet technology to provide easy access to current information from remote locations or provides assistance in accessing urgently needed information. This ability to access new information or communicate with distant resources will definitely benefit any business activities, including the ornamental industry.

5. Disease management project – The focus of this project is to address current disease and related problems affecting aquaculture production in Hawaii. Training workshops were conducted to transfer basic disease diagnosis, treatment and prevention techniques to farmers. The project has also provided technical support to freshwater ornamental fish growers in Hawaii. The foundation built by this project will assist aquaculture, including marine ornamental farming, in reducing potential losses from disease.

6. Marine food fish culture project – Since 1993, this project has conducted a series of research activities to improve technology in live feed production, reproduction and nutrition for marine food fish. The knowledge gained from this project is applicable to the development of seed production of marine ornamental fish.

The following are CTSA-funded projects directly related to the development of ornamental industry in the region.

1. Freshwater ornamental fish project – This project first received funding in 1993 and was the first CTSA project that addressed issues related to the ornamental industry. This project assists farmers in establishing broodstock for new desired species and develops and transfers production technology to existing and new freshwater ornamental farms. More than 11 species have been introduced to Hawaii farms under this project. According to the Aquaculture Development Program of the State of Hawaii, the number of farms has increased from approximately 25 in 1994 to nearly 45 in 1997. By 1998, the number of farms increased by almost four times. In 1997, the estimated gross sale of freshwater fish was approximately $450,000.

2. Marine ornamental fish projects – In 1998, CTSA began work on marine ornamentals. Initial objectives focused on conducting several preliminary culture trials of larvae collected from the ocean and developing a list of candidate species for the industry. From preliminary surveys, Yellow Tang is the top choice followed by Pygmy angelfishes, Sargassum fishes, Hawkfishes and 3-spot damselfish. In 2000, a new multi-institutional project will begin. Several institutions will work together to develop hatchery technology for marine ornamental species. The main focus for year one of this three-year project is to establish broodstock populations and resolve the problem of first feeding. The model species selected for cultivation and study are the Yellow tang (*Zebrasoma flavescens*), flame angelfish (*Centropyge loriculus*) and Clown coris (*Coris gaimard*).

3. Projects on soft and hard coral culture **-** CTSA funded a project to study the propagation of hard coral in Guam. After the completion of the project, a training workshop on propagation technique was conducted under a different funding source. Recently, CTSA and University of Hawaii Sea Grant program published a manual to provide a step-by-step guide to soft coral farming in the tropical Indo-Pacific region under CTSA's Pacific Extension Project. A new project is also planned to conduct a study on the culture of eight commercially valuable soft and hard corals in the Pacific.

CTSA's Industry Advisory Council recognizes the importance and potential of the ornamental industry in overall aquaculture development in the region and CTSA will continue to provide funding in this area in the coming years. However, the limited funding available from CTSA is not sufficient to encourage rapid progress in this industry. For substantial and sustainable development of this industry, it requires a multi-institutional approach and cooperation between funding agencies. We have to analyze and to identify the problems impeding the development of the industry. While we focus on technology development, it is also very important to work with local communities and other stakeholders to achieve CTSA's goal of sustainable development of the marine ornamental industry.

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BEHAVIORAL APPROACHES FOR AQUACULTURE AND STOCK ENHANCEMENT IN PACIFIC THREADFIN

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ABSTRACT

Understanding behavioral characteristics of target species is essential for improving their aquaculture technology and conservation strategy. With this concept we studied behavioral characteristics of Pacific threadfin, *Polydactylus sexfilis,* (Valenciennes) juveniles. First, the ontogeny of schooling behavior was observed in hatchery tanks reared with different dietary conditions. Pacific threadfin formed schools from day 19 if the proper amount of docosahexaenoic acid (DHA) was provided in their diet. A second experiment was to evaluate ontogenetic changes of learning capability and stress recovery in this species. Juveniles at 50 mm and 90 mm in FL were better in their learning capability compared to smaller (22 mm, 36 mm) or larger (130 mm) groups. Stress recovery was quicker in larger fish at 90 mm and 130 mm. The third study was to estimate the ontogenetic changes of predator avoidance against bluefin trevally. Juveniles at 70 mm and 100 mm were eaten easily, whereas juveniles at 140 mm and 190 mm survived steadily. In the fourth experiment we compared behavioral rhythm between the wild-collected and the cultured juveniles. Both wild and cultured fish swam faster at night than in the daytime. Wild fish lost their tidal rhythm after three days of captivity.

Keywords: *Polydactylus sexfilis*; behavioral ontogeny; stock enhancement; schooling; learning; docosahexaenoic acid

Introduction

Hatchery production techniques in aquatic species are generally based on their survival, growth, deformity and chemical analysis of body contents (reviewed by Watanabe and Kiron, 1994; Sargent et al., 1997). These characters are basic criteria to produce “healthy” fish; however, behavior of these animals may reflect more subtle, but still important differences on their conditions. Even though most skillful hatchery technicians pay great attention to larval fish behavior, such observations have rarely been published (but see Navarro and Sargent, 1992; Brown et al., 1997).

In this paper four different experiments conducted on Pacific threadfin juveniles are reviewed. In each experiment, a behavioral approach was utilized to improve aquaculture techniques and stock enhancement strategies.

The first study was the observation of patchiness formation in larvae and juveniles in rearing tanks. Three different dietary conditions were provided and the behavior was observed with the least intrusion and no sacrifice of fish. Patchiness, defined as a dense aggregation at the surface, is supposed to be important in natural waters as their planktonic prey also form patchiness (Jillett and Zeldis, 1985; Davis and Olla, 1995). Information concerning the cause and process of patchiness formation can also contribute to improving hatchery production techniques. Schooling is an important antipredator behavior especially for juvenile fish (Pitcher and Parrish, 1993). If juvenile fish have any disability in school formation, such fish may not be able to survive under wild conditions.

The second experiment was to examine the ontogenetic changes of learning capability and stress recovery. Learning capability was measured by reward conditioning and stress recovery was measured by the time taken to start active feeding in experimental tanks (Masuda and Ziemann, 2000).

The third experiment was to test two hypotheses: 1) there is a certain size at which Pacific threadfin can avoid benign predators, and 2) stressed threadfin juveniles suffer higher predation risk as compared to stress-free individuals. As a predator species, we used adult bluefin trevally *Caranx melampygus* Cuvier, which is a common carangid predator in the habitat of threadfin juveniles.

Any animals or plants should have their activity rhythm adapted to their environment (Schwassmann, 1971). This may be controlled by the external stimuli such as light, temperature, and tide, as well as by the internal circadian rhythm (Olla and Studholme, 1972). If animals were raised in captivity, their rhythm may be different from that of the wild population. The aim of the fourth experiment was to examine the daily and lunar behavioral rhythm of wild and cultured threadfin. Behavior of both wild-caught and cultured fish were video-recorded simultaneously and analyzed. Field sampling and gut content analysis data were also included to extend indoor data to the field.

Materials and Methods

Experiment I

Eggs of threadfin were incubated in 12 replicate 1500-liter black conical tanks at a density of 40 eggs per liter. They hatched on the next day (D0). Larvae were fed with rotifers *Brachionus plicatilis* O. F. Müller from D2 to D15, and *Artemia sp.* nauplii from D11 to D25. Rotifers and *Artemia* nauplii were enriched with fatty acids emulsion containing 0, 30, or 50% DHA and EPA (DHA/EPA = 0.6, SELCO™; each treatment defined as no-, medium- or high-DHA), with four replicate tanks in each treatment. The water temperature of rearing tanks was kept between 25.5 to 26.9 °C.

Six individuals on D20 and three individuals on D25 were sampled from each tank and were fixed in 5% formalin. Their standard lengths (SL) were measured later. Data were compiled in each dietary condition and average SL was compared using ANOVA followed by Fisher's PLSD (Howell, 1997).

As a criterion of survival in rearing tanks, we weighed all the live fish by wet weight in each tank on D 25 (defined as the biomass). The average biomass in each dietary condition was compared by ANOVA followed by Fisher's PLSD.

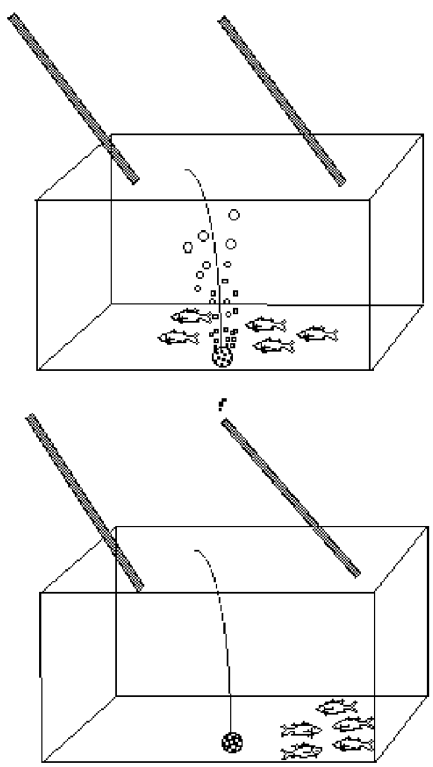
Observations of patchiness formation were conducted between 7:30 and 8:30 every morning from D2 to D25. The number of fish in the densest patchiness in the surface was counted. For the estimation of number, a piece of cardboard (10 X 20 cm) was folded in an L-shape and was put above the densest area. The shade of the cardboard was projected in ca. 1-liter volume, and the number of fish in this projection volume was easily counted. Density when they formed the densest patchiness was compared among dietary treatment by ANOVA.

The presence or absence of schooling was also observed daily. For quantitative analysis of schools, underwater pictures were taken on D22 and D24 (Nikonos-V 35 mm lens with a close up lens). Water supply and aeration was stopped about 5 minutes before taking pictures to prevent the noise of water current. Separation angle (Masuda &Tsukamoto, 1998a) was calculated from one photograph in each tank. For the calculation of separation angle, 20 individuals were randomly chosen from each shot and the angle to the nearest neighbor was measured for each. The average of this value was defined as the separation angle in each tank. Average separation angles in four replicate tanks were compared among treatment using ANOVA followed by Fisher's PLSD.

Experiment II

Pacific threadfin were hatched according to the routine procedure (Ostrowski & Molnar, 1998); they were fed with rotifers from D2 to D15 and *Artemia* nauplii from D10 to D25. Commercial pellets (Moore-Clark Co. Nutra Starter Salmon, Canada) were provided from D14. Average size of the pellets was increased from 0.5 mm on D14 to D20 (when fish were 5-11 mm standard length) to 0.9 mm on D21 D24 (11-14 mm fork length: FL), 1.4 mm on D25 to D35 (14-35 mm FL), 2.0 mm on D36 D40 (35-50 mm FL), 2.5 mm on D41 to D65 (50-100 mm FL), and 5.0 mm from D66. Five different fish size classes were used for experiments: 22 mm, 36 mm, 50 mm, 90 mm, and 130 mm. They were hatched on 13 September 1998 except for 36 mm fish, which were hatched on 9 November 1998. Fish were randomly sampled from nursery tanks and stocked into experimental tanks. An additional five to ten fish were sampled from the same nursery tank and length was measured. At completion, all fish used for the experiment were measured in length (Table 1). No individual fish was used in more than one experimental trial.

Six glass tanks (90 X 32 X 42 cm) were set in a quiet room, each tank separated by walls. Five individuals were stocked in each tank for each size class (6 replicates in each size). Water was exchanged at a rate of about 3 l per min and temperature ranged 25-27 °C. Tanks were separated from observers by a thick black vinyl sheet and feeding was conducted through one of two PVC pipes which were hung from the ceiling (Fig. 1). The aeration could be switched on and off by the observer. Behavior of fish was recorded, through viewing holes placed in the black sheet, using a video camera (Video Hi 8 Handy Cam,



Sony).

Fig. 1. Experimental design to study learning capability of Pacific threadfin juveniles. We used stopping aeration as a conditioned stimulus and feeding as an unconditioned stimulus.

When the fish were stocked into the tanks they tended to stay to either side of the tank. Pellets were provided from different sides of the tank other than where the fish tended to aggregate. We used the same size pellets as used in nursery tanks in each stage (Table 1). Every morning at 08:00 fish were fed about 5% of whole fish body weight of pellets in each tank. As a conditioned stimulus, aeration in the tank was stopped 1 minute prior to feeding (Fig. 1). Video recording was conducted from 1 minute before stopping the aeration to 1 minute after the pellets were provided (3 minutes of daily recording for each tank). Three periods were defined as pre-signal period (from 1 minute before stopping aeration), signal period (from stopping the aeration to providing pellets), and feeding period (for 1 minute after providing pellets). The feeding trial was conducted for 10 days.

The following parameters were assessed through frame-by-frame analysis of video tapes: 1) Feeding latency (defined as the time between the appearance of pellets on the video frame and the first feeding behavior; this value ranged from 0 to >60 seconds) and stress recovery period (defined as the time, in days, to display active feeding, feeding behavior within 10 seconds of appearance of pellets, after fish were being stocked in the experimental tanks). 2) Learning capability. Each tank was divided into two areas, feeding and non-feeding, and the number of fish appearing in each feeding area was counted every 2 seconds. These values were compared at pre-signal and signal period in each tank using *t*-test (*N*=60); if the signal period value was larger than the pre-signal period value, the fish were considered to have begun learning the conditioning stimulus (Fig. 1). The difference in the number of fish appearing in the feeding area from pre-signal to signal period was defined as learning index. In the early stages of learning, this index was expected to be higher than 0. The number of days required for learning the conditioning stimuli was then defined as learning capability of each group of fish and was compared among size classes.

Both stress recovery period and learning capability were compared among different size classes using ANOVA followed by the Dunn's test (Howell, 1997). When one group of fish did not show active feeding, or did not learn, within 10 days, the value was conservatively assigned as 11 days (as Deeley & Benfey, 1995).

Experiment III

Five adult bluefin trevally (FL=420-450 mm; 1680-1990 g) were used as predators. They were of wild origin but had been captivity for 6 months. They were fed commercial pellets, but from 1 week before conducting experiments thawed smelts were fed once every morning.

Four different size groups of threadfin juveniles were used in this experiment as 70 mm, 100 mm, 140 mm and 190 mm in fork length. They were all hatchery reared and were fed commercial pellets until being put in the experimental tank.

The experiment was conducted from May 1 to June 23, 1999 using a circular tank (3.6 m in diameter, 0.6 m in depth) up to April 21, then after that we used a square tank (6.3X6.3 m, 0.6 m in depth). Bluefin trevally were kept in the experimental tank and were fed thawed smelts every morning at 8:00, except when we performed the releasing experiment described below.

Ten juveniles (in case of 190 mm fish, five individuals) were collected from holding tanks and were length measured, then put into a net-pen (90X120X60 cm depth) hung in the tank of bluefin trevally. After a 24-hour acclimation, fish were released either gently (control group) or after giving stress of 1-minute air exposure (stress group). Observation was conducted for the following 1 hour and the attacks by bluefin trevally on Pacific threadfin were counted. Surviving individuals were counted at 1 hr, 3 hr, 6 hr, and 24 hr after the release. The number of survivors was accumulated in each trial and divided by 50 in 70-140 mm fish and by 25 in 190 mm fish. This was defined as survival index, ranging from 0, if all individuals died within 1 hour, to 1.0, if all individuals survived 24 hours. Four to five trials were conducted for each condition in each size group, and 34 release trials in total.

Experiment IV

Sampling

Wild Pacific threadfin were sampled by beach seining on the north side of Kailua Beach, Oahu on eight different days: June 28, July 6, 13, 20, 28, August 4, 11, and 19, 1999, corresponding to two cycles of full moon, last quarter, new moon, and first quarter. Sampling was conducted between 9:15 and 12:30. Fish were transferred to the indoor facility within 1 hour after sampling. Five individuals were used for the behavioral experiment, and the rest were used for gut content analysis. On July 13 only five individuals were sampled in Kailua Beach. Therefore we used three individuals caught on the same day at Waimanalo Beach (ca.15 km south from Kailua Beach) for gut content analysis. On July 20 only four individuals were sampled in 30 tows. Therefore we conducted experiments with four individuals and we did not conduct gut content analysis.

Cultured fish were hatched on February 6, 1999 and were fed with enriched rotifers, *Artemia* nauplii, and commercial salmon pellets (Moore-Clark Co. Nutra Starter Salmon, Canada) according to routine procedure. They were kept in a circular tank (2.5 m diameter, 0.8 m depth) before used for experiment. The size of cultured fish was matched to that of wild fish as much as possible. On July 28 we caught only small size of fish, so we used cultured fish with different FL from the wild.

Gut contents

Gut contents were compared in fish collected on each sampling day in 3 to 12 individuals. Prey species appearing in each gut were identified and weighed. Gut content index was defined as GCI=100*gut content weight (g) / Body weight (g).

Experimental design of daily activity rhythm recording

Both wild and cultured fish were length-measured before the experiment, and then put into experimental tanks (90X32X42 cm) set in a quiet room; walls separated each tank.

Behavior of wild and cultured threadfin was video-recorded in a photoperiod-controlled room. Their behavior was recorded continuously for the following 4 days using two time-lapse video recorders (SVT-124, SONY). An infrared illumination (INF-IL 01, wave length 880 nm, Polaris Industries, Atlanta) was provided to help record their behavior in darkness in each tank.

Two tanks were prepared: one was for wild fish and the other was for cultured fish. Five fish were stocked in each tank. No feeds were provided. In the series 1 experiment, lights were on from 530 to 1930 hours (14 hours light, 10 hours dark). In the series 2 experiment lights were kept on 24 hours continuously to see if there was any internal activity rhythm.

Video analysis

Video analysis was conducted on an hourly basis for 4 days. Three behavioral indices were analyzed separately: swimming speed, swimming depth, and schooling.

Swimming speed was calculated based on the distance the central individual in the group traveled in two frames of videotape. The distance on the monitor was then calibrated using a scale attached on the tank. Since two frames of videotape corresponded to 0.87 sec, the calibrated distance was divided by 0.87 to attain the swimming speed (mm/sec). This value was then divided by the average fork length of the group to express in FL/sec. Swimming speed was measured 10 times with 10 sec interval per hour.

For the criteria of swimming depth, markers were put on the tank to divide the tank depth into three areas as surface, middle, and bottom. When a fish was in the surface, middle, or bottom area, 2, 1, or 0 point were given. The sum of these points in all five fish was divided by the number of fish (5). This value was calculated based on 10 times measurement, each 10 sec apart, and the average was defined as swimming depth index.

As an index of schooling, inter-individual distances, i.e., distances to the nearest neighbor, were defined. The distance to the nearest neighbor was measured for each individual, and the average for five individuals was calculated from 10 frames. This value was then divided by the average FL of the group to compare among groups of different sizes.

Results

Experiment I

Average standard lengths on D20 were 6.5, 6.0, and 6.2 mm in no-DHA, medium-DHA and high-DHA treatment, respectively; those on D25 were 8.8, 9.1, and 9.8 mm, respectively (Table 1). In either case there was no significant difference among treatments (ANOVA; p=0.22, N=72 on D20 and p=0.18, N=36 on D25), although high-DHA fish tended to be slightly larger than no-DHA fish on D25 (p=0.07, N=24; Fisher's PLSD). The average ±SD biomass on D25 was 17.2±7.8 g/m^3, 89.9±9.8 g/m^3, and 83.3±13.0 g/m^3 in no-, medium-, and high-DHA groups, respectively. The average biomass in no-DHA group was significantly smaller than the other two groups (p<0.001, N=12; Fisher's PLSD).

Patchiness was first recognized on D6. Larvae formed denser patchiness (60-250 individuals per liter) on D7-8, then gradually became less patchy. On D10 they began to settle to the bottom and on D16 patchiness in the surface disappeared. Density in the surface was as few as 1-3 per liter at D20. Patchiness formation was not affected by dietary enrichments (Fig. 2). The average peak densities of each of four tanks in no-DHA, medium-DHA and high-DHA treatment were 91.3 ± 35.7, 122.5 ± 87.7, and 73.3 ± 4.7 (individuals per liter, mean ± SD; ANOVA, p=0.24, N=12).

On D8 some individuals started to swim against the current in the tank (rheotaxis), and on D10 some individuals started to form denser patchiness at about 20 cm depth rather than surface. On D14 dense aggregation on the bottom (swarms) appeared. These swarms existed until D19 in tanks of medium- and high-DHA groups, and until D21 to 23 in tanks of no-DHA. High mortality was observed in each tank when fish were forming swarms on the bottom.

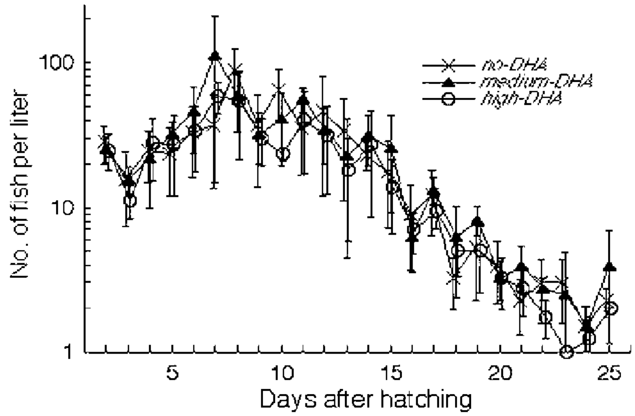
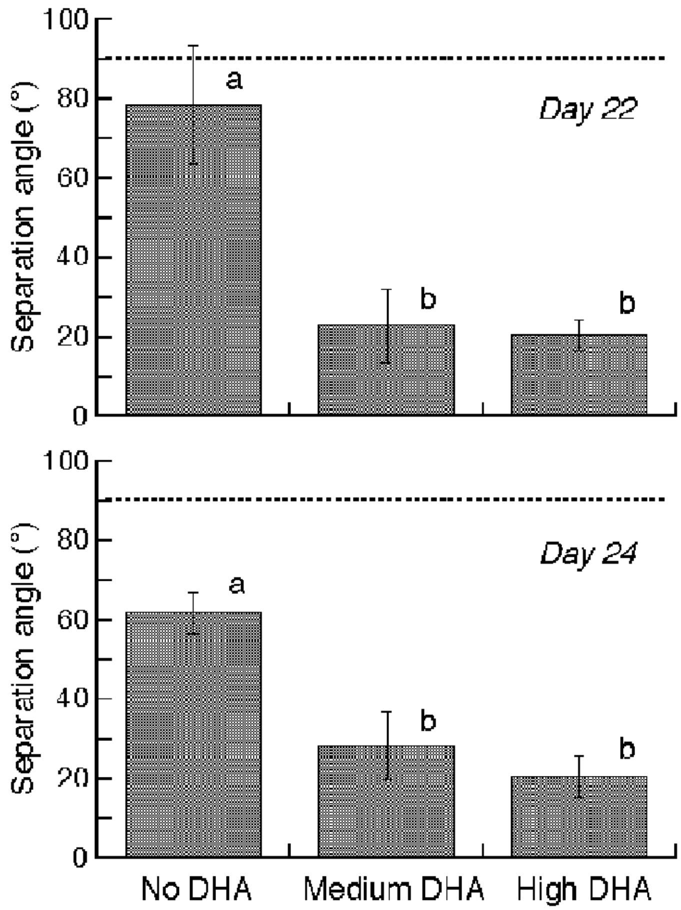


Fig. 2. Patchiness formation of threadfin larvae in rearing tanks. X: no-DHA, s: medium-DHA, m: high-DHA. Each plot represents mean and SD of four replicates.

The development of schooling behavior was strongly influenced by dietary treatments (Fig. 3). Schooling behavior was first observed on D19 in medium- and high-DHA tanks. In the fish of no-DHA tanks, schooling was not observed through the end of observation period (D25).

Fig. 3. Mean ± SD separation angle of threadfin in rearing tanks on day 22 and 24. Dotted line represents 90º, or the value expected when fish were randomly oriented. Means of different letters are significantly different ($p<0.001$)..


100
80
60
40
20
0
Separation angle (°)
a
b
b
Day 22
100
80
60
40
20
0
Separation angle (°)
a
b
b
Day 24
No DHA
Medium DHA
High DHA

Mean separation angles on D22 in no-, medium- and high-DHA tanks were 78.6 ± 15.0, 23.0 ± 9.2, 20.6 ± 4.1 (degree, mean ± SD), respectively, and those on D24 were 61.9 ± 5.3, 28.4 ± 8.5, and 20.7 ± 5.3, respectively (Fig. 3). On both days, separation angle in the no-DHA tanks was significantly larger than other two groups (ANOVA followed by Fisher's PLSD, $p<0.001$, N=12), demonstrating that medium- and high-DHA groups of fish presented parallel orientation, whereas those in the no-DHA group did not.

Experiment II

Fish in the 36 mm class were slowest to start feeding actively followed by 50 mm and 22 mm fish. Fish at 90 mm and 130 mm size classes were the fastest in recovering from stress (Fig. 4). Average stress recovery time was significantly different among groups ($p<0.01$ in ANOVA, $F_{4, 25}=19.5$, n=6 for each group).

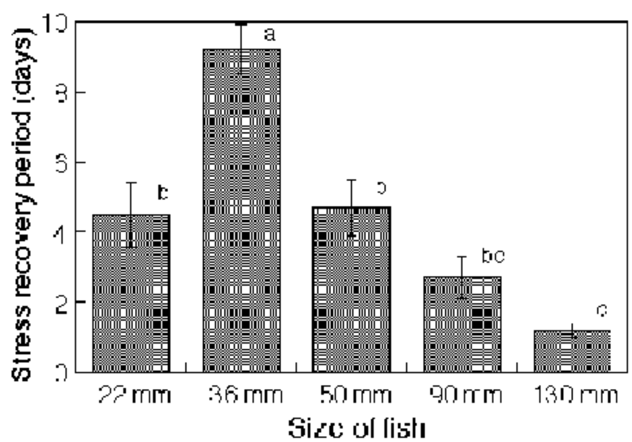
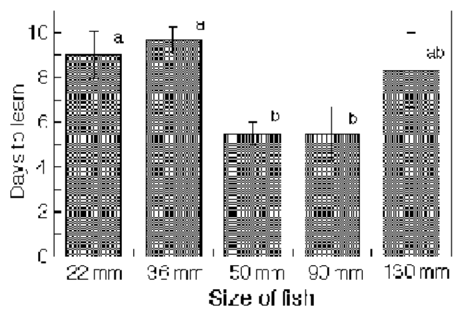


Fig. 4. Average value of stress recovery period in different size of fish. Bars indicate SE (n=6 each) and letters give significance levels (P<0.05, Dunn's test).

Time required for learning the conditioning was significantly different among groups ($p=0.02$ in ANOVA, $F_{4, 25}=3.3$; Fig. 5). Fish in 50 mm and 90 mm showed better learning capability compared to smaller ($p<0.03$, Dunn's test) or larger ($P=0.07$, Dunn's test) groups.



Days to learn
0
2
4
6
8
10
a
a
b
b
ab
22 mm
36 mm
50 mm
90 mm
130 mm
Size of fish

Fig. 5. Average number of days taken to learn the conditioning in five different sizes of fish. Bars indicate SE (n=6 each) and letters give significance levels (p<0.05, Dunn's test).

Experiment III

Threadfin juveniles of 70 mm FL were eaten within 1 minute with only 3 to10 times of attack both in stressed and control groups (Fig. 6). The 100 mm fish were eaten within 7 minutes at most with the attack of 5 to 35 times. Stress loaded fish were eaten significantly more quickly than control ($p<0.05$, t-test). When bluefin trevally encountered larger juveniles as 140 mm, they attacked as many as 43 to 114 times. Still some of these juveniles survived 6 to 24 hours after their release into the tanks. Among the 190 mm fish the number of attacks ranged 26 to 363 times. Most of them survived until 24 hours after their release.

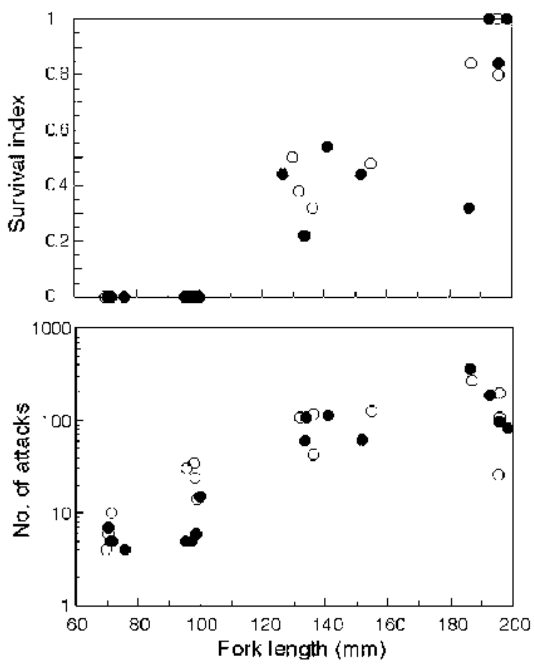


Fig. 6. Ontogenetic changes of antipredator performance in the Pacific threadfin against bluefin trevally. l: stress-loaded, m:control.

The number of attacks was significantly different between 70 mm and 100 mm fish, and between 100 mm and 140 mm fish ($p<0.05$, n=16 and $p<0.01$, n=18, respectively; t-test). Survival index was significantly different between 100 mm and 140 mm size class, and between 140 mm and 190 mm size class ($p<0.01$, t-test).

Experiment IV

Catch per unit effort and gut contents

Gut contents were very low on the two full-moon sampling days, very high on one new-moon day, and intermediate on other sampling days (Fig. 7). There were significant differences among sampling days (ANOVA followed by Fisher's PLSD, $p<0.05$). Their major food items were crustaceans. Fish juveniles were also found occasionally.

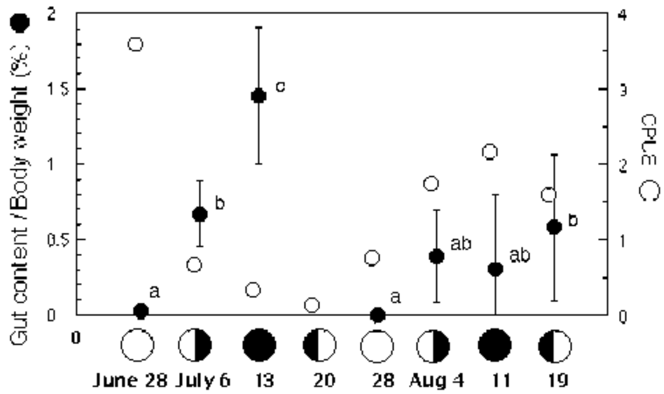


Fig. 7. Gut contents (l) and catch per unit effort (m) of the Pacific threadfin sampled at different phases of the moon. Means of different letters are significantly different (p<0.05).

CPUE tended to be high when the gut content index was low. There was weak but significant negative correlation between gut content index and CPUE ($y=-0.174x +0.674$, $R^2=0.102$, $p<0.0001$).

Behavioral rhythms in experimental tanks

Video analysis was completed only for the first series (light-dark condition) but not for the second series (light-light condition).

Both wild and cultured fish swam faster at night compared to the daytime (Fig. 8). Swimming speed of cultured fish was faster than the wild. Difference between wild and cultured fish was obvious for the first two days, but their swimming speed became almost the same on the third and fourth days.

Fish in both groups tended to stay near the bottom of the tank; off-bottom swimming was observed more often at night than during the daytime. The incidents of off-bottom swimming increased after 4 days among the wild fish, but in the cultured fish swimming depth was consistent for the whole observation period.

Both wild and cultured fish stayed in schools at night. Inter-individual distance of the school tended to be larger (i.e. schooling more loosely) at night in both groups. Wild fish showed smaller inter-individual distance (tight school). The difference between wild and cultured was negligible in the fourth day.

Tidal curves were imposed in our results (solid lines in Fig. 8; based on Click Tide Hawaii, Coconut Info). Wild fish showed tidal rhythm, swimming faster when the tide comes in, whereas this rhythmicity was not clear in the cultured fish. Tidal rhythm of the wild fish disappeared on the third day of observation.

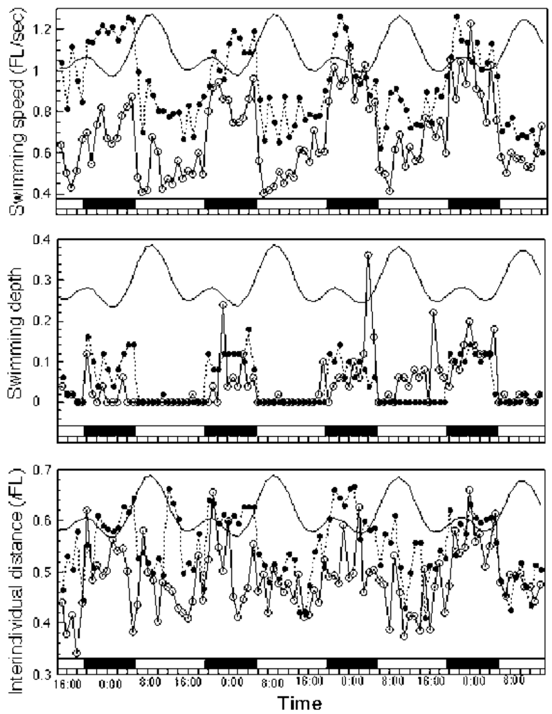


Fig. 8. Daily behavioral rhythms of wild (m) and cultured (l) Pacific threadfin juveniles on four consecutive days. Solid lines represent tidal rhythm.

Discussion

Patchiness Formation and Schooling Behavior

We found that threadfin larvae formed patchiness at the surface at D7 and then settled to the bottom beginning at D14. Schooling behavior with parallel orientation first appeared at D19 in medium- and high-DHA groups. The standard length (SL) of largest individuals at that time was about 8 mm (Table 1). In northern anchovy *Engraulis mordax* L. schooling was first observed at D20, 11 to 12 mm SL (Hunter and Coyne, 1982), in the striped jack *Pseudocaranx dentex* (Bloch et Schneider) at D25 to D30, 12 to 16 mm TL (Masuda and Tsukamoto, 1998a), and in herring *Clupea harengus* L. at D 90, 35 mm TL (Gallego and Heath, 1994). In most species studied so far schooling behavior appeared soon after metamorphosis. Since threadfin attain juvenile stage at about 8 mm SL (Masuda et al., unpublished data), our results in medium- and high-DHA groups are consistent with the results in other species with this respect.

The timing of the development of schooling behavior in threadfin (D19) was slightly faster than other sympatric tropical species such as striped jack, bluefin trevally *Caranx melampygus*, or milkfish *Chanos chanos* Forsskål, all of which develop schooling at between D25 to D30 when they are reared at 25-27 °C (Masuda and Tsukamoto, 1998a; Augustin Molnar and Chris Demarke, Oceanic Institute, pers. com.). Thus when threadfin larvae and milkfish larvae were reared together in the same tank, threadfin developed schooling behavior faster and showed predatory behavior first, resulting in high mortality of milkfish by the predation of threadfin (C. Demarke, pers. com.). Although we do not have behavioral data of wild threadfin larvae and early juveniles, they are probably taking advantage of their fast development of schooling and predatory behavior, which enables them to feed on other piscine species from early juvenile stages. For the nursery production of this species, providing strong current is critically important to make them naturally size-graded and thus avoid cannibalism (Ostrowski et al., 1996).

Behavior of fish larvae is often controlled by phototaxis, rheotaxis and other simple behavior. Striped jack larvae show strong phototaxis from 3.5 mm TL and rheotaxis from 4.5 mm TL, both could have been the cause of patchy distribution in rearing tanks (Masuda and Tsukamoto, 1996). Patchiness of threadfin may also be attributed to such taxis.

In our experiment fish reared with the medium- or high-DHA diets started to school at D19, while fish fed with the no-DHA diet did not school even at D25. This was in contrast to the patchiness formation, which suffered no difference from dietary condition. This discrepancy can be explained by the different basis of these two behaviors. Patchiness formation is probably due to the phototaxis and rheotaxis of larvae and physical effect of buoyancy, current, etc. Therefore as the fish reach certain size they form patchiness passively. Schooling behavior may require more complicated response using the CNS, and for the development of CNS, DHA supplement in late larval stage seems to be more important than early larval stage.

High mortality was observed in most tanks when the larvae were forming swarms on the bottom. Formation of these swarms on the bottom may be due to the balance among calcification, formation of swim bladder, and muscle development. At D15 the larvae have well calcified heads, while they do not have fully developed swim bladders. This should have made the larvae strongly negative buoyant, as is reported in northern anchovy and Atlantic herring (Blaxter, 1986). They might not have developed red muscles and thus could not sustain swimming upward, resulting in high mortality on the bottom. Fish in medium- and high-DHA groups developed their swimming ability better and thus overcome this period at D19, while fish in no-DHA group continued to suffer high mortality until D23 to D25.

Thorisson (1994) suggested that the metamorphosis period in addition to first feeding may be the critical period for the survival in cod. This may also be the case in threadfin, since they suffered high mortality during late larval stage. Growth in the no-DHA group was not different from those in medium- or high-DHA groups, but the survival expressed in the biomass was very low. This was probably because threadfin could attain metamorphosis size without much dietary DHA, whereas DHA was essential to go through metamorphosis and develop thereafter. This may be related to the construction of the CNS in juvenile fish, as dietary DHA is incorporated into the brain during metamorphosis (Masuda et al., 1999).

Stress test by air exposure is a common method to measure the activity of larval and juvenile fish. This method is often applied to measure the quality of fish reared under different dietary conditions (e.g. Izquierdo et al., 1989). Furuita et al. (1998), however, reported that in Japanese flounder *Paralichthys olivaceus* (Temminck et Schlegel), larvae reared without essential fatty acids have shown a high survival in the activity test as the fish reared with DHA-enriched groups. That was also the case in the yellowtail *Seriola quinqueradiata* (Temminck et Schlegel) juveniles (Masuda et al., 1999). Sakakura et al. (1998) demonstrated that yellowtail juveniles reared with vitamin C deficient diets did not form schools, although their recovery in the air exposure test was not significantly different from vitamin C provided groups. We also measured survival after air exposure of 1 minute and found that there was no significant difference among dietary treatment groups (Kim et al., unpublished data). Therefore the air exposure test might not be as reliable a measurement as believed.

The present paper demonstrates that dietary DHA deficiency results in lack of schooling behavior in juvenile threadfin, and that this delay of the development was associated with high mortality in DHA deficient groups in their early juvenile stage. We have shown that behavioral observation can be a useful tool to measure the condition of fish. Applications of standardization of behavioral criteria are needed to improve hatchery production techniques in marine fish species.

Ontogeny of Learning Capability

Through this experiment it was found that 1) fish at 36 mm and 50 mm take a longer time to recover from handling and transportation stress compared to smaller or larger fish, 2) fish at 50 mm and 90 mm were better at learning compared to smaller or larger fish.

According to our field sampling, Pacific threadfin juveniles recruit to surf zone of sandy beach at 50 to 120 mm fork length (Ziemann & Friedlander, 1998). High learning capability at 50 mm and 90 mm may represent innate high adaptability at these stages. Such adaptability should be essential when they are recruiting to the coastal habitat, since their food items and distribution may be more or less site-specific.

Laboratory experiments support the idea that although feeding and antipredator behaviors are innate, they can be improved and fine-tuned through experience (Magurran, 1989; 1990; Zaragoza *et al.*, 1994). Olla and Davis (1989) demonstrated that coho salmon *Oncorhynchus kisutch* Walbaum exposed to the threat of benign predator (lingcod *Ophiodon elongatus* Girard) survived in greater numbers than did the unexposed salmon. Those experiments, together with the present results, suggest that we could condition cultured juvenile fish to feed on wild prey and avoid predators, at certain stages, and to improve their survival after release. For such conditioning, our results suggest that 90 mm Pacific threadfin are ideal because they have a higher learning capability and are fast to recover from handling stress.

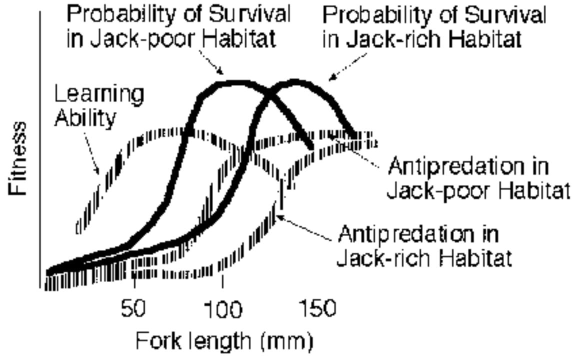
Ontogeny of Anti-predator Performance

Present experiment suggested that for 420 to 450 mm bluefin trevally as predators, there is a size refuge between 100 mm and 130 mm. Although not many of 130 mm fish survived in this experiment, these fish should have survived better in the wild condition, since this experimental situation was more advantageous to predators; threadfin could have escaped before they were attacked as many as 100 times if they were in the wild.

We understand that after growing over 100 mm threadfin can survive attacks of this predator with relatively high probability. This size may change depending on the size of predators.

Predation rarely occurred between 6 hours and 24 hours after the release, corresponding to 4 p.m. and 10 a.m. the following day. This means that predation by bluefin trevally occurs mostly during the day, or, threadfin, having survived the first attack, can survive relatively easily.

Those experiments suggest that in general, predator avoidance experiment can provide valuable information precedent to stock enhancement. Based on this and previous experiments, we can conclude that as an internal factor of learning capability, 50 to 90 mm juveniles are more suitable for release, whereas from the predator avoidance aspect, fish larger than 100 mm are preferable (Fig. 9). The latter factor may change depending on the size, species, and amount of predators at the release site. Therefore



we should better decide size at release after assessing size and amount of potential predators in each release site.

Fig. 9. Adaptability of released fish should be a product of internal factor (learning capability) and environmental factor (size and amount of predators). The peak of adaptability (=proper size at release) may shift to bigger or smaller side depending on the amount of predators.

Behavioral Rhythm

Wild fish caught on new moon tended to have higher amount of gut contents. This may be partly because crustaceans are more active at new moon nights compared to other phase of the moon. Since their major predators such as carangid fish are assumed to be visual predators, threadfin may have less predation pressure while feeding during new moon nights, resulting in higher gut contents.

Gut contents index and CPUE had a negative correlation. This may be because when they feed enough they stay away from surf zone, whereas when they are starved, they stayed in surf zone to feed in the daytime, resulting in higher CPUE.

This laboratory experiment suggested that the threadfin is a nocturnal species, since both swimming speed and swimming depth was higher at night in both wild and cultured fish. This nocturnal activity may be related to either feeding behavior or migratory behavior. Since they are bottom feeders, off-bottom behavior observed at night may be related to migration rather than feeding. Radio tagging and releasing experiment in our group also demonstrated that threadfin stay still in the daytime and move around at night (Friedlander et al., unpublished data). Nocturnal activity was also reported in sand goby *Pomatoschistus minutus* (Pallas) (Gibson and Hesthagen, 1981).

Wild fish showed high activity at the predicted incoming tide. This tidal rhythm was not obvious in day 4 of the experiment. Therefore we assume that they lose this tidal rhythm in three to four days.

Swimming speed of wild and cultured fish got closer in the experimental period and became almost identical in day 4. This suggests that cultured threadfin may take three to four days to adjust to the tidal rhythm in the natural waters after release.

In conclusion, both field sampling and laboratory experiments suggested that new moon nights would provide better condition for threadfin compared to other moon phases. Therefore it is recommended to release threadfin around the new moon to improve their survival potential in the stock enhancement of this species.

Implications for Ornamental Fish Culture and Conservation

Most marine finfish studied so far require a DHA supplement in their diet. The amount they require differs depending on species. Present results suggest that DHA enrichment is particularly important in the latter part of larval stages to pass metamorphosis and develop proper behavior in the juvenile stage. Such an idea is directly applicable to any marine fish culture including ornamental fish.

The peak of learning capability in the Pacific threadfin was coincident with the timing of recruitment from offshore to the surf zone. Suppose each species has a peak of such learning capability, then in ornamental fishes, such a period may be suitable to introduce to an aquarium, so that they can adapt to new environment with less difficulty.

Since almost every species of animal has its own behavioral rhythm, the systematic knowledge of such rhythm will help a lot in dealing with each species. There is a large number of publications reporting studies of daily or annual rhythms of fishes, whereas very few present work on lunar rhythms. Considering that most marine ornamental fish originate from tropical waters and in tropical waters lunar rhythmicity of the environment could be more dominant than the annual rhythm, the lunar rhythms of ornamental fish may be a promising subject to be studied.

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APPLICATION AND TRANSFER OF OI TECHNOLOGIES ON AQUATIC FEEDS AND NUTRITION TO MARINE ORNAMENTALS

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ABSTRACT

The development, production, and use of cost-effective aquatic feeds, whether in the form of live natural food organisms or manufactured compound aquafeeds, is central to the successful operation of all intensive aquaculture systems, including the production of marine ornamentals.

The paper reviews the activities of The Oceanic Institute’s Aquatic Feeds and Nutrition (AQUAFAN) Program, and in particular its research activities related to the implementation of a five-year research project on the development of shrimp feeds; the project is funded by the Agricultural Research Service (ARS) of the United States Department of Agriculture (USDA). The program places particular emphasis on a multi-disciplinary and holistic approach to aquatic nutrition and feed research, and the need to develop feeds and feeding strategies tailored not only to the specific target species but also to the intended farming system.

The feeding options currently available for the production of marine ornamentals are briefly reviewed, including 1) the use of live, fresh or frozen natural food organisms, 2) the use of live, fresh or frozen natural food organisms in conjunction/combination with dry feed materials or supplemental compound aquafeeds, and 3) the use of nutritionally complete artificially compounded aquafeeds. In view of the almost total absence of information concerning the dietary nutrient requirements of marine ornamentals, the starting point in developing practical feeding strategies for marine ornamentals is to first study and understand the natural feeding habits of the species in question, including both food preferences and feeding behavior over the entire life cycle. As a first step the nutritional composition of the major food items consumed will serve as a good template from which to develop artificial feeds for the species in question. Examples of reported feeding habits of Surgeonfishes and Tangs (Family *Acanthuridae*) are presented, together with nutritional enrichment techniques routinely employed for common live food organisms used for larval rearing.

Keywords: aquatic feeds, nutrition, live food organisms, marine ornamentals

Introduction

The ornamental fish industry has been one of the fastest growing segments of the aquaculture industry; the sector was recently valued at $250 million worldwide, and would be worth twenty times this amount ($4 billion) if one included related merchandising products such as aquariums, fish food, algae, gravel etc. (Ounaies, 1998). However, in marked contrast to freshwater ornamental fish where over 90% of the fish traded are produced through aquaculture, the marine ornamental fish trade is almost totally reliant (99%) upon wild-caught fish. Moreover, the high demand for marine ornamentals by aquarists and hobbyists (their market value reportedly reaching over US $1000 per kg, compared with about $100 for their freshwater counterparts) has in many exporting countries resulted in the widespread use of environmentally destructive fishing practices, with the consequent risk of depleted natural fish stocks (through overfishing), habit destruction (through the use of explosives and poisonous chemicals), and the introduction of exotic aquatic diseases (Andrews, 1990; Gomes, 1996).

It is widely recognized that one of the major factors limiting the growth and global expansion of the marine ornamental fish industry is the ready availability of suitable feeds and feeding regimes, particularly for brood fish and newly hatched larvae. The aim of the present paper is to briefly review the research activities and approach of The Oceanic Institute's Aquatic Feeds and Nutrition (AQUAFAN) Program, and to provide some general guidelines for the development of practical feeds and feeding regimes for the production of marine ornamentals.

The OI AQUAFAN Program

Staffing

The Oceanic Institutes has been actively engaged in aquatic feeds and nutrition research since 1984 (Baranowski *et al*., 1984) and the AQUAFAN Program currently has 18 staff, including six research scientists, two research associates, two research assistants, seven research technicians, and one information specialist. The program prides itself in its multidisciplinary and holistic or systems approach to aquatic feeds and nutrition research, and in particular, its ability to conduct fundamental classical studies on marine warmwater crustacean and finfish nutrition, as well as applied studies on ingredient processing, commercial aquafeed manufacture, aquatic microbiology, and development and use of environmentally sound on-farm feed and pond management practices.

Research Infrastructure

The AQUAFAN Program possesses several unique attributes which contribute to its success in conducting research on aquatic feeds and nutrition, including:

- Four Indoor Controlled Laboratories (ICL) for conducting experimental feeding trials with marine crustaceans and/or finfish under clean-water laboratory conditions; Facility A: 75 x 52-L rectangular glass rearing tanks, Facility B: 36 x 52-L rearing tanks, 12 x 500-L digestibility measurement tanks; Facility C: 60 x 52-L rearing tanks, Facility D: 24 x 52-L rearing tanks;

- One Outdoor Mesocosm Laboratory (OML), containing 56 x 1.4 m^3 experimental microcosm tanks for conducting outdoor feeding trials under conditions designed to mimic intensive clear-water or green-water outdoor managed tanks;

- Central Analytical Laboratory for the routine analysis of feed ingredients, aquafeeds, animal tissue samples, and tank/pond water; routine analyses including proximate composition, minerals and trace elements, bomb calorimetry, amino acids, fatty acids, specific vitamins and nutrients, pellet stability, pellet texture, as well as chemical and microbial water and waste-water analyses; and

- Laboratory Aquafeeds Production Facility for the experimental production of semi-purified and practical crustacean/finfish feeds, including a CPM laboratory-scale pellet mill with a triple pass conditioner, an Insta-Pro Model 600 dry extruder, a 150-pound mixer, a 50-pound ribbon blender, a Hobart mixer and a 400-pound-per-hour food chopper, a Jacobson Model

16H Air-swept pulverizer, a hammer mill, a meat grinder/crumbler, a chilled feed storage room with plastic storage bins and weighing scales, a Despatch forced-air drying oven with an 18-foot chain belt conveyor, a two-door vertical drying cabinet with air-blower, a 3-door -30°C freezer, and vent fans.

Strategic Objective and Major Research Program

The long-term strategic objective of the AQUAFAN Program is to provide technical support and assistance to the aquaculture and aquafeed manufacturing sector (and associated industries, including feed ingredient suppliers) in the U.S. and the international community. To accomplish this, the program conducts basic as well as applied research that focuses on developing new and improved aquatic feeds and associated feeding technologies. These feeds and feeding strategies are tailored to the individual requirements of the intended target species and farming system. They are also designed to be economically viable, and environmentally compatible with the sustainable development of the aquaculture sector.

The main research activities of the AQUAFAN program are at present almost entirely related to the implementation of a five-year (1998-2002) research project funded by the Agricultural Research Service (ARS) of the United States Department of Agriculture (USDA) concerning the development of shrimp feeds. The mission of the project is to conduct research to advance U.S. feeds technology that enhances the nutritional, environmental, and economic effectiveness of marine aquaculture. The overall goal of the project is to develop second-generation feeds technology and management for the intensive culture of high health, genetically improved Pacific white shrimp (*Litopenaeus vannamei* Boone, formerly *Penaeus vannamei* Boone) that optimizes economic returns while minimizing any possible harmful effects on the environment, and in particular:

- Develop models for the nutritional and energy needs of *Litopenaeus vannamei* and intensive shrimp culture systems for this species, as these relate to feed inputs;

- Define the ingredient and finished feeds processing parameters, as well as the associated nutritional specifications, which will optimize production of *L. vannamei*, pond system stability, and discharge water quality/quantity under intensive culture conditions; and

- Develop an economic analysis of intensive shrimp production systems as a function of feed inputs (feed types and feeding strategies) and the interactions of feed inputs and environmental conditions of the production system.

Feeding Options for Marine Ornamentals

The feeding strategies currently available for marine ornamentals include:

- Use of live, fresh or frozen natural foods. This is by far the most commonly used feeding strategy for marine ornamentals, and involves the use of one or more natural food items, including algae, wild phytoplankton, rotifers, copepods, cladocerans, wild zooplankton, nematodes, tunicates, echinoderms, brine shrimp, annelid worms, and cut/minced tissue preparations (i.e. muscle and/or gonads from selected marine fish, crustaceans, cephalopod molluscs etc.). For example, Danilowicz and Brown (1992) used a combination of algae, rotifers, wild zooplankton, and *Artemia salina* (Linnaeus 1758) nauplii to rear damselfishes [*Dascyllus albisella* (Gill) and *D. aruanus (*L.)] from first feeding larvae to marketable size at approximately 10 weeks of age (41.2% survival). Similarly, Zhang and Creswell (1998) used a combination of microalgae (*Chaetoceros* sp. and *Isochrysis* sp.) and *Artemia salina* nauplii for the production of larval *Lysmata wurdemanni* (a marine ornamental shrimp) from first feeding to sexual maturity (after 50 to 70 days).

- Use of live, fresh or frozen natural food organisms in combination with dry feed materials or supplemental compound aquafeeds. This is the second most commonly used feeding strategy, and is normally employed after the critical larval/weaning rearing phase where larger feed particles can be more readily consumed and the nutritional demands of the target species are less demanding. For example, Alayse (1984) successfully used a combination of rotifers and brine shrimp nauplii for the larval rearing of the anemone fish *Amphiprion ocellaris* (Cuvier)*;* the nutritional value of the rotifer can be enhanced by also providing a mixture of dry food directly to the anemone larvae (larval survival increased from 5% to 40% over a 30-day period).

- Exclusive use of a nutritionally complete, artificially compounded aquafeed for part or all of the culture cycle. This is the least common feeding strategy for marine ornamentals, and the ultimate goal of all nutritionists, aquarists, and hobbyists alike. This approach would greatly simplify the feeding process, and if successful, would facilitate the rearing of hitherto difficult fish species, and in so doing would promote expansion of the marine ornamental fish-rearing sector. For example, the omnivorous anemone fishes *Amphiprion* sp. have been successfully grown from postlarval to market size exclusively on a dry compound aquafeed (Joe Lichtenbert – personal communication, November 1999).

Important Considerations

In view of the almost total absence of information concerning the dietary nutrient requirements of marine ornamentals (Ako and Tamaru, 1999; Earle, 1995), the starting point in developing practical feeding strategies for marine ornamentals is to first study and understand the natural feeding habits of the species in question, including both food preferences (physical and nutritional characteristics) and feeding behavior (planktivore, herbivore, omnivore or carnivore; surface, mid-water or bottom feeder; day or night-time feeder; continuous or discontinuous feeder) over the different stages of the life cycle. As a first step the nutritional composition of the major food items consumed by the different life stages (larvae, fry, juveniles, adults) will serve as a good template from which to develop artificial feeds for the species in question. For example, in describing the natural feeding habits of Surgeons and Tangs (Family *Acanthuridae*), Garratt (1996) reported that they are essentially bold algal grazers, whereas anemone fish have been reported to be omnivorous feeders, consuming a combination of benthic algae and planktonic copepods (Allen, 1972).

Concluding Remarks

Finally, in view of the current widespread use of live food organisms for marine ornamentals, it is recommended that dietary enrichment techniques be used so as to optimize and/or enhance the nutritional characteristics and value of live food organisms. This can be achieved through the use of live food organisms enriched with liquid emulsions containing mixtures of essential nutrients, including 1) the highly unsaturated fatty acids (22:6*n*-3, 20:5*n*-3, 20:4*n*-6 AA) and phospholipids for improved fecundity, fertility, and larval growth/survival; 2) the antioxidant vitamins C and E for improved disease resistance and reproductive performance; 3) the carotenoid xanthophylls and astaxanthin for improved pigmentation, reproductive performance, and larval survival/growth; and 4) probiotics, including live bacteria and yeasts, for improved disease resistance and growth [for review see Dhert et al. (1997) and Lavens and Sorgeloos (1996)].

In general, it is recommended that marine ornamental fish be fed frequently with small amounts of artificial feeds over a 24-h feeding period, and that a green-water culture system be maintained in order to ensure the continuous supply of live planktonic food organisms and a stable hygienic aquatic environment for the cultured species.

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