Ornamental reef fish aquaculture and collection in Hawaii

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ABSTRACT

Ornamental fishes endemic to Hawaii's reefs are a valued resource and a staple of the marine aquarium trade, worldwide. At present, the market for Hawaiian ornamental reef fish is supplied entirely by the export of wild-captured animals, but the long-term sustainability of this practice is debatable. The success of breeders of ornamental fishes elsewhere, and concerns about overexploitation of wild fishes have stimulated interest in the development of an industry based on the captive propagation and rearing of Hawaiian ornamental fishes. Initial attempts to spawn and rear the larvae of various marine ornamental fishes in Hawaii were carried out in the early 1970s. The results of these culture efforts, conducted primarily at the Oceanic Institute and the University of Hawaii's Hawaii Institute of Marine Biology on Oahu, have varied in success. For the most part, these results have appeared previously only in dissertations or in reports distributed locally. Technological improvements in marine aquarium husbandry and in the culture of edible marine fishes have both benefited practitioners of ornamental reef fish culture, and promise to do so in the future. Our objective in this paper is to review the progress that has been made in the captive cultivation of ornamental marine fishes and to provide an overview of the status of the marine aquarium industry in Hawaii.

INTRODUCTION

Market considerations

Aquarium-keeping perennially ranks among the most popular hobbies in the United States (Hennessy, 1986). Due to relatively recent advances in technology, the popularity of the saltwater aquarium fish component of the ornamental fish trade has grown rapidly. The annual revenue of the global aquarium industry (including fish, plants, invertebrates, equipment and supplies) is estimated between US$4 billion and US$15 billion (Corbin and Young, 1995; Davidson and Corbin, 1992). In Hawaii alone, revenues of $7.2 million were produced by the aquarium industry sector in 1989 (Miyasaka, 1991). Of this, 70% was from the sale of marine fish, 17% from freshwater fish, and 11% from equipment. The US committee for the General Agreement of Tariffs and Trade has predicted that the global aquarium industry is likely to continue to expand in the coming years by 10–15% annually (Corbin and Young, 1995).

Many of the technological developments in the marine aquarium industry were the direct result of applied scientific research. For instance, in the early 1900s, scientists as well as the more advanced aquarium enthusiasts working with closed-water

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aquarium systems were dependent upon recipes which outlined the proportions of the basic chemical constituents needed for an approximate duplication of natural sea water (Moe, 1992). However, since the development of the first commercial sea salt mixes about thirty years ago, multiple brands are now available to the aquarist including several formulas specifically designed to support live coral displays. A variety of monitoring kits and meters are also available for the measurement of a range of water chemistry parameters, including pH, salinity, and concentrations of various organic and inorganic compounds in the water. Similarly, the equipment used to maintain a stable chemical and biological environment within recirculating marine aquaria is constantly improving and expanding (Moe, 1989; 1992; Spotte, 1979). Traditional activated carbon and undergravel filters have largely been replaced by more sophisticated and efficient filtration methods such as trickle filters, protein skimmers (or foam fractionators), and ion exchange resins. Disinfection technology such as ultraviolet irradiation and ozonation has also become more commonly practiced among dedicated aquarists. Continual advancement in mechanical, chemical, and biological filtration as well as sterilization methods have made the maintenance of a living reef tank – complete with healthy corals and other invertebrates – a far less daunting challenge than it was a decade ago. As a consequence of these incremental improvements in reef tank technology, public exposure to and popular knowledge of reef organisms has increased steadily. Market demand has increased both in terms of the numbers of animals and the number of species routinely in demand. This growth in the global market for ornamental fishes has been accompanied by a growing demand for many of the endemic Hawaiian species (Department of Land and Natural Resources (DLNR), 1988), and a continuing interest in overcoming the obstacles associated with their captive cultivation.

Conservation and management issues

The global demand for ornamental reef fish has resulted directly in increased collection rates of natural stocks in heavily collected areas like Hawaii, the Caribbean, and the Philippines (Walsh, 1978). Several countries in Asia and South America have begun to implement collection restrictions of certain ornamental fish species that are intensely exploited (Corbin and Young, 1995). In an unpublished study, L. Taylor and R. Nolan (cited by Nolan, 1978) made a preliminary assessment of the ecological impact of marine aquarium fish collecting in Hawaiian waters. The population dynamics of the most commonly collected marine aquarium fishes were extrapolated from monthly catch reports recorded by the Department of Fish and Game for the period of July 1, 1973 to June 30, 1974. It should be noted that the quantities of fish listed in such reports are based on voluntary reporting by collectors, which is not subject to validation; underreporting is a distinct possibility. The population trends of reef fishes were largely inconclusive, however, due to natural seasonal variations as well as shifts in fishing intensity for that particular year of the study (Nolan, 1978). To our knowledge, baseline population studies of ornamental reef fishes have never been carried out on a statewide basis in the Hawaiian Islands, so collection pressures and declines in stocks can not be quantified in terms other than reported export numbers and perceived patterns of change. Available data are insufficient for calculation of catch per unit effort, and for the use of other standard fisheries modeling tools.

Paine (1969), in his work on reef population structure, referred to those species that have a substantial impact upon the population densities of other members of the community as 'keystone' species. The removal of such species from a reef community was found to upset the ecological balance of that community. For instance, a reduction in the abundance of a predator, either carnivorous or herbivorous, may result in population increases in one or more prey species. Similarly, heavy collection pressure on only one of several species competing for a limited resource may lead directly to compensatory changes throughout the reef community (see Robertson, 1996). Even if a certain keystone species is collected within the maximum sustainable yield, it follows that the impact could exceed the effects on that species alone, suggesting more widespread and possibly detrimental effects. For this reason, it appears likely that sustained collection pressures on favored species over the long term may lead to some degree of restructuring of reef communities.

Currently, no reliable maximum sustainable yield statistics have been established for any species of Hawaiian ornamental reef fishes. Consequently, almost no restrictions limiting the number, individual size, season, or particular species collected exist for Hawaiian ornamental reef fish (Walsh, 1978; DLNR, 1997). Size restrictions do exist for several Hawaiian game fish such as the whitespot goatfish (*Parupeneus porphyreus*), the orangespine surgeonfish (*Naso lituratus*) and the parrotfish (*Scarus* spp.). Some seasonal restrictions have also been imposed on game fish inhabiting reef environments. Though the juveniles of many of these species are considered aquarium fish, regulations specific to the collection of aquarium fish are minimal. Some general regulations restricting collection methods and protecting invertebrate species do apply (DLNR, 1997), and a collecting permit is required.

Limited research on the ecology and population dynamics of individual species, especially of rare species such as the Tinker's butterflyfish (*Chaetodon tinkeri*) and the longnose hawkfish (*Oxycirrhites typus*), suggests that heavy collection pressure could eventually result in the localized extinction of some species (Walsh, 1978). Despite the threat of overexploitation, and the occasional introduction of legislative measures intended to manage reef fish population, the collection of marine ornamentals in Hawaii remains essentially unrestricted.

Aquaculture background

Efforts to develop alternatives to the exploitation of reef organisms by means of captive cultivation have been very limited. The pioneering research efforts in the culture of marine ornamental fishes have taken place primarily in Florida and California (Madden, 1978), and more recently in Puerto Rico. Far more research has focused on practical and biological aspects of marine fishes for the purpose of food production and the replenishment of natural stocks. For instance, food fishes such as the Florida pompano, *Trachinotus carolinus* (Jory *et al.*, 1986), and the red drum, *Sciaenops ocellatus* (Hysmith *et al.*, 1983) are currently under investigation as candidates for aquaculture. Similarly, the striped bass (*Morone saxatilis*), recognized as both a popular sport and food fish, has been the subject of extensive research efforts for more than two decades (Brown *et al.*, 1989; Kerby *et al.*, 1983). Some of the advances in edible marine fish culture, such as the development of spawning induction methods and larval diets, carry over into the cultivation of ornamental species.

In 1973, Aqualife Research became the first company to market captive-bred marine aquarium fish commercially (Mclarney, 1985). Established in Florida by Martin A. Moe Jr., Aqualife relocated to the Bahamas in the mid-1980s (Mclarney, 1986). The initial successes of this company with such popular reef fishes as the percula clownfish (*Amphiprion ocellaris*) and the Atlantic neon goby (*Gobiosoma oceanops)* established a lasting benchmark for marine ornamental fish culture operations. Because the larvae of these and other demersal spawners tend to be easier to raise than those of pelagic spawners, several species of clownfishes and gobies comprise the majority of the aquarium fish produced by Aqualife Research (Thresher, 1984). In addition to these staple species, there are reports of some success raising several species of angelfishes including a hybrid produced by crossing the grey angelfish (*Pomacanthus arcuatus*) with the French angelfish (*P. paru*) (Moe, personal communication). Angelfishes, like most butterflyfishes, surgeonfishes, and wrasses, are pelagic spawners and are therefore more difficult to culture in captivity.

Target species

Among the numerous families of reef fishes most abundantly represented in the marine ornamental fish trade are damselfishes (Pomacentridae), butterflyfishes (Chaetodontidae), angelfishes (Pomacanthidae), surgeonfishes (Acanthuridae), and wrasses (Labridae). These popular fishes offer a range of potential subjects for captive breeding efforts. Madden (1978) selected five species for pilot commercial culture in Hawaii based on reproductive parameters and adaptation to captivity. These were the long-nosed butterflyfish (*Forcipiger flavissimus*), the Hawaiian domino damselfish (*Dacyllus albisella*), the seargent major (*Abudefduf abdominalis*), Potter's angelfish (*Centropyge potteri*), and the lemon butterflyfish (*Chaetodon miliaris*). Other families of marine aquarium fish that have reportedly spawned in captivity may also be suitable for culture (Thresher, 1984). Among these, cardinalfishes (Apogonidae), anglerfishes (Antennariidae), lionfishes (Pteroidae), and basslets (Pseudochromoids) appear promising. Some progress has been made in the cultivation of the seahorses (Syngnathidae) although, the consistency of production remains a challenge. Certain species of reef fishes belonging to such families as the jawfishes (Opistognathidae), pufferfishes (Tetraodontidae), porcupinefishes (Diodontidae), gobies (Gobiidae), and combtooth blennies (Blenniidae) have not only been spawned in captivity but have been reared to adult size on one or more occasions. This diverse mix of species presents a range of suggested starting points to the aspiring culturist, including very popular and less common fishes exhibiting a wide variety of reproductive and developmental characteristics.

Damselfishes

Of the damselfishes, the seargent major (*Abudefduf abdominalis*), Hawaiian domino damselfish (*Dascyllus albisella*), and white-tailed damselfish (*D. aruanus*) have been the subjects of applied research in Hawaii, with promising results. Because of the relative straightforwardness of rearing some of the readily-available damselfishes in Hawaii and the Caribbean (*Amphiprion* spp.), expansion into more exotic and highly-valued damselfishes appears inevitable. Other brightly-colored Indo-Pacific damselfish species such as the blue-green chromis (*Chromis viridis*), blue damselfish (*Pomacentrus coelestis*), blue devil (*Chrysiptera cyanea*), and blue-streak devil (*Paraglyphidodon oxyodon*), all share the attractions of relatively large larvae and good commercial potential. A similarly appealing balance of hatchery and market considerations also applies to some of the more esoteric clownfishes, which include a variety of Pacific *Amphipiron* species that are not endemic to Hawaii.

To our knowledge, the seargent major or maomao (*Abudefduf abdominalis*), was the first of the Hawaiian reef fishes subjected to a concerted effort to close the life cycle (Helfrich, 1958; May, 1967). These studies examined, and to some extent demonstrated, the feasibility of cultivating a marine ornamental fish, although they did not specifically emphasize potential applications in the aquarium trade. Commercial collection and export of reef fish from Hawaii began in the 1960s, and the production of ornamental fish to supply this trade did not become a serious interest of the Hawaii aquaculture community until the 1970s (P. Helfrich, personal communication).

Past efforts to rear *Pomacentrus coelestis* and similar damselfish species have resulted in some success (Thresher, 1984). Because of the known breeding capacity and hardiness of captive damselfishes, this family appears suited for captive rearing in Hawaii. Their modest prices and apparent abundance from wild sources, however, raise concerns about the potential cost-effectiveness of hatchery production. This could, however, become cost effective if legislation restricting wild capture were implemented.

Butterflyfishes

The perennial popularity of butterflyfishes in the aquarium trade makes them obvious candidates for consideration for the development of captive rearing methods. Several species of butterflyfishes have been studied in Hawaii, including the long-nosed butterflyfish (*Forcipiger flavissimus*), lemon butterflyfish (*Chaetodon miliaris*), and masked butterflyfish (*C. lunula*). These studies include behavioral, population structure, and practical cultivation studies. Hormone-induced spawning techniques developed in Hawaii were used successfully on *F. flavissimus* (Madden and May, 1977), although larval rearing beyond the initiation of feeding proved problematic.

The fourspot butterflyfish (*C. quadrimaculatus*), domino butterflyfish (*C. unimaculatus*), and multiband butterflyfish (*C. multicinctus*) regularly rank among the ten most commonly collected aquarium fish in Hawaii (van Poollen and Obara, 1984). Because of its relative hardiness in captivity, the threadfin butterflyfish (*C. auriga*) also appears to be suited for consideration as a candidate for aquaculture in Hawaii (Emmens, 1990).

Angelfishes

Of the angelfishes, the Potter's angelfish (*Centropyge potteri*) has consistently been a focus of attention in Hawaii. Potter's angelfish, which is unique to Hawaii, appears to be an ideal model species from among this economically important family of fishes (Emmens, 1990). The pygmy angelfishes (*Centropyge* spp.) command good markets, and are relatively well-adapted to captivity and handling. The small size of pygmy angelfish makes them a favorite of hobbyists as well as a laboratory model for studying angelfishes. Other possible candidates for culture include the flame angelfish (*C. loriculus*), lemonpeel (*C. flavissimus*), blue-and-gold angelfish (*C. bicolor*), dusky angelfish (*C. bispinosus*), and Fisher's angelfish (*C. fisheri*). The Fisher's angelfish is endemic and particularly rare, and consequently commands a high price. Like the butterflyfishes, members of the angelfish family are strikingly colorful and much in demand on the global market.

Other families

Captive rearing efforts on the surgeonfishes (also known as tangs) and wrasses have been limited thus far (Thresher, 1984). At least two species of wrasses, the ornate wrasse (*Halichoeres ornatissimus*) and redtail wrasse (*Anampses chrysocephalus*) are commonly collected in Hawaii (van Poollen and Obara, 1984). Because of size and aggressiveness, large tanks may be necessary for some broodstock wrasses and surgeonfishes; consequently both egg production and larval rearing problems will require attention. Spawning may be practical when pairs or schools are isolated in large broodstock tanks or housed in spacious public display aquaria. The vast array of colors and intricate markings found among these fishes are a major incentive for a focused effort to resolve practical spawning and larval rearing methods for these two families. The yellow tang (*Zebrasoma flavescens*), clown tang or orangespine surgeonfish (*Naso literatus*), and Achilles tang (*Acanthurus achilles*) are all prime candidates for culture trials. These three fish rank among the five most commonly collected reef fish for the aquarium trade in Hawaii, with the yellow tang perennially in the number one position.

Focus

The proceedings of a conference on Pacific Island Mariculture held in Hawaii in early 1973 reported a methodical evaluation and ranking of numerous groups, families, or species for their mariculture potential, but made no mention of production of any ornamental species for the aquarium trade (Hawaii Institute of Marine Biology (HIMB), 1973). Interest in the cultivation of ornamental reef fishes in Hawaii appears to have been spurred by the initial commercial success (by Aqualife) in the Caribbean, during the same year (discussed above). From this point forward, marine aquarium species have been at least considered in prioritizing efforts, although most often dismissed as technically impractical.

Several attempts to initiate research and development in the commercial production of captive-bred ornamental reef fishes have been undertaken over the past twenty-five years in Hawaii. The results of many of these experimental culture trials, however, were preliminary by nature and often not reported. Because marine aquarium fish are approximately ten times greater in value per specimen when compared to freshwater aquarium fish, the incentive to develop marine culture techniques is obvious (Corbin and Young, 1995). The state of Hawaii has the potential to become not only a major producer of commercially-cultured marine aquarium organisms but to stimulate the growth and development of a new market in the aquarium fish industry as well. This paper reviews the general ecology and distribution of common Hawaiian reef fish families, the collection process, and past and present efforts to culture marine ornamental fishes in Hawaii. Future research efforts focusing on key problem areas that are inhibiting further progress are then recommended.

GENERAL ECOLOGY OF HAWAIIAN REEFS

The physical distribution of fishes and the characteristics of the environments in which they are found are important determinants of the suitability of specimens for the aquarium trade. In addition, knowledge of the natural habitat is a central concern in any captive rearing effort. Lighting, water chemistry, diet, turbulence, and other characteristics of the areas from which fish are taken must be taken into consideration by hobbyists and culturists.

Geography

The majority of reef fish collected for the aquarium trade in Hawaii are from the southeastern islands of the chain (the populated islands of the State of Hawaii). The older islands of the northwestern end of the island chain are remnants of extinct volcanic islands, most of which have already weathered away and sunken leaving crescent-shaped reefs called atolls (Chave *et al.*, 1976). Further to the southeast are the larger main islands of Kauai, Oahu, Molokai, Maui, Lanai, and Hawaii. These younger islands are only partially encircled by fringing reefs. The biggest and youngest island of Hawaii has relatively little coral reef cover and is predominated by lava.

Biogeography

The origin of the inshore fish species of Hawaii is presumably the Indo-West Pacific (Gosline, 1965). Planktonic larvae from the Indonesia-Malay Archipelago drift to Hawaii via currents such as the Kuroshio and North Pacific currents to the west and north of the Hawaiian Islands, respectively (Fielding and Robinson, 1987). Due to the isolated subtropical location of the Hawaiian Islands, the diversity of marine species in Hawaii is limited when compared to that of Indonesia and much of the South Pacific. Only 450 species of inshore fishes have been estimated to inhabit Hawaiian waters (Fielding and Robinson, 1987) as contrasted with places of higher reef biodiversity such as the Philippines. The number of individuals of each species, however, tends to be higher in Hawaii than in other tropical locales. Hawaii also has a large number of endemic reef fishes estimated to be approximately 20–30% of the total local fish species (Fielding and Robinson, 1987).

Vertical zonation of habitats

The coral reef habitat of eastern Hawaii is generally categorized into four vertical zones as described by Gosline and Brock (1960). Connell (1978) hypothesized that species diversity increases in areas where lower frequencies of disturbance are encountered. Wave action is the primary determining factor for both the boundaries and diversity of species of each zone. The habitats (in order of increasing depth) are the supra-surge zone, surge zone, reef-protected zone, and sub-surge zone. Each zone is a slightly different environment that accommodates several to many common marine aquarium fish. In the following discussion, the reef fish frequently encountered in the habitats described are typically not restricted to those zones but overlap in their range. Certain families of fishes are represented in all or most of the habitats described. In particular, species of gobies (Gobiidae), surgeonfishes (Acanthuridae), wrasses (Labridae), and damselfishes (Pomacentridae) are common in all four of the zones.

Supra-surge zone

The uppermost zone is the supra-surge or splash zone. This zone is located above the mean-tide level and is characterized by tide pool formations. The pools are generally found above the area of predominant wave activity. Because of the variable physical conditions of tide pools, the fish species found in this zone tend to be hardy and highly adaptive to daily environmental fluctuations. Several species of gobies and blennies (Blenniidae) reside in these tide pools (Gosline, 1965). Damselfishes of the genus *Abudefduf* are sometimes encountered in this zone as well. In addition to providing habitats for adult fish, the tide pools also serve as nurseries for the larvae of some reef fish species such as the surgeonfish *Acanthurus sandvicensis* and the damselfish *Abudefduf sordidus* (Gosline and Brock, 1960).

Surge zone

The next level is the surge zone located from less than a meter above and below the mean-tide level to four or more meters in depth. This habitat is characterized by constant wave surge activity. Exposed to powerful wave action from winter storms generated in the northern Pacific, the northern shores of the Hawaiian Islands are typically characterized by the rose or cauliflower coral (*Pocillopora meandrina*) and yellow-lobed coral (*Porites lobata*). Lobate coral is the more dominant species in this environment due to its sturdier structure and lower profile. Other corals common in this zone are species of the genera *Montipora*, *Pavona*, and *Leptastrea* (AECOS Inc., 1982). Many more numerous species of damselfishes, gobies, and blennies live in this habitat as compared to the supra-surge zone (Gosline, 1965). Also abundant in the surge zone are surgeonfishes of the genus *Acanthurus* and a variety of wrasses and moray eels (Muraenidae).

Reef-protected zone

The typical range of the reef-protected zone is less than a meter from the surface to a depth of about ten meters (AECOS Inc., 1982). Physically, this zone is characterized by minimal wave disturbance and optimal light penetration. These traits are vital to the symbiotic zooxanthellae found in the tissues of many reef-building stony corals. The quantity of light rapidly diminishes at further depths, thereby altering the species composition of corals as well as the reef organisms dependent upon them for survival. Little disturbance is encountered in both the reef zone and the deeper sub-surge zone. Consequently, the diversity of life in these two closely related zones is typically higher than in the shallower, more turbulent zones.

This zone is characterized by a variety of substrates including sand, rubble, algae, corals, and coralline algae (Reed, 1978). Coralline species such as *Hydrolithon reinboldii* and *Sporolithon erythraeum* are commonly found in the reef-protected zone. The calcium carbonate secretions of these algal species contribute a significant proportion of reef-building material to the community.

A variety of coral species grow within the reef-protected zone as well. Commonly found on the southern shores of the Hawaiian Islands is the fragile finger-coral, *Porites compressa* (AECOS Inc.,1982; Chave *et al*., 1976). This branching coral is often the dominant species due to its relatively high profile, large surface area, and shading effect on its shorter, less effective competitors. Shelter for many species of reef fish is provided by these irregularities in the reef formations. Other corals commonly found in this zone are bracket coral (*Montipora verrucosa*), lace coral (*Pocillopora damicornis*), *Pocillopora meandrina, Porites pukoensis*, *Porites lobata* and *Montipora patula* (Reed, 1978). These coral and coralline algal species provide the foundation of the reef ecosystem.

Many species of reef fishes inhabit the reef-protected zone (Gosline, 1965), and consequently these areas are consistently subjected to collection pressure. The same species of gobies, blennies, damselfishes, surgeonfishes, and wrasses found in the surge zone are also typically encountered within the quiet waters of the reef-protected zone. The butterflyfishes (Chaetodontidae) of the genus *Chaetodon* are common members of the coral reef community as are the cardinalfishes (Apogonidae) of the genus *Apogon*. Parrotfishes (Scaridae) are found in abundance feeding upon the coral polyps of the reef. An assortment of eel families also inhabits the reef-protected zone. Many species of moray eels, particularly of the genus *Gymnothorax*, are common predators of the reef. A wide array of snake eels (Ophichthidae) and a few species of conger eels (Congridae) can also be found on the reef. These protected waters serve as an ideal environment to a few species of pipefishes (Syngnathidae) such as *Doryrhamphus melanopleura* and *Syngnathus balli*. The moorish idol, *Zanclus cornutus*, is a popular aquarium fish most commonly found within the reef-protected zone.

Sub-surge zone

The sub-surge zone is characteristically similar to the reef-protected zone with the exception of attenuated light intensity. The seaward reef slope is an example of a sub-surge zone habitat. The boundaries of this zone are vague but can be described as the depth where wave surge becomes negligible to a depth in excess of 200 m.

The coralline alga *Porolithon gardineri* is the dominant calcareous algae of the seaward slope of the ridge (Reed, 1978). Other calcareous algae include *Porolithon onkodes* and the green alga *Halimeda discoidea*.

With the exception of *Pocillopora damicornis*, most of the corals found in the reef-protected zone are also found at these greater depths (Gosline, 1965). Other species of coral found in this zone are *Leptastrea purpurea*, *Pocillopora meandrina*, *Montipora verrucosa*, and *Anthelia edmondsoni* (Reed, 1978). Another conspicuous member of the sub-surge zone is the giant finger coral (*Pocillopora eydouxi*).

In this environment, blennies are relatively scarce. However, species of wrasses, gobies, butterflyfishes, cardinalfishes, moray eels, triggerfishes (Balistidae), and squirrelfishes (Holocentridae) are more abundant. Surgeonfishes are commonly found in this zone including the popular yellow tang (*Zebrasoma flavescens*), the orangespine surgeonfish (*Naso lituratus*), *Ctenochaetus strigosus*, and *Acanthurus nigrofuscus*. Damselfishes, particularly of the genus *Chromis*, are found in this environment as are the angelfishes (Pomacanthidae). The popular pygmy angelfishes such as the flame angelfish (*Centropyge loriculus*), Potter's angelfish (*C. potteri*), and Fisher's angelfish (*C. fisheri*) also inhabit these depths.

COLLECTION OF MARINE ORNAMENTAL FISH IN HAWAII

Collection regulations

Permits to collect aquarium fishes in Hawaii are administered by the Division of Aquatic Resources in the Department of Land and Natural Resources (DLNR). According to statutes outlined by the DLNR, 'an Aquarium Fish Permit may be issued to persons who possess facilities to maintain fish alive and in reasonable health, for the use of fine mesh traps or nets, other than thrownets, for the taking of certain aquatic life (DLNR, 1985).' Any type of freshwater or marine organism to be used for commercial sale, public display, or as a pet can be collected with the use of this permit. There is a modest fee involved in obtaining this permit, and certain restrictions and reporting requirements are involved. The destruction of live corals or the use of explosives, electro-fishing devices, chemical poisons, or intoxicants in the capture of aquarium organisms is prohibited. Poisons such as arsenic derivatives and Clorox® are still used by collectors in developing countries such as the Philippines (Daigle, 1978). Although, the appalling consequences of such destructive collection methods are widely known, blatant violations are occasionally reported in Hawaii. Generally, however, it is felt that these practices are becoming less common due to the high mortality rate of captured specimens and to increasing environmental awareness among collectors and aquarists alike.

Though the collection of live rock and coral is prohibited in Hawaii, virtually no restrictions apply to the collection of other aquarium organisms. The collection of reef organisms from sites designated as marine reserves such as Hanauma Bay on Oahu is also prohibited. The number and size of marine ornamental fish collected, however, is not regulated by the state. Commercial collectors must report on a monthly basis to the DLNR the number of all aquarium fish designated for export, by species, although the degree to which this can be enforced is questionable. These data can provide a general indication of the collection intensity of aquarium fish species in the state.

Collection methods

An adaptation of the method of collection described by Daigle (1978) is widely used in Hawaii. Collectors commonly use small boats such as the Boston Whaler, ranging within the vicinity (10–15 miles) of the port to allow reasonably efficient and rapid transport back to the holding facility. Divers using SCUBA gear typically collect organisms at depths of 20–50 feet near the shore. Collectors may dive to depths in excess of 150 feet, however, to collect rarer species such as the Tinker's butterflyfish (*Chaetodon tinkeri*). Local collection sites are rotated approximately every month to allow natural stocks to replenish themselves.

Collectors usually work individually, each carrying their own collection equipment, most often at depths of 60 feet or less. Each collector has a barrier or fence net about 3 feet high and up to 50 feet in length (approximately 30–35 feet of working length underwater). The nets are equipped with fine-meshed monofilament with floats attached to the top margin of the net and lead weights along the bottom. The barrier net is set in a semi-circular fashion on the seaward or deeper slope of the area where fishes intended for capture are found. Using a fine-mesh hand net, the diver then slowly herds the fish toward the barrier net. Before reaching the barrier net, the collector selects one particular fish, one healthy in appearance and of a desirable size for its species. Juvenile fish are generally not targeted because they are often considered too susceptible to the stress of handling. Among many desirable species, fully mature fish are usually left behind, in part because younger fish are more readily marketable. This practice also contributes to the maintenance of reef populations. With the hand net, the selected fish is eventually trapped and gently placed into a holding bucket. The process is repeated until four to eight fish have been captured per bucket. Full buckets are attached to a decompression line and brought to the surface at a rate of approximately 10 feet every 30–40 minutes. Sufficient time is necessary for most fish to decompress and acclimate to decreasing hydrostatic pressures associated with ascent. If brought to the surface too quickly, the gases within the swimbladder of many teleost fishes expand and cause moderate to severe stress or physical injury to the fish. Once in the boat, the fish are transferred either to aerated buckets where the water is changed periodically or to a large holding tank similar to those used for live baitfish.

At the collector's facility, the fish are graded according to size and compatibility with one another and placed into holding tanks averaging 100 U.S. gallons in volume. The fish are kept in quarantine for observation for a period of approximately 2–5 days, often in mixed-species groupings. After acclimation, the fish are then prepared for export.

More than half of the captured fish are shipped via air transport. Most fish are packed individually in double polyethylene bags. The water in each bag is carefully modified to match the conditions of the tank water. After the air in the bag is replaced with pure oxygen, the bag is sealed and placed in an insulated container; typically styrofoam-lined cardboard boxes are used for shipping. The containers carrying fish are sealed then shipped to their distributors. To avoid jeopardizing the health of the fish, a maximum of 40 h travel time is allowed for shipments. As a general rule of thumb, shipping periods of less than 24 h are considered reasonable in terms of survival rates. Collection methods in Hawaii are considered to be among the most environmentally sound in common usage. Packing densities are often reduced for shipments requiring longer transit times, in order to minimize the risk of mortality (Cole *et al*., 1999).

THE MARINE AQUARIUM MARKET IN HAWAII

The saltwater aquarium fish consumer market in Hawaii is presently being supplied through the collection of wild specimens. Approximately half of the marine aquarium fish in Hawaii are collected locally and the other half are imported from other sources in the Pacific (Miyasaka, 1991). The five most commonly collected ornamental reef fish species in Hawaii during the period from 1974 to 1982 are the yellow tang (*Zebrasoma flavescens*), long-nosed butterflyfish (*Forcipiger* spp.), Potter's angelfish (*Centropyge potteri*), clown tang (*Naso literatus*), and Achilles tang (*Acanthurus achilles*). Among the five species recorded, *Z. flavescens* was the most intensely exploited fish in Hawaii (van Poolen and Obara, 1984). In 1989, the majority of the marine ornamental fish from the Hawaiian market were exported to the mainland United States (82%) while the remainder were exported to Asia (8%), Europe (6%), and other foreign markets (Miyasaka, 1991). To our knowledge, no endemic marine aquarium fish species are commercially cultured in Hawaii, although at least two commercial ventures have begun the breeding of clownfishes, dottybacks, and other marketable species. The successful cultivation of live corals at the Waikiki Aquarium and a trend favoring the legalization of live rock culture for export have also stimulated interest in marine ornamental invertebrate culture.

HISTORY OF CULTURE EFFORTS IN HAWAII

The majority of the research on marine ornamental fish culture in Hawaii remains unpublished, or documented only in reports, proceedings, and theses. Corbin (1977) analyzed energy budgets in the whitespot goatfish, *Parupeneus porphyreus*, concluding that the nitrogen requirements for this species were comparatively higher than those documented for several temperate species. In addition, lipids were found to be the main energy source metabolized during the settlement of pelagic *P. porphyreus* larvae into juveniles.

Corbin's research for his thesis (published in 1977) was cited in the first aquaculture planning study written by the Hawaii State Department of Planning and Economic Development (DPED) in 1976. In the report, the progress and potential of various aquaculture programs in Hawaii, including the culture of marine and freshwater aquarium fish was summarized. In a subsequent DPED report (1977), the economic feasibility of culturing a potential aquaculture candidate species (both edible and ornamental) on a commercial scale was evaluated using a list of nine criteria:

1. The species can be successfully bred in captivity in Hawaii.
2. The climatic and environmental characteristics of Hawaii are suitable for normal growth and development of the species.
3. The availability and quality of both labor and facilities in Hawaii are adequate for developing culturing methods.
4. The diet of the species from larval to adult stages is known and is easily obtainable (from a cultured stock, natural stock, or commercial distributor) at a reasonable cost.
5. The species can be raised under economically feasible conditions allowing for large-scale commercial production.
6. The technical procedures used to rear the species are established or have been attempted with a sufficient degree of success.
7. Any remaining problems are well defined and amenable to solutions.
8. The absence of any legal constraints to culturing or selling the species.
9. The species has an established market to which export is not economically prohibitive.

Based upon the criteria listed above, marine ornamental reef fish were eliminated from the final list of recommended species for aquaculture in Hawaii by the DPED.

The first large-scale investigation of reef fish culture took place at the Oceanic Institute on Oahu in 1974. Spawning and larval rearing experiments of approximately 35 species of reef fish were attempted, with limited success. Among six species designated as first priority for research, two of them, the long-nosed butterflyfish (*Forcipiger flavissimus*) and lemon butterflyfish *(Chaetodon miliaris*), clearly qualify as marine ornamentals. The culture of the damselfish, *Abudefduf abdominalis*, or seargent major, was also studied at OI but was classified as a potential bioassay organism. Among another six species ranked as second priority, three were marine ornamental fish: the yellow tang (*Zebrasoma flavescens*), Potter's angelfish (*Centropyge potteri*), and the masked butterflyfish (*Chaetodon lunula*). Because these trials were exploratory and somewhat preliminary in nature, their results were not published. Some spawning and larval survival was reported, but none of these life cycles were closed in the course of these early trials.

Madden and May (1977) then made a joint effort to continue the culture of ornamental reef fish at both the Oceanic Institute and the Hawaii Institute of Marine Biology, respectively. Four of the five species selected for experimental culture trials had been previously used as the subjects of spawning/rearing trials: *C. potteri*, *C. miliaris*, *A. abdominalis*, and *F. flavissimus*. The domino damselfish, *Dascyllus albisella,* was the fifth experimental species. This exploratory investigation was intended to stimulate further research and development in Hawaii and to establish a more sound scientific background in the culture of marine ornamental fishes. The authors concluded that because these experiments on *C. potteri* and *C. miliaris* were conducted outside of the natural season of sexual maturation of each, even those attempts to induce spawning with hormonal treatments were unsuccessful. Nevertheless, because of its hardiness in captivity, *C. miliaris* was recommended as a model fish for the culture of other species in the family Chaetodontidae. Similarly, further research on *C. potteri* was recommended due to its popularity in the aquarium fish industry as well as the documented occurrence of a natural spawning by a pair of captive fish (Lobel, 1975). Future spawning trials of *C. miliaris* and *C. potteri* could be carried out during the natural spawning season (December to March) or possibly conducted out-of-season by manipulating environmental reproductive cues.

Two demersal spawners were tested during this study – the damselfishes *D. albisella* and *A. abdominalis*. The inherent advantages to culturing demersal spawners (ie. producing benthic eggs) over broadcast spawners (ie. producing pelagic eggs) immediately became evident. Because these fish lay their eggs directly on to a substrate such as a rock or coral fragment, the egg masses are more visible and easily handled as compared to those from broadcast spawners. Furthermore, demersal eggs tend to be larger than pelagic eggs and the hatching larvae are usually more physically developed than those from pelagic eggs. Regardless of whether the eggs are demersal or pelagic, the larval stages of virtually all reef fishes are pelagic. The seahorses and pipefishes, which incubate their young in a pouch, and the banggai cardinalfish, *Pterapogon kauderni*, which is a mouthbrooder, are notable exceptions but neither was studied by Madden and May (1977).

Efforts to promote natural or hormone-induced spawning of *D. albisella* or natural spawning of *A. abdominalis* in captivity were unsuccessful, and disease outbreaks occurred among the broodstock fish (Madden and May, 1977). Some rearing trials were carried out using *A. abdominalis* hatched from wild eggs collected in Kaneohe Bay, Oahu. Two of three rearing trials produced small but encouraging numbers of settled juveniles; in the best of these trials, forty-seven specimens survived the larval to juvenile metamorphosis (Madden and May, 1977).

Though the larval rearing trials of the butterflyfish *F. flavissimus* were unsuccessful, at least in terms of the production of viable juveniles, artificial spawning via hormone injection (Human Chorionic Gonadotropin or HCG) was successful (Madden and May, 1977). None of the larvae produced this way survived past the sixth day of development – a time typically associated with a failure to initiate larval feeding. Fertility in the three clutches produced using this method appeared to depend upon the timing of the injections relative to ovarian development. Presumably, continued work with the culture of this species would lend itself well to the application of ovarian cannulation and staging of eggs in order to determine the best time for hormonal induction of final maturation.

Fertilized egg masses of the triggerfish, *Balistes fuscus*, were incidentally collected by Madden from the sand at the bottom of the reef tank at Sea Life Park, Hawaii (Madden and May, 1977). Larvae hatched approximately 36 h after the initial deposition of the eggs. Similar to the larvae of *F. flavissimus*, however, all larvae had died by the sixth day of incubation, again probably indicating a failure of larvae to feed. Although triggerfishes produce benthic clutches, their eggs and larvae are typically closer in size to those of pelagic-spawning reef fishes (well below 1 mm egg diameter).

Additional work on egg and early larval development of *C. potteri* was carried out at the Waikiki Aquarium by Bourke and Kraul in 1979 (R. Bourke, personal communication). Spawning was promoted by HCG injection, and eggs were fertilized either naturally or by mixing eggs with milt *in vitro*. About 10% of eggs hatched, but efforts to rear the larvae beyond the age of 8 days failed. The need for larval feeds capable of meeting the nutritional requirements of smaller larvae, in the food particle range of approximately 50 microns in diameter or smaller, remains an obstacle to the culture of many desirable species.

Danilowicz and Brown (1992) turned their attention to the rearing of two damselfish species that are popular in the aquarium trade, *D. albisella* and *D. aruanus*. Wild *D. albisella* egg clutches were collected in Kaneohe Bay, Oahu and fertilized eggs of *D. aruanus* were obtained from captive broodstock at the Hawaii Institute of Marine Biology. Hatching rates ranged from 80% to 100%. Larvae were reared in a greenwater system with wild zooplankton and rotifers added, followed by the regular addition of *Artemia* nauplii to the rearing tanks around the seventeenth day. Danilowicz and Brown (1992) reported that larvae began to metamorphose and settle as juveniles between 23 and 35 days after hatching. The most successful of the four trials produced 103 individual *D. albisella*, all of which attained a marketable size within about 70 days after hatching. The larval survival rate for that particular trial was 41.2%.

RECOMMENDATIONS FOR ORNAMENTAL AQUACULTURE DEVELOPMENT IN HAWAII

Focus of research in Hawaii

To help encourage an ornamental aquaculture industry in Hawaii, Davidson and Corbin (1992) suggested that research efforts should concentrate on four areas of production: (1) ornamental fish farming technology including feeds, animal health, etc.; (2) the engineering and operation of ornamental aquaculture systems; (3) ornamental aquatic plant production; (4) technology transfer and industry development. These efforts should focus on both fresh and salt water components of the industry. Such universal problems as larval food production, tank design, and water quality control are commonly associated with the culture of all marine fish. Because raising marine ornamental fishes is fundamentally similar to rearing marine food and sport fishes, researchers from these and other related disciplines would mutually benefit with a more open exchange of information and techniques. Thus, a cooperative effort among research institutions, aquarium hobbyists, and public aquarium biologists would more rapidly resolve many of the basic problems associated with finfish aquaculture. Once these constraints have been solved, the progress of ornamental reef fish aquaculture in Hawaii and elsewhere will undoubtedly accelerate.

Many of the larval rearing attempts in the past have failed due to a lack of consistency in the supply of acceptable and nutritionally complete foods. The larvae of many ornamental reef fish are small in size, particularly those of pelagic-spawning species. Thus, conventional food types such as *Artemia* nauplii either grow too quickly in size to be consumed by the larvae or are too large initially. These foods often require the addition of nutrients, such as supplemental fatty acids. Studies focusing on the larval ecology of marine reef fishes may provide key insights into the dynamics of the planktonic food web. From these studies, a dependable culture of suitable food organisms such as species of unicellular algae, rotifers, and copepods may then be developed. With the production of nutritious and sustainable larval food supplies, further advances in the commercial production of ornamental reef fish will become more probable.

The maintenance of water quality during the critical stages of larval development has been another major constraint. Opinions vary as to the suitability of natural versus artificial seawater, and the capabilities of recirculating as compared with flow-through culture systems. The metabolic activity of larvae and food organisms coupled with fouling caused by the decay of uneaten food can result in critically high levels of metabolites. Due to the sensitivity of the larvae, more effective methods of maintaining water quality will facilitate larval survivability and ultimately increase the yield of marketable fish.

In addition to common larval rearing methods, both natural and artificial means of spawning should be studied further. A more thorough understanding of the natural spawning cycles and their environmental cues, of the various families of ornamental reef fishes, might provide insight and better control of the natural spawning behavior of captive fishes. Manipulation of such environmental conditions as photoperiod and seawater temperature may induce repeatable spawns in fish without the use of potentially costly chemical stimuli. On the other hand, the refinement of artificial spawning techniques would provide even greater control over the production cycle of captive-bred reef fish.

As the industry develops and expands, more sophisticated methods of managing and improving genetic stocks could become available, as has been the case in freshwater fish (Davidson and Corbin, 1992). In the longer term, genetic marker-assisted selection and possibly genetic engineering efforts may be used for enhancing disease resistance, appearance, and other desirable characteristics of the ornamental species of interest.

CONCLUSIONS

The mild climate and good water quality of Hawaii provide ideal conditions for establishing an ornamental aquaculture industry (Davidson and Corbin, 1992). Year-round culture of tropical ornamentals can be accomplished in Hawaii without the threat of winter frost that occasionally occurs in Florida. The availability of broodstock, shipping and distribution considerations, and interest in both the business and technology of marine ornamentals favor the development of marine ornamental fish aquaculture.

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