CHAPTER 6

Marine Aquarium Fish

Richard L. Pyle

I. INTRODUCTION

Over the past two decades there has been a tremendous increase in the popularity of marine fishes for aquaria, due in part to a greater understanding of their captive requirements. In the freshwater aquarium fish industry, many species are regularly bred in captivity, and a significant number of fishes in trade are supplied by such captive breeding efforts. Attempts at commercial-scale captive reproduction of marine fish species have met with only limited success. A few types of fishes which lay demersal eggs, such as anemonefishes (*Amphiprion*), have been successfully reared in fairly large numbers, and the technology and methodology have improved substantially in recent years. Several authors (Madden, 1978; Wood, 1985; Whitehead *et al.*, 1986; Perino, 1990; Iversen, 1991; Moe, 1992) suggest that the potential for captive-bred fishes to supplement wild-caught animals does exist, and they emphasise a need for continued research efforts in this field. However, captive breeding efforts on a commercial scale are presently very limited, and collecting fishes from coral reefs will undoubtedly remain the most economical method of procuring the majority of marine aquarium fish species for many years to come.

Relatively few studies have investigated the volume and scope of the industry on a world-wide basis. Axelrod (1971) and Conroy (1975) reviewed the industry, particularly with respect to the collection and exportation of tropical freshwater species. The total retail value of ornamental fishes (both freshwater and marine), including all equipment and accessories relating to the care of fishes, was estimated at about US$4 billion. Another study (Anon., 1979) estimated the retail value of the ornamental fish in the United States for 1972 at about US$250 million. Conroy (1975, p. 5), stated that "saltwater fish only formed approximately 1 per cent of the total ornamental fish imports into the U.S.A. during 1972 and 1973", but he went on to point out that the likelihood for the expansion of the industry in subsequent years was "extremely promising". Indeed, the marine aquarium trade has increased dramatically in the past two decades. Wood (1985) reported that the total annual c.i.f (cost, insurance, freight) value of marine aquarium animals was around US$25-40 million, which constitutes an estimated 13 per cent of the total trade. McLarney

(1985) estimated that in 1985, US$100 million was spent on the purchase of tropical reef fishes.

The major suppliers of wild-caught marine aquarium fishes are the Philippines (Albaladejo and Corpuz, 1981, 1984; Albaladejo *et al.*, 1984), Hawaii Taylor, 1974; Katekaru, 1978; van Poollen and Obara, 1984; Anon., 1988), Caribbean Sea (including Florida), Indonesia (Kvalvagnaes, 1980), Mexico, Red Sea, Sri Lanka (Senanayake, 1980; Wood, 1985), Mauritius, Kenya (Samoilys, 1988a), Maldives, Seychelles, Taiwan, and the Pacific region (Randall, 1987; Lewis, 1988). According to Whitehead *et al.* (1986), fishes collected in the Philippines, Hawaii, and the Caribbean may account for as much as 96 per cent of the international trade. However, this appears to be an overestimation. The major importers of marine aquarium fishes are Europe, Japan, and the United States.

Vast expanses of coral reefs surrounding Pacific islands harbor large numbers of reef fishes. Marine aquarium fishes are presently, or have at one time been, collected and exported from Australia, Palau, Cook Islands, Federated States of Micronesia, Fiji, Guam, Hawaii, Kiribati, Marshall Islands, Philippines, Tonga, Western Samoa and Vanuatu. Exporting companies have also previously operated in Western Samoa and Vanuatu, but at the time of writing, companies at these localities are no longer in operation.

With the exception of Hawaii, Guam, and the Philippines, all Pacific exporters operate within member countries of the Forum Fisheries Agency (FFA). Due to the paucity of published information, it is difficult to make estimates of the total number and value of fishes exported from FFA member countries. However, preliminary data indicate that around 200,000-250,000 fish with an approximate export value of US$1-$1.5 million are exported annually from FFA member countries other than Australia.

A report on the volume and scope of the industry in Australia is presently being compiled by the Department of Primary Industries (Samoilys, *pers. comm.*). Whitehead *et al.* (1986) estimate that between 150,000 and 300,000 fish with an approximate value of between US$0.5-1 million are annually collected from Cairns, Australia. Data from 1990 collections indicate that 117,600 fishes were collected from this area (R. Pearson, *pers. comm.*). If these estimates are correct, then the Pacific region (excluding Hawaii, Guam, and the Philippines) accounts for 4-10 per cent of the world trade in marine aquarium fishes. Within the member countries of the FFA, reviews of the marine aquarium fish industry have been conducted in Australia (McKay, 1977; Whitehead *et al.*, 1986; Samoilys and Green, in prep.), Fiji (Lewis, 1988), and Papua New Guinea (Perino, 1990). The last author discussed the feasibility of the industry in Papua New Guinea where no such industry presently exists. In Australia, future studies are planned for the Great Barrier Reef (as noted in Samoilys and Green, *in prep.*).

II. BIOLOGY

Fish species forming the bulk of the trade are generally those with the combined characteristics of small size, bright or gaudy colouration, non-restrictive diets, and overall adaptability to captive environments. Juveniles of larger species and species with particularly unusual behavior or characteristics (*e.g.*, frogfishes [Antennariidae] and moray eels [Muraenidae]) are also in demand. Species which are drab or cryptically coloured, pelagic, or have very specialised diets are generally avoided by collectors.

There are too many Pacific fish species of potential economic value to the marine aquarium industry to be listed here. In most cases, fishes can be discussed at the family level, because species within a given family usually share similar characteristics. The most important fish families in the marine aquarium trade are Pomacanthidae (angelfishes), Chaetodontidae (butterflyfishes), Acanthuridae (surgeonfishes and tangs), Labridae (wrasses), Serranidae (groupers and basslets), Pomacentridae (damselfishes and anemonefishes), Balistidae (triggerfishes), Cirrhitidae (hawkfishes), Blenniidae (blennies), and Gobiidae (gobies). Some biological and ecological characteristics of these fish families are summarised in Table I. Myers (1989) and Randall *et al.* (1990) provide excellent guides to the reef fish species of the central and western Pacific Ocean and include a great deal of pertinent biological information. Perino (1990) presents a relatively comprehensive list of Western Pacific marine aquarium fish species, including export prices from various localities.

Due to the vast diversity of fish species collected for the aquarium trade, it is difficult to make generalizations about the biology and ecology of these fishes as a whole. However, because most of these species inhabit coral reefs, it is appropriate to discuss the attributes of reef fish ecology and reef fish community structure.

SPAWNING

Reef fishes exhibit a wide variety of reproductive strategies. Some fishes, such as many butterflyfishes (Chaetodontidae), form monogamous mated pairs. Others, such as the pygmy angelfishes (Pomacanthidae, genus *Centropyge*), form polygamous harems consisting of a single male and several females. Still others, such as surgeonfishes and tangs (Acanthuridae), spawn in mass aggregations.

Daily, monthly, and annual periodicity in peak spawning times has been demonstrated for many species of reef fishes (Thresher, 1984). Spawning tends to occur at dusk or dawn, during full or new moon, and with some amount of seasonal variation. Specific times and strategies vary between different species, and sometimes between populations of the same species in different

Table I. Ecological characteristics of fish families most often collected for aquarium purposes.

Family	Feeding strategy	Reproductive Strategy[a]	Habitat
Pomacanthidae (Angelfishes)	Herbivore/ Omnivore	Harem-forming/pair-forming; some species protogynous; spawn at dusk; pelagic eggs	Shallow to deep reef; rubble/coral
Chaetodontidae (Butterflyfishes)	Omnivore/ Planktivore/ Corallivore	Pair-forming/ school-forming; pelagic eggs	Shallow to deep reef; coral and ledges
Acanthuridae (Surgeonfishes and Tangs)	Herbivore	School-forming; spawn at dusk in large groups; pelagic eggs	All habitats (depending on species
Labridae (Wrasses)	Omnivore	Harem-forming/ school forming; protogynous; spawn at all times of day[b]; pelagic eggs	All habitats (depending on species
Serranidae (Groupers and Basslets)	Carnivore/ Herbivore/ Planktivore	Harem-forming/ Pair forming/ Aggregate forming; protogynous; spawn at dusk; pelagic eggs	All habitats[b]; Anthiinae form aggregations above the substrate

Family	Feeding strategy	Reproductive Strategy[a]	Habitat
Pomacentridae (Damselfishes)	Herbivore/ Planktivore/ Omnivore	Harem-forming/ Aggregate-forming; spawn in morning; demersal eggs	Shallow reef coral/rubble; *Amphiprion* inhabit sea anemones
Balistidae and Monacanthidae (Triggerfishes and filefishes)	Omnivore	Harem-forming/ Aggregate-forming; demersal sometimes pelagic eggs; some species build nests	All habitats (depending on species); refuge in holes on reef
Cirrhitidae (Hawkfishes)	Carnivore	Harem-forming; spawn at dusk; pelagic or demersal eggs	Shallow reef often in association with coral
Blenniidae and Gobiidae (Blennies and Gobies)	Omnivore	Wide variety of reproductive strategies, depending on species	All habitats (depending on species)

a From Thresher (1984)

b Depending on species

localities. Actual spawning usually occurs very rapidly, and fertilization virtually always takes place externally.

EGGS AND LARVAE

There are two basic strategies employed by reef fishes with respect to eggs: parental care, and no parental care. Reef fishes which devote parental care to their eggs are usually either demersal egg-layers (such as the damselfishes [Pomacentridae] and gobies [Gobiidae]), or mouth brooders (such as cardinalfishes [Apogonidae]). By providing parental care for the eggs, these fishes are able to enhance the offspring survival rate; however, extra time and energy are expended and clutch sizes are smaller.

Most species of coral reef fishes, on the other hand, forego any parental care and spawn pelagic eggs. Gametes are released in the water column, and the fertilised eggs drift as plankton for some period of time before hatching. Although the eggs are more vulnerable to predation, greater numbers of them are spawned and no energy is expended by the parent in caring for the clutch. Barlow (1981) reviewed parental care and dispersal among coral reef fishes and pointed out that smaller species (*i.e.*, less than 100 mm standard length) tend to invest more parental care than do larger species.

Regardless of the extent of parental care given to eggs, almost all reef fish species of interest to the aquarium trade spend their larval stage adrift in the plankton. This planktonic larval stage allows the species to disperse. Although some studies have suggested that spawning times and places seem to coincide with pelagic gyres which increase the likelihood of larvae returning to the site of spawning (*e.g.*, Johannes, 1978a), most larvae probably settle out at a considerable distance from the site of spawning (Ehrlich, 1975; Barlow, 1981; Doherty *et al.*, 1985).

Unfortunately, only a few studies on the dynamics of pelagic larvae and their dispersal patterns have been conducted, so very little specific information is known. Leis and Miller (1976) noted that larvae of species with demersal eggs are most abundant in nearshore waters, while larvae of species with pelagic eggs tend to be more abundant offshore. Doherty *et al.* (1985) argue that the adaptive significance of larval dispersal is related to "patchy and unpredictable survival in the pelagic habitat", citing computer simulations to support their assertions. Fishes may remain in the planktonic larval stage for periods up to several months. Evidence also indicates that some fishes may prolong their larval stage if no suitable habitat is in the vicinity at the time of larval maturation.

RECRUITMENT TO CORAL REEFS

After spending sufficient time adrift in the currents and upon reaching a suitable habitat, fish larvae settle from the water column to the reef, and in a short period metamorphose into juveniles. The cues which govern the timing of this settlement period are not well understood; some studies suggest that visual cues are important, and others have found evidence for olfactory cues. Several studies on the Great Barrier Reef (Sale and Dybdahl, 1975; Russell *et al.*, 1977; Talbot *et al.*, 1978) showed that although most species may recruit to the reef at any time of year, there was a strong peak in recruitment during the summer months. Walsh (1987) found similar seasonality in the spawning and recruitment in Hawaii and Williams (1983) described recruitment variability on daily, monthly, and seasonal scales. Whether or not a particular individual fish succeeds in surviving after settling onto the reef may depend on a great number of factors, most of which are associated with reef fish community structure.

COMMUNITY STRUCTURE

There is continual debate in contemporary scientific literature concerning the dynamics of coral reef fish community structure. Different field and laboratory studies on different reef fish species and in different parts of the world have led to nearly equally diverse conclusions about the factors regulating community structure.

Order versus Chaos hypotheses: One of the cornerstones of the aforementioned scientific debate is whether or not reef fish communities reach some form of equilibrium in species diversity and composition. If coral reef fish assemblages do attain some form of equilibrium, then disturbances to the community (*e.g.*, the removal of certain fishes from the reef) should eventually be corrected when larvae of the removed species recruit to the vacancies left on the reef. Equilibrium in this sense may be thought of as an assemblage of certain species with certain biological requirements, such that the given assemblage composition maximises resource utilization of the given reef.

This equilibrium theory (or "order" theory) is an extrapolation of models used to explain terrestrial communities, and was first applied to reef fishes by Smith and Tyler (1972). The theory maintains that fish species have evolved to exploit highly specific niches, and that the observed high diversity of species on coral reefs is maintained by minimal niche overlap and reduced competition between species.

The disequilibrium (or "chaos" theory), on the other hand, holds that reef communities can and do fluctuate in composition, and that many species have broadly overlapping ecological requirements. Bohnsack (1983a, p. 223) summed up the differences: "...the order hypothesis emphasises stability, constancy, similarity, and deterministic factors in community structure, and the chaos hypothesis emphasises variability, differences, and chance factors."

The controversy has been reviewed several times (Smith, 1977; Helfman, 1978; Bohnsack, 1983a), and a number of "compromise" assertions have been proposed (*e.g.*, Smith, 1978). Greenfield and Johnson (1990) and Sale (1991) provide the most recent publications discussing the issue.

Numerous studies have been conducted on the Great Barrier Reef (Sale and Dybdahl, 1975; Russell *et al.*, 1977; Talbot *et al.*, 1978; Sale, 1980a; Anderson *et al.*, 1981; Doherty, 1983) probing the question of equilibrium. Most of these studies, along with others conducted elsewhere in the world (*e.g.*, Bohnsack, 1983b) demonstrated that when a community is disturbed (*e.g.*, if the reef is denuded of fishes), then recolonization takes place in an unpredictable way (*i.e.*, the fish population does not return to its original composition). These investigators generally concluded that there was little constancy of recruitment patterns from year to year. Furthermore, several of these studies revealed that species "turnover" takes place at relatively high rates (see also Bohnsack, 1983a; Williamson, 1978).

Natural population fluctuations in coral reef fish species have also been described by other authors. Wood (1985) outlined several examples of seasonal variation in the abundance of certain species of interest to the aquarium trade in Sri Lanka, which, according to Williams (1983) and Walsh (1987), are likely the result of varying recruitment patterns. Jonklaas (1985) reported on sudden large scale population increases of certain reef fish species (also in Sri Lanka).

Although this evidence favors the chaos theory, proponents of the order theory respond that the geographic scales of these studies were too small, and that equilibrium is more evident on a larger scale (*i.e.*, an entire island, rather than a single patch reef) (Gladfelter and Gladfelter, 1978; Anderson *et al.*, 1981; Alevizon *et al.*, 1985). Furthermore, Clarke (1988) presented evidence that habitat selection and species interactions are important determinants of community structure on small patch reefs, thus indicating some degree of order even on a small scale. Other studies (*e.g.*, Gladfelter and Gladfelter, 1978; Greenfield and Johnson, 1990) have provided strong evidence supporting habitat partitioning among species of coral reef fishes.

Although Sale (1977) argues that the planktonic larval stage fundamentally differentiates coral reef communities from terrestrial communities, Anderson *et al.* (1981) concluded that reef fish communities may indeed function in a way that is consistent with models of terrestrial community equilibrium, as long as the range of distribution for fishes is viewed on a geographic scale proportional to their range of larval dispersal.

Factors regulating recruitment: At the heart of the 'order versus chaos' controversy, and of great interest to fisheries biologists, is the question of what factors limit the recruitment of fishes to coral reefs. Few researchers disagree that almost all of the recruitment to coral reefs is through larval settlement, rather than adult immigration. Talbot *et al.* (1978) noted, "Almost all recruitment to the [study's] artificial reefs was by juvenile fishes newly settled from the plankton", and Doherty (1983) found that the reefs in his experiments "....were mostly repopulated by larval fishes (recruitment), rather than by already recruited fishes (immigration)." Reese (1973) presented evidence that several species of butterflyfishes (Chaetodontidae) and damselfishes (Pomacentridae) remained in relatively small territories and home ranges for extended periods of time. In general, most fish families of interest to the aquarium trade inhabit relatively small territories and do not emigrate to other reef areas (*pers. obs.*). Therefore, larval recruitment patterns are important to understand when considering the resiliency of a coral reef to repopulate after heavy collecting efforts.

According to the order theory, the likelihood of a given recruit surviving on a reef depends mostly on the existing species composition on that reef. Chaos theory, on the other hand, maintains that available resources (particularly refuge sites), are the greatest limiting factor of recruitment, and which particular species fills a vacancy depends largely on chance factors. Two studies (Doherty, 1983; Shulman, 1984) have found evidence that recruitment of fishes does not seem to depend on the abundance of resident conspecifics or heterospecifics, thus favouring the disequilibrium view. However, elements of both views undoubtedly play a significant role in reef fish community structure.

III. PACIFIC REGION FISHERIES INFORMATION

Within FFA member countries, there are at least eight aquarium fish export companies operating in Pacific islands (including Palau, Christmas Island, Fiji, Kwajalein, Majuro, Pohnpei, Rarotonga, and Tarawa), and a number of others in Australia (particularly in Queensland). Some companies have been actively exporting fishes for as little as one year and others for as many as eighteen years, with an average of about five years. An aquarium fish export company in Western Samoa has only recently closed down. At least one company has also operated in Vanuatu, but none presently exists at that locality.

In order to obtain current and comprehensive information on the present exports of aquarium fish from the Pacific (specifically FFA member countries), a survey form was drafted and sent to all known companies in the region. There are many aquarium fish collectors in Australia and survey forms were not sent to all of them. However, information regarding the aquarium fish industry in this area was obtained from two recent studies (Whitehead *et al.*, 1986; Samoilys and Green, *in prep.*). Additionally, information from other Pacific localities was obtained from Lewis (1988) and Perino (1990).

EMPLOYMENT ASPECTS

Although most export companies are foreign-owned, a majority of the personnel employed are local residents. For example, Lewis (1988) reports that

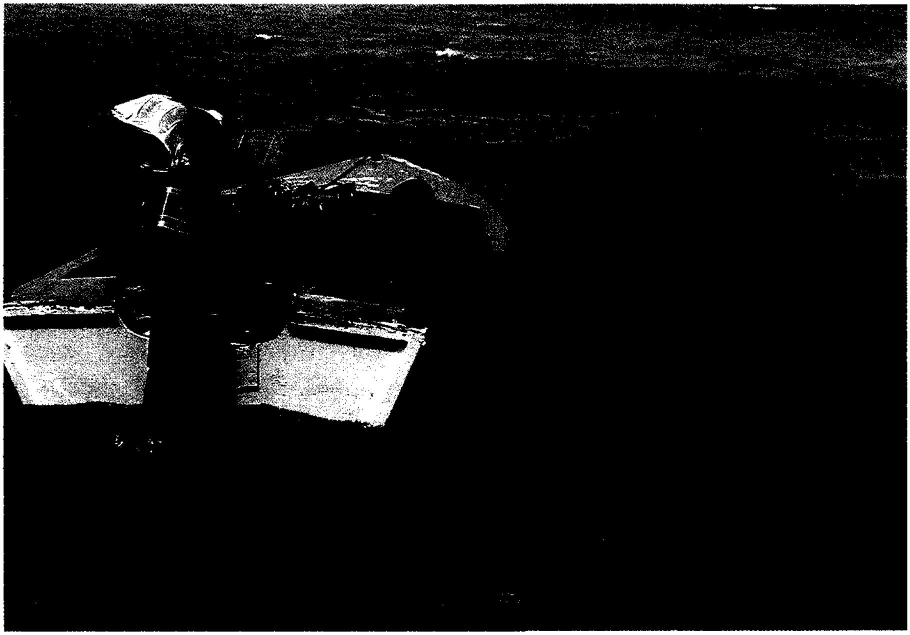

Figure 1. A typical boat used for the collection of aquarium fishes in the Pacific. Note the plastic barrels used to hold fishes and dive gear. Photo: Richard L. Pyle.

in 1987, over 90 per cent of the fishes exported from Fiji were collected by local divers. Survey data indicate that companies in the Pacific islands employ from 3-10 collectors who work 20-36 hours per week, 10-30 hours actually diving. They make from 7-18 dives per week, depending primarily on the type of equipment used (*e.g.*, collectors operating on surface-supplied air make fewer, but longer dives than do those using SCUBA). Most collectors are paid by the fish, rather than by salary. Fish prices are usually 20-50 per cent of the selling price, depending on the species. Collectors earn US$3,000-10,000 annually in the Pacific and as much as US$34,000 in Australia. Wages reflect local economies, and the collectors' annual earnings are usually on a par with, or above, the average salaries for the country.

In addition to collectors, other personnel may be employed to assist in warehouse maintenance or packing. Companies operating in the Pacific employ from 1-10 people for these non-collecting activities. In almost all cases, the owner of the company participates in both collecting and packing.

FISH COLLECTING TECHNIQUES

Aquarium fish collecting techniques are varied in style and methodology, and often reflect local habitat conditions and available materials. Two books (Straughan, 1973; Jonklaas, 1975) have been published which describe the collection and transport of live aquarium fishes in fairly extensive detail. These references offer a wealth of information regarding specific techniques to collect and care for a wide variety of fishes. Perhaps more important, both of these authors express a great deal of concern for the protection and preservation of coral reef ecosystems, and many of their discussions serve to emphasise the importance of non-destructive collecting techniques and proper reef management. Chave and Lobel (1974) and Daigle (1978) also discuss collection and transportation techniques in some detail, particularly those methods employed by collectors in Hawaii.

Although a few aquarium fishes are collected by snorkelers, the vast majority of fishes are collected by divers breathing compressed air at depth. The availability of SCUBA equipment and compressors at many Pacific islands has made SCUBA the main source of compressed air, but collectors in a few areas have employed the use of surface-supplied air or 'Hookah' systems. The most valuable species tend to be found in outer reef areas, so boats are usually required to transport divers to collecting sites (Fig. 1). Companies in the Pacific operate from 1-5 (usually only one or two) boats, with 3-5 divers on each boat. Boats are in use for 2-6 days of the week.

Collecting healthy fishes requires a tremendous amount of skill and experience. Many collectors have spent years honing their skills and developing new techniques for particular species of fishes. Although some fishes may

Table II. Commercial aspects of fish families most often collected for aquarium purposes in FFA member countries[a].

Family	Method of collection	Per cent of Export (No.)	Per cent of Export (US$)	Approx selling price (US$)[b]
Pomacanthidae (Angelfishes)	Hand net and Poker; Small Barrier net	24	46	5-25
Chaetodontidae (Butterflyfishes)	Hand net; occasionally Barrier Net	11	10	2-8
Acanthuridae (Surgeonfishes and Tangs)	Large Barrier Net and Hand Net	1	1	4-20
Labridae (Wrasses)	Barrier Nets and Hand Nets	7	12	3-15
Serranidae (Groupers and Basslets)	Hand Net, Barrier Nets; Hook and line	2	1.5	2-10

Family	Method of collection	Per cent of Export (No.)	Per cent of Export (US$)	Approx selling price (US$)[b]
Pomacentridae (Damselfishes)	Hand Net, occasionally Poker, Trap	29	13	0.70-2.50
Balistidae and Monacanthidae (Triggerfishes and filefishes	Hand Net	4	2.5	2-12
Cirrhitidae (Hawkfishes)	Hand Net, occasionally Small Barrier Net	2	3	3-7
Blenniidae and Gobiidae (Blennies and Gobies)	Hand Net	5	3	1-4
Other	Assorted	15	8	-

a Percentage figures are rough estimates extrapolated from available data.
b Price ranges do not include unusually high priced rare species.

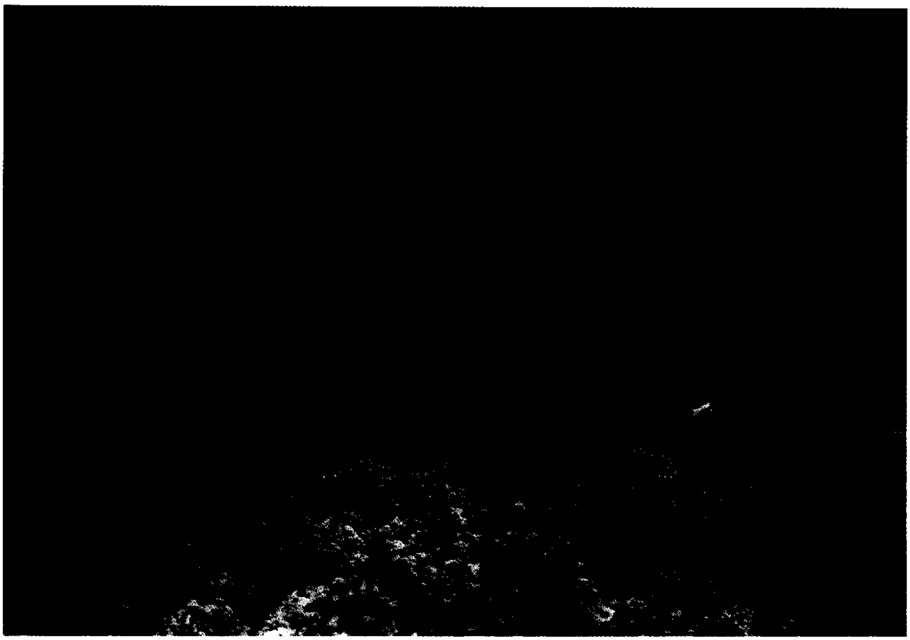

Figure 2. A barrier net set up on a coral reef. Photo: Richard L. Pyle.

be taken with traps or other collection methods, the vast majority of aquarium fishes exported from the Pacific region are collected with hand nets and barrier nets. Collection methods for particular families are listed in Table II.

Hand nets: Hand nets are, in general design, some sort of mesh material strung around a hoop, which is usually attached to a handle. Most hand nets used in the collection of medium-sized and larger fishes are constructed of 1/2-inch (13-mm) or 3/4-inch (19-mm) stretch-eye monofilament mesh; finer polyfilament meshes are used for smaller species and juveniles. Hand nets vary in size, shape, and dimensions, depending on the particular habitat, target fish species, or collector preference.

Some collectors prefer to use two nets, one in each hand, to corner fishes in crevasses on the reef. Others use a single hand net in conjunction with a metal or fiberglass rod or pole (called a 'poker'). In the latter case, the net is placed in a strategic position covering the exit of the fish's refuge, and the poker is inserted into the coral to scare the fish into the net. Hand nets require a great deal of skill and practice to use efficiently. Less experienced collectors may increase their proficiency by using hand nets along with a barrier net.

Barrier nets: The general design of a barrier net (Fig. 2) is a rectangular section of monofilament netting, weighted along the bottom with lead or chain, and buoyed along the top with small floats. Although barrier nets vary in size almost continuously from less than a meter in length to as many as 20 m in length, they can be placed in one of two categories: large and small.

Large barrier nets are usually in excess of 10 m in length and a meter in height, and are used by two or more divers working together to collect schooling fishes (particularly surgeonfishes and tangs [Acanthuridae] and wrasses [Labridae]). The net is set in a V-shape, and the divers, each equipped with a pair of hand nets (or a single hand net and a poker), carefully herd or "drive" the fish into the apex of the net. To increase the success rate of collecting the more "flighty" kinds of fishes, divers may bring the ends of the barrier net together after concentrating the fish in the apex, thereby completely enclosing them within the net.

Small barrier nets are always fewer than 5 m in length, and range from about 0.5 to 1 m in height. The lead-line of small barrier nets is made of closely spaced lead weights or chain. This configuration of weight allows the net to "hug" the contours of the substratum more closely. Small barrier nets are carried and used by a single diver who works primarily with hand nets. Due to its small size, it can be carried about on the dive, either by hand or in a small pouch or pocket, and deployed when necessary. The small barrier net can be set either in a V configuration like the large barrier net, or may be simply laid down among rubble, following the particular substratum contour.

In general, a good choice of net-set location corresponds well with the given topography of the reef in relation to the particular habits of the target fish species. For example, many fishes are easily "driven" along ledges or through underwater channels in the reef, and the barrier net should be set to take best advantage of these kinds of topographies. Optimal herding paces and techniques vary from species to species, and depend on the specific habitat.

Traps: Traps were not listed among the collection techniques for any of the exporting companies which returned survey forms. In general, traps are not ideally suited for the collection of aquarium fishes because they are not species-selective, and they are usually only useful for collecting larger fishes. However, traps do serve as a potential source of aquarium fishes, as pointed out by Straughan (1973), Jonklaas (1975), Randall (1987), and others.

Rather than set traps specifically for aquarium fishes, the most efficient means of collection in this manner is to remove carefully and care for any aquarium fishes inadvertently collected in food-fish traps. Because most fishes of interest to the aquarium trade are not valuable food fishes, increased productivity of traps can be achieved if aquarium fishes are removed while still alive (rather than go to waste). Small plexiglass or clear plastic traps have also been used in the collection of aquarium fishes. These are described in some detail by Straughan (1973) and Jonklaas (1975), and are usually designed to collect a particular species of fish.

Chemicals: No surveyed companies reported using any chemicals in the collection of fishes, and personal observations indicate this to be true. Several kinds of chemical substances have been used to aid in the collection of aquarium fishes elsewhere in the world, however. The chemicals are usually taken by divers in small plastic squeeze bottles and dispersed on coral reefs to stun or anaesthetise fishes, causing them to vacate the protective coral cover, which facilitates easy collection. The most widely used, and perhaps most destructive, chemical for the collection of marine aquarium fish is sodium cyanide. It is used extensively in the Philippines and Indonesia, and perhaps in Mexico as well.

Numerous articles lambasting this toxic chemical in the collection of aquarium fishes have been published in the popular and scientific literature (*e.g.*, Dempster and Donaldson, 1974; Ireland and Robertson, 1974; Noyes, 1975; Dawson Shepherd, 1977; Dewey, 1980; Plessis *et al.*, 1981; Robinson, 1981; Randall, 1987; and many others). Many fishes collected with this chemical die immediately; others perish as much as a month later from extensive liver damage (Dempster and Donaldson, 1974; Herwig, 1980; Bellwood, 1981a, 1981b). At the very least, fishes collected with sodium cyanide suffer much elevated post-capture mortality rates. Furthermore, sodium cyanide may also kill corals and other invertebrate life (Randall, 1987), rendering a portion of the reef lifeless and unable to sustain future fish recruits. *Under no circumstances should this poison be tolerated for the commercial collection of aquarium fishes.*

Another chemical employed to collect aquarium fishes is quinaldine. Quinaldine is a coal-tar derivative which, when dissolved in alcohol or acetone, will quickly anaesthetise fishes. A study on the effects of this chemical and its solvents on corals (Jaap and Wheaton, 1975, p. 14) concluded that there was "minimal or no long-term damage to corals exposed to tested quinaldine solutions." Perino (1990, p. 8) pointed out:

> Tranquilizing chemicals, such as Quinaldine, have no adverse impact on marine life and allow collection of cryptic species without the use of disrupting methods. A self-limiting factor in extensive use of quinaldine is the cost of the compound and solvent. Fish collected with this chemical will not suffer secondary effects and capture-related injuries are minimal.

Other collection techniques, beyond those mentioned above, have been used in the Pacific and elsewhere to capture marine aquarium fishes. Collectors, particularly experienced ones, often develop unique collection techniques for specific kinds of fishes in certain habitats. Most of these involve variations of net methods, such as modified hand or barrier nets, used for particular situations. Many of these are discussed in Straughan (1973) and Jonklaas (1975). An additional type of net often used by snorkel divers in Sri Lanka is the 'moxy' net described by Wood (1985). The majority of these other methods, however, do not contribute substantially to the number of fishes collected for the aquarium trade.

TRANSPORT TO HOLDING FACILITIES

After collection, fishes are usually transferred to some sort of *in situ* container. Mesh or plastic bags are occasionally used, but most often the fish are placed in a rigid plastic container, perforated with holes to allow water circulation, and equipped with a spring-loaded door.

Decompression: Most species of fishes taken for aquarium purposes possess a gas-filled swimbladder which provides the fish with buoyancy control. Although fishes lacking this organ may be brought to the surface directly from any depth, those that have a swimbladder must be carefully decompressed if collected from deeper than about 10 meters. Different species require different amounts of decompression, and larger individuals of a given species require more than juveniles.

One way to accomplish proper decompression is to bring the fishes up slowly enough to allow them to remove the excess gas molecularly through their circulatory system. This method is most useful for fishes collected at moderate depths (10-25 m). However, for particularly sensitive species, or fishes collected at deep depths, decompression by this method may require many hours to complete. A number of collectors have employed the technique of puncturing the swimbladder with a hypodermic needle upon ascent, thereby venting off excess gas (Fig. 3). Although this method is used widely throughout the

Figure 3. The author using a hypodermic needle to release excess gas from the swimbladder of a fish. This method of decompression, if performed properly, is the most effective and efficient to bring up fishes safely from deeper water. Photo: Lisa A. Privitera.

Pacific, including Hawaii, it has drawn criticism in the popular literature. If performed by an experienced collector, and if the fish is subsequently placed in clean water conditions, however, this technique is actually the safest and least stressful for the fish.

Divers may also require decompression (for different physiological reasons), especially after deep or long dives. All collectors breathing compressed air should be fully certified in SCUBA, and should be very familiar with decompression requirements. Many collectors have suffered from decompression sickness (the 'bends') at one time or another. Although most such instances have not led to debilitating injuries, several have resulted in permanent paralysis or death. The importance of proper training in the use of SCUBA by aquarium fish collectors cannot be over-emphasised.

Transport to warehouse: Once brought successfully to the surface, fishes must be transported to holding facilities. Collectors who operate from a boat usually keep fish in large plastic garbage cans or other containers filled with clean seawater. The temperature of the water may quickly rise in the containers under bright tropical sunlight, and oxygen depletion and ammonia buildup can quickly deteriorate water quality to below critical life support levels. Therefore, water must be changed regularly.

Upon reaching shore, the containers may need to be transported overland to a warehouse facility. Water changes are not usually feasible, and if the duration of the journey exceeds 15 to 20 minutes, the water needs to be aerated. This can be accomplished in several ways, usually by small battery-driven air pumps or by slowly "bleeding" air from SCUBA tanks.

WAREHOUSE AND HOLDING FACILITIES

Aquarium fish warehouse facilities in the Pacific region vary in size from about 50 to 200 square meters, with an average area of about 100 square meters. The location of the warehouse is usually chosen such that it is situated near the ocean where clean seawater may be readily taken, in an area with easy access to roads, and reasonably close to an airport. Other considerations which have been taken into account by Pacific companies when choosing a warehouse location include proximity to boat ramps and protective harbors, proximity to good collecting areas, protection from bad weather conditions, land cost, and availability of reliable electricity and other utilities.

Fishes are maintained alive in large fiberglass-covered wooden tanks, plexiglas tanks (Fig. 4), or other plastic containers. The capacity of these holding systems in Pacific companies varies from 5,000-60,000 liters, with an average of about 20,000 liters. Aggressive species (such as angelfishes [Pomacanthidae]) are isolated from one another to prevent fighting among individuals. Isolation can be achieved by placing the fishes in perforated plastic buckets or small

Figure 4. A typical warehouse holding system using plexiglass tanks. Note the small compartments above, which are used to isolate aggressive fishes to prevent them from fighting. Other companies in the Pacific use fiberglass-covered wooden holding tanks. Photo: Richard L. Pyle.

plastic cups. Some systems are designed with numerous compartmentalized plexiglass tanks, eliminating the need for buckets or cups.

Although many companies have installed plumbing to facilitate pumping fresh seawater directly from the ocean into the warehouse, most holding systems recirculate the water through filters for the majority of the time, and only pump in fresh seawater during periodic water changes. Most of these recirculating systems include some form of "wet/dry" filtration, where water is trickled over a coral rock or plastic media, then passes through submerged filtration media. This design has proven useful in providing sufficient aeration and biological filtration to the water.

Many of the companies have also installed large swimming pool-type sand filters, and most incorporate ultra-violet sterilization systems. The latter component is used to kill disease-causing micro-organisms in the water. In addition, some companies reduce disease problems by treating their water with copper sulfate, and many use antibiotics such as nitrofurazone to reduce the possibility of infections.

FISH EXPORT

The feasibility of exporting aquarium fishes from a given locality depends largely on the frequency and reliability of regularly scheduled flights to international destinations. Most fishes collected in the Pacific are exported to Hawaii or California, where they are often transshipped to other destinations. However, if airline connections are available, some companies may export directly to Europe and elsewhere.

Packing fishes: The standard method of shipping live aquarium fishes is explained fully in Miller (1956). Basically, fishes are placed in a plastic bag one-quarter filled with seawater, inflated with pure oxygen, and packed in sturdy styrofoam containers for air-freight shipment. Shipping boxes may hold as many as 50-60 small fishes (or as few as one or two large fishes), and may weigh about 15-30 kilograms each. Packaged as such, fishes will usually remain healthy for 24-48 hours.

Fishes are generally maintained in the holding tanks for several days prior to shipping. This ensures that they are healthy and in good shape, and that they have had time to purge their digestive systems (so as not to foul the water in transit). Water for packing the fishes is collected from the ocean, not taken from the holding system, to further ensure optimum quality. Some shippers treat the shipping water with antibiotics or anaesthetics (McFarland, 1960), or both.

Shipping bags are polyethylene plastic, and range in size from about 10 x 20 cm for the smallest fishes up to about 60 x 60 cm for the largest fishes. Bags are often double, triple, or even quadruple-layer, with newspaper between each layer to mitigate punctures from fish spines. After filling with oxygen, bags are

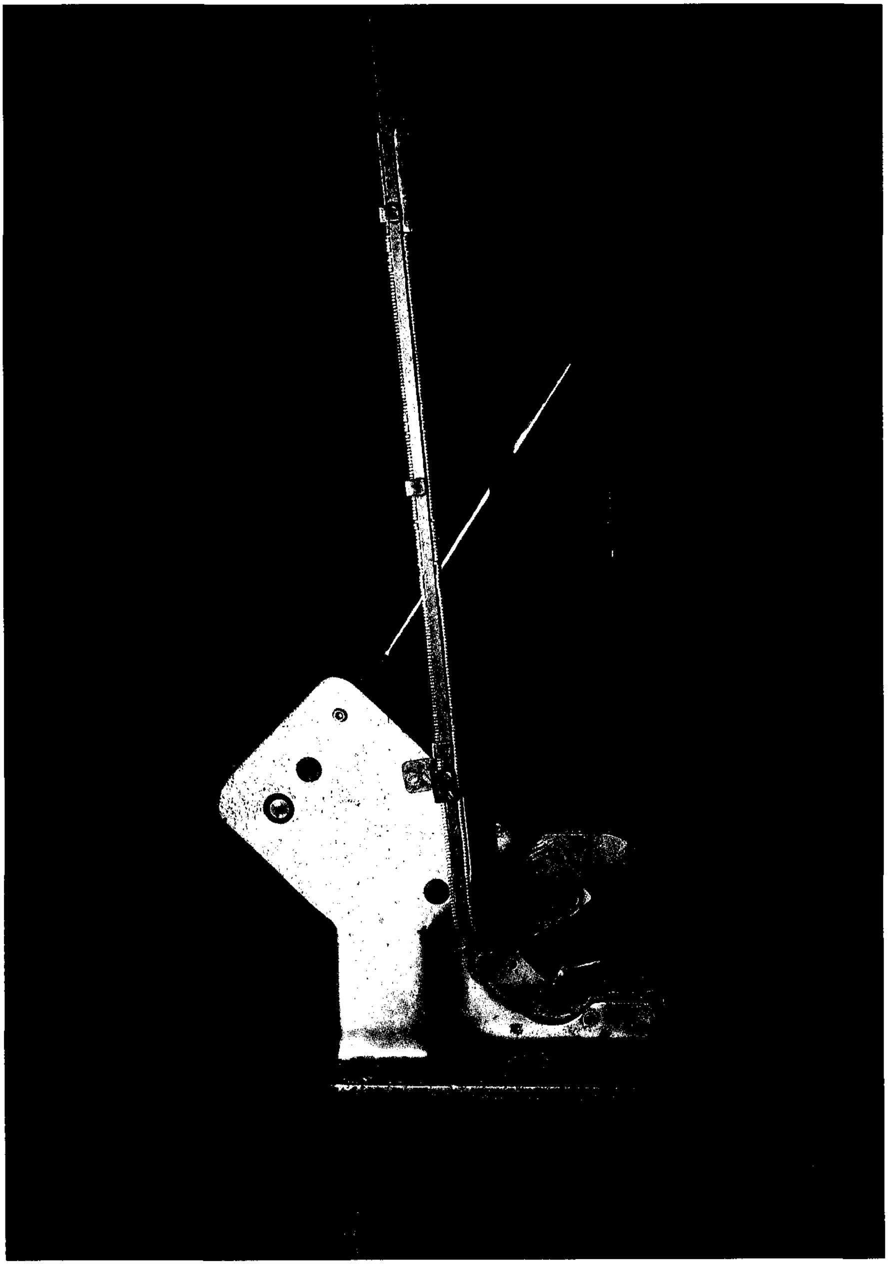

Figure 5. The efficiency of sealing plastic shipping bags is increased with the use of this type of "clip machine". Although expensive and difficult to obtain, these devices are indispensable when packaging large numbers of fishes. Photo: Richard L. Pyle.

sealed either with a rubber band or a metal clip. The clips are quickly dispensed from a "clip machine" (Fig. 5), which greatly increases large-scale packing efficiency. Rubber bands are applied by hand, and are usually only used for large bags. Bags are then placed in styrofoam or sturdy cardboard boxes for shipment.

Shipping fishes: The frequency and destination of aquarium fish shipments out of the Pacific region, particularly from Pacific islands, are limited by the number of flights departing the particular location. Surveyed companies make from 1 to 12 (average of three) shipments per week, each consisting of about 20-40 boxes of fish. Most of these shipments range in duration from about 10 to 30 hours, and freight rates are generally about US$1-3 per kilogram. At the time of writing, destinations of shipments originating in the Pacific region include Hawaii, Los Angeles, San Francisco, Japan, and the United Kingdom.

MORTALITY

When collected by methods other than sodium cyanide, levels of post-collection mortality are generally low. Most companies surveyed reported pre-shipment mortality rates of about 1-2 per cent, and there is no reason to doubt this figure. Fishes which die usually do so as a result of improper decompression or abuse from other fishes, factors which are well-controlled by most. Included within these reported mortality figures are fishes which are released back to the ocean because they are not suitable for exportation (*e.g.*, fishes with deformities or torn fins). Wood (1985) estimated that the total pre-export mortality of fishes collected in Sri Lanka was 15 per cent. This higher mortality rate is likely due to the extended duration of transport from collection site to holding facilities characteristic of the Sri Lankan industry.

A certain amount of mortality also occurs during shipment. Fishes which die in transit are customarily deducted from payment to the exporting company, increasing the incentive to the exporter to ensure healthy fishes and proper packing. Actual shipping mortality is usually proportional to shipment durations, but averages about 5-10 per cent for shipments from the Pacific region. This estimate does not differ significantly from Wood (1985), who estimated 10 per cent shipping mortality out of Sri Lanka. In general, local wage rates, regularity and reliability of airline connections to market destinations, competitive freight rates, and availability and cost of land are the most important economic factors to consider when determining the feasibility of the establishment of an aquarium fish export business at any particular locality.

IV. DEVELOPMENT AND MANAGEMENT OF FISHERY

The potential for the establishment of a marine aquarium fish export business exists at any locality with coral reefs and regularly scheduled air transport

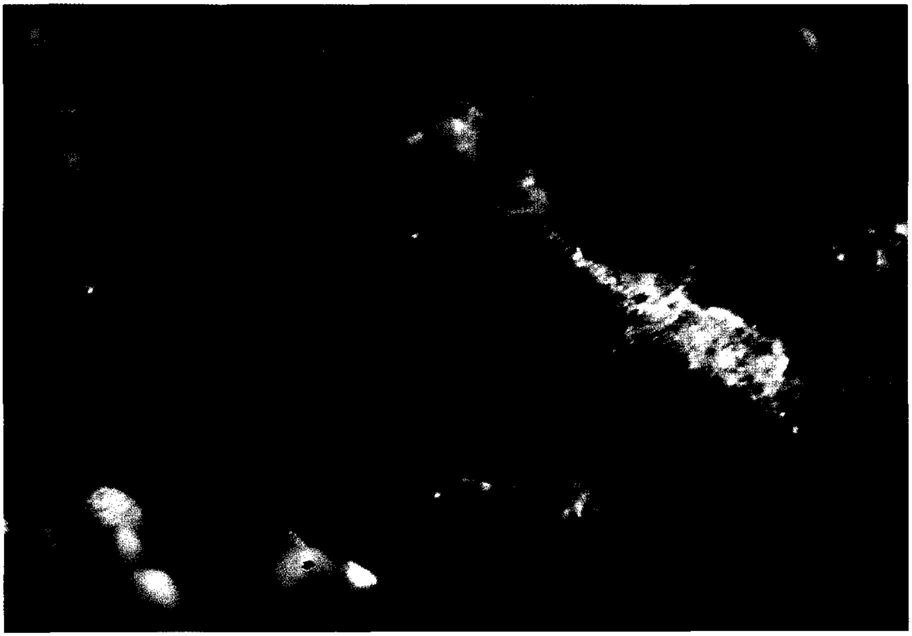

Figure 6. The beautiful red Flame Angelfish (*Centropyge loriculus* [Günther]). This species is the top export species of the Pacific (in terms of both numbers and value) and is responsible for as much as 70 per cent of the income of several companies. Photo: Richard L. Pyle.

services. Pacific islands are host to vast expanses of coral reefs harboring countless numbers of fishes, and serve as ideal localities for such exporting companies to become established. Effective development and management of this natural resource depends largely on the intelligent implementation of guidelines designed to maximize the efficiency of such an industry, while ensuring the long-term preservation of the coral reef ecosystem.

ASSESSMENT OF RESOURCES

The first step in any fishery is the assessment of local resources. Such information can aid in the formulation of optimal sustainable yields, and can lead to maximizing resource exploitation while minimizing adverse effects to local environments. In addition to assessing local stocks of fish species, the extent and quality of reef area and habitat should also be considered.

Habitat composition: Habitats conducive to the collection of aquarium fishes are rubble slopes, ledges, drop-offs, and certain coral reef areas. Flat rock areas with scattered small patch reefs or coral outcroppings are good collection grounds for certain fishes, as are harbors, seawalls, and quiet lagoons. Reefs with particularly lush growths of coral (especially table and staghorn corals [*Acropora* spp.]) do not serve well as collecting grounds, because such substrata provide ample escape routes for fishes and many sharp projections which can tear nets.

An assessment of the extent of favourable collecting sites and their accessibility (either from shore or by boat) should be made prior to establishing an export station. Perino (1990) made such an assessment of areas in Papua New Guinea, and he provides further elucidation on determining suitable habitat composition and location.

Species composition: For many companies operating in the Pacific (and elsewhere), 70-98 per cent of the income is earned from ten or fewer species. As much as 80 per cent of the income may come from only one or two species. Thus, economic viability of companies often depends on a few species of moderate to high value which are abundant enough to be regularly collected in high numbers. A prime example is the Flame Angelfish, *Centropyge loriculus* (Günther) (Fig. 6). This species alone forms the bulk (as much as 70 per cent) of the annual earnings of several companies in the Pacific. The relative importance (in terms of both numbers and values) of the various families of fishes taken in the Pacific for the marine aquarium trade are listed in Table II.

Another important aspect of species composition worthy of consideration is the availability of endemic fishes. For several companies, economic viability is enhanced by the presence of a certain species found only in that area. Export companies which offer exclusive supplies of endemic species can often boost sales of other species as well. For example, the Potter's Angelfish (*Centropyge*

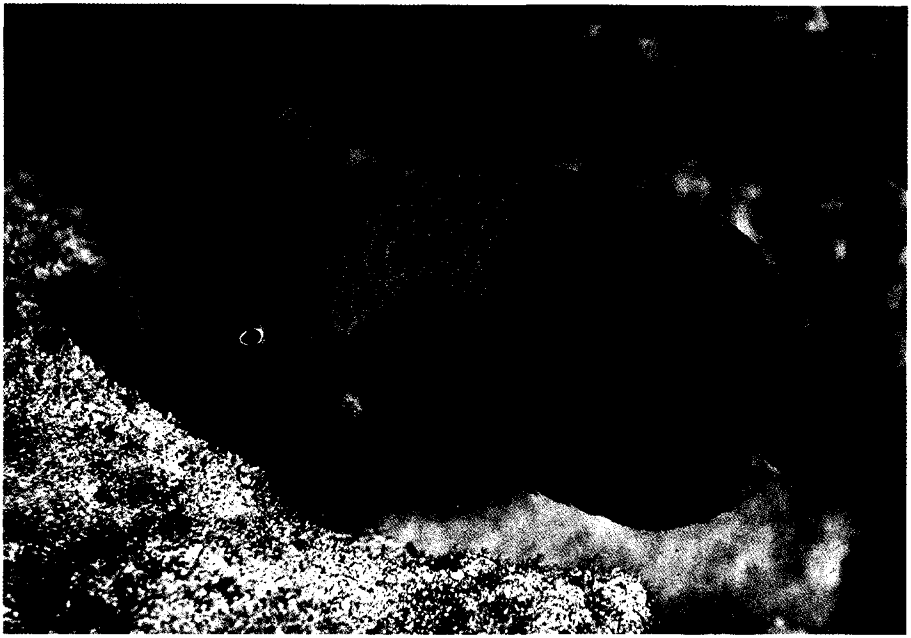

Figure 7. The Potter's Angelfish (*Centropyge potteri* Jordan and Metz) is endemic to the Hawaiian Islands and has consistently been in the top four species exported from Hawaii for the marine aquarium trade. Photo: Richard L. Pyle.

potteri Jordan and Metz, Fig. 7), a Hawaiian endemic, has remained consistently among the top four species collected for the marine aquarium trade in Hawaii since 1973. Wood (1985) cautions that endemic species should be more carefully managed, due to their restricted distribution and increased likelihood of being subject to over-fishing. Other authors, however, have pointed out that endemic species are quite often among the most abundant, thus less susceptible to over-exploitation.

Some species of fishes (particularly angelfishes [Pomacanthidae]) which are rare or deep-dwelling can command wholesale prices upwards of US$200-1200 each. Although very few individuals (usually fewer than ten) are exported annually, they still may constitute a significant portion of a company's earnings. It should be noted, however, that many of the aforementioned collectors who have suffered serious cases of decompression sickness (including death) have done so as a result of attempts to collect such species.

MANAGEMENT OF RESOURCES

The uncertainty of reef fish population dynamics and the paucity of data concerning the effects of aquarium fish collecting on coral reefs have rendered the designing of appropriate management schemes a difficult task. Numerous publications have addressed the issue of general reef fish conservation and management (*e.g.*, Simberloff and Abele, 1976; Johannes, 1978b; Salm and Proud, 1981; Bradbury and Reichelt, 1982; Johannes, 1982; Russ, 1984; Wells, 1984; White, 1984a; Bradbury, *et al.*, 1985; Chesher, 1985; Holthus, 1985; Russ, 1985; Sale *et al.*, 1986). Although most of these have focused on management of food fisheries, several others (Lubbock and Polunin, 1975; Taylor, 1978; Walsh, 1978; Albaladejo and Corpuz, 1984; Albaladejo *et al.*, 1984; Wood, 1985; Whitehead, *et al.*, 1986; Randall, 1987; Lewis, 1988; Samoilys, 1988b; Perino, 1990) have discussed the issue specifically with regard to aquarium fish collecting.

Wood (1985) pointed out that there is a great deal of variation in the way aquarium fish export industries operate in different parts of the world. In localities of relatively large geographic area, such as Australia, Hawaii, the Philippines, Indonesia and Sri Lanka, the industry is often composed of several large exporting companies supplied by many different independent collectors. Lubbock and Polunin (1975) suggest that the numbers of collectors and exporters be limited in areas where competition among different companies for the same resources may persist (all of the reports which suggest that fish collecting activities have had impact on reef fish populations have examined areas where this over-competitive situation exists).

In regions of smaller size, the industry usually consists of a single export company which employs several collectors. Lewis (1988, p. 4) provides a

Figure 8. Certain species of fishes, such as this stunning Ornate Butterflyfish (*Chaetodon ornatissimus* Cuvier), feed only on live coral and almost inevitably starve in captivity. Species with such restricted diets should probably not be collected for the marine aquarium trade. Photo: Richard L. Pyle.

review of the industry in Fiji, and writes, "Other than self-imposed observance of [the Fiji government's] Exploitation Guidelines, no management measures have been necessary." The general conclusion of this report was that the management procedures had been a success, and that stricter control was unnecessary. This seems to hold true for other export companies operating in Pacific islands. In general, fewer restrictions are required to ensure adequate protection of resources in small insular localities where only one export company operates, than are needed in areas with several companies competing for the same stocks of fishes. Management schemes, therefore, should be designed accordingly.

Environmental impact of aquarium fish collecting: There are two general considerations regarding the effect of aquarium fish collecting on coral reef environments. Besides the obvious potential damage due to removal of fishes from the reef, harm to the environment may come in the form of habitat destruction. Randall (1987) provides one of the most recent and comprehensive contributions concerning the impact of aquarium fish collection on coral reefs.

Most authors who have discussed the impact of collecting on coral reef fishes (*e.g.*, Lubbock and Polunin, 1975; Wood, 1985; Randall, 1987; Lewis, 1988, Samoilys, 1988a; Perino, 1990) agree that very few species of reef fishes are in danger of becoming extinct as a result of aquarium fish collecting. No species of coral reef fish is presently listed by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) as either endangered or threatened.

However, some disagreement exists in the literature regarding the impact that collecting may have on local populations of coral reef fishes. Lubbock and Polunin (1975) and Wood (1985) cite observations of reduced numbers of chaetodontids (butterflyfishes) in heavily collected Sri Lankan reef areas and Albaladejo and Corpuz (1984) noted that reefs frequented by aquarium fish collectors in the Philippines were unusually depauperate in species of interest to the aquarium trade. Walsh (1978) supported the notion that collecting activities could have a substantial impact on fish populations (particularly rarer species) in Hawaii. Walsh, as well as Lubbock and Polunin (1975), also pointed out that excessive selective removal of certain species of fishes for the marine aquarium trade may have extensive and unobvious ramifications to the coral reef community.

On the other hand, Randall (1987, p. 30) writes, "Some conservationists have opposed the collecting of aquarium fishes on the grounds that it causes a significant depletion of the population of species of coral reef fishes. In general, this is not true." He goes on to say that many of the species taken for the aquarium trade are among the most abundant: "The populations of these species are enormous and the take by aquarium fish collectors negligible." Perino (1990) noted that no noticeable decline in reef fish populations had occurred in Fiji despite six years of collecting activity. All of these authors on both sides of the issue concede that their conclusions are based largely on personal observations and conversations with divers, and all agree that further study is required. Three studies involving in-the-field research techniques have been conducted to determine the impact of aquarium fish collecting on coral reef fish populations.

Nolan (1978) observed populations of the five most collected species of Hawaiian reef fishes and compared the difference between collected and uncollected reefs. Results of his study indicate that the collectors had no detectable impact on fish populations. In fact, evidence suggests that populations of some of the species actually *increased* over the course of the study. Samoilys (1988a) looked at the impact of collecting in Kenya, and Samoilys and Green (in prep.) conducted a survey on the Great Barrier Reef. In the latter study, visual census techniques were used to determine the relative abundance of chaetodontids (butterflyfishes) at two separate reef sites, one of which is regularly visited by aquarium fish collectors, while the other is protected from collecting. Results of this study were inconclusive: although they determined that populations at the collected reef were significantly lower than those at the uncollected reef, they could not attribute this disparity in populations to the effects of aquarium fish collecting.

Catch report records from Hawaii (summarized by Taylor, 1974, van Poollen and Obara, 1984, and Anon., 1988), a location subject to relatively intense collecting pressure, indicate that catch per unit effort (CPUE) values have not declined substantially since 1973. It should be noted, however, that data pertaining to these CPUE values are difficult to interpret, because the 'unit of effort' is ambiguous and imprecise. Whitehead *et al.* (1986) discussed the implications of reef fish community structure theory on the possible impacts of fish collecting. They warned that applications of these theories towards predicting such effects are limited not only because of the uncertainty of the theories, but also because effects of collecting would be unpredictable even if community structure dynamics were well understood.

The greatest problems associated with impact assessment studies involve the difficulties in controlling for natural population fluctuations. Relative abundances of certain fish species may fluctuate over time, either seasonally, or from year to year. As mentioned earlier, such natural populations fluctuations have been reported in the literature (*e.g.*, Williams, 1983; Jonklaas, 1985; Wood, 1985; Walsh, 1987), and have also been observed by many aquarium fish collectors. The aforementioned *in situ* studies have attempted to control for natural population fluctuations by comparing concurrent surveys of collected and uncollected reef areas.

Besides the actual removal of fishes from the reef, physical and ecological damage to habitats can occur as a result of aquarium fish collecting activity. Many authors have discussed this problem, and Randall (1987) offers a comprehensive summary. Although some of the damage may occur as a result of activities incidental to collection techniques (such as broken coral from boat anchors or divers' swim fins), the greatest area of concern is with inappropriate collecting techniques.

The use of sodium cyanide is perhaps the most notoriously destructive method for the collection of aquarium fishes. In areas where this chemical is used extensively (such as in the Philippines), sections of coral reefs may be denuded of life, rendering the habitat unfit to harbor healthy coral reef communities. Such wastefulness inevitably leads to long-term damage to the environment. Clorox bleach, another destructive poison used for the collection of food fishes, has not been reported as a method of aquarium fish collection. Use of explosives is an equally destructive fish capture method. Although several authors have reported its use in the taking of aquarium fishes, this method is most often employed for collecting food fishes. The damage to coral reefs as a result of this method are obvious (see Alcala and Gomez, 1987, for a review of this problem).

Other concerns of habitat destruction mentioned by Randall (1987) (and others) include breakage of coral due to collecting efforts. Coral may be broken intentionally by a collector while attempting to drive a fish from shelter, or unintentionally as a result of setting or untangling barrier nets or from swim-fins (flippers). In general, however, most experienced collectors are aware of the repercussions of such destruction, and most take care not to destroy the habitat which serves to support new recruits in subsequent years.

Reef fish population declines due to natural causes of habitat destruction (such as storms or temperature anomalies) are also well documented. For example, Pfeffer and Tribble (1985) described the effects of a hurricane on Hawaiian reef fish populations, and the subsequent impact to the marine aquarium fish collecting industry in the area.

Bohnsack (1983b) documented the significant declines in fish species and numbers on certain Florida reefs following an unusual cold spell. Natural events such as these often dwarf the scale of impacts resulting from aquarium fish collecting activities.

Conservation policies: No countries with existing aquarium fish industries have yet imposed limits on the numbers of fishes allowed to be taken for the marine aquarium fish trade. As far as most data indicate, such limitations may be unnecessary in areas such as the Pacific islands where only one company actively collects and exports aquarium fishes from each locality. Limitations on the number of collectors or exporters may be considered in areas where certain reef areas are subject to intense fishing pressure from several competing companies. At least one area, the Northern Mariana Islands, has outlawed collection of fishes for aquarium purposes altogether (T. Donaldson, *pers. comm.*).

Other measures providing sufficient protection of the environment while allowing exploitation of reef fish resources have been proposed. Several authors (Lubbock and Polunin, 1975; Walsh, 1978; Siri and Barnett, 1980; Wood, 1985; Whitehead, *et al*., 1986) have suggested that areas of the reef be periodically closed to fishing activity to allow new recruits time to become established and to reduce over-all collecting pressure. Such closures, however, would be most useful only if designed with an adequate understanding of local spatial and temporal patterns of fish recruitment.

Perhaps more useful and easily implemented is the establishment of permanent marine sanctuaries, parks, and preserves wherein fishing is forbidden. Randall (1971; 1978; 1980; 1982; 1987), although a supporter of the marine aquarium industry, has strongly emphasised the need for such parks to provide areas where breeding populations are sustained and undisturbed. Other authors (*e.g*., Randall and Schroeder, 1962; White, 1984b; Wood, 1985; Whitehead *et al*., 1986) have also recommended that such preserves be established as a conservation policy. These refuges also provide excellent areas for marine ecological research and serve as control areas for studies addressing the impact of fishing pressure on reef fish populations. Furthermore, these parks can be selected for their aesthetic appeal as areas where sport-divers can see and photograph fishes in a natural, undisturbed habitat. Several large areas of the Great Barrier Reef in Australia have been set aside as marine parks, and a number of authors (*e.g*., Kelleher and Kenchington, 1982; Morris, 1983; Dinesen, 1985; Gilmour and Craik, 1985; Woodley, 1985; Dinesen, 1988) have discussed the logistics and effectiveness of maintaining these refuge areas.

A recent controversy between fish collectors and dive tour operators in Kona, Hawaii, was settled by the establishment of marine conservation zones, selected by mutual agreement between the dive operators and the collectors, where no fish collecting is permitted (Suzuki, 1989). Randall (1978) suggests that these preserves need only comprise 1-2 per cent of coastline, and he emphasises that such areas must be closed to *all* forms of fishing, not just aquarium fish collection. Some authors have suggested that policies should include restrictions on collecting rare species (Lubbock and Polunin, 1975; Walsh, 1978; Wood, 1985; Whitehead, *et al*., 1986) and species which are not likely to survive in captive environments, such as certain species of butterflyfishes (Chaetodontidae) which feed only on coral polyps (fig. 8). Wood (1985) lists 29 species of fishes suggested to be "vulnerable" to over-fishing, and she recommends additional protection for these species. Perino (1990), however, points out that variable weather conditions, deep reef areas, and vast expanses of reef areas unsuitable for collecting serve as natural measures of harvest control.

Perhaps the most important conservation measure which should be rigorously enforced is that collectors only employ appropriate collecting techniques. Damaging collecting techniques such as dynamite fishing and the use of sodium cyanide should be strictly outlawed. All Pacific companies responding to the survey said that they would support a Pacific-wide ban on the use of sodium cyanide. Tests for determining the presence of cyanide in organic tissue have been developed (Marsden, 1959; Mitchell, 1974) and would facilitate enforcement of such a ban. Other collecting chemicals, such as quinaldine and rotenone, should be allowed by special permit only (such as for scientific study, or perhaps, in the case of quinaldine, for limited use in the collection of aquarium fishes).

Many countries require that aquarium fish collectors be licensed in some way. Collectors in Hawaii and Guam must obtain one permit for the use of fine-mesh nets, and an additional permit for the commercial collection of aquarium fishes. Similarly, collectors and exporters must be licensed in Australia, Kenya, Mauritius, Maldives, Sri Lanka, and many other places. Most authors agree that such licensing is needed to ensure that collectors and exporters are knowledgeable and competent in capturing and caring for fishes. With an adequate level of expertise, mortality can be reduced so as to minimise needless suffering and death of reef fishes. Another condition often stipulated in the licensing policy is that records be maintained by collectors and exporters as to the number of fishes taken.

Monitoring resources: Monitoring of aquarium fish resources can be carried out by evaluation of fish-catch statistics or by direct observation on the reef. Studies in Hawaii (Taylor, 1974; van Poollen and Obara, 1984; Anon., 1988) have relied more heavily on data obtained from fish-catch reports submitted by collectors. These kinds of data, while useful for determining CPUE figures, may not provide much information on the impact of fish collecting on local stocks (due to the extent of natural population fluctuations). Field-based studies, on the other hand, are perhaps more useful in that they are more likely to account for natural temporal variations in the reef ecosystem.

White (1988) studied the relationships between butterflyfish (Chaetodontidae) occurrence and reef habitat parameters using visual censusing techniques, and suggested that these fishes may serve as good indicator species for overall reef health. Samoilys and Green *(in prep.)* also used visual censusing techniques on butterflyfishes to help reveal the impact of aquarium fish collecting on coral reef areas in Australia. The latter study, which controlled for natural population fluctuations by comparing census data between collected and uncollected reefs, provides a useful example of how further studies may be conducted. Nolan and Taylor (1977) assessed various reef fish censusing parameters and concluded that "the transect method of estimating fish populations is accurate if care is taken in selecting transecting length, a standardized method suitable for the habitat is used, sufficient numbers of replicates are conducted, and trained observers are used."

RESEARCH OPPORTUNITIES

Although the marine aquarium fish industry has provided occasional scientific contributions in the form of new species discoveries and zoogeographic range extensions (*e.g.*, Carlson and Taylor, 1981), data most frequently culled from the industry are CPUE figures. As mentioned earlier, a number of management schemes stipulate that collectors report total catches on a regular basis.

Such information could offer insights into natural population fluctuations, as well as provide further evidence for resolving the "order" versus "chaos" controversy of reef fish community structure. However, it should be pointed out that inaccurate data may be more detrimental than no data at all.

Exact guidelines for submission of such reports should be mutually agreed upon between government officials and collectors, and records should either be kept by the company itself or kept by fisheries agencies under strict confidentiality (in the interest of economic privacy and to ensure accuracy of data).

The area in most need of scientific study is assessing the potential environmental impacts of aquarium fish collecting on coral reef communities. The three investigations already mentioned (Nolan, 1978; Samoilys, 1988a; Samoilys and Green, in prep.) attempted to address this issue by comparing relative abundances of fishes on collected versus protected reefs. Although these studies provided important information with interesting implications, they also emphasised the need for continued research efforts.

Careful consideration should be exercised in the design of these experiments, so as to control for natural population and species composition fluctuations, as well as impact from other human activities such as food-fishing, excessive sport diving, and shoreline development. Samoilys and Green (in prep.) provide many useful suggestions for the implementations of such research programs. These kinds of studies might best be carried out in the form of community structure experiments.

Another area of study worthy of continued research efforts is in commercial-scale captive breeding experiments. Although wild-caught fishes will remain the primary source of most marine aquarium fishes for many years to come, the possibility for captive-bred fishes to supplement the supply of certain species still exists (Madden, 1978; Wood, 1985; Whitehead, *et al.*, 1986; Perino, 1990; Iversen, 1991). For example, Wood (1985) pointed out that anemonefishes (Pomacentridae, genus *Amphiprion*) are at particular risk to over-exploitation. Not only are these fishes easily located and collected by divers, but their removal from the anemones in which they live renders the anemones vulnerable to predation (Godwin and Fautin, 1992). Anemonefishes have already been bred in captivity on a commercial scale, thus serving as ideal candidates for future captive breeding studies.

Iversen (1991) compiled an extensive report on the aquacultural potential of marine aquarium fishes in Hawaii. The report was prompted by the successful rearing of two species of damselfishes of the genus *Dascyllus* by the Hawaii Institute of Marine Biology. It emphasized the need to expand support for research into the rearing of marine aquarium fish species as a viable aquacultural activity.

Perino (1990) suggested that locations in the vicinity of tropical coral reefs are good sites for this kind of research activity, because of the warm, stable climate, abundance of clean seawater, and availability of wild fishes. Information obtained from such studies would be useful not only for captive breeding industries, but also to researchers interested in the life history biology of reef fishes.

V. INVERTEBRATES

Live marine invertebrates, such as corals, anemones, crustaceans and others, are also a part of the marine aquarium industry. Although these kinds of animals have been maintained in aquaria for many years (Straughan, 1970), the demand for them has increased substantially with the recent popularization in the United States of "mini-reef" aquarium systems (systems designed to meet the captive requirements of invertebrates). Most of the invertebrates in trade originate from the Philippines. Marine invertebrates are presently not exported from Pacific islands, but 16,800 invertebrate animals were reportedly collected in Australia in 1990 (R. Pearson, *pers. comm.*).

A wide assortment of species from several phyla, including Porifera (sponges), Cnidaria (=Coelenterata) (corals, anemones, and others), Platyhelminthes (flatworms), Annelida (fan worms and feather worms), Mollusca (nudibranchs, octopuses and seashells), Arthropoda (crustaceans), Echinodermata (sea cucumbers, sea urchins, and sea stars), are in trade. Of these, corals and anemones (Class Anthozoa), fan worms (Class Polychaeta), nudibranchs (Subclass Opisthobranchia), crustaceans, and a few sponges are the most frequently collected groups. Other invertebrates, as well as some algae, enter the trade in the form of "live rock" (coralline rock encrusted with an assortment of invertebrate life). Walls (1982) offers a comprehensive guide to marine invertebrates which summarises the biology of the aforementioned phyla; Wood (1983) and Veron (1986) detail a great deal of coral biology; and Kühlmann (1985) gives a good review of coral reef ecology in general.

Although the potential for marine invertebrates to serve as additional exploitable resources exists in tropical coral reef areas, very little has been documented regarding the environmental impact of their removal from the reef. A number of writings have appeared in popular aquarium literature regarding their exploitation, and Wood (1985, p. 113) suggests that "stony corals [should be] protected...because their removal and disturbance is known to have particularly serious consequences. Possibly there are other invertebrates that should [also be protected], but this requires further study." The commercial collection of corals and "live rock" has been outlawed in Hawaii and Florida. Feddern (1990), however, argued that commercial harvest of "live rock" in Florida is negligible, and that with proper management, the fishery can continue without causing excessive harm to the ecosystem. Sprung (1991) advocated that the harvest of "live rock" in Florida be allowed to continue and suggested that aquaculture would serve well as a supplemental source.

The exploitation of marine invertebrate organisms should not necessarily be prohibited entirely. There is considerable demand for them, and such demand is likely to increase. They may therefore serve as an additional fisheries resource which, if carefully managed, may be exploited without undue harm to the coral reef ecosystem. Most invertebrates can probably be collected and managed in much the same way as reef fishes. However, the commercial harvest of stony corals and "live rock" should be pursued in moderation until further study can be conducted regarding the environmental impact of this kind of habitat disturbance.

ACKNOWLEDGEMENTS

I would like to express my sincere thanks to Lisa A. Privitera, who assisted immeasurably throughout all aspects of the compilation of this chapter, especially with regard to its critical review. I would also like to thank A. Wright, M. Samoilys, R. Pearson, and R. Iversen for providing useful publications and information, and P. Boserio, C. Boyle, N. Davis, A. Nahacky, J. Preble, F. Walsh, P. Wilder, and P. Williams for completing survey forms and providing other information concerning the marine aquarium fish trade in the Pacific.

REFERENCES

Albaladejo, V.D. and Corpuz, V.T. (1981). A market study of the aquarium fish industry of the Philippines: an assessment of the growth and mechanics of the trade. *Proc. 4th Int. Coral Reef Symp.*, Manila 1, 75-81.

Albaladejo, V.D. and Corpuz, V.T. (1984). *Marine aquarium fish research and resource management.* Bureau of Fisheries and Aquatic Resources, Republic of the Philippines.

Albaladejo, V.D., Corpuz, V.T. and Asuncion, J.T. (1984). *Final report on status assessment of the collecting areas of aquarium fishes in Santiago Island in Bolinao, Pangasinan conducted last February 18 to March 4 1984.* Bureau of Fisheries and Aquatic Resources, Republic of the Philippines.

Alcala, A.C. and Gomez, E.D. (1987). Dynamiting coral reefs for fish: a resource-destructive fishing method. In *Human Impacts on Coral Reefs: Facts and Recommendations.* (B. Salvat, ed.). pp. 51-60. French Polynesia: Antenne Museum E.P.H.E.

Alevizon, W., Richardson, R., Pitts, P. and Serviss, G. (1985). Coral zonation and patterns of community structure in Bahamian reef fishes. *Bull. Mar. Sci.* **36**(2), 304-318.

Anderson, G.R.V., Ehrlich, A.H., Ehrlich, P.R., Roughgarden, J.D., Russell, B.C. and Talbot, F.H. (1981). The community structure of coral reef fishes. *Am. Nat.* **117**(4), 476-495.

Anon. (1979). *International trade in tropical aquarium fish.* Geneva: International Trade Centre (UNCTAD/GATT). 137 pp.

Anon. (1980). *Master Plan for the Development of Fisheries in Sri Lanka 1979-1983.* Ministry of Fisheries, Sri Lanka.

Anon. (1988). *Report to the Fifteenth Legislature State of Hawaii Regular Session of 1989. Subject: Report on House Concurrent Resolution No. 291, House Draft 1, Senate Draft 1. Requesting the Department of Land and Natural Resources to take appropriate measures to manage and to conserve tropical fish resources.* Department of Land and Natural Resources, State of Hawaii. December, 1988. 10 pp.

Axelrod, H.R. (1971). *The aquarium fish industry - 1971.* T.F.H. Publ. Inc., Ltd. Jersey City, N.J.

Barlow, G.W. (1981). Patterns of parental investment, dispersal and size among coral reef fishes. *Env. Biol. Fish.* **6**, 65-85.

Bellwood, D.R. (1981a). Cyanide...An investigation into the long term histological effects of sodium cyanide doses upon the gastro-intestinal tract of *Dascyllus trimaculatus*. Part one. *Freshwat. Mar. Aquar. Mag.* **4**(11), 31-35, 75-76.

Bellwood, D. R. (1981b). Cyanide...An investigation into the long term histological effects of sodium cyanide doses upon the gastro-intestinal tract of *Dascyllus trimaculatus*. Part two. *Freshwat. Mar. Aquar. Mag.* **4**(12), 7-9, 87-88.

Bohnsack, J.A. (1983a). Species turnover and the order versus chaos controversy concerning reef fish community structure. *Coral Reefs* (1983) 1, 223-228.

Bohnsack, J.A. (1983b). Resiliency of reef fish communities in the Florida Keys following a January 1977 hypothermal fish kill. *Env. Biol. Fish.* **9**(1), 41-53.

Bradbury, R.H. and Reichelt, R.E. (1982). The reef and man: rationalizing management through ecological theory. *Proc. 4th Int. Coral Reef Symp.* **1**, 119-223.

Bradbury, R.H., Reichelt, R.E. and Green, D.G. (1985). Policy = F (theory, data, models, tools) rational solutions to coral reef conservation. *Proc. 5th Int. Coral Reef Cong.* **4**, 247-251.

Carlson, B.A and Taylor, L.R. (1981). *Holacanthus griffisi* a new species of angelfish from the Central Pacific Ocean. *Freshwat. Mar. Aquar. Mag.* **4**(5), 8-11.

Chave, E.H. and Lobel, P.S. (1974). *Marine and Freshwater Aquarium Systems for Tropical Animals.* Honolulu, Hawaii: Sea Grant Advisory Report. 88 pp.

Chesher, R. (1985). Practical problems in coral reef utilization and management: a Tongan case study. *Proc. 5th Int. Coral Reef Cong.* **4**, 213-217.

Clarke, R.D. (1988). Chance and order in determining fish-species composition on small coral patches. *J. Exp. Mar. Biol. Ecol.* **115**, 197-212.

Conroy, D.A. (1975). An evaluation of the present state of world trade in ornamental fish. *FAO Fisheries Technical Paper, No.* **146**. 128 pp.

Daigle, G. (1978). Commercial fish collecting. In *Papers and Comments on Tropical Reef Fish. Working Paper No.* **34**. (L. Taylor and R. Nolan. eds.) pp. 13-17. Sea Grant College Program, University of Hawaii.

Dawson Shepherd, A.R. (1977). Collected in the Philippines. *The Aquarist* **7**(10), 5-14.

Dempster, R.P. and Donaldson, M.S. (1974). Cyanide - Tranquilizer or poison? *Aquar. Dig. Internl.* **2**(4), 21-22.

Dewey, D. (1980). Editorial. *Freshwat. Mar. Aquar. Mag.* **3**(12), 4 and 6.

Dinesen, Z.D. (1985). Day-to day management of Capricorna, the first section of the Great Barrier Reef Marine Park. *Proc. 5th Int. Coral Reef Cong.* **4**, 253-258.

Dinesen, Z.D. (1988). Complementary management of marine parks and island national parks in the Great Barrier Reef. *Proc. 6th Int. Coral Reef Symp.* **2**, 363-368.

Doherty, P.J. (1983). Tropical territorial damselfishes: is density limited by aggression or recruitment? *Ecology* **64**, 176-190.

Doherty, P.J., Williams, D.M. and Sale, P.F. (1985). The adaptive significance of larval dispersal in coral reef fishes. *Env. Biol. Fish.* (2), 81-90.

Ehrlich, P. R. (1975). The population biology of coral reef fishes. *Ann. Rev. Ecol. Syst.* **6**, 211-247.

Feddern, H.A. (1990). Live rock for the marine aquarium. Letter to the editor. *Freshwat. Mar. Aquar. Mag.* 13(6); 2-3.

Gilmour, A. and Craik, W. (1985). A framework for monitoring the Great Barrier Reef Marine Park. *Proc. 5th Int. Coral Reef Cong.* **4**, 265-270.

Gladfelter, W.B. and Gladfelter, E.H. (1978). Fish community structure as a function of habitat structure on West Indian patch reefs. *Rev. Biol. Trop.* **26** (suppl. 1), 65-84.

Godwin, J.R. and Fautin, D.G. (1992). Defense of host actinians by anemonefishes. *Copeia* **1992**(3): 902-908.

Greenfield, D.W. and Johnson, R.K. (1990). Community structure of Western Caribbean blennioid fishes. *Copeia* **1990**(2), 433-448.

Helfman, G.S. (1978). Patterns of community structure of fishes: summary and overview. *Env. Biol. Fish.* **3**, 129-148.

Hemley, G. (1984). U.S. imports millions of ornamental fish annually. *Traffic (U.S.A.)* **5**(4), 1, 18-20.

Herwig, N. (1980). Disease prevention and control. *Freshwat. Mar. Aquar. Mag.* **3**(5), 12-15, 85-87.

Holthus, P.F. (1985). A reef resource conservation and management plan for Ponape Island (Caroline Archipelago, Micronesia). *Proc. 5th Int. Coral Reef Cong.* **4**, 231-236.

Ireland, P.J. and Robertson, G.C. (1974). A review of evidence relating to the use and effects of sodium cyanide and other methods commercially employed in coralfish collecting. *British Marine Aquarists Association, Booklet No.* **2**. 15 pp.

Iversen, R.T.B. (1991). Aquaculture of Hawaiian damselfish and other ornamental reef fish for Hawaii's aquarium fish trade. Unpublished report prepared for the Hawaii Institute of Marine Biology, University of Hawai'i. 96 pp.

Jaap, W.C. and Wheaton, J. (1975). Observations on Florida reef corals treated with fish collecting chemicals. Florida Department of Natural Resources. *Florida Marine Research Publications* **10**, 1-18.

Johannes, R.E. (1978a). Reproductive strategies of coastal marine fishes in the tropics. *Env. Biol. Fish.* **3**, 65-84.

Johannes, R.E. (1978b). Traditional marine conservation methods in Oceania and their demise. *Ann. Rev. Ecol. Syst.* **9**, 349-364.

Johannes, R.E. (1982). *Reef and lagoon resource management in Western Samoa.* SPREP. S.P.C. Noumea: 30pp.

Jonklaas, R. (1975). *Collecting Marine Tropicals.* T.F.H. Publ. Inc., Ltd. Jersey City, N.J. 224 pp.

Jonklaas, R.S.L. (1985). Population fluctuations in some ornamental fishes and invertebrates off Sri Lanka. *Symposium on Endangered Marine Animals and Marine Parks.* Paper No. **47**. 12-16 January 1985. Cochin, India.

Katekaru, A. (1978). Regulations of tropical reef fish collecting. In *Papers and Comments on Tropical Reef Fish. Working paper No.* **34.** (L. Taylor and R. Nolan, eds.). pp. 35-42. Sea Grant College Program, University of Hawaii.

Kelleher, G.G. and Kenchington, R.A. (1982). Australia's Great Barrier Reef Marine Park: making development compatible with conservation. *Ambio* **11**(5), 262-267.

Kühlmann, D.H.K. (1985). *Living Coral Reefs of the World.* Arco Publishing, Inc., New York. 185 pp.

Kvalvagnaes, K. (1980). *The ornamental fish trade in Indonesia.* FAO: INS/78/061, Special Report. UNDP/FAO National Parks Development Project, Bogor, Indonesia. August 1980.

Leis, M. and Miller, J.M. (1976). Offshore distributional patterns of Hawaiian fish larvae. *Mar. Biol.* **36**, 359-367.

Lewis, A.D. (1988). A coral reef fishery for aquarium fish - the Fiji experience. *Workshop on Pacific Inshore Fishery Resources. Background Paper No.* **31**. South Pacific Commission. Noumea, New Caledonia. 8 pp.

Lubbock, H.R. and Polunin, N.V.C. (1975). Conservation and the tropical marine aquarium trade. *Environ. Conserv.* **2**(3), 229-232.

MacArthur, R.H. and Wilson, E.O. (1967). *The theory of island biogeography.* Princeton Univ. Press, Princeton, N.J.

Madden, W. (1978). Aquaculture of tropical reef fish. In *Papers and comments on Tropical Reef Fish. Working Paper No.* **34**. (L. Taylor and R. Nolan. eds.) pp. 27-34. Sea Grant College Program, University of Hawaii.

Marsden, K. (1959). Determination of traces of cyanide in fish tissues. *The Analyst* **84**, 746-747.

McFarland, W.N. (1960). The use of anaesthetics for the handling and the transport of fishes. *California Fish and Game* **46**, 407-431.

McKay, R.J. (1977). The Australian Aquarium Fish Industry, *Fisheries Paper No.* **25**. Australian Government Publishing Service, Canberra. 36pp.

McLarney, B. (1985). Pioneers in saltwater aquarium fish: Part I. *Aquaculture Magazine* **11**(6),38-45.

Miller, R.R. (1956). Plastic bags for carrying and shipping live fish. *Copeia* **1956**(2), 118-119.

Mitchell, N.D. (1974). Quantification of the picrate test for cyanide in plant genetic studies. *Can. J. Genetics Cytol.* **16**, 895-897.

Moe, M.A. (1992). *The Marine Aquarium Handbook: Beginner to Breeder,* Revised Edition. Green Turtle Publications, Plantation, Florida. 320 pp.

Morris, G.C. (1983). The Great Barrier Reef Marine Park: a unique management concept. *Parks* **8**(3), 1-4.

Myers, R.F. (1989). *Micronesian Reef Fishes.* Coral Graphics, Barrigada, Guam. 298 pp.

Nolan, R.S. (1978). Hawaii tropical reef fish study. In *Papers and comments on Tropical Reef Fish. Working Paper No.* **34**. (L. Taylor and R. Nolan, eds.) pp. 27-34. Sea Grant College Program, University of Hawaii.

Nolan, R.S. and Taylor, L.R. Jr. (1977). Fish censusing: method or mirage? Unpublished manuscript.

Noyes, J.C. (1975). Collecting without drugs. *Mar. Aquarist.* **6**(7), 5-12.

Perino, L. (1990). Assessment of the feasibility of establishing an aquarium fish industry in Papua New Guinea. *FFA Report* **90/30**. South Pacific Forum Fisheries Agency, Honiara, Solomon Islands. 35 pp.

Pfeffer, R.A. and Tribble, G.W. (1985). Hurricane effects on an aquarium fish fishery in the Hawaiian Islands. *Proc. 5th Int. Coral Reef Cong.* Vol. **2.**, 331-336. Abstract. Tahiti, French Polynesia.

Plessis, Y.B., Chauvier, G. and Mortier Gabet, J. (1981). Les coulisses de l'aquariologie, science et flàau de la nature. *Vie et Marine* **3**, 11-14.

Ramsey, J.S. (1973). A sampling of U.S. aquarium fish imports. Abstract. *Bull. Assoc. SE Biologists* **20**(2), 76.

Randall, J.E. (1971). Progress in marine parks. *Sea Frontiers* **17**(1), 2-16.

Randall, J.E. (1978). Marine preserves - an answer. In *Papers and comments on Tropical Reef Fish. Working paper No.* **34**. (L. Taylor and R. Nolan, eds.). pp. 6-7. Sea Grant College Program, University of Hawaii.

Randall, J.E. (1980). Conserving marine fishes. *Oryx* **15**(3), 287-291.

Randall, J.E. (1982). Tropical marine sanctuaries and their significance in reef fisheries research. *The Biological Basis for Reef Fishery Management*. pp.167-178. NOAA Technical Memorandum NMFS-SEFC-80.

Randall, J.E. (1987). Collecting reef fishes for aquaria. In *Human Impacts on Coral Reefs: Facts and Recommendations*. (B. Salvat. ed.). pp. 29-39. Antenne Museum E.P.H.E., French Polynesia.

Randall, J.E., Allen, G.R. and Steene, R.C. (1990). *The Complete Divers' and Fisherman's Guide to Fishes of the Great Barrier Reef and Coral Sea*. Crawford House Press, Bathurst, Australia. 507 pp.

Randall, J.E. and Schroeder, R.E. (1962). New underwater park. *Sea Frontiers* **8**(1), 8-17.

Reese, E.R. (1973). Duration of residence by coral reef fishes on "home" reefs. *Copeia* **1973**(1), 145-149.

Robinson, S. (1981). Who needs drugs? Confessions of an organic fish collector. *Freshwat. Mar. Aquar. Mag.* **4**(7), 14-17, 85-87, 90.

Russ, G. (1984). Effects of protective management on coral reef fishes in the Philippines. *ICLARM Newsletter* **7**(4), 12-13.

Russ, G. (1985). Effects of protective management on coral reef fishes in the central Philippines. *Proc. 5th Int. Coral Reef Cong.* **4**, 219-224. Tahiti, French Polynesia.

Russell, B.C., Anderson, G.V.R. and Talbot, F.H. (1977). Seasonality and recruitment of coral reef fishes. *Aust. J. Mar. Freshwater Res.* **28**, 521-528.

Sale, P.F. (1977). Maintenance of high diversity in coral reef fish communities. *Am. Nat.* **111**, 337-359.

Sale, P.F. (1978). Coexistence of coral reef fishes - a lottery for living space. *Env. Biol. Fish.* **3**, 86-102.

Sale, P.F. (1980a). Assemblages of fish on patch reefs - predictable or unpredictable? *Env. Biol. Fish.* **5**(3), 243-249.

Sale, P.F. (1980b). The ecology of fishes on coral reefs. *Oceanogr. Mar. Biol.* **18**, 367-421.

Sale, P.F., ed. (1991).*The Ecology of Fishes on Coral Reefs*. Academic Press, Inc., New York. 754 pp.

Sale, P.F. and Dybdahl, R. (1975). Determinants of community structure for coral reef fishes in an experimental habitat. *Ecology* **56**, 1343-1355.

Sale, P.F., Eckert, G.J., Ferell, D.J., Fowler, A.J., Jones, T.A., Mapstone, B.D. and Steel, W.J. (1986). *Aspects of the demography of seven species of coral reef fishes, with recommendations for their management*. Report to Great Barrier Reef Marine Park Authority, PO Box 1379, Townsville, Queensland 4810, Australia. 57 pp.

Salm, R.V.S. and Proud, K.R.S. (1981). Guidelines needed for the commercial exploitation of coral reef fishes. *Conservation Indonesia* **5**(1), 5-6.

Samoilys, M.A. (1988a). A survey of the coral reef fish communities on the Kenyan coast. *Technical Report for Ministry of Tourism and Wildlife, Kenya*. WWF (International) Project 3797 Kenya. 38 pp.

Samoilys, M.A. (1988b). Abundance and species richness of coral reef fish on the Kenyan coast: the effects of fishing and protective management. *Proc. 6th Int. Coral Reef Symp.* Vol. **2**. pp. 261-266. Townsville, Australia.

Samoilys, M. and Green, A. (in prep). The effects of collecting coral reef fish for the aquarium trade: A review and a preliminary study on the northern Great Barrier Reef.

Senanayake, F.R. (1980). *The ornamental fish fishery in Sri Lanka*. Marga Institute (Sri Lanka Centre for Development Studies). 15 pp.

Shulman, M.J. (1984). Resource limitation and recruitment patterns in a coral reef fish assemblage. *J. Exp. Mar. Biol. Ecol.* **74**, 85-109.

Simberloff, D.S. (1976). Species turnover and equilibrium island biogeography. *Science (Wash.)* **194**, 572-578.

Simberloff, D.S. and Abele, L.G. (1976). Island biogeography theory and conservation practice. *Science (Wash.)* **191**, 285-286.

Siri, P. and Barnett, C. (1980). From reef to retailer: the collection of marine aquarium fish: Part one. *Freshwater Mar. Aquar. Mag.* **3**(9), 7-11, 89-92.

Smith, C.L. (1977). Coral reef communities - order and chaos. *Proc. 3rd Int. Coral Reef Symp.* Vol. **1**, xxi-xxii. Miami, Florida.

Smith, C.L. (1978). Coral reef communities: a compromise view. *Env. Bio. Fish.* **3**, 109-128.

Smith, C.L. and Tyler, J.C. (1972). Space resource sharing in a coral reef fish community. In *Results of the Tektite program: ecology of coral reef fishes*. (B.B. Collette and S.A. Searle, eds.), pp. 125-170. *Bull. Nat. Hist. Mus. Los Angeles County*. Vol. **14**.

Sprung, J. (1991). Reef notes. *Freshwat. Mar. Aquar. Mag.* **14**(7):78,80,82, 190.

Straughan, R.P.L. (1970). *The saltwater aquarium in the home*. A.S. Barnes and Co. Cranbury, N.J. 419 pp.

Straughan, R.P.L. (1973). *The Marine Collector's Guide*. A.S. Barnes and Co., Inc. Cranbury, New Jersey. 222 pp.

Suzuki, S. (1989). Users work to end Kona conflict. *Univ. of Hawaii Sea Grant Publ.* **11**(12), 1, 4.

Talbot, F.H., Russell, B.C. and Anderson, G.R.V. (1978). Coral reef fish communities: unstable high-diversity systems? *Ecol. Monogr.* **49**, 425-440.

Taylor, L. (1974). *A summary of catch statistics for Hawaii's aquarium-fish Fishery*. July 1973 - June 1974. Hawaii Cooperative Fishery Unit, University of Hawaii. 25 September 1974. 24 pp.

Taylor, L. (1978). Tropical reef fish management: issues and options. In *Papers and comments on Tropical Reef Fish. Working Paper No.* **34**. (L. Taylor and R. Nolan. eds.). pp. 3-5. Sea Grant College Program, University of Hawaii.

Thresher, R.E. (1984). *Reproduction in reef fishes*. T.F.H. Publ. Inc., Ltd. Jersey City, New Jersey. 399 pp.

van Poollen, H.W. and Obara, A.M. (1984). Hawaii's marine aquarium fish industry profile. *Studies on Marine Economics No.* 3. April 1984. Sea Grant College Program, University of Hawaii. 21 pp.

Veron, J.E.N. (1986). *Corals of Australia and the Indo-Pacific.* Angus and Robertson Publishers. N.S.W, Australia.

Walls, J.G., (ed.). (1982). *Encyclopedia of Marine Invertebrates.* T.F.H. Publ. Inc., Ltd. Neptune City, N.J. 736 pp.

Walsh, W.J. (1978). Aquarium reef fish collecting: promise or problem? In *Papers and comments on tropical reef fish. Working Paper No.* **34**. (L. Taylor and R. Nolan, eds.). pp. 8-12. Sea Grant College Program, University of Hawaii.

Walsh, W.J. (1987). Patterns of recruitment and spawning in Hawaiian reef fishes. *Env. Biol. Fish.* **18**(4), 257-276.

Wells, S.M. (1984). What's happening to the coral reefs? Part 1. *ICLARM Newsletter* 7(4), 12-13.

White, A. (1984a). Effects of protective management on coral reefs in the Philippines. *ICLARM Newsletter* 7(4), 9-11.

White, A.T. (1984b). *Marine parks and preserves: Management for Philippine, Indonesian, and Malaysian coastal reef environments. Unpubl. PhD dissertation,* Geog. Univ. of Hawaii. 274 pp.

White, A.T. (1988). *Chaetodon* occurrence relative to coral reef habitats in the Philippines with implications for reef assessment. *Proc. 6th Int. Coral Reef Symp.* Vol. **2**., pp. 427-432. Townsville, Australia.

Whitehead, M., Gilmore, J., Eager, E., McGinnity, P., Craik, W. and McCleod, P. (1986). Aquarium fishes and their collection in the Great Barrier Reef region. *Great Barrier Reef Marine Park Authority Technical Memorandum.* GBRMPA-TM-13, 39 pp.

Williams, D.McB. (1983). Daily, monthly and yearly variability in recruitment of a guild of coral reef fishes. *Mar. Ecol. Prog. Ser.* **10**, 231-237.

Williamson, G.B. (1978). A comment on equilibrium turnover rates for islands. *Am. Nat.* **112**, 241-243.

Wood, E. (1983). *Corals of the World.* T.F.H. Publ. Inc., Ltd. Neptune City, New Jersey. 256 pp.

Wood, E. (1985). *Exploitation of coral reef fishes for the aquarium trade.* 4 Gloucester Road, Ross-on-Wye, Herefordshire HR9 5BU: Marine Conservation Society. 121 pp.

Woodley, S.J. (1985). The Great Barrier Reef Marine Park: the management challenge. *Proc. 5th Int. Coral Reef Cong.* **4**, 259-264. Tahiti, French Polynesia.

Wright, A. (1989). Current research activities associated with fisheries development in South Pacific Forum Countries. *FFA Report* **89/92**. South Pacific Forum Fisheries Agency, Honiara, Solomon Islands. 49pp.