The potential for the restoration of marine ornamental fish populations through hatchery releases

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ABSTRACT

Populations of tropical and subtropical marine fish are being depleted worldwide to supply increasing demands of the aquarium industry and fresh seafood market. Overfishing and destructive harvest techniques have left some marine fish populations virtually extirpated in a number of primarily underdeveloped countries. In situations where only small remnant populations and significantly degraded habitat remain, population recovery even under the complete absence of collection will be slow, with the high potential for population loss due to natural environmental and recruitment variability. Stock enhancement, supplementing natural recruitment with hatchery produced fry, has the potential to significantly increase the rate of population recovery while maintaining population vigor.

Stock enhancement research on Pacific threadfin has demonstrated measurable positive impacts on recreational and commercial fisheries for this species in experimental scale releases; similar successes can be expected for enhancement efforts directed toward species of ornamental value. The major technological barrier to ornamental fish enhancement, the development of appropriate culture capabilities, is being addressed in research directed to the commercial production of fish for the aquarium trade.

INTRODUCTION

The global trade in ornamental fishes (both fresh and salt water) has been estimated at nearly one billion dollars (Young, 1997), with marine ornamentals comprising between 10–20% of the total value (Andrews, 1990; Pyle, 1993). As is the case with a majority of the world's commercial fisheries, many populations of marine ornamental fish are severely depleted. Localized declines in butterflyfishes in Sri Lanka and anemonefishes in Kenya (Lubbock and Polunin, 1975) and declines in abundance of eight species of marine ornamentals in Kona, Hawaii, targeted by aquarium collectors (Tissot and Hallacher, 1999) were attributed to over collection. Landings of marine ornamentals (live rock, other invertebrates and fish) in Florida increased from 1990 through 1994, then decreased, despite increases in collection permit holders (Lee *et al.*, 1999). Decreases in landings after 1994 in the face of increased collection effort signals the onset of overfishing and resource depletion.

In addition to overfishing, various methods used to collect ornamental fish, ranging from simple surround nets which may dislodge fragile corals, to the use of poisons (Lubbock and Polunin, 1975) which can cause widespread coral destruction, have themselves altered or destroyed essential habitat (Lubbock and Polunin, 1975; Randall, 1987; Johannes and Riepen, 1995). Overfishing and

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destructive fishing represent some of the greatest threats to reefs worldwide (World Resources Institute, 1998). Drive-in and blast fishing utilize highly-destructive and non-selective methods to collect food fish (Carpenter and Alcala, 1977; McManus, 1997), destroying the common reef habitats which support both food and ornamental fish.

The demand for marine ornamentals is expected to increase, with resultant continued overfishing and habitat destruction. Much of the market demand for the more popular ornamentals such as clownfish, yellow tangs and angelfish may eventually be satisfied with cultured fish, once culture technologies have been established (Main *et al.*, 1999). However, the ready availability of cultured species could decrease their desirability for collectors, placing increased collection pressure on rare, non-cultured species.

As with the recreational and commercial fisheries, resource managers of a depleted ornamental fishery have several management options: regulation of wild collection (closed seasons; limits on gear types and/or sizes; total ban on collecting), restoration of degraded habitat (coral transplantation; construction of artificial reefs) and establishment of natural reserves (see Friedlander, 2000). However, these options depend for recovery on natural recruitment processes, which can be slow for severely depleted populations (Shaffer, 1987), and are subject to high inter-annual variability (Hjort, 1914; Cushing, 1975; Lasker, 1978; Houde, 1987; Salminen *et al.*, 1995).

Another management option for ornamental species that is just beginning to receive consideration by resource managers for commercial and recreational marine fisheries is stock enhancement, the restoration of depleted fisheries through release of hatchery-reared fish. Stock enhancement is expected to decrease the recovery time of a depleted population, compared to other management options, by reducing larval and early juvenile mortality and decreasing inter-annual recruitment variability. For ornamental species with specific juvenile recruit habitat requirements (e.g. particular species of coral for damselfish: Tolimieri, 1995; patches of sand-rubble for coral trout: Light and Jones, 1997), directed releases can also focus recruitment on the best available habitat.

MARINE STOCK ENHANCEMENT FOR COMMERCIAL AND RECREATIONAL SPECIES

The enhancement of marine wild fish stocks has only begun to be developed as a responsible management tool. Throughout the world, enhancement is now being examined and assessed in a systematic and comprehensive way (Howell *et al.*, 1998). Technological developments in culture and tagging technology now provide the capability to perform quantitative enhancement experiments with large numbers of healthy fry. Culture technology development for some marine fishes has progressed to the point where we understand and can control the culture requirements that are necessary to produce large numbers of fingerlings on demand. Similar efforts are being directed toward the development of culture capability for ornamental fish. While tagging technologies for recreational and commercial fishes primarily uses coded-wire tags on fish at least 50 mm in length, chemical marking (Tsukamoto *et al.*, 1989) is an option for ornamental fry which typically recruit at smaller (20 mm) sizes.

World-wide, enhancement experiments on fish and invertebrates have been performed to determine optimal release strategies, examining the effects of size at release, season of release, and release sites on survival through the juvenile stage or recruitment to the fishery (Tsukamoto *et al.*, 1989; Bannister and Howard, 1991; Kitada *et al.*, 1992; Kent *et al.*, 1995; Leber, 1995; Leber *et al.*, 1995; Willis *et al.*, 1995; Ziemann *et al.*, 1998), and positive contributions to local fisheries have been demonstrated (Kitada *et al.*, 1992; Leber *et al.*, 1995; Friedlander and Ziemann, in press).

The questions that arise from an ability to implement stock enhancement relate to an understanding of the system into which fish are being released and the ability to design enhancement programs which have positive impacts to the fishery without causing negative impacts to the wild stocks or the environment (Blankenship and Leber, 1995; Munro and Bell, 1997). General guidelines for a responsible approach to the design and implementation of stock enhancement programs have been developed (Blankenship and Leber, 1995). Specific technical areas of concern for enhancement research and implementation have also been highlighted (Pruder *et al.*, 1999).

Major technical components of a responsible enhancement program are:

- Species selection: select species that are designated as overfished;
- Culture technology: establish broodstock population, develop maturation, spawning, hatchery and nursery capability;
- Fishery demographics and ecology: establish basic information on essential fish habitat, population demographics, basic ecological features of selected species;
- Genetics management: determine wild stock genetic structure, develop genetics management plan for broodstock to maintain wild stock genetic variability;
- Health management: develop health management and quarantine guidelines;
- Tagging technology: develop or adapt tagging technology (internal tags, chemical or genetic markers);
- Behavior and conditioning: assess critical wild fish behavior, compare wild and cultured fish behavioral patterns, develop conditioning protocols;
- Release and recovery strategies: develop transport protocols, design release experiments, conduct release optimization experiments (size, site and season);
- Cost/benefit analysis: determine relative cost to produce fry, assess direct and indirect benefits of enhancement.

STOCK ENHANCEMENT OF PACIFIC THREADFIN IN HAWAII

Many of the factors which would need to be considered in the enhancement of marine ornamentals have been examined for species of recreational or commercial importance. The research conducted at the Oceanic Institute on Pacific threadfin

(*Polydactylus sexfilis*, known locally as moi) (Ziemann *et al.*, 1998; Ziemann and Friedlander, in press; Friedlander and Ziemann, in press) can serve as a model for potential enhancement research focused on marine ornamentals. The objectives in examining release strategies were to determine optimal combinations of release site, season and size to increase the relative survival of released fish, and to quantitatively measure enhancement success as the recruitment of cultured moi into the recreational fishery.

For some ornamental species, body size and substrate for settlement are specific (e.g. many species of damselfish settle onto particular species of coral: Meekan *et al.*, 1995). Many other ornamentals have less specific recruitment requirements, and experiments to examine the effects of release size, season and site will be necessary to optimize enhancement releases. The design of such experiments has been developed for Pacific threadfin and other species.

Pilot-scale release experiments of cultured Pacific threadfin were conducted from 1993 to 1997 (Ziemann *et al.*, 1998). During this period, over 345,000 cultured juveniles were released into Hawaiian coastal waters to evaluate release strategies for this species, to assess the influence of numbers released on recruitment success, and the impact of released fish on the recreational fishery. The general strategy of experiments conducted in 1993, 1994, 1996, and 1997 was to release approximately 10,000–100,000 coded-wire-tagged juveniles at each of two sites, using various sizes of fish (spanning 48–150 mm, fork length) and at different seasons. In subsequent months, tagged fish were recaptured to monitor their survival and growth in the nursery habitats, and their recruitment to the fishery. During three of the four release years (1993, 1994, and 1996) and at all release sites during those years, the largest size class (110–130 mm fork length) of fish released had the highest relative survival rate, as indicated by the number of specimens recaptured by beach seine in the months following release. This same trend persisted for fish that had recruited to the fishery, defined here as those having reached the State minimum legal size limit of 7 inches TL ($\sim$145 mm FL) and having been in the wild for more than 30 days after release. During the fourth release year (1997), there was no clear size-related pattern in survival, although the smaller size classes did appear to have slightly higher recapture percentages. The differences in size-related survival between years suggests that the factors controlling juvenile survival vary between years, related to annual changes in physical or biological conditions in the nursery habitat (Ziemann and Friedlander, in press).

The recruitment of ornamentals to reef habitats is highly seasonal (Russell *et al.*, 1977; Eckert, 1984). Experiments to examine the effects of season and release size for captive bred ornamentals could follow the designs used for other species such as mullet (Leber *et al.*, 1997) and Pacific threadfin (Ziemann *et al.*, 1998). Leber *et al.*, (1997) observed no difference in survival between five size classes of striped mullet released into appropriate habitat in spring. They observed significant differences in size-related survival for releases conducted in summer, with large fish surviving at higher rates than small fish. They hypothesized that the seasonal differences in size-related survival were due to greater predation on larger fingerlings during spring rather than lower survival of smaller fingerlings during the summer.

One of the issues associated with conducting a stock enhancement program is establishing the appropriate number of fish to be released. Among the factors involved in this decision is determining the capacity of the nursery habitat for survival and growth of juvenile fish and the likelihood of released fish reaching adult/reproductive stage (Miller *et al.*, 1997). The quality of the nursery habitat depends on a range of attributes (temperature, salinity, turbidity, food availability, etc.) that are interdependent and cannot be viewed in isolation from one another (Gibson, 1994). High quality habitats are assumed to be those where growth, survival, and future reproductive potential are optimized for the species in question.

The capacity of the nursery habitat to support juvenile fish is based on both physical and biological factors. For ornamental as well as food fish, important spatial physical factors include substrate type, habitat complexity, and proximity to adjacent habitats (Sale, 1972; Luckhurst and Luckhurst, 1978; Carr, 1991; Booth, 1992). Temporal physical factors include changes in temperature, salinity, turbidity, river input, and wave energy. Predation and competition for resources are important biological processes that can influence the abundance, distribution and survival of juveniles in the nursery habitat (Sweatman, 1985, 1988; Jones, 1987; Booth, 1992).

Experiments utilizing releases of hatchery-reared fish can be conducted to address fishery issues. As part of a stock enhancement program for Pacific threadfin in Hawaii, over 340,000 fingerlings were tagged and released in sandy shoreline nursery habitats along the windward coast of Oahu between 1993 and 1997. A variety of stocking densities and release habitats provided an opportunity to examine density-dependent effects on survival, growth, and migration patterns over a range of conditions (Ziemann and Friedlander, in press). More than 180,000 threadfin were released into Kahana Bay, with numbers per release ranging from 10,000–99,000 fish. Catch rates of hatchery-reared threadfin in Kahana Bay increased with stocking density up to 40,000 fish, and then declined slightly with the release of 99,000 individuals. Adjacent sites showed a linear increase in catch rates of hatchery-reared fish with increased stocking density in Kahana Bay, supporting the hypothesis that high stocking density resulted in emigration to nearby habitats.

The quantity of nursery habitat available, because of its demonstrable relationship with stock abundance, may be the most important factor in determining overall levels of recruitment in the juvenile phase. Many reef fish have been shown to exhibit specific substrate requirements ('quality'). No matter how good the quality of the habitat, if habitat is not present in sufficient quantity for successful recruitment (Tolimieri, 1995; Light and Jones, 1997; Lewis, 1997) then recruitment and survival is bound to be affected (Smith and Tyler, 1972; Jones, 1991).

The nursery habitat for Pacific threadfin juveniles is generally limited to the shallow breaker zone along sandy beaches. Such habitat is generally discontinuous, being separated by reaches of rocky coast or headlands. The amount of physical substrate available to juveniles may be a limiting factor for juvenile threadfin survival. In the experiment described above, density-dependent growth of hatchery-reared threadfin in Kahana Bay was evident from declining growth rates with increased stocking density. The growth rates showed that crowding and food limitation might inhibit growth of hatchery-reared threadfin in small bays such as Kahana. The release of approximately 97,000 fish in Kailua, a much larger bay, did not appear to affect the growth of hatchery-reared threadfin during the 1997 release year.

The quantity of suitable nursery habitat available to a species may have far-reaching effects on its population size (Brock *et al.*, 1979; Walsh, 1985). Habitats of limited extent can only support limited populations. Limitations on habitat quantity can apply throughout the life of an individual or at a particular stage. In the case of Pacific threadfin, where nursery habitat appears to be limited to a narrow band of high wave activity, sandy beach environment, and for some ornamentals whose nursery habitat may be individual coral heads (Tolimieri, 1995), these various habitats can be disjunct, i.e. limited in physical size and separated by more or less extensive areas of inhospitable or otherwise inappropriate habitat. The availability of this habitat may also change over time, e.g. in some instances, sandy beaches may be formed or eroded away depending on the strength and direction of the wave regime, and coral heads may be destroyed by storm surge, and thus unavailable for recruitment at the time of larval settlement.

A critical question for stock enhancement of all fish species seems to be whether nursery areas are ever saturated with settling larvae. Three primary models have been developed to explain the population dynamics of reef fish (resource limitation model, recruitment limitation model, predation control model). The recruitment limitation model maintains that the supply of larvae is insufficient to saturate the nursery habitat (Doherty, 1981, 1983; Jones, 1991; Doherty and Fowler, 1994). If that situation is true for a particular species, then the addition of hatchery-reared fingerlings may enhance annual recruitment. If habitat saturation is a regular occurrence, however, then annual differences in the numbers of eggs produced and early larval survival will have little effect on juvenile recruitment variability, and enhancement will not provide any significant benefit to recruitment. If, however, saturation is a rare phenomenon, annual fluctuations in larval supply to the nursery grounds will generate variability in the annual number of recruits which will subsequently only be dampened by density-dependent processes such as competition for resources or predation during the juvenile phase.

The limits of carrying capacity in nursery habitats can have important implications for development of a stock enhancement strategy. Carrying capacity based on the area or volume of physical habitat can function to set an absolute upper limit on the number of individuals that survive to recruit to the fishery (sum of wild and stocked) per year. In order to maximize the effectiveness of a stocking program operating in such a density-limiting environment, multiple small releases at many sites rather than large releases at a few sites would be required (Ziemann and Friedlander, in press).

Except in cases where the natural stocks have been eliminated or critical habitat has been lost, stock enhancement should be seen as a short-term effort to supplement natural recruitment until the native stock has recovered to levels that are again self-sustaining. One scenario for such an enhancement effort could be large releases over a short (e.g. five year) period, in combination with restrictions on catch. However, such a rapid recovery plan may not be feasible if habitat size restricts the absolute numbers of releases. For example, it has been shown for Kahana Bay that not only is Pacific threadfin juvenile survival diminished but growth is also inhibited in high stocking density environments (Ziemann and Friedlander, in press).

The bottleneck to recruitment presented by poor juvenile survival may be overcome, in some instances, by releasing fish that have been hatchery-reared to the adult stage, thus bypassing the juvenile survival limitations imposed by habitat size and losses due to predation. The capability to raise large numbers of fish under healthy conditions for later release as adults is generally available, however the costs involved may outweigh the benefits to the fishery that would be gained by a more rapid recovery.

POTENTIAL ROLE OF STOCK ENHANCEMENT IN THE RESTORATION OF ORNAMENTAL FISHES

The application of the stock enhancement concept to ornamental fishes presents considerable challenges due to the various species' particular characteristics. Significant differences in life histories and behaviors exist between ornamental fishes and the coastal fishes (e.g. striped mullet, Pacific threadfin, red drum, snook) heretofore examined in stock enhancement research. Some of these differences are summarized in Table 1.

Table 1. Comparison of ecological and life history characteristics of coastal marine fish species for which stock enhancement research has been done and marine ornamental fish

Characteristic	Coastal species (Pacific threadfin (*Polydactylus sexfilis*) Striped mullet (*Mugil cephalus*))	Ornamental species (various kinds)
Reproductive age	Early reproducers (age 1–3 years)	Late reproducers (often age 5+ years) e.g. Surgeonfishes, wrasses
Spawning strategy	Group spawners	Form spawning pairs e.g. Anemonefish, angelfish
Spawning habitat	Pelagic spawners	Benthic spawners e.g. Damselfish, anemonefish
Nursery habitat	Large nursery habitats	Specific, limited nursery habitat e.g. Damselfish, coral trout
Adult range	Large, common adult ranges	Limited territorial adult ranges e.g. Damselfish, angelfish, anemonefish
Habitat carrying capacity	High habitat carrying capacity	Limited habitat carrying capacity e.g. Damselfish, wrasses, angelfish

Experience from research on other marine species shows that the restoration of depleted stocks utilizing hatchery-raised fish is a viable management option (Kitada *et al.*, 1992). Knowledge gained from ongoing culture and enhancement research will support the implementation of responsible restoration and enhancement of marine ornamental fish populations. Stock restoration for ornamental fishes will require, in addition to the capability to spawn and rear fingerlings, attention to aspects of ecology, behavior, genetics, habitat requirements, habitat carrying capacity, and benefit/costs.

Stock enhancement can only act as a component to an integrated management strategy aimed at conserving fish stocks. The underlying problems associated with the Pacific threadfin fishery are similar to those facing many ornamental fish species: intense local harvest as well as habitat loss due to coastal and upland development. An integrated management plan, in addition to stock enhancement, should include licensing of collectors, improved data collection, enforcement of existing regulations and/or changes to these regulations, and the establishment of functional marine protected areas. The National Oceanic and Atmospheric Administration Strategic Plan (NOAA, 1995) identifies three major fisheries management goals, which would apply to ornamental fisheries equally as well as to commercial or recreational fisheries: building sustainable fisheries, recovery of protected species, and sustaining healthy coasts. Management strategies for marine ornamentals which recognize (1) the need to address fishing pressure through regulations based on knowledge of the species' life history; (2) conservation of multi-species complexes and their essential fish habitat; and (3) recovery of depleted stocks through aquaculture-based recruitment enhancement will provide the best opportunity for achieving these management goals.

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