Harvest of Settlement Stage Reef Fish for Small-scale Grow-out or Stock Enhancement; a Feasibility Study on the Family Haemulidae*

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ABSTRACT

Mortality rates of reef fishes are typically very high in the first few weeks after settlement. Capture, rearing and release of reef fish before or shortly after settlement may provide an opportunity to increase survival. Increasing survival at this stage could be a sustainable way of increasing fisheries resources. Visual censuses of juvenile grunts (Haemulidae) during settlement pulses from January to March 2001 and July to September 2001 in Tortola, British Virgin Islands were used to estimate local post-settlement mortality rates on a back-reef, seagrass/sand halo area. Concurrently, settling haemulids were captured from another location and reared in aquaria and sea cages. For fish smaller than 15 mm TL, aquarium-based rearing trials were used to compare the efficacy of feeding with wild-caught plankton or feeding with brine shrimp nauplii. Internally lit sea cages were tested against a plankton-pump food-delivery system for fish larger than 15 mm. Fish growth rates were rapid and mortality rates in sea cages were low for fish greater than 15 mm in size. Results are discussed in relation to potential applications for stock enhancement or mariculture.

KEY WORDS: Post-settlement mortality, post-larval fish feed, settlement-stage reef fishes.

INTRODUCTION

There now exists a wealth of information on the settlement and post settlement stages of coral reef fishes. In particular, the evidence demonstrating the population-limiting role of settlement stage mortality is considerable (Doherty et al in press, Roberts 1996 and references therein, Shulman et al 1987, Watson et al, in review). Exceptionally high mortality rates of many reef fish species during early settlement has led to interest in development of interventionist management strategies (Doherty 1994, Hair et al 2001, Watson et al in review). Harvest of fish before or shortly after settlement may provide an opportunity to increase the resource output from the settlement period. Capturing fish before they are subject to post-settlement mortality, and transferring them to rearing programs, has the potential to yield over 90% more fish than capture of the same cohort two weeks after settlement (Watson et al in review). Preliminary experiments, rearing settlement-stage lutjanids with light attracted plankton, showed that high survival rates and rapid growth is possible (Watson et al 2001). If significant numbers of settlement-stage fish can be reared successfully with low mortality, using low-technology systems, they may be a valuable source of "seed" for small-scale mariculture operations, or localized stock enhancement projects (Doherty 1994). While the economics of such an approach may not be appropriate for application in many commercial fisheries, the method may have application as a fisheries management tool in discrete, over-exploited artisanal fisheries.

This paper examines the mortality rates of haemulids shortly after settlement and the potential use of cheap and simple technology for rearing these fish to a size where mortality rates are much lower. As the recently settled fish are generally very fragile, and have restrictive food requirements, answers to the following questions are needed to assess the feasibility of early harvest and the use of simple rearing systems: What is the level of post-settlement mortality in the wild? Can it be reduced in captivity? How many fish settle each month? Is harvest of low-cost zooplankton food possible? Is it suitable for rearing haemulid fish?

Different species of haemulids often settle together and are indistinguishable from each other at this stage, however post rearing identification revealed that approximately 80% of settlement shoals were French grunt (*Haemulon flavolineatum*). White grunt (*H. plumieri*), Blue-striped grunt (*H. sciurus*) and Tomtate (*H. aurolineatum*) made up most of the remaining 20%. Fish of this family possess the following biological features which make them ideal candidates for such a study. First, they settle in large numbers virtually all year round (McFarland et al 1985), ensuring a constant supply of fish for small-scale grow-out or stock enhancement. Second, cohorts settle onto the same habitats and do not appear to move for two weeks, thereby providing an opportunity to quantify post-settlement mortality rates within this time period. Third, haemulids are planktivorous throughout most of their juvenile life phases, making them ideal candidates for rearing with simple and inexpensive plankton-attraction rearing systems. In addition, later juveniles will readily feed on chopped fish. Fourth, juvenile haemulids have been found to exhibit high site fidelity to daytime resting locations (Helfman et al 1982), a feature which would considerably simplify any stock enhancement experiments. Fifth, adult haemulids are of moderate economic value to small-scale artisanal fishers (Gaut & Munro 1983)

The disadvantages and challenges of working with haemulids lie in the small size of settling individuals (around 8.5 mm total length) (Helfman et al 1982). Fish this size present considerable challenges in rearing, as they are fragile and require very small, live food. They are also extremely sensitive to water temperature, chemistry, parasites and pathogens (Olla et al 1998, Montgomery-Brock et al 2001). Also, haemulids do not appear to be attracted to light (Watson and Munro, in review) and therefore have to be harvested after settlement. This means that some post-settlement mortality occurs prior to collection, reducing the scope for increasing production compared to species that can be caught in light traps prior to settlement.

MATERIALS AND METHODS

Mortality Rates of Settling Fish in the Wild.

This study focused on shallow habitats within the channel between Tortola and Beef Island in the British Virgin Islands because previous censuses showed that settlement-stage haemulids were present in large numbers between sand halo and seagrass habitats adjacent to back reef areas. A 170 m strip of back reef habitat, which was bordered to the east and west by land, was selected. About 200 m to the north, the fore reef dropped to island shelf at a depth of 20 m. To the south, it was bordered by dense seagrass at a depth of 1-3 m extending from the back reef for 50 m and ending in a sandy channel 5 m deep (Fig. 1). A pilot visual census was carried out for two weeks in December 2000 to determine likely settlement sites. Based on observations during the pilot survey, a 10 m by 6 m grid of 4 m^2 quadrats was laid out spanning the sand halo/seagrass interface, so that a line of five 4 m^2 quadrats covered each of three habitats; seagrass, seagrass/sand-halo interface and sand-halo (upper inset, Fig. 1). Numbers of fish on the grid were counted by visual census daily from January to April and July to September 2001 with few interruptions, giving 116 days of observations. Haemulid fish sizes were estimated and grouped into the following categories: 5-15 mm, 16-20 mm, 21-25 mm, 26-30 mm, >30 mm. In addition, the observations from July to September 2001 were extended to cover the whole back-reef area (170 m). Observations from the grid and wider back reef survey were used to generate mean settlement mortality estimates for the 5-15 mm and 16-20 mm size classes. The assumption was made that, if one of the three habitat categories was preferred, then any post-settlement movement of fish was likely to increase observed numbers on the preferred habitat, rather than decrease observed numbers. Thus estimates of mortality from this study may be conservative.

A one-way ANOVA, and post hoc Tukeys test, were used to test the null hypothesis: that there was no difference between the numbers of haemulids settling in sand-halo/seagrass interface habitats and in sand-halo or seagrass habitats.

Growth and Mortality Rates of Fish Fed with Brine Shrimp Nauplii and Plankton.

Haemulids which had settled over-night were carefully captured from a sand patch, 2.5 m deep, 500 m to the south of the settlement study site (Fig. 1). Fish of 6-15 mm could be captured easily by gently herding them towards a 0.3 mm mesh funnel net with a 1 m^2 aperture, which ended in a glass jar. All ‘in water’ movements of fish this size were done slowly and with great care being taken not to startle or stress the fish (earlier attempts at capture using a 1 mm mesh sweep net resulted in 98% mortality within the first two days). Once inside the glass jar, the fish were slowly brought to the surface and placed in a blue plastic bucket of fresh seawater. Fish were then transferred into a 95 l aquarium set up to simulate the sand-halo/seagrass habitat, with substrate and plants taken from the capture site (stocking density 1.58 fish l^{-1}) The aquarium had an under-gravel filter and was divided by a piece of plexiglass fitted with a 0.3 mm mesh window. This allowed for circulation and ensured that microbe content and water chemistry of both sides of the aquarium remained the same.

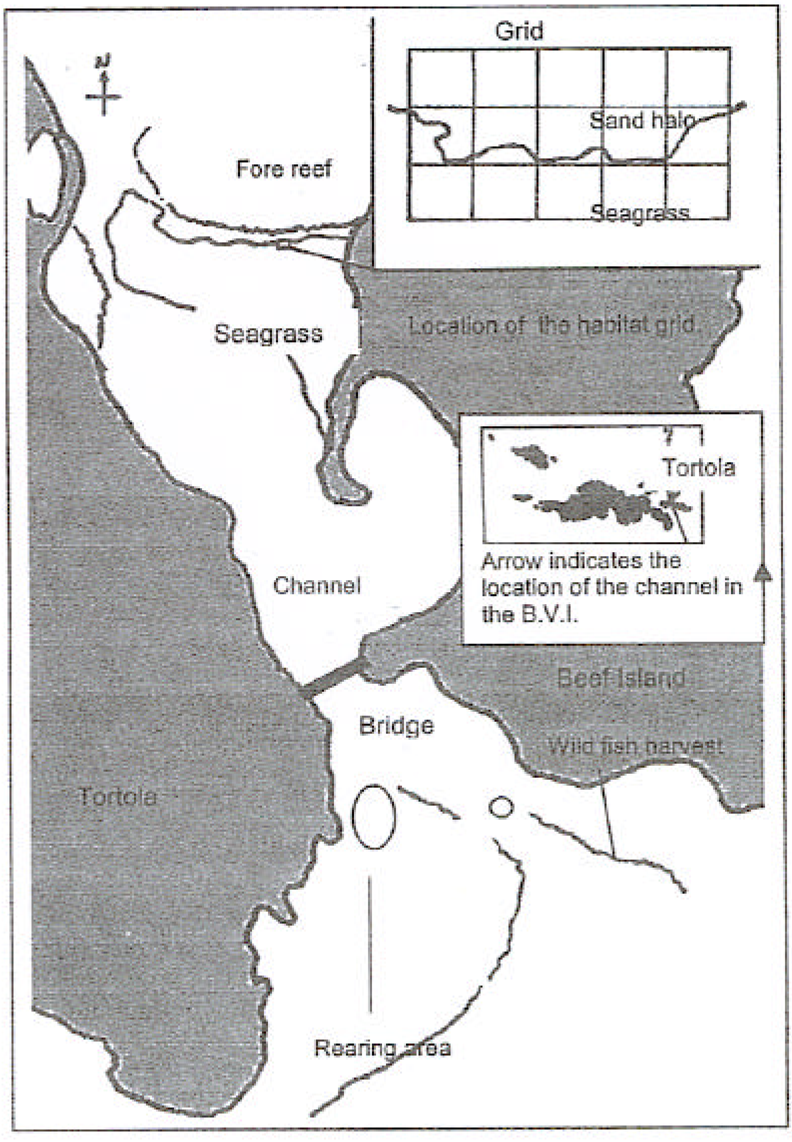

Figure 1. Map of the channel showing location of wild mortality study rearing site for sea cage experiments, and wild fish harvest site

Fish in one side of the aquarium were fed brine shrimp nauplii whereas those on the other were fed live plankton harvested overnight by a plankton-attraction feeding-system (Power and Watson, in review). Prior to feeding the plankton was screened for parasitic isopods. Fish were fed until feeding behaviour ceased, morning, noon and evening. Aquarium water was exchanged with fresh seawater at a rate of ¼ tank day^{-1}. This experiment was run five times, twice for 8 days and three times for 16 days. Treatments were randomly swapped between sides of the aquarium each time. The aquarium was cleaned and reset with fresh substrate between the two, 8-day replicates, but left with the same substrate for the 16-day replicates. Fish were removed at the end of each experimental period, counted and measured against markings on the bottom of a transparent container. They were then transferred to the sea cage rearing experiments (see below). Thus, different fish were used for each of the five trials.

Growth and Mortality Rates of Fish Reared in Sea Cages.

To avoid some of the water quality and intermittent feeding problems associated with rearing the fish in aquaria, fish were also placed in small (6 l) "sea cages" fitted with the plankton pump system described by Power and Watson (in review). The plankton pump minimised water quality problems by providing a flow of water for half an hour of every hour on a 24-hour cycle. This flow of water not only reduced the buildup of waste and microbe populations within the cage, but was also likely to contain small quantities of suspended food during daylight hours to supplement the zooplankton attracted to the light at night. The pump also offered the opportunity to filter plankton before it reached the fish without severely restricting the flow of water through the cage.

Sea cages were situated over 2 m deep seagrass beds adjoining a channel (Fig. 1). Experiments were designed to test a variety of rearing strategies that may have potential for extensive application. The first sea cage experiment used fish that had been in aquaria for 8 days. Three treatments were set up, each with three 6 l cylindrical sea cages of 1mm mesh. Each sea cage was stocked with haemulids (mean TL 17.8 mm) at a density of 3.3 fish l^{-1}. The first treatment was designed to supply and retain plankton filtered by 1 mm mesh, at night, as well as exchange water and supply ambient plankton during the day. The outflow pipes from a plankton pump were fitted with 1mm filter bags and the sea cages were lined with ultra-fine mesh (<0.01mm). The cages were secured so that the outflow pipes delivered filtered plankton directly to the fish. The second treatment was designed to supply filtered plankton at night and exchange water and ambient plankton during the day, without any retaining mechanism. A second plankton pump was fitted with 1mm filter bags and cages as in the first treatment. The third treatment, a control, was designed to attract plankton to a light inside each sea cage, where fish could feed on them at night. This treatment had no water exchange or mechanism to retain plankton or supply it during the day. Three 1 mm mesh sea cages were each fitted with an internal light source (9W, 115V, 0.1 A) before being sealed and suspended one meter below the surface. These treatments were spaced 20 m from each other and run concurrently for a period of 8 days.

A second sea cage experiment was designed to investigate the potential for cheap automation of rearing newly settled haemulids. Fish were caught and transferred to nine 6 l cylindrical sea cages of 1 mm mesh, at a density of 1.6 fish l^{-1}. These cages were split evenly between three experimental treatments. The first treatment was designed to provide the correct size food for the smallest of the fish and retain it throughout the night and day. For this treatment, three outflow pipes from a plankton pump were each fitted first with 1mm and then 0.3 mm mesh filter bags. The three sea cages, which had been lined with ultra-fine mesh (<0.1mm) before being stocked with fish, were then secured to the outflow pipes so that filtered plankton of <0.3 mm diameter was delivered directly to the fish. The second treatment was designed to supply plankton which had passed through a 1mm filter, retain it at night with light attraction, as well as exchange water and ambient plankton during the day. A second plankton pump was fitted with 1mm filter bags and three sea cages with internal lights (9W,115V, 0.1A). In the third treatment, three sea cages were each fitted with an internal light source (9W, 115V, 0.1 A) before being sealed and suspended one meter below the surface. The lights attracted plankton through the 1 mm mesh, where fish could feed on them during darkness. This treatment had no water exchange or mechanism to retain or supply plankton during the day. All treatments were run concurrently for a period of 8 days and spaced 20 meters from each other.

Planktonic Food Supply.

Plankton pump output for the months February to December 2000 was sampled at full moon and new moon. A 200 ?m plankton net and collection jar was attached to one of the outflows of the plankton pump, operated for half an hour each hour, throughout the night. Mean flow from each output was 0.85 l minute^{-1}. The volume of plankters collected each night was estimated from ten 1% sub-samples using a grid marked out with 1 mm squares. Plankters were grouped into the following categories: Copepoda, Mysidacea and unidentified crustacean larvae (after Todd and Laverack 1991). All other plankton forms were excluded from this investigation on the basis of their absence from fish stomach contents. Data were split between new moon and full moon samples and then further split into seasons, defined as the following periods: February-April, May-August and September-December. A two-way ANOVA was used to test the null hypothesis that there were no differences in the supply of plankton between seasons and within lunar cycles.

RESULTS

During a pilot visual census of the area, settlement-stage haemulids were observed in large numbers where the sand halo bordered the seagrass and on small sand patches within the seagrass. Numbers of fish observed further into the sand halo and in dense seagrass were minimal. Mean monthly settlement on the grid for January to June and August was 89.5 (+/- 204; max = 716) fish. Settlers showed a highly significant preference for the sand-halo/seagrass interface habitat ($p = <0.001$), accounting for 70.9% of total number of settlers recorded on the grid. Any movement of fish generally occurred within this habitat with shoals moving <2m overnight. Mean natural mortality after six days, calculated from the relative abundances at each settlement peak, was 65% (SD = 17.3). This correlated well with natural mortality calculated from the 37 day survey of the whole back reef area, which gave a mortality of 58.4% five days after peak settlement and 70% after six days. In addition, after 14 days a conservative mortality estimate of 67% was calculated by addition of surviving numbers of settlers to the subsequent peak in numbers for the succeeding size class (16-20 mm).

Table 1 gives a summary of the most significant results from the aquarium rearing experiments. The lowest mortality after 8 days was 10% for fish fed on brine shrimp and 25% for fish fed on plankton. Fish feeding behaviour between the two treatments appeared to differ little in duration. However, fish appeared to feed selectively on plankton, with prey being expelled after 29% of strikes. In contrast, fish rarely hesitated to consume brine shrimp. Mean mortality for both treatments was lower than 30% with no significant difference in sizes of fish by the end of the trial ($p = 0.32$). Mortality in the 16-day treatments was much higher than for 8 days, with the mortality rate increasing with each successive replicate. Forty percent of dead fish, removed from the final plankton-fed replicate, had spined crustacean larvae lodged in their throats.

Table 1. Summary of results from aquarium rearing experiments with haemulid fishes caught from the wild, shortly after settling.

Fish size	Treatment	Period	Feed time	Mean % mortality	Lowest % mortality	No. replicates	Rearing density fish l^{-1}
6-10 mm	Fed brine shrimp nauplii	8 days	Day	14 +/- 5.7	10	2	1.6
6-10 mm	Fed harvested plankton	8 days	Day	27 +/- 2.9	25	2	1.6
6-10 mm	Fed brine shrimp nauplii	16 days	Day	61 +/- 29.6	27	3	1.6
6-10 mm	Fed harvested plankton	16 days	Day	65 +/- 13.3	66	3	1.6

Stomach contents analysis of eleven plankton-fed fish (9.7 mm, mean TL +/- 1.03) contained 22% copepoda, 34% unidentified crustacean larvae and 44% mysids. Mean volume of stomach contents at satiation was 0.8 mm^3.

The lowest mortality rates from sea cage rearing experiments were achieved with the simple internally illuminated 1 mm mesh sea cage (Tables 2 and 3). Mean mortality rates of settlement size fish (Table 2) did not decrease when they were provided with filtered plankton or when plankton was retained during the day, although one replicate had 10% mortality. Mean mortality rates of fish pre-reared in aquaria (Table 3) and fed filtered plankton from the plankton pump was very high in the treatment where no retaining mechanism was provided, and not significantly lower than the wild mortality where food was retained.

Table 2. Summary of results from sea cage rearing experiments with haemulid fishes caught from the wild, shortly after settling.

Fish size	Treatment	Period	Feed time	Mean % mortality	Lowest % mortality	No. replicates	Rearing density fish l^{-1}
6-10 mm	Fed plankton: light inside cage	8 days	Night	29 +/- 25.4	7	3	1.6
6-10 mm	Fed plankton: Plankton pump, ultra fine mesh & 0.3mm filter.	8 days	Night & Day	60 +/- 45.8	10	3	1.6
6-10 mm	Fed plankton: Plankton pump, 1mm filter & light in cage.	8 days	Night	50 +/- 20	30	3	1.6

Table 3. Summary of results from cage rearing experiments with haemulid fishes which were pre-reared in aquaria for 8 days.

Fish size	Treatment	Period	Feed time	Mean % mortality	Lowest % mortality	No. replicates	Rearing density fish l^{-1}
16-20 mm	Fed plankton: light inside cage	8 days	Night	0	0	3	3.3
16-20 mm	Fed plankton: Plankton pump, ultra fine mesh & 1 mm filter.	8 days	Night & Day	83 +/- 10.4	75	3	3.3
16-20 mm	Fed plankton: Plankton pump, 1mm filter.	8 days	Night	92 +/- 2.8	90	3	3.3

Planktonic food supply varied throughout the year with significantly greater numbers of copepods and unidentified crustacean larvae being caught from September-December (p= <0.001 & <0.001 respectively), while mysid volumes were four times higher during May-December than in February-May. Differences in volumes of plankton between full moon and new moon were not significant for crustacean larvae (p= >0.9), but were significant for copepods and mysids (p = <0.001 and <0.001 respectively) with higher volumes at full moon. Interaction between moon phase and season was highly significant (p= <0.001). Comparison of mean volumes of plankton output for the three categories present in fish stomachs (Fig. 2), with mean volume of stomach contents, gave a crude estimate for the number of fish that may be reared with a plankton based diet from each plankton pump output (four to each pump). This estimate was based on fish feeding to satiation four times in an eight hour feeding period; double the feeding rate used for hatchery rearing lutjanid postlarvae (Turano et al 2000). This capacity was estimated at between 270 and 280 fish (9.7 mm mean TL).

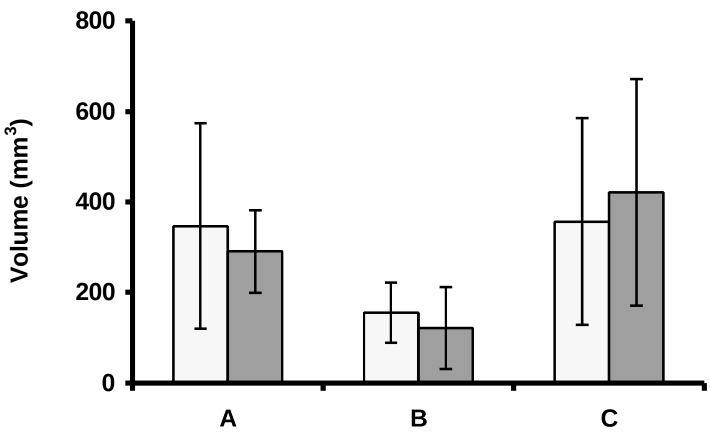

Figure 2. Mean total volumes of planktonic food per sample for 10 months February-December 2000. A Copepoda, B unidentified crustacean larvae and C Mysidacea. Full moon; dots and new moon; gravel. Error bars indicate 95% CI.

DISCUSSION

The greatest mortality of haemulid post-larvae in the wild occurs during the first six days after settlement, with only ~30% of fish surviving beyond 14 days. Whilst we cannot entirely rule out the effects of movement from this calculation it would appear that these results are consistent with estimates from other studies of settlement mortality (Doherty et al in press, Sulman & Ogden 1987, Roberts 1996 and references therein, Watson et al in review).

The results (Table 1) from feeding with brine shrimp nauplii and filtered plankton in aquaria show that the survival of recently settled haemulids can be increased substantially by rearing them in captivity. The best results from a combination of rearing strategies show that 10% mortality at 14 days can be achieved using a combination of feeding with brine shrimp nauplii and subsequent rearing in sea cages. Rearing fish in sea cages from settlement yielded 7% mortality. Mean mortality rates from each treatment present a slightly different picture with projected mortality at 16 days of around 30%. Even so, this still represents a large potential increase in production compared to natural rates of mortality. The high survival (100%) of fish reared from 8-16 days with internally illuminated sea cages, indicates that subsequent grow-out is likely to have low mortality. The same cannot be said for wild cohorts, where an average of 5% may reach maturity (Sulman et al 1987). Preliminary extended rearing trials of up to 40 days show mortality lower than 5% between day 16 and day 40 is possible, but observations indicate that interspecific aggression may increase with size. It would be advisable, therefore, to separate species as early as possible. The appropriate age for release of reared fish has yet to be determined. However, Helfman et al (1982) suggest that juveniles between 40 and 120 mm TL which have succeeded in learning the appropriate gregarious forage and resting behaviour, are far less likely to be preyed upon than smaller fish. If reared fish can be habilitated in a predator free environment with wild individuals at this size (Olla et al 1998), their mortality may be similarly low.

Some of the results point to areas for improvement and problems with the use of plankton as a cheap food. The fact that dead fish were found with spined crustacean larvae lodged in their throats appears to point to a breakdown in the normal prey selection behaviour. It is possible that early morning delays in supplying plankton to fish may disrupt their natural dawn feeding behaviour and result in hasty and inappropriate prey selection. While plankton supplies were variable, samples always contained more than enough food of the right size and variety. Interestingly, attempts to improve early sea cage rearing with various plankton filtering and retaining mechanisms, proved far less effective than a 1 mm mesh 6 l sea cage with an internal light. There appeared to be no adverse effects to fish from the reversal of the natural daylight feeding behaviour. Results from this rearing method may be improved by taking measures to control external parasites with techniques like hydrogen peroxide dips (Montgomery-Brock et al 2001).

This study shows that there is considerable potential for increasing the survival of fish at settlement, thereby creating a way to improve fisheries production by growing-out the additional fish in small-scale mariculture operations or in stock enhancement programs.

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