Use of Light-attracted Zooplankton for Rearing Post-settlement Coral Reef Fish

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KEY WORDS: Juvenile mortality, light attracted plankton, recruitment

ABSTRACT

Settlement stage *Lutjanus synagris* and *Ocyurus chrysurus* were caught in light traps set off fore reefs in the British Virgin Islands and raised in floating mesh cages tethered in water 1 - 2 m deep. Lights were designed to attract plankton into the cages and provide live natural food for the fish. Plankton taxonomic composition around lights was compared with samples from plankton tows in adjacent water, as well as with gut contents of cage reared and wild fish. Fish mortality and growth were followed over the first few weeks of life and compared with results from a field trial assessing natural mortality and growth. Cage rearing reduces the exceptionally high early post-settlement mortality typical of *Ocyurus chrysurus* from approximately 80% to 40% within the first month. We suggest two uses for this technique, a) to help speed recovery of over-exploited stocks within no-take marine reserves b) to rear settlement stage ornamental species until they are large enough to survive on artificial food. Light traps and cage culture in combination could replace destructive fishing practices on reefs exploited for the aquarium trade.

INTRODUCTION

Light attracted plankton has previously been investigated for culture of freshwater pike-perch *(Stizostedion lucioperca)* fry (Schlumpberger and Ziebarth 1981, Jaeger and Nellen 1983, Jaeger et al. 1984, all cited in Hilge and Steffens 1996). This paper reports preliminary investigations into the feasibility of collecting settlement stage reef fish and rearing them past their initial mortality hurdle by using light attracted zooplankton as food. High post settlement mortality is typical of many coral reef fishes. Shulman and Ogden (1987) found >90% natural mortality in French grunts *Haemulon flavolineatum* during the month after settlement, and this rate may be characteristic for species that settle in pulses, and/or form schooling aggregations of juveniles (Roberts 1996, and references therein).

We discusses potential uses for this rearing technology both to enhance recovery of recruitment overfished reef fish stocks within protected areas and to provide a non-destructive alternative income for fishers raising ornamental species for the aquarium trade.

MATERIALS AND METHODS

Settlement stage reef fishes were caught using light traps modified from a design by Stobutzki and Bellwood (1997). The traps consisted of 40 x 40 x 40 cm aluminium 'angle-iron' frames supporting transparent plexiglas panels. On each side of the trap a clear funnel ran the height or width of the cube, (two vertical and two horizontal) each with an opening of 12mm. The light was a 'stand alone' system inserted into the top of the main trap. It consisted of an O'ring sealed plastic box, housing two six volt rechargeable batteries and connected to a clear plastic tube containing an 8 watt fluorescent bulb. A light sensitive switch mounted on the top of each light box turned the trap on at dusk and off at dawn. An advantage of this modular design is that changing batteries and mending equipment did not require the entire light trap to be taken ashore. Buckets set beneath the main trap retained the fish as traps were hauled. Traps were set at a depth of 2 m, 100 - 200 m offshore of three fringing reefs on Tortola, British Virgin Islands around new moon periods in 1998 and 1999. Commercially important yellowtail and lane snappers (*Ocyurus chrysurus*, *Lutjanus synagris*) caught in light traps were reared in floating cages (125 L, mesh size 3 mm) tethered in 1 - 2 m of water for approximately one month to investigate the feasibility of rearing reef fish on light attracted plankton. At night, each cage was lit with either an 8 watt light module from the light traps or a 9 watt mains powered light sealed with silicone into plastic drinks bottles and appropriately fused. All cages were regularly scrubbed of algae. The order and variety of experiments described below were unavoidably constrained by unpredictable availability of fishes in monthly settlement pulses over the recruitment season.

Early Mortality in Caged and Wild Fish

Survival of *Lutjanus synagris* reared under two different stress regimes was examined to isolate the effect of handling stress on survival. For two cages (both with 45 fish initially) handling stress at first capture from the light trap was minimised by not touching the fish and by keeping them in extra large aerated buckets until placing them in the cage as the earliest opportunity. One group was counted and measured every week, while the other was sampled only fortnightly. *L synagris* reared in two other cages (with initial numbers of 35 and 40) received no special treatment at capture and were both sampled weekly. Survival of *O. chrysurus* in two cages (initial n = 35 and 63) was recorded weekly to investigate density dependence in mortality.

As part of a parallel study, early juvenile natural mortality of *O. chrysurus* was estimated from daily censuses of an area of seagrass 25 x 50 x 1-1.5 m in depth. The area was divided into 5 x 5 m squares. One observer swum concentrically around each individual section until the entire area of each square was covered. Each census took a total of 2 - 2.5 hours. Daily censuses were performed during the 11 days leading up to peak settlement in September 1999 and for six days following. Over the next nine days a different observer conducted censuses. Resumption of observations by the original observer identified bias in numbers of fish observed (but not the proportion of size classes – see section on growth below) and nine days data were dropped from the analysis of mortality. Observations then continued every other day for a further 11 days until the pulse of settlement became indistinguishable from other juveniles. Temporal patterns in abundance were assumed proportional to the processes of settlement and natural mortality (as in McGehee 1995). We also assume disappearance of fish represented mortality rather than movement, and that any emigration from the census area would be balanced by immigration. We base this assumption on the enormous size of the census area relative to observed home ranges of settlement stage *O. chrysurus (*Watson and Gell in prep and see discussion*)*, and on results from a preliminary mark recapture experiment which found elastomer tagged *O. chrysurus* moved only a few metres after settlement (Watson and Gell in prep). The day when the number of settlement size fish peaked (91 compared to only four 10 days earlier) was assumed to represent the settlement event, and numbers of fish remaining over time were expressed as a percentage of that number for comparison with mortality in cage reared fish.

Estimates of Early Juvenile Growth for *L. synagris* and *O. chrysurus*, and Comparison of *O. chrysurus* Growth in Cage Reared and a Natural Population

Early juvenile growth was estimated from weekly measurements of two groups of *O. chrysurus* (n = 35 and 63) and three groups of *L. synagris* as in the mortality section above (n = 45 'low stress', n = 35 and n = 40). Data from the 'low stress' trial measured fortnightly were excluded as there were only two data points. Total lengths of wild fish from the September settlement peak were estimated (to the nearest 0.5 cm) during daily censuses of the seagrass grid until the cohort could no longer be clearly distinguished (about 25 days). Modal length from field observations was plotted against modal length of *O. chrysurus* (grouped to the nearest 0.5 cm) reared in two cages in order to compare growth of captured and wild fish.

Food Availability and Feeding Preferences

Zooplankton was sampled from water adjacent to floating cages using a mini-plankton net (30 cm diameter aperture) towed at approximately one knot for five minutes. Zooplankton attracted into cages was sampled with two swipes of a dip-net in an empty cage every five minutes over a 25 minute period. Gut contents were analysed for seventeen cage-reared *O. chrysurus* (total length 20-40mm) caught at night. Gut contents were also analysed for ten wild *O. chrysurus* (22 - 50 mm total length) caught during the day. Percent composition by volume in the water samples and in fish guts (individuals within each sample pooled) were compared to examine selective feeding behaviour.

RESULTS

Early Mortality in Caged and Wild Fish

Survival of *L. synagris* was greater in 'low stress' higher density cages (n = 45) than in 'high stress' lower density cages (n = 35 and n = 40) (Figure 1.). Two cages where initial handling stress was minimized had approximately 80% survival after three weeks, compared to cages stocked at lower initial densities (23% and 12% less fish) where survival was around 50% within two weeks. After initial capture, weekly measuring did not appear to have a marked affect on survival. Thus a large part of early mortality of *L. synagris* (and probably *O. chrysurus*) in cages appears to be due to initial handling stress.

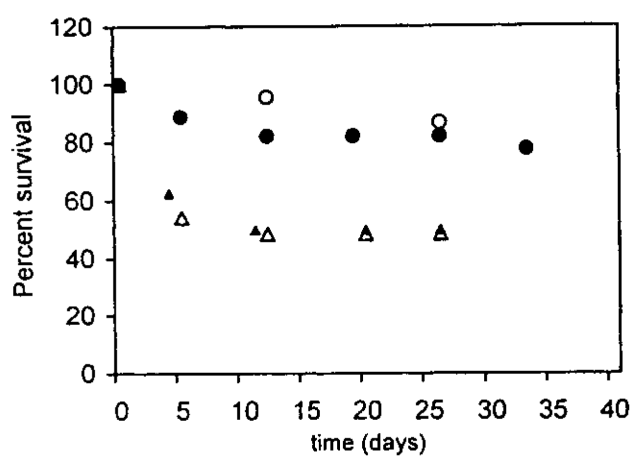

Figure 1. Percent survival of *Lutjanus synagris* against time in cages for four rearing regmines; triangle, initial n = 40; no special treatment; open triangle initial n = 35, no special treatment; circle initial n = 45, 'low stress' regime, sampled weekly; open initial n = 45, 'low stress' regime sampled fortnightly

Survival of *O. chrysurus* at initial densities of n=35 and n=63 over approximately one month were very similar (Figure 2) suggesting that mortality is not density dependent up to at least 0.5 fish per litre. Survival in these two cages was approximately 30% higher than estimates of survival from wild fish after one month (Figure 2). Daily censuses estimated mortality of *O. chrysurus* to be 80% within one month in the wild. Cage reared fish had a mortality of approximately 30-40% over the same time period. Mortality in all three groups fitted exponential curves (see equations on the graphs), i.e. 'type three' mortality. The curve fitted through the wild population was not forced through an intercept of 100% since the actual number of settlers is not known because settlement took place over a number of days during which mortality was already operating.

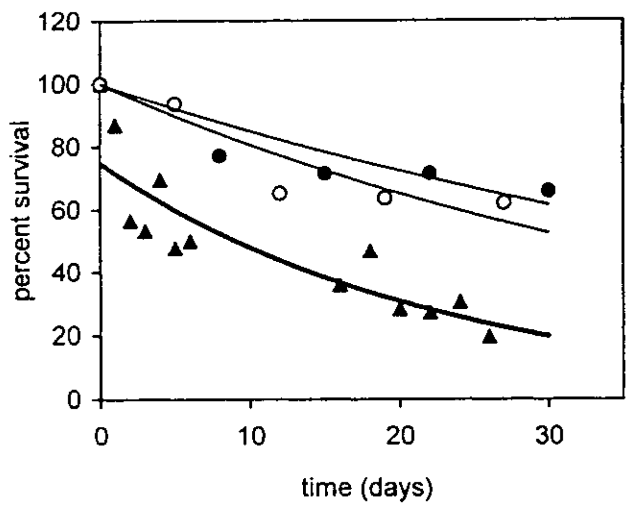

Figure 2. Percent survival against time for *Ocyurus chrysurus* < 1 month since settlement and reared in floating cages (closed circles initial n = 35, $y = 100e^{-0.0162x}$, $r^2 = 0.71$, open circles initial n = 63, $y = 100e^{-0.0125x}$, $r^2 = 0.80$) compared with percent survival in the wild estimated from daily field censuses of one monthly cohort (triangles, $y = 74.831e^{-0.0445x}$, $r^2 = 0.83$)

Comparison of Growth in Natural and Cage Reared Fish.

Early juvenile growth in cages was linear for both *O. chrysurus* and *L. synagris* and shows no signs of density dependence between 0.28 and 0.5 fish per litre (Figure 3 and Figure 4.). Modal length of *O. chrysurus* in cages was not significantly difference to modal length of the September 1999 cohort censused in the wild over the first month (Figure 5).

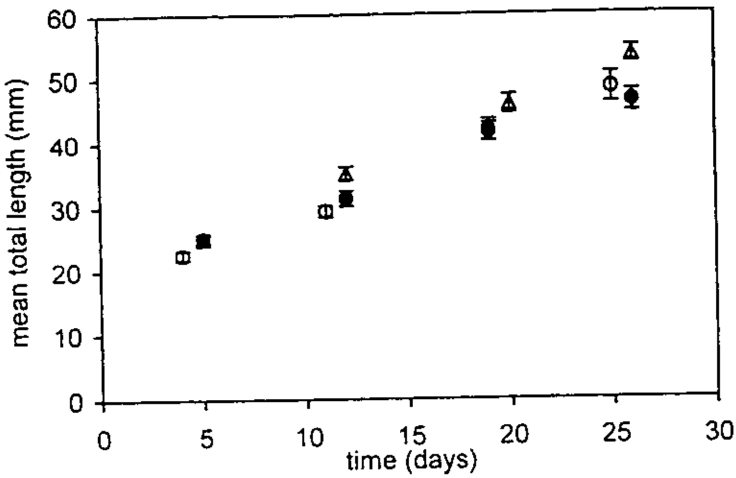

Figure 3. Mean total length (mm) of *Lutjanus synagris* against time in cages for three rearing regimes; closed circle initial, n = 45, 'low stress' y = 1.05*X + 19.7, r^2 = 0.98; triangle initial, n = 35, 'high stress' y = 1.35*X + 18.5, r^2 = 0.99; open circle initial n = 40, 'high stress' y = 1.275*X + 16.72, r^2 = 0.99. Error bars represent 95% confidence levels.

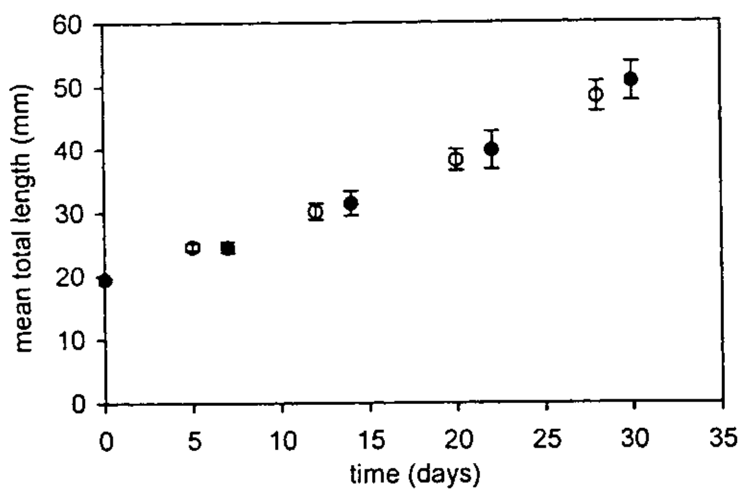

Figure 4. Mean total length (mm) of *Ocyurus chrysurus* against days in cage for two groups; closed circles initial n = 35, y = 1.0383*X = 17.99, r^2 = 0.99; open circles initial n = 63, y = 1.0081*X + 19.01, r^2 = 0.99. Error bars represent 95% confidence levels

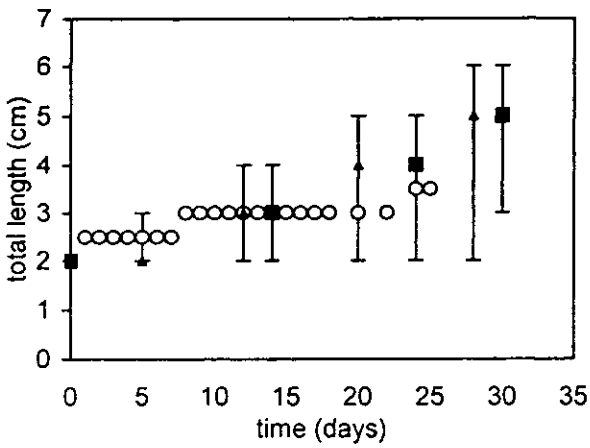

Figure 5. Modal total lengths of *Ocyurus chrysurus* (less than one month since settlement) estimated to the nearest 0.5 cm from field observations (open circles) and two cage culture experiments (square and triangle) against time in days from peak settlement and from date of capture in light traps, respectively. Error bars for caged fish indicate size range.

Food availability and feeding preferences

Zooplankton samples taken from tows in water adjacent to floating cages and from dip-net sweeps inside lighted cages show zooplankton attracted to the lights is similar to that in open water (Figure 6). Both wild and cage reared *O. chrysurus* fed selectively, and included fish (mostly juvenile 'bait fish' - Atherinidae and Clupeidae) in their diet (34% and 13% respectively). These fish, which are attracted to lights, avoided dip-nets and the plankton tow. Malacostraca make up very similar volumes in the diet of both wild and caged fish (43% and 40% respectively). Caged fish also ate annelid worms (23%) attracted up off the bottom by the light. Combined with growth estimates, the data suggest zooplankton provides an adequate food source comparable with a natural diet for early juvenile snappers.

DISCUSSION

Our results demonstrate that the 'low tech', low maintenance technique of rearing reef fish using light attracted plankton supports growth at least equal to that in the wild, and substantially reduces mortality over the first month. We suggest two potential uses of this technique. In coral reef areas where recruitment over-fishing has diminished the supply of new recruits, recovery of fish populations may be extremely slow even if fishing ceases. For example, identical studies comparing reef fish settlement to the heavily exploited reefs on the north Jamaican shelf, and to the moderately exploited reefs in the British Virgin Islands found orders of magnitude differences in settlement rates (Munro and Watson 1998; Munro and Watson 1999), implying that stock recovery will take many years. If reefs are self-seeding recovery may not occur without intervention. Light traps may be a means of catching juvenile reef fish for stock enhancement (Doherty 1994). Using the techniques described here, settlement stage fish could be collected from a relatively large area, reared for several weeks, and concentrated within a marine protected area.

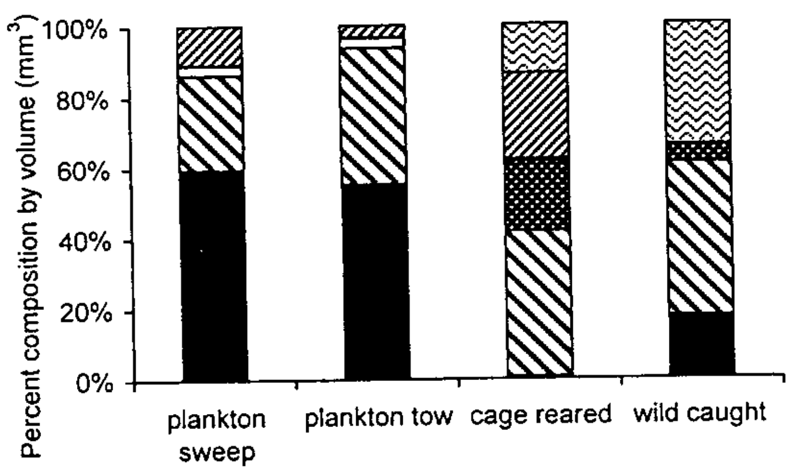

Figure 6. Percent composition by volume for plankton sweeps inside floating cages, a plankton tow in water adjacent to floating cages, and cages reared (n = 17, total length 20 - 40 mm) and wild (n = 10, total length 25 - 53 mm) *Ocyurus chrysurus*. Key: black = Copepoda, grey = Ostracoda, wide hatching = Malacostraca, thin hatchin = Annelida, wavyline = fish, dotted = Crustacean debris

This technology is intended for heavily exploited populations where even a slight increase in juvenile survival from small releases would be valuable. Stock enhancement has been heavily critizised as uneconomic (Hilborn 1998), inappropriate (Scarnecchia 1988, Meffe,1992), difficult to evaluate (Leber et al. 1996, Hilborn 1998), and potentially harmful to wild populations through introduction of disease or through genetic selection for inappropriate characteristics (Schramm and Piper 1995). However, most enhancement efforts have been large scale, expensive 'high tech.' programs raising up to several million fish from eggs to fingerlings. The present approach is low cost, low maintenance, and rears only wild caught stocks on site. Fish are fed with natural food before release to an unfished native habitat. The methods might be suitable for small scale marine protected areas projects in developing countries were coral reef fisheries resources are under the greatest threat.

In this study, cage rearing had the potential to decrease mortality in the first month after settlement from approximately 80% to around 40%. This estimate is probably conservative due to inaccuracies in the censuses of wild fish. It was not possible to measure the true natural settlement rates both because visual observations may miss many fish and because numbers of settling fish increased rapidly over several days and mortality before the settlement peaked was ignored in our analysis. For many reef fishes, mortality is thought to be highest soon after settlement (Victor 1986, Doherty and Sale 1986, Sale and Ferrell 1988). Furthermore, we compared natural mortality with *O. chrysurus* reared in cages before development of faster, low stress handling techniques at capture. Results from *L. synagris* suggest cage mortality can be reduced to around 20% with careful handling.

Perhaps one of the most important criticisms of stock enhancement is that artificially reared fish lack the behaviour necessary to ensure survival in the wild. A parallel study of 'early juvenile' snapper behaviour in seagrasses (Watson and Gell in prep) found that recently settled *O. chrysurus* and *L. synagris* (approximately 2 - 3 cm) remain almost stationary near the bottom and pick plankton from the water column. They rarely move more than 20cm from their initial position and tolerate conspecifics of the same size. However, from approximately 3 - 3.5 cm their range becomes considerably bigger (several square metres), they switch to feeding on benthic invertebrates and act aggressively towards similarly sized conspecifics. Thus cage rearing is probably most suited to rearing fish to approximately 3 - 3.5 cm (3 - 4 weeks).

The present study, which was designed to test the feasibility of the technology, has not addressed the question of whether cage reared fish subsequently released have a higher overall survival than wild fish from the same cohort. High mortality in the first few days after settlement (or release) may be due to unfamiliarity with the habitat. However, rearing in semi-natural environments (Masuda and Tsukamoto 1998 and references therein) and conditioning to the habitat (Olla et al. 1994) have been shown to reduce post release mortality. An evaluation phase is planned for 2000. Despite his many criticisms, Hilborn (1998) concedes that stock enhancement programs are most likely to succeed where wild stocks are essentially gone. This is the case for commercially fished stocks on many overexploited reefs. Even where high mortality makes cost per surviving individuals substantial, the value should be considered in terms of survivor reproductive potential rather than the contribution to stock numbers (Stoner and Glazer 1998).

The second application we suggest for rearing fish on light attracted plankton is to supply ornamental reef fish to the aquarium trade. Widespread use of destructive collecting techniques, such as sodium cyanide, often leads to high mortality in captured fish, does substantial harm to the reef ecosystem, and has made development of sustainable collection techniques an international concern. However, growing consumer demand for 'eco-labled' fish suggests sustainable aquarium fisheries could provide a valuable alternative income for fishers, particularly where overfishing is currently degrading coral reef resources. We suggest fish could be reared on light attracted plankton from late pelagic/settlement size until they are big enough to thrive on artificial food. Catching fish before they reach the 'wall of mouths (Kaufman et al. 1992) on the reef provides an opportunity to avoid high post-settlment mortality. Where natural populations are already overexploited, a proportion of the fish caught for the aquarium trade could also be grown past their initial 'mortality hurdle' and used to enhance natural populations

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