ARTIFICIAL REEF RESEARCH IN BROWARD COUNTY 1993-2000: A SUMMARY REPORT

Submitted to:
Broward County Department of Planning and Environmental Protection
218 SW First Avenue
Fort Lauderdale, FL 33301

Submitted by:
Richard E. Spieler, Ph.D.
Oceanographic Center
Nova Southeastern University
8000 N Ocean Drive
Davie, FL 33004

INTRODUCTION

Broward County Department of Planning and Environmental Protection (DPEP) and Nova Southeastern University (NSU) have been collaborating on artificial reef research for the past seven years. This paper gives a brief overview of ten completed studies from 1993-2000. These studies entailed approximately 1000 hours of artificial reef construction, 2000 hours of SCUBA diving, 1300 hours of boat time and 1000 hours of data analysis. A detailed discussion of the results has been, or will be, published elsewhere (Gilliam et al., 1995; Sherman et al., 1999; Gilliam, 1999; Sherman, 2000; Sherman et al., in press a, b). In addition, detailed reports of the individual studies are available from DPEP (Spieler, 1995a,b; 1998a,b,c; 2000).

The goal of our studies is to examine the functional attributes of artificial reefs as they relate to physical and biological characteristics of the Broward County marine environment. These attributes and characteristics include: species and community recruitment dynamics; attractants; volume; profile; complexity; void space; deployment depth; larval abundance; and seasonality. A number of these aspects have been examined elsewhere but, to the best of our knowledge, the project as a whole is unique in Florida. The project has been undertaken with the express purpose of determining the optimal design criteria for artificial reefs to enhance recreational fishing and other marine resources of Broward County.

Concrete modules of varying designs and numbers are used in the studies. With one exception, a study using stacks of tetrahedrons, the modules are small (about 1 m^3) and used as stand-alone, model reefs (30 m or more from other reefs) in replicates of eight to ten for each experimental treatment (Figures1-6). The methodology of all studies involved visual fish census. This was accomplished by divers using SCUBA who record all fish within 1 m of a reef on a slate marked with five size classes (<2, 2-5, 5-10, 10-20, and 20+ cm). Species, number of fishes, and estimated total length (by size class) of each individual were recorded and the resulting data subjected to statistical analysis.

STUDIES

Study 1: Potential for using tire chips as aggregate in concrete artificial reefs

The purpose of this study was to evaluate, from a biological perspective, a tire-concrete aggregate that uses tire shreds mixed into concrete as a suitable reef building material. Evaluation consisted of comparing the biological assemblages associated with tire-aggregate reefs to standard gravel-aggregate reefs of the same design. Four artificial reefs of tetrahedron modules (Figure. 2) were placed off Fort Lauderdale in seven meters of water, two reefs of each type of aggregate. Each reef contains 25 small (1 m/side) and 25 large (1.3 m/side) tetrahedrons stacked in a random configuration. The reefs were monitored at monthly, or less, intervals for 28 months. The status of the biological assemblages were assayed by: visual census (fishes); underwater-video taping, collection (invertebrates) and scanning electron microscopy (initial microscopic colonizers). The reefs acquired a diverse assemblage of fishes and invertebrates over the course of the study; 105 species of fishes and over 120 taxa of invertebrates were recorded. There were no apparent significant differences among the biological assemblages, between the two types of reefs, which could be readily ascribed to the difference in construction material. Based on these results, it appears that the tire-aggregate is an appropriate material for artificial reef construction and may be an ecologically positive method of tire disposal (Spieler, 1995; Gilliam, et al. 1995).

Study 2: Fish assemblages and recruitment at shallow versus deep-water sites.
Reef Balls™ (Pallet Ball™ configuration, approximately 1.3 m diameter, 1 m high)(Figure. 3) were placed at two sites, eight modules per site. The sites were at depths of 7 m and 21 m, 1.6 km apart, offshore Ft. Lauderdale. The reefs were censused monthly for fishes over a 19 month period. After each monthly census, all fishes were removed from the reefs with a piscicide. A total of 88 species were recorded in the study, with significantly greater diversity on the deep reefs (monthly mean of 7.6 species deep, 3.0 shallow, $p<0.001$, ANOVA). Biomass (calculated from length) and abundance of larger fishes (> 5 cm) were significantly higher on the reefs at 21 m than at 7 m ($p<0.001$). There were more small fishes (< 5 cm) at the shallow site ($p<0.05$). Although it is not clear what variable(s) associated with the two depths is responsible for the differences, our results highlight the potential differences in artificial reef and ambient environment interactions within a localized area (Spieler, 1998b; Sherman et al., 1999).

An additional study, with a different reef type ("Fish-condo") (Figure. 4), also addressed the questions of shallow versus deep reefs and obtained similar results as Study 2 (see discussion of Study 7-10 below). In our area, it appears that artificial reefs designed to recruit forage fishes (grunts) are most effective if placed inshore in shallow water and reefs designed to attract some species of juvenile snappers and grouper are best placed in deeper water.

Study 3: Attractants for settlement on artificial reefs.
This research experimentally examined the hypothesis: recruitment and aggregation of fishes to artificial reefs can be increased by using a floating attractant. The experimental design selected to test this hypothesis consisted of comparing the fish assemblages between two groups of Reef Balls™ (10 Pallet Balls™ each) in 21m water that either have a single 10 m floating line attached (streamer reefs) or no attached line (control reefs).

Streamer reefs did not differ from controls, for total fishes, species, or biomass, for any size class ($P>0.05$, ANOVA). These results do not support a recommendation for the

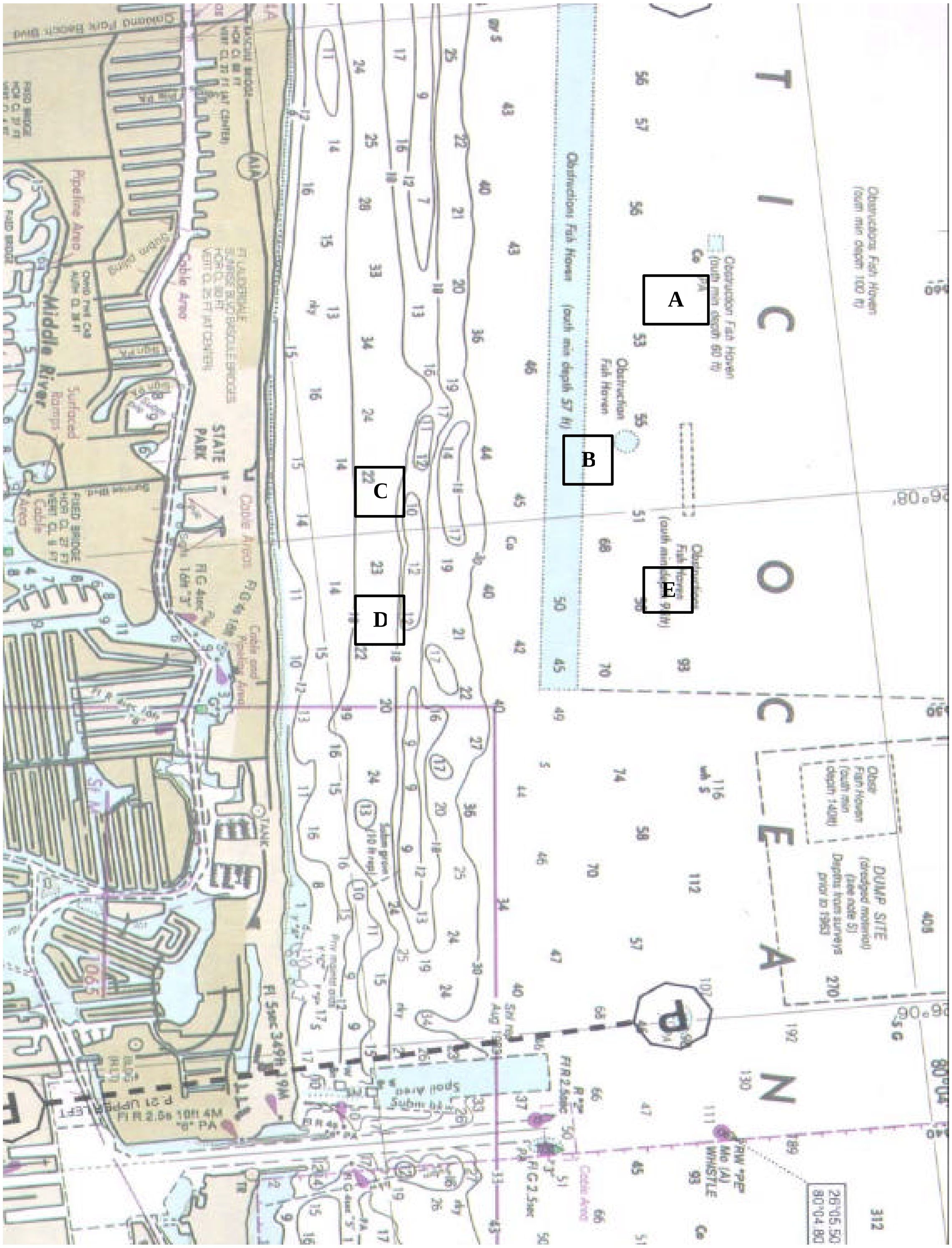

Figure 1. Study sites: A = study 3, 4; B, C = study 5; D, E = studies 1, 2, 6 -10.

Figure 2. “Tetrahedrons” are commercial modules that stack in a stable configuration and offer multiple-size interstices

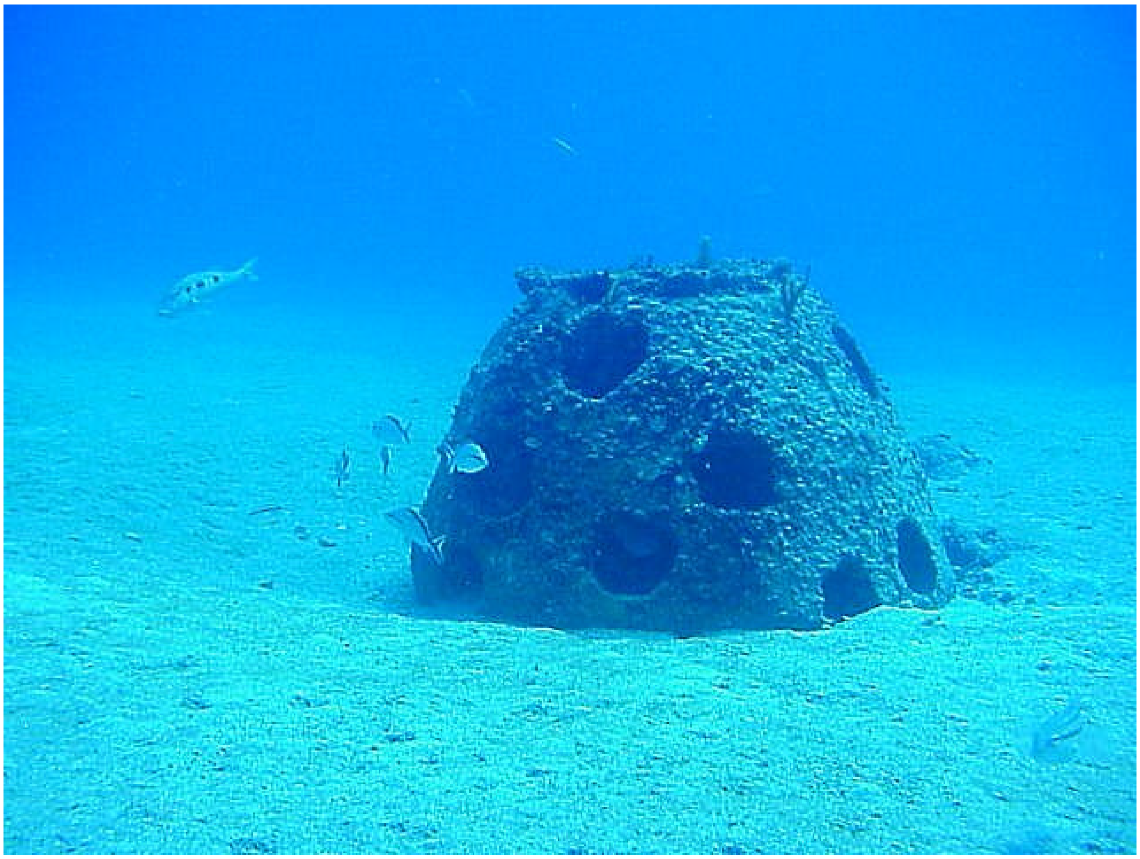

Figure 3. “Reef Ball™” module, is a commercial module, readily manufactured in replicate and easy to deploy.

Figure 4. “Fish-condo” module, a cubic meter in size, constructed by filling an external skeleton of waste concrete block with concrete and reinforcing rebar. The design was inspired by the undercuts and overhangs of hard-bottom ledges and outcroppings offshore Broward County.

use of floating line to enhance recruitment and assemblage formation to artificial reefs in Broward County. (Spieler, 1998b; Sherman, et al. submitted)

Study 4: Complexity versus void space in small artificial reefs

This study was run in conjunction with Study 3. It examined the hypothesis: structural complexity is superior to extensive void space for acquiring an assemblage of fishes at an artificial reef. Testing the hypothesis consists of comparing the fish assemblages between two groups of Reef Balls™ (10 Pallet Balls™ each) that either had concrete block in the central void space (block reefs) or no concrete block (control reefs).

Reef Balls™ with block had higher numbers of fishes, species and biomass than control reefs ($P<0.05$, ANOVA). These results suggest an important role for structural complexity in artificial reef design. An immediate recommendation to come out of this research is: artificial reef managers using Reef Balls™ should consider adding material to the central void space to increase the associated assemblages. A more general recommendation to artificial reef designers is: increase complexity and decrease void space (hole or shelter size) to an appropriate size for the species being managed. (Spieler, 1998b; Sherman, et al. submitted).

Study 5: Complexity and refuge size

This study examined two hypotheses using Swiss-cheese modules (Figure. 5): 1) complexity is an important aspect of artificial reef design for determining the associated assemblages of fishes; and 2) shelter-size is an important aspect of artificial reef design for determining the associated assemblages of fishes. The hypotheses were tested using 60 modules at two water depths, 7 and 23 meters (two sub-studies of 30 modules each). Each sub-study consisted of three groups of ten modules. One group had 12 small tunnels (approximately 7.5cm^2), a second group had 12 large tunnels (approximately 15cm^2) and the third had six small and six large tunnels. The tunnels penetrated from one side of the cube to the other, with six of the tunnels horizontal and perpendicular to the other six (Figure. 5). Thus, a comparison of fish assemblages on large-tunnel to small-tunnel reefs offered insight into the importance of refuge size. A comparison of mixed-tunnel reefs to those with a single tunnel size should offer insight into the importance of complexity in artificial reef design.

In general, little difference was noted in the number of fishes (all species combined) among the three tunnel configurations for any size class (Spieler, 1998a; Sherman et al. in press b). At both the inshore and offshore sites there were more 20+ cm fish and more total fish (all sizes) associated with large or mixed tunnel size reefs than with small tunnels ($P<0.05$, ANOVA/SNK). Surprisingly, inshore there were also more juveniles (<5 cm) on the large tunnel reefs than those with small tunnels ($P<0.05$, ANOVA/SNK). Likewise, the number of species, by size class did not differ much among the three reef types. At both inshore and offshore reefs there were more 20+ cm species on the large or mixed tunnel reefs and at the inshore site there were also more total species on the large and mixed tunnel reefs ($P<0.05$, ANOVA/SNK). A statistical comparison between inshore and offshore reefs such as was done in Study 2 was not accomplished because the substrate of the two sites differed.

Figure 5. “Swiss cheese” module, is a cubic meter of waste concrete with 12 tunnels running through the block from side-to-side. The tunnels differ in size (see Study 5). This design was selected, from the literature, to examine the role of complexity and allow a comparison of the Broward marine environment with studies done elsewhere.

Because reefs with mixed tunnel sizes did not differ from those with only large tunnels, the first hypothesis, that complexity is an important aspect of artificial reef design, was not supported. However, this conclusion is contradicted by other studies done in South Florida (e.g., Study 4) indicating the hypothesis may not have been adequately addressed by the model reefs used in this study.

Because there were fewer total fishes and species on reefs with small tunnels, this study supports the supposition that shelter size is an important aspect of artificial reef design. Additional research is required to determine optimum shelter sizes and configuration to meet the specific management needs and biology of Broward County.

Study 6: Optimal configuration of multiple modules.

This study examined the hypothesis: spacing among artificial reef modules affects associated fish assemblages. For this study Fish-condo modules (Figure. 4) were configured into four equilateral triangles, with a module at each apex. There are four different sized triangles, with two replicates of each size. The smallest triangle has 0.33 m space between the modules; the second has 5m sides; the third 15m and the fourth 25m sides. In addition, sets of two touching modules and a single module were censused (Figure 5). All modules were deployed in 7m of water and censused monthly, weather permitting.

Fish abundance differed amongst months for all size classes as well as total fish ($p<0.01$, ANOVA). For total fish highest levels occurred during spring and summer ($p<0.05$, SNK). However, examination of the individual size classes indicates some discrepancy for example, the smallest fish, <2cm, had highest and lowest levels during winter months. There was no significant difference amongst spacing treatments for total fish abundance. Nonetheless, there was a trend for the 0.33m and 25m spacing treatments to have higher numbers of fish than the 5m or 15m treatments. There were highly significant differences among both spacing treatments and months for species richness ($p<0.0001$, ANOVA). In general there were more species present during the spring and summer months ($p<0.05$, SNK). The highest numbers of species were on the 0.33m and 25m spacing treatments and the fewest on the 5m treatment. However, the number of species per individual module was highest on the single module and the 25m and 15m spacing treatments. It was lowest on the modules of the double module treatment, and 0.33m and 5m spacing treatments ($p<0.05$ SNK) (Spieler 2000).

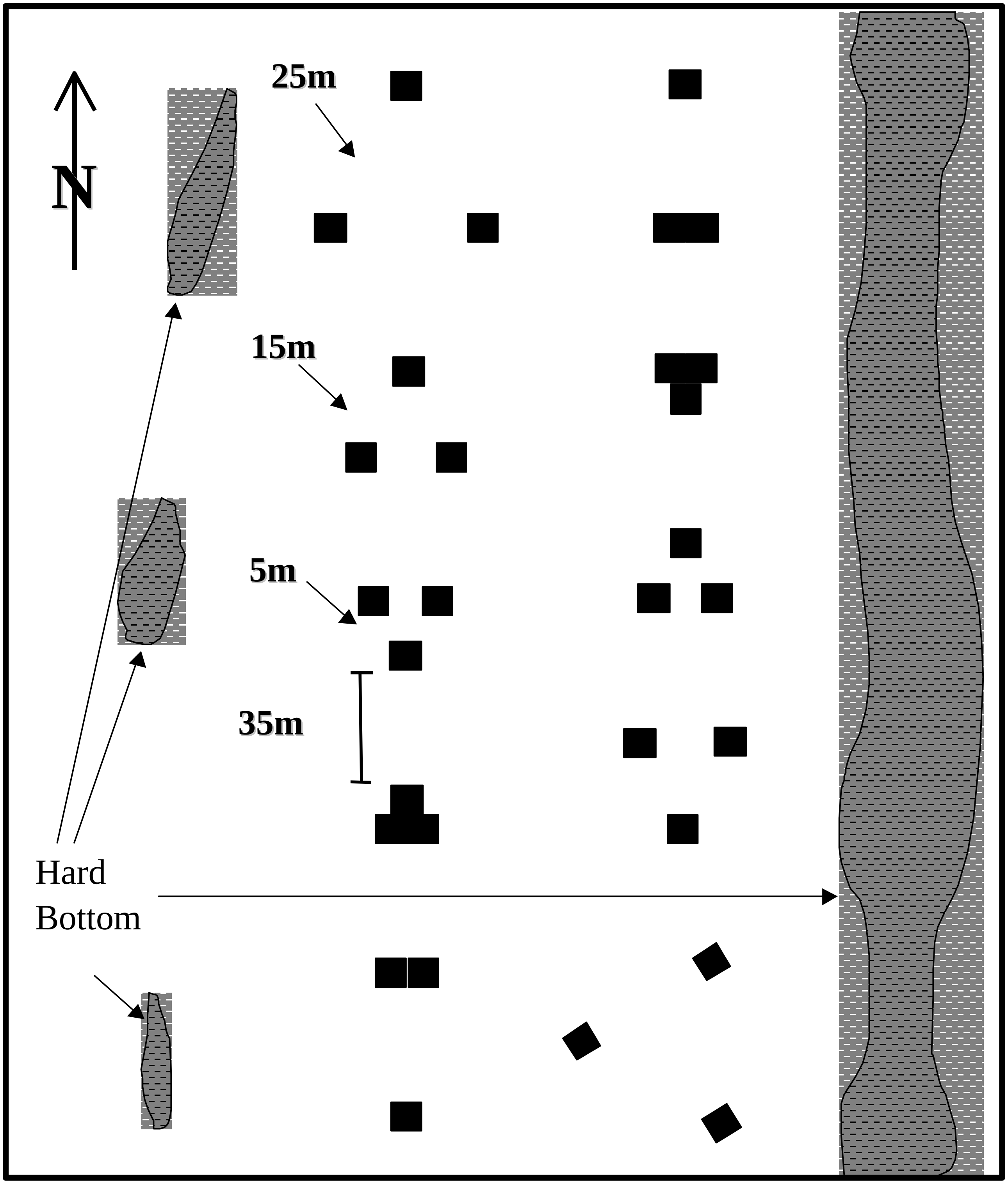

Figure 6. Study site**.** Six experimental groups of reef modules were replicated on inverted North-South lines. Groups consisted of single, double, and triple modules, the triple modules formed equilateral triangles with 0.33, 5, 15, or 25m sides.

Although other interpretations of the data are possible, it appears that the 0.33m spacing modules performed as a single reef, or a very large module. Comparing the 5m, 15m, and 25m treatments to each other and the single module treatment leads to the conclusion that the modules negatively interfered with each other; for example fishes on one module competing for a food resource with fishes on another module, and that the greater the spacing the more this negative interaction was reduced. These results suggest that "more bang for the buck" will be obtained for a given amount of artificial reef material by making widely separated individual reefs rather than one large one.

Study 7: Substrate availability.
Study 8: Resident population effects on recruitment and settlement.
Study 9: Predation effects on recruitment and settlement.
Study 10: Recruit availability and settlement seasonality.

Studies 7-10 were run concurrently in a single, large multivariate project. A total of sixty Fish-condo reefs were used in the four studies. Forty reefs were deployed in 7 m of water on sandy substrate and 20 reefs were similarly deployed due east of the first site in 21 m of water. All the reefs were censued for fishes monthly for 18 months (Spieler, 1998; Gilliam, 1999; Sherman, 2000).

Studies 7 and 8 tested the role of resident fishes on recruitment. Ten inshore and ten offshore reefs were cleaned of all fishes with a piscicide each month after the census. Another ten of both inshore and offshore reefs served as controls and received no treatment. Presumably, if reef resources (e.g., substrate) are limiting there would be more recruits (settlers from the plankton) each month to reefs without residents (Study 7). Likewise, if the resident fishes were affecting recruitment the reefs with residents (controls) would differ from reefs where the fish were removed monthly (Study 8).

Study 9 examined the role of predation by adding refuge for juvenile fish (i.e. caging that excluded predators). Ten inshore reefs were fully caged on the four open sides (top and bottom of the module are solid) with plastic screening (17 mm^2 grid), and ten inshore reefs were partially caged by placing cage material on only two sides. The partially caged reefs were used as controls for the caging material as they still allowed predators access to the interior of the reef. If predation is an important factor in fish recruitment it would be expected that the fully caged reefs would have more monthly recruits than any other treatment.

Study 10 examined recruitment-limitation by looking at the variation in recruit abundance within a treatment (i.e., caged, partially-caged, cleaned or control reefs) both monthly and seasonally. If recruits are in unlimited supply their numbers should be equal within a treatment.

A total of 877 censuses were accomplished and a total of 52,185 fish of 118 species counted. Juvenile grunts (0-5 cm long) (family Haemulidae) predominated; they made up 84% of the inshore fishes and 52% offshore. Excluding the caged treatments, there were no statistically significant differences in new recruit abundance (0-5 cm) between reefs that were cleaned of fishes and those that had residents, at either the deep or shallow sites. There was however a difference between the two sites in recruits as well as several other variables. The reefs in deep water had both more total fishes and more species than the inshore reefs (also see Study 2). In addition, several species of groupers (Serranidae) and snappers (Lutjanidae) were recorded on deep but not on shallow reefs. There were seasonal differences in the number of fishes recruited, with high recruitment during summer months and low recruitment during the fall and winter. Overall, the fully caged reefs had significantly more juvenile fishes than any other treatment, including partially caged reefs (which had more larger fishes than the fully caged reefs). However, the differences between caged and non-caged treatments were evident only during periods of peak recruitment. During periods of low recruitment there were no differences in the numbers of fishes, or biomass, among treatments.

These results may be interpreted as the Broward County marine environment not being substrate limited (Study 7 and 8). It appears, therefore, that an artificial reef program aimed at increasing hard bottom substrate would not substantially increase the numbers of fishes. The local area is apparently recruitment limited, especially at certain times of year (Study 10). However, this limitation appears to be secondary to the role of predation in structuring reef fish assemblages in this area (Study 9). Because Broward County may be refuge limited for juvenile fishes, an artificial reef program aimed at increasing juvenile refuge could, at a minimum, increase the forage base for game fish, and depending on site selection may also increase the numbers of game fish.

Analysis across studies

Excluding the tetrahedrons in study 1, three different reef-module types (Fish-condo, Reef Ball, and Swiss Cheese) were used with seven different treatments/designs in studies where single modules represented individual reefs (studies 2-10). Each of the basic reef designs was approximately the same size ($1m^3$) and was made of the same material (waste concrete) but with different structural attributes. Over the course of the studies, the reef types acquired significantly different fish assemblages in terms of fish abundance, recruit abundance, size class distributions, species richness, and species composition.

At the deep sites (20-21m depth) the Fish-condo count reefs (studies 7 & 8) and the Reef Balls™ (study 4) with block had significantly more total fishes (all size classes combined) and significantly greater species richness than any other reef design. These two reef designs were followed by the Fish-condo clean reefs (study 7 & 8) which were significantly less than the count Fish-condo and Reef Balls with block probably because they were cleaned of fishes each month. All other treatments at deep sites were significantly lower for both total fishes and species richness. Total juvenile fishes (all fishes <5cm TL) were significantly greater on the count and clean Fish-condo reefs than any other reef design or treatment at similar depth (20m). At the shallow sites (7m depth) the large Swiss cheese reefs, mixed Swiss cheese reefs (study 5), count Fish-condo reefs, and clean Fish-condo reefs were not significantly different from each other, but were significantly greater than both the small Swiss cheese reefs and Reef Balls for total fishes total juveniles (<5cm TL), and species richness. Caged reefs (study 9) had significantly greater numbers of juvenile fishes than all other reef types .

There are many factors that contribute to reef design. Reefs constructed with a variety of refuge sizes and a complex internal structure appear to acquire a larger and more species rich fish assemblage. This may be due to one or more possible structural attributes. An important design criterion is structural complexity. Caley and St. John (1996) concluded that both abundance and species richness could be modified by differences in refuge availability and habitat complexity. Friedlander and Parrish (1998) found on natural reefs in Hawaii that both for major trophic guilds and overall fish assemblages, abundance and biomass was higher on reefs that were more topographically complex. Likewise, in the Red Sea, Roberts and Ormond (1987) found that size and diversity of fish assemblages were positively correlated with biological diversity and refuge complexity (hole size) of the substrate. Thus, despite the results of study 5, the results of all the studies, taken as a whole, corroborate the importance of structural complexity in fish assemblage formation. Table 1 shows a comparison of mean fish abundance and species richness on the different reef types at the deep sites (Sherman, 2000).

Table 1. Deep Reefs

Reef Type	Mean Fish Abundance	Mean Total Species
Rinker Reef	75	11
Untreated Reef Ball	25	8
Swiss Cheese	38	6
Reef Ball with blocks	58	12

CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

Artificial reefs need to be designed to function for specific tasks, at specific sites, in specific geographic areas. For example, in Broward County, artificial reefs aimed at increasing the numbers of forage fishes, such as grunts, should be designed with extensive juvenile refuge and deployed inshore. Reefs designed to increase fish diversity or enhance recruitment of some game fishes (i.e. some snappers and groupers) should likewise have juvenile refuge, but be deployed further offshore. It does not appear that simply increasing substrate in our area will increase the numbers of fish, presumably because of the extensive areas of hard-bottom in Broward County. It is unlikely that these findings can be extrapolated to other geographic areas with differing species mix, substrate, or current patterns.

We believe that an artificial reef program is feasible that would aid in effectively managing local fish resources. However, we caution that a substantial amount of additional research is required before our results should be translated into a major management program. Before such a program is initiated we need to understand the current, diverse bottlenecks in the axes from settlement to harvest. To follow a single thread: our results indicate an artificial reef program could be successful in increasing the populations of juvenile grunts, which are an important food source for many game fish. However, we do not know: 1) is there sufficient refuge for an increased population of larger, sub-adult grunts; and if so 2) is there sufficient food available for an increased population of grunts; and if so 3) how would an increased population of grunts affect populations of other fishes that share the same food resource (i.e. some snappers); or 4) how would an increased population of planktivorous juvenile grunts affect the numbers of settling larval fishes, including game fish - to mention just a few areas of concern. In addition, it is also not even known if Broward game fish are food limited and if increasing their food base would significantly increase their numbers. Similar questions can be posed for other species-groups of interest.

In view of ongoing and future beach renourishment projects, the replacement of inshore fish refuge with artificial structure should be a research priority. Such research would determine the current status of available inshore refuge and the associated juvenile fishes as well as experimentally examine differing artificial structure optimal for mitigating the effects of lost refuge.

Also of interest, from an artificial reef perspective, is the deep-water environment of Broward Co. This 200 – 500' deep area is poorly characterized but ROV’s have returned with pictures that leave the impression of a relatively flat substrate of soft sediment with occasional patches of hard bottom with some low relief. Several derelict vessels have been deployed in this area for recreational fishing. By all reports these artificial reefs have been quite successful as fishing “hot

stream, with its abundant larval supply, combined with the apparent low relief, and low refuge, of the natural substrate, may indicate that this area is ideal for using artificial reefs to increase fish resources in Broward Co. The apparently abundant and diverse fish assemblages on the artificial reefs support such a hypothesis. However, without a full characterization of both the natural and artificial deep-reef assemblages it is difficult to distinguish between production and simple aggregation. The potential of this area for increasing fish production makes it a high priority for future research.

To conclude, we believe that the Broward County artificial reef research program has been a step in the right direction for understanding how to manage our resources; but, much more is required. Funding agencies and, more importantly, the public that supports them, need to be educated in the critical role of applied research. In an ideal world we would have an educated public demanding an increase in fish populations, to increase the numbers that can be caught, rather than simply demanding ways to increase the catch of the dwindling numbers of those in place.

REFERENCES

Caley, M.J. and J. St. John 1996. Refuge availability structures assemblages of tropical reef fishes. J. Anim. Ecol. 65: 414-428.

Friedlander, A.M. and J.D. Parrish. 1998. Habitat characteristics affecting fish assemblages on a Hawaiian coral reef. J. Exp. Mar Biol. Ecol. 224: 1-30.

Gilliam, D., K. Banks and R.E. Spieler. 1995. Evaluation of a tire-concrete aggregate for artificial reef construction. ECOSET Proc. 1: 345-350.

Gilliam, D.S. 1999. Juvenile fish recruitment processes in south Florida: a multifactorial field experiment. Doctoral dissertation. Nova Southeastern University, Dania, FL. 111 pp.

Roberts, C.M. and R.F.G. Ormond 1987. Habitat complexity and coral reef diversity and abundance on Red Sea fringing reefs. Mar. Ecol. Prog. Ser. 41: 1-8.

Sherman, R.L. 2000. Studies on the roles of reef design and site selection in juvenile fish recruitment to small artificial reefs. Doctoral dissertation. Nova Southeastern University, Dania, FL. 173 pp.

Sherman, R.L., D.S. Gilliam, and R.E. Spieler. 1999. A preliminary examination of depth associated spatial variation in fish assemblages on small artificial reefs. Jour. Of Appl. Ichth. 15(3): 116-122.

Sherman, R.L., D.S. Gilliam and R.E. Spieler. Site dependant differences in artificial reef function. Bull. Mar. Sci. (in press, a).

Sherman, R.L., D.S. Gilliam and R.E. Spieler. Effects of refuge size and complexity on recruitment and fish assemblage formation on small artificial reefs. Proc. Gulf Carib. Fish. Instit. (in press, b).

Sherman, R.L., D.S. Gilliam, and R.E. Spieler. Artificial reef design: void space, complexity, and attractants. ICES J. Mar. Sci. (submitted).

Spieler, Richard E. 1995a. Evaluation of a novel material for recycling tires into artificial reefs. Final Report to Broward County Office of Natural Resource Protection. 143pp

Spieler, Richard E. 1995b. A preliminary study of fish recruitment to “Reef Ball” artificial reefs in shallow and deep water. Contract completion report to Broward County Office of Natural Resource Protection.

Spieler, Richard E. 1998a. Artificial reef design: complexity and shelter size. Contract completion report to Broward County Office of Natural Resource Protection. 38pp

Spieler, Richard E. 1998b. Artificial reef design: void space, complexity, and attractant. Contract completion report to Broward County Office of Natural Resource Protection. 179pp

Spieler, Richard E. 1998c. Recruitment of juvenile reef fishes to inshore and offshore artificial reefs: final report. Contract completion report to Broward County Office of Natural Resource Protection. 118pp.

Spieler R., D. Gilliam, R. Sherman, K. Banks, C. Corbett-Elder and L. Jordan. 1999. Artificial Reef Research In Broward County: The Last Six Years. IN: Florida Artificial Reef Summit ‘98. Horn, W. (Ed). Florida Dept. Environ. Protection. pp 60-68.

Spieler, Richard E. 2000. Effects of module spacing on the formation and maintenance of fish assemblages on artificial reefs. Contract completion report to Broward County Office of Natural Resource Protection.

ACKNOWLEDGEMENTS

This research was funded mainly through grants from the Florida Department of Environmental Protection (C-8300, OFMAS-004, OFMAS-050, OFMAS-065, OFMAS-091, OFMAS-132). Grants from The South Florida Fishing Classic Inc. and CSR Fish-condo Materials Inc., likewise, aided our research. Personnel from DEP, DPEP, and CSR Fish-condo Materials Inc. also provided technical expertise in varying aspects of the research. Students from the NSU Oceanographic Center volunteered essential assistance with reef construction and diving. Much of this report has been published verbatim in the proceedings of the 1999 Artificial Reef Summit (Spieler et al., 1999)