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The Use of Midwater Fish Aggregating Devices

To Attract Marine Fish At Two North Carolina Fishing Piers

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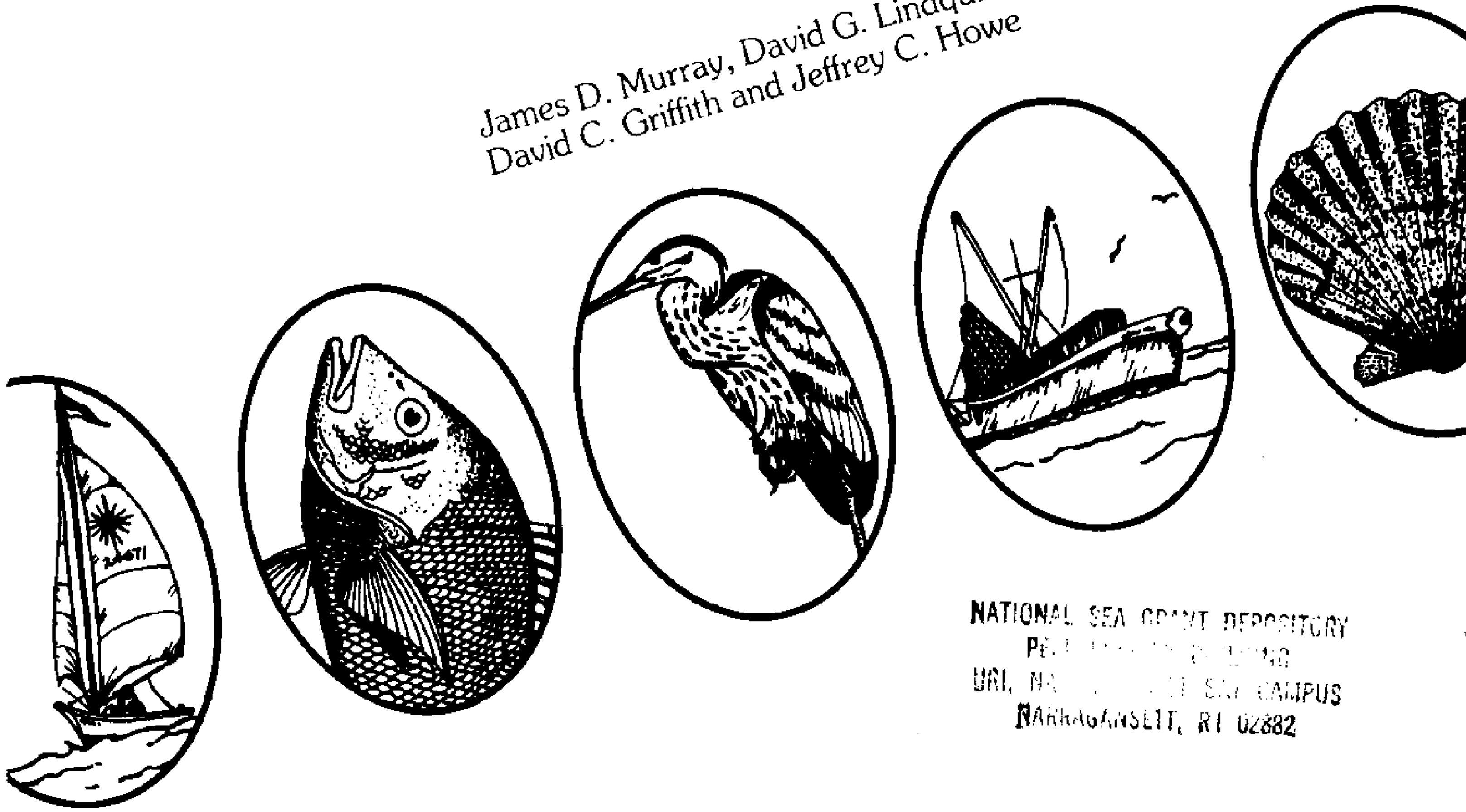

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THE USE OF MIDWATER FISH AGGREGATING DEVICES TO ATTRACT MARINE FISH AT TWO NORTH CAROLINA FISHING PIERS

INTRODUCTION

Several hundred fishing piers line the coast of the United States, providing hundreds of thousands of man days of recreational fishing. The North Carolina coast contains 34 fishing piers (Goldstein, 1978), each providing thousands of man days of recreational fishing per year. These piers contribute significantly to the local economies where they are located.

For many years pier owners have grappled with the idea of improving pier fishing by concentrating fish near the pier. Traditional artificial reef development has been impossible because 1) it would place obstructions on the bottom where pier fishermen would lose their gear, 2) it is difficult to obtain permits to place hard rubble on the bottom in the surf zone because of the potential for erosion problems, and 3) the placement of a hard rubble reef would be expensive. Therefore, about the only method of fish enhancement attempted has been to chum off of piers. However, chum availability and its high costs have been a problem in recent years, and this practice is no longer used.

In recent years, due in part to rising energy costs, there has been increased effort toward the development of midwater fish aggregating devices (FADs). The purpose has been to aggregate fish in order to reduce the search time for commercial and recreational fishermen. McIntosh Marine, Inc., an early leader in FAD development, has introduced relatively inexpensive, lightweight FAD units which can be purchased by sport or commercial fishermen to privately concentrate and enhance fisheries. Work by Shomura and Matsumoto of the National Marine Fisheries Service, Honolulu Lab (Shomura and Matsumoto, 1982), has demonstrated the units will aggregate pelagic fish in offshore areas. In most cases, they indicate a doubling or tripling of fish catches. Wickham et al. (1973), Wickham and Russell (1974), and Hammond et al. (1977) showed that various kinds of midwater structures were attractive to coastal pelagic sportfish off Panama City, Fla., and the central South Carolina coast. Again, these studies indicated a doubling in sportfish catches when compared to unenhanced control areas. McIntosh has also done some preliminary work off of a Florida fishing pier and the results look promising (Ft. Lauderdale News-Sun Sentinel, 1983). A South Carolina study using midwater attractors as trolling alleys (Myatt, 1981) demonstrated an 80.3 percent increase in trollfishing strikes over the midwater attractors when compared to trolling over similar unimproved ocean areas.

In the fall of 1983, a small grant was obtained from the UNC Sea Grant College Program to investigate the potential of FADs to aggregate fish in the nearshore ocean environment and to determine if catch per unit of effort could be improved on fishing piers. It was hypothesized the FAD units would remain intact in the nearshore environment, and would attract pelagic sportfish to the FAD units. It was further hypothesized that these fish would move back and forth from the units to the pier and be available to catch. Specifically, the objectives were as follows:

1. to determine the aggregation capabilities, by number, size, and fish species, of the McIntosh FADs in the nearshore North Carolina coastal environment;

2. to determine the durability of the FADs in this environment;

3. to determine the effect of the FADs on catch per unit of effort by species on a North Carolina fishing pier using a control pier as a base; and

4. to determine fishermen's attitudes toward the FADs.

II. Methodology

Site Selection

The primary factors associated with choosing a site were the proximity and similarity of two adjacent piers. One pier was to be FAD enhanced while the other was to act as a control. Similarity factors included length of pier, depth at the end, seasonality and fishing restrictions. Two piers at Wrightsville Beach, Johnnie Mercer's Fishing Pier and Crystal Fishing Pier, were chosen. (Fig. 1). Each were approximately 1000 feet (305 m) in length, had similar sandy bottom characteristics, and had approximately the same water depth of 750 feet (229 m) from the end of the pier. Both pier owners indicated that fishing success at their piers had deteriorated in recent years, and welcomed the project as an attempt to improve fishing. In addition, the site was close to the graduate students employed in the project from the University of North Carolina at Wilmington.

Wrightsville Beach, N.C. is a barrier beach 5 miles (8 km) southeast of Wilmington, N.C. It is a highly developed barrier island 4.5 miles (7 km) in length, with a full range of tourist-oriented facilities. It contains only two fishing piers approximately 1.6 miles (2.6 km) apart (Fig. 1). The piers have operated for several decades. Mercer's Pier has a greater range of supporting services nearby such as arcades, gift shops, parking facilities, and it receives more visitation. The Crystal Fishing Pier, toward the south end of the island, was renovated in 1983 and features a new onshore restaurant. A large jetty at the south end of the island at Masonboro Inlet may influence nearshore migration patterns of fish for Crystal Fishing Pier.

Although the pier owners welcomed the potential application of the project, there is competition between them for fishermen, and they were concerned about comparisons being made between the two. From the outset we attempted to accommodate their concerns. Since surveys were planned to determine catch per unit of effort (CPUE), we originally planned to also obtain a socio-economic profile of fishermen. However, one pier owner objected to this approach, so no attempt was made to collect this data. We also promised to not disclose data on CPUE

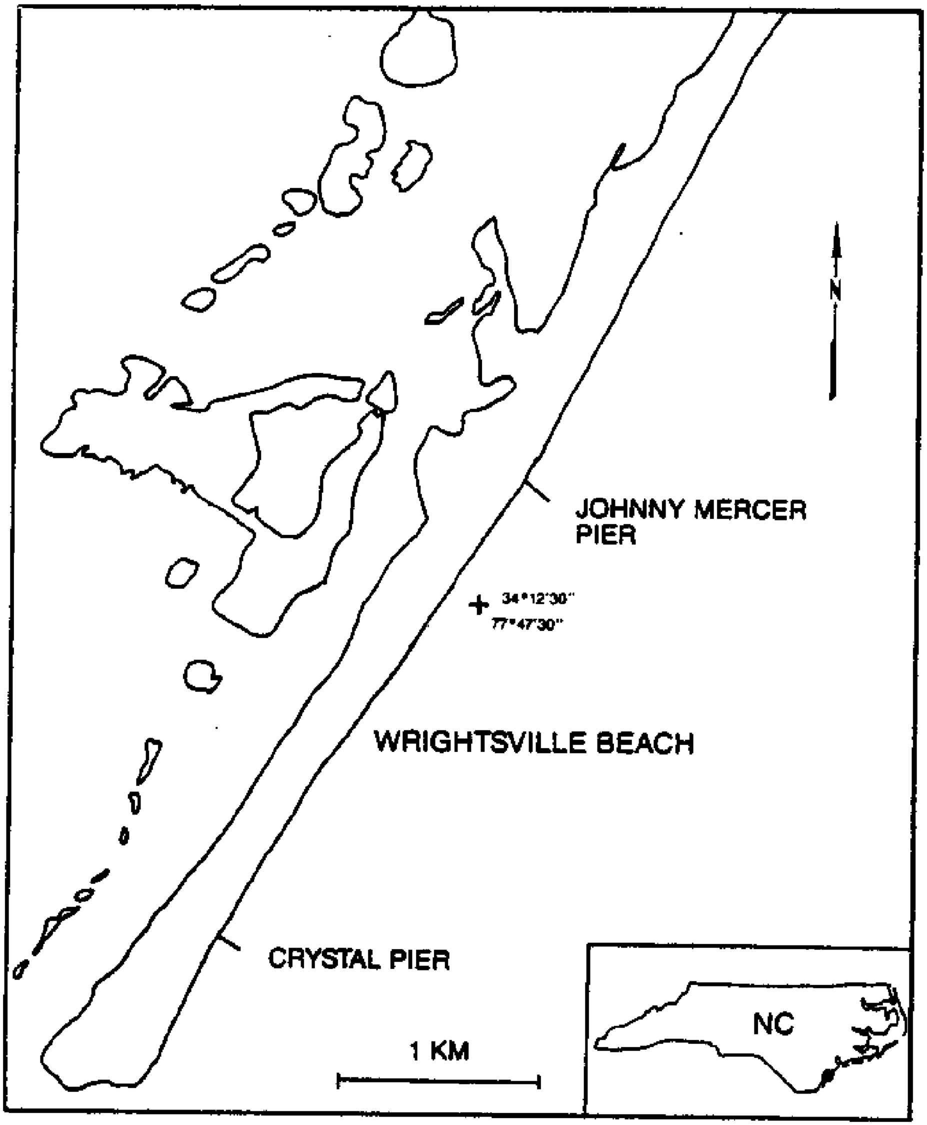


Fig. 1: Location of piers

for the individual piers. Therefore, in the following sections, the piers will be identified as Pier A and Pier B.

Another concern was that as word about the location of the FADs spread among fishermen, they would use only the FAD-enhanced pier, thereby harming business on the pier without the FAD. Consequently, we developed a rotation schedule for the FADs and alternated the FAD units between the two piers every five to six weeks. Additionally, the surface marker buoys were left off the ends of both piers during the entire period in order to disguise the location of the FADs to fishermen.

Another potential problem was the loss of fishing gear and/or fish due to entanglement with the FADs. The pier owners were quite adamant about placing these far enough away to avoid this. A 750-foot (229 m) location distance from the end of the pier was agreed upon, since some fishermen using float rigs were capable of fishing this far out. Further, in North Carolina pier owners have exclusive rights to use of an area 750 foot (229 m) from the sides and end of their pier. It was theorized that pelagic fish would roam between the perimeter of the units and the pier and be available to catch. This distance may have been unnecessarily restrictive, and will be discussed later.

A final concern was that the interviewers might bother the fishermen. The key to overcoming this was to select and train students who were personable and pleasant to the fishermen and the pier owners or managers. The student interviewers worked hard to keep a rapport with the pier owners, keeping them abreast of project results and listening for any complaints by the pier owners.

Permits

Twenty-two concrete-filled tires were required to anchor each pier's system. This was considered fill under provisions of the N.C. Coastal Area Management Act (CAMA). Thus, a permit was necessary from both CAMA and the U.S. Army Corps of Engineers. An application for a permit to excavate and/or fill was completed and sent to CAMA with a copy to the Wilmington district office of the Corps of Engineers. The processing of the permit is handled by the N.C. Office of Coastal Management. The N.C. Division of Environmental Management reviews the permits and determines the need for a state water quality certification, which was not necessary for this permit. Comments from other federal review agencies are furnished to the state through Corps procedures. The Corps will issue the permit if there are no unresolved differences of state-federal positions or policy.

Permission was required from the N.C. Marine Fisheries Commission to place surface buoys in the water column. The commission's endorsement was also requested by CAMA. A presentation about the project was made to the commission in the fall of 1983. It was also requested of the commission that they proclaim the area off both piers research exclusive zones and ban recreational and commercial fishing traffic. Both proposals were passed unanimously.

Once CAMA and the Corps received the permit applications, it was publicly announced through legal notices, and citizens had 30 days to object to the project. It was also forwarded to the riparian property owners, in this case the pier owners for their comment. Since the pier owners had been fully briefed about the project prior to this formality, no objections were made. In general, at least two months should be allowed for obtaining the necessary permits.

Procedure

The purpose of the study was to determine the FADs' durability and aggregation capabilities in the nearshore environment and to see if catch per unit of effort on the fishing piers could be improved. The first two objectives were conducted by divers underwater, while the third was conducted by survey techniques on the piers.

During a 10-week period in the fall of 1983 (the first week of October through the second week of December), graduate students interviewed pier fishermen to obtain CPUE data on the piers. This was prior to FAD enhancement which began on May 3, 1984. The purpose was to obtain pre-test data to determine whether one pier naturally outfished another and to pre-test the survey instrument. Two graduate students sampled fishermen simultaneously 3 days per week and three hours per day. The days of the week and the hours of the day were chosen randomly from a random numbers table. Each day was divided into three parts, 6:00 a.m. to 12 noon, 12 noon to 6 p.m., and 6 p.m. to 12 midnight. Each of these three periods were broken into 6 one-hour segments and the time slot for each segment was chosen randomly. For example, during week one, Thursday, Friday and Saturday were chosen. On Thursday the students interviewed fishermen between 6:00 a.m. and 7:00 a.m., 2:00 p.m. and 3:00 p.m., and 8:00 p.m. and 9:00 p.m. The effective fishing area of each pier was approximately 750 feet (229 m), and the pier was divided and recorded in three 250-foot (76 m) sections---the nearshore, the middle and the end. Again, students were interviewing fishermen simultaneously at each pier during those times. The purpose was to reduce day, time, and weather variables as much as possible. Attempts were made to interview all fishermen except when the pier was too crowded to make this possible. At these times, an equal number of fishermen were chosen from each section of the pier.

The data recorded included the date, time, fisherman number, number of fishing rods used, wet gear time (in minutes x rods used), number and mean weight of fish caught by species, and weather conditions such as wave height, wind speed and direction and water temperature. Weight was recorded by a portable 50-pound scale. The species listed included bluefish, spot, kingfish, king mackerel, pompano, Spanish mackerel, sheepshead, flounder and other (see appendix).

During the 1984 season the survey instrument was continued while both piers were alternately enhanced with FADs. The only change in the survey as reflected in the survey instrument pre-test was a standardization of the weather recordings to allow for easier coding of the data. The anchoring and marker buoy system were installed at both piers in early May 1984 with assistance from the N.C. Division of Marine Fisheries artificial reef team. Three strings of six FADs strung 60 feet (18 m) apart were attached to the mooring system on Pier A. Surveying on the piers began on May 3, 1984. The following list shows the schedule of FAD locations and interviews during 1984.

May 3 - June 14	Pier A
June 17 - July 30	Pier B
July 31 - Oct. 16	Pier A

The original plans were to move the FADs back to Pier B in mid September, but the eye of a major hurricane, Diana, passed near the site on September 13. The UNC-W boat used in moving the FADs and collecting underwater visual observations was damaged by the hurricane, making it impossible to move and inspect the FADs until Oct. 16. However, the pier surveys continued during this time. Of the fifteen FAD units in the water prior to the hurricane, eight were lost, and the remaining seven were in relatively poor condition.

Figure 2 shows the configuration of the FADs off Crystal Pier. The strings of 6 FADs at each end were angled slightly toward the pier to act as a lead for fish migrating along shore. A total water depth of approximately 25 feet (8 m) was recorded at the FADs at mean low tide. A 15-foot (4.6 m) nylon line was strung between the anchor and a float. The FAD was attached to this line 5 feet below the float or 15 feet from the bottom. In general, the higher a midwater reef is from the bottom the more effective it is in aggregating fish (D.O. Myatt, personal communication).

The FAD units were donated by McIntosh Marine Inc. Six-foot-long (1.8 m) fiberglass rods extended from a fiberglass reinforced plastic nose cone at 35° angles from the vertical FAD line to form an umbrella shape. The nose cone is shackled to the vertical line running from the anchor to the float, 5 feet from the float (Fig. 3). Small flotation buoys are fitted at the ends of the rods in order to provide neutral buoyancy so that the unit floats perpendicular to the vertical FAD line (Fig. 3). When first placed in the water, the units tend to float with the open end toward the surface. But after about four weeks, fouling organisms gathered, and the FADs began to float more perpendicularly. Between the rods and enwrapping them was 1/4-inch (6 mm) knotless nylon mesh. The nose cone was attached to a trapeze ring tied into the vertical FAD line to allow for 360° movement so that the units could orient to the current (Fig. 4).

As noted above, the anchoring system was composed of 22 concrete-filled tires placed along the bottom in three 300-foot (91 m) sections (Fig. 5) with the tires being located at 60-foot (18 m) intervals. Two 1.6-foot (0.5 m) lengths of 0.8-inch (21 mm) diameter galvanized chain, positioned vertically and horizontally, were embedded in the cement-filled tires (Fig. 6). The purpose of the chain was two-fold. First, the chain allowed a series of 6 or 8 concrete-filled tires to be joined using the 5/8-inch (16mm) ground line, and secondly, the midwater FADs could easily be attached and detached using a brass snap clip. Six standard 4S Danforth anchors were added to the ends of each of the three strings of FADs approximately 8 feet from the end tire (Fig. 6). One quarter-inch (6 mm) nylon line was used for the vertical line from the anchor to the FAD float, while 5/8-inch (16 mm) nylon

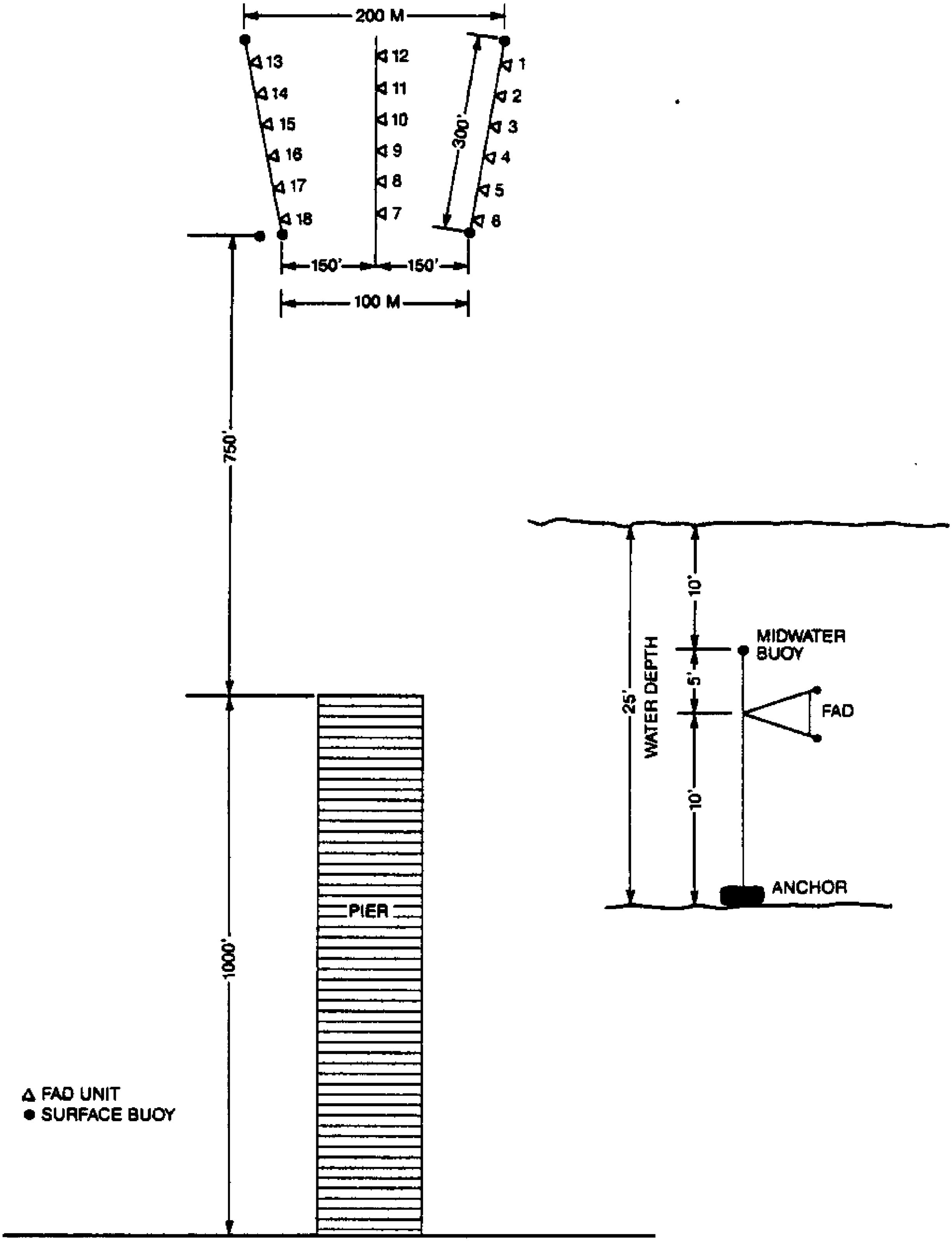


Fig. 2: Configuration of FADs

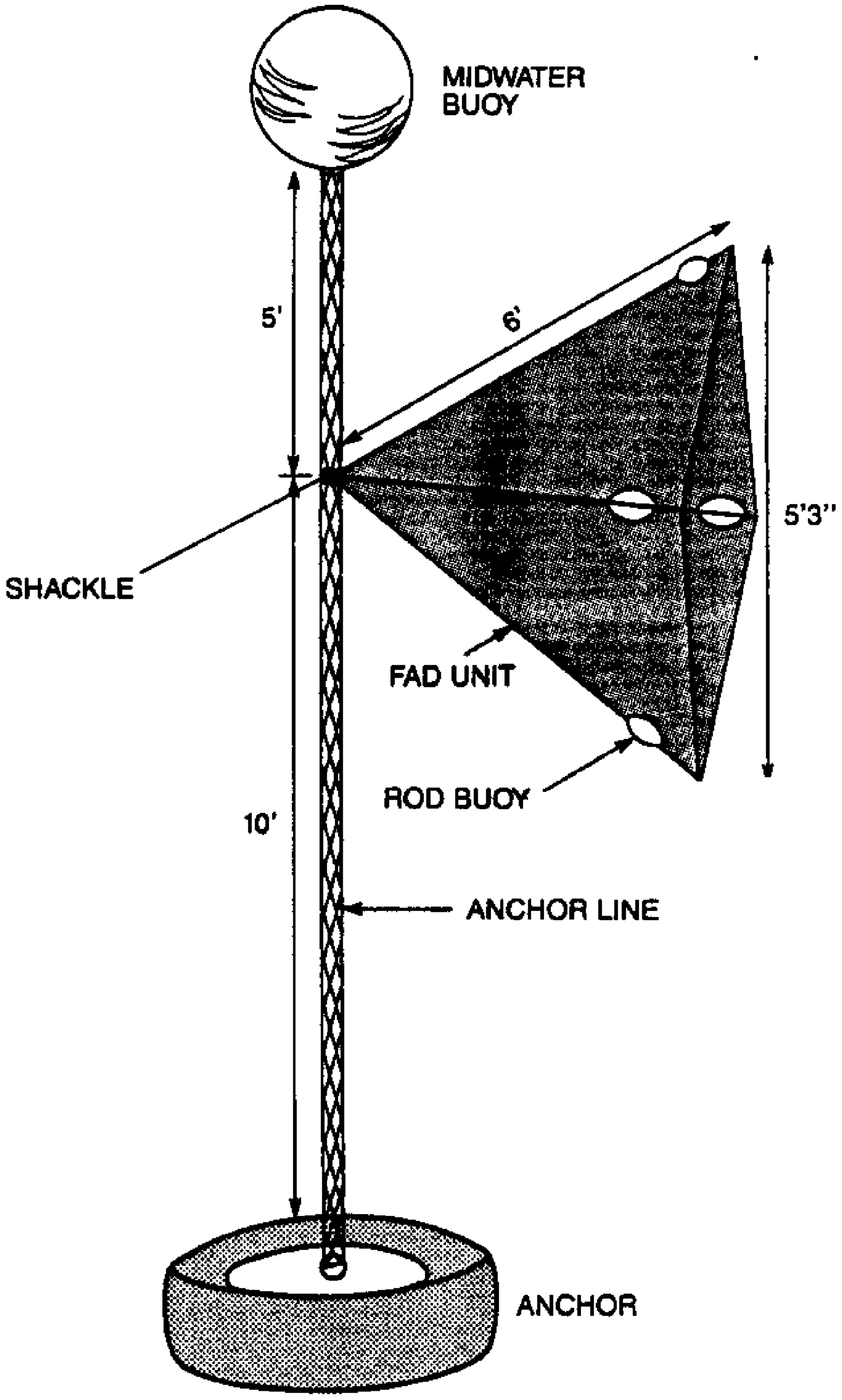


Fig. 3: An individual FAD unit

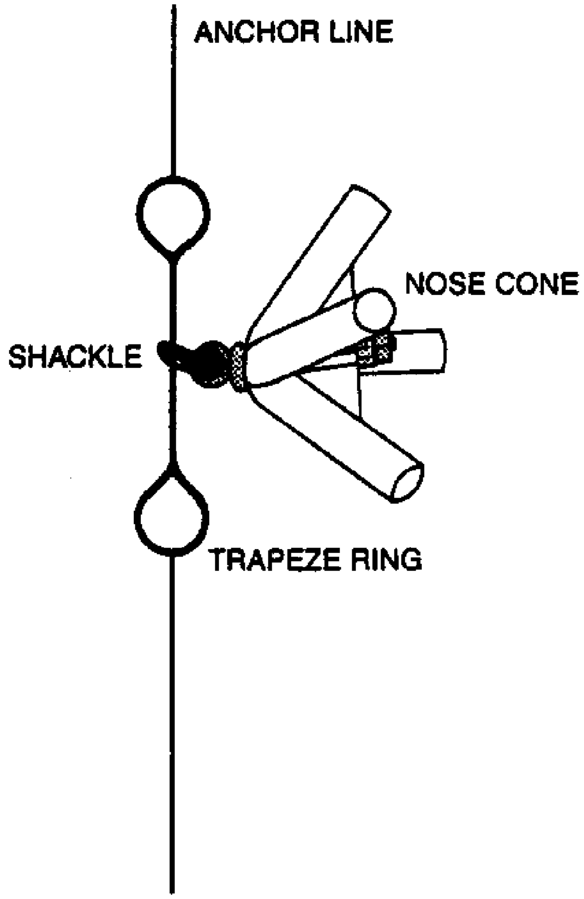


Fig. 4: Close-up of FAD shackle attachment

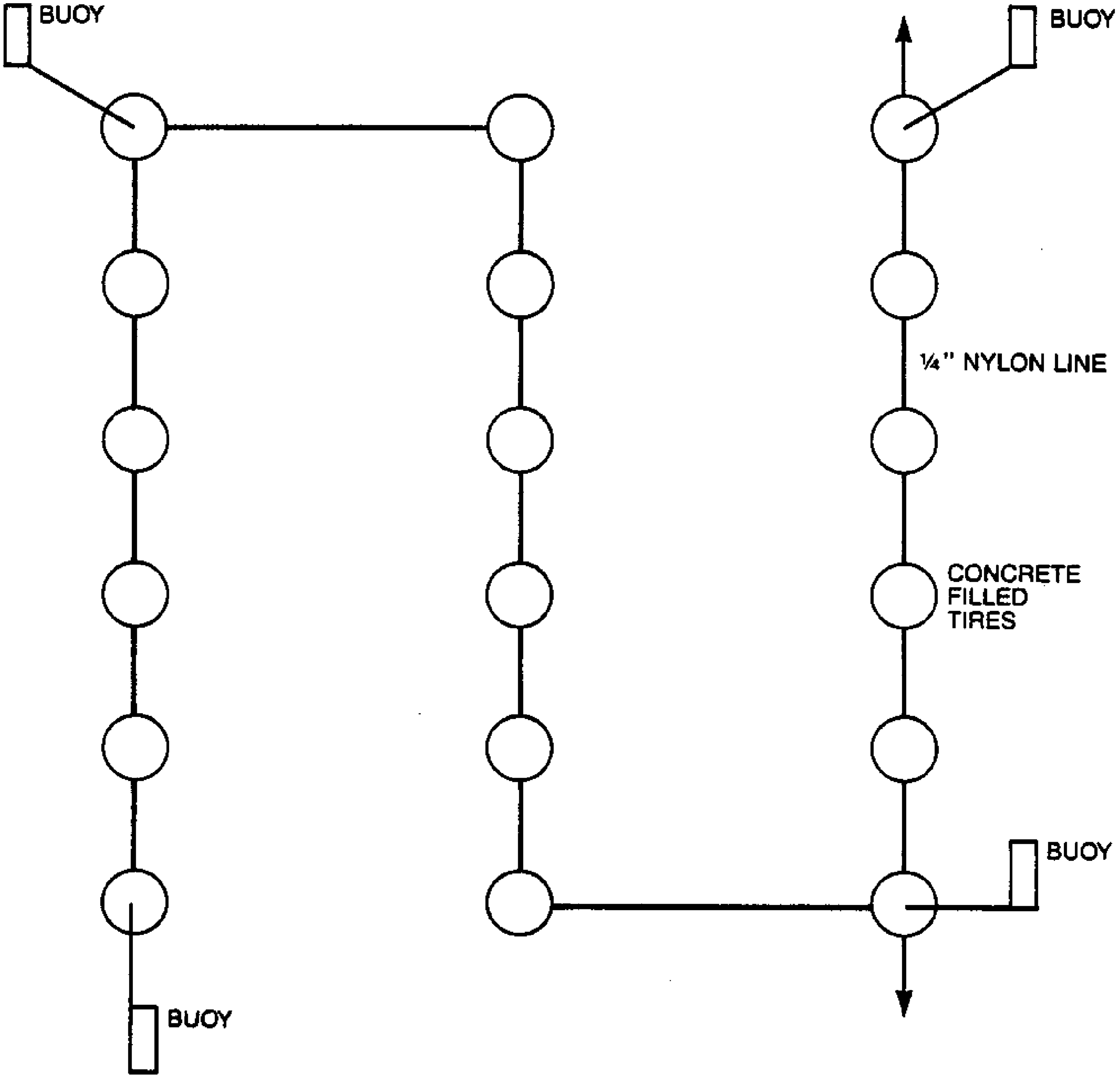
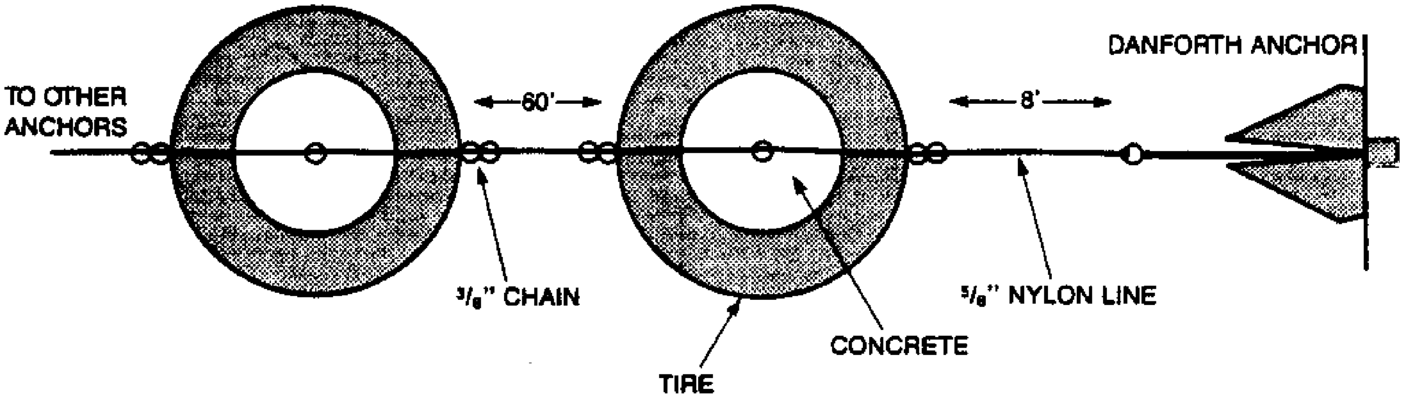


Fig. 5: Anchoring system

TOP VIEW



SIDE VIEW

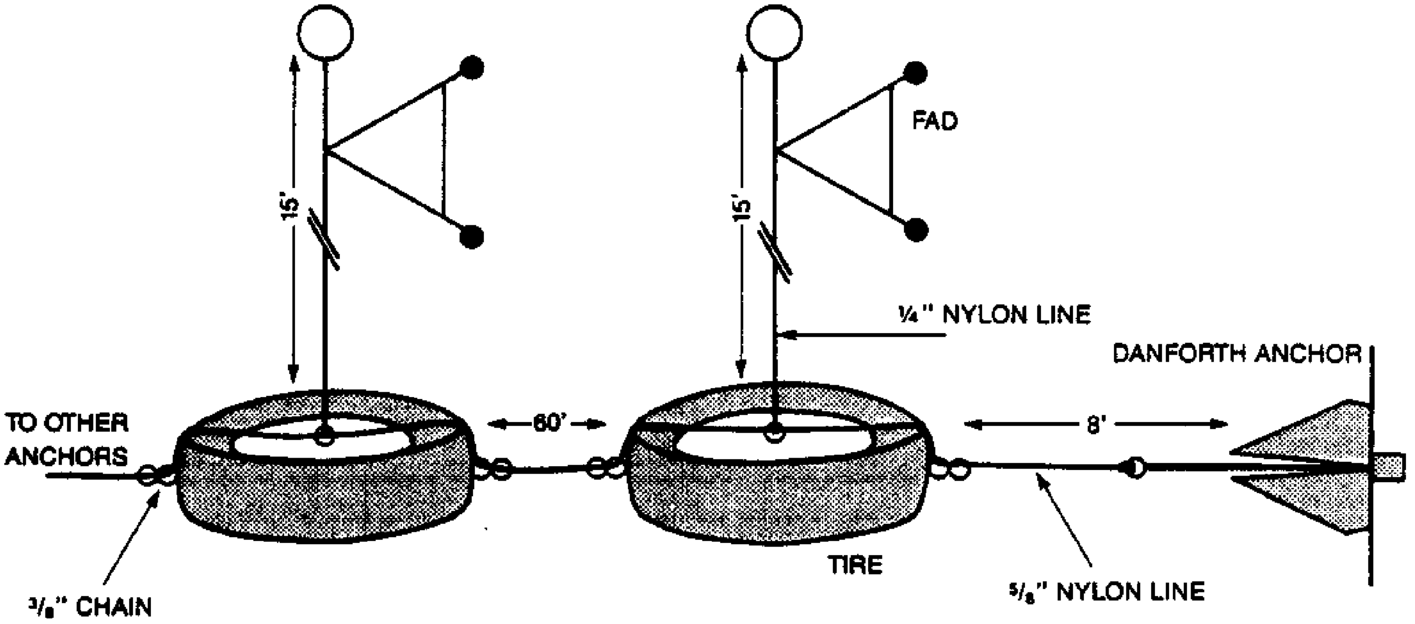


Fig. 6: Close-up of anchoring system

line was used horizontally between the tires along the bottom. The sites off both piers were marked by standard artificial reef buoys donated by the N.C. Division of Marine Fisheries. These buoys (Curd Enterprizes, Mt. Pleasant, S.C.) were 61 inch (155 cm) X 9 inch (23 cm) diameter A.B.S. plastic and polyfoam cylinders. Approximately 25 inches (64 cm) of the buoy length extended below water. Five-eighths-inch (16 mm) nylon line was used to anchor surface marker buoys.

The artificial reef surface buoys were marked as follows: Artificial Reef - Research Area, No Deep Trolling, No Anchoring. The two study sites were officially designated as Research Sanctuaries by the N.C. Division of Marine Fisheries (proclamation RS-1-84, issued 27 March 1984). The Research Sanctuary designation was necessary in order to avoid damage to the FADs by commercial and recreational fishing gear except for hook and line fishing, and trolling or casting with surface or shallow-running lures and baits.

Deployment of FADs

On May 2 and 11, 1985, the concrete tire anchors, ground lines, surface buoys and buoy lines for Pier A and Pier B, respectively, were preassembled aboard the Division of Marine Fisheries 23-foot (7m) work boat. Upon arrival at the pier, a range finder was used to determine the location of the study site. Temporary buoys were deployed to mark the locations of the three ground lines. Two end tire anchors and danforth anchor were dropped overboard together at the landward end of the north string of materials. The line connecting the second and the third tire anchors was payed out as the boat proceeded toward the seaward end of the string. The tire anchor was positioned on top of the boat's wash board and allowed to slip overboard as the line became taut. The remaining tire anchors and danforth were deployed in this manner. The remaining surface buoy line was tied to the stern of the boat and pulled until the entire ground line became taut and straight. The surface buoy was then released and a diver set the danforth anchor with the exception of the middle strings at each site which did not have surface buoys. The other strings were deployed in a similar manner.

On May 3, the 18 preassembled FADs were attached to the tire anchors by means of brass swivel snaps at Pier A. A brass eyebolt was initially attached to the vertical 1/4-inch (6 mm) line by allowing the line to pass through the eye of the bolt. Knots were tied on both sides of the eyebolt to hold the FAD at the proper position. This method proved unsatisfactory because the 1/4-inch (6 mm) line quickly became worn at the eyebolt and one FAD was lost due to a parted line. This problem was solved by inserting stainless steel sailboat trapeze rings (Fig. 4) into the vertical line. The eyebolts were then attached to the bar between the rings by a 1/4-inch (6 mm) galvanized shackle. This solution was not totally satisfactory. In three months, the galvanized shackles showed a significant amount of corrosion, and on August 12, one FAD was lost due to a parted shackle. It was not realized that the use of brass eyebolts coupled to galvanized steel shackles coupled to a stainless steel fitting sets up an ideal case for galvanic corrosion due to dissimilar metals in seawater. The zinc galvanizing and steel are the most active metals in the connection

(S.M. Rogers, Jr., personal communication). Our short-term solution to this problem was to replace the galvanized shackle. A longer-term solution would have been to switch to galvanized eyebolts and shackles or to replace the galvanized shackles with brass (S.M. Rogers, Jr., personal communication).

A second problem involving the nose cones occurred four to five weeks into the study. Some of the PVC nose cones were beginning to collapse due to stress caused by the rods on the rod pockets. This was because the nose cones had been drilled out to replace the factory-installed swivels with the brass eyebolts. The manufacturer informed us that the original swivels would freeze up due to dissimilar metal corrosion. The drilling weakened the structural integrity of the PVC plastic, causing them to partially crack around the rod pockets. The manufacturer supplied new nose cones made of fiberglass reinforced plastic (FRP). These proved more durable even under hurricane-force surf conditions.

Underwater Census Of Fish Aggregations around FADs

Visual estimates of the fish associated with the FADs, the surface buoys, the concrete-filled tire anchors, and midwater buoys marking locations for fish counts at the control area were conducted at approximately biweekly intervals from May to August 1984. Fish censusing began on May 19, 1984, and was intended to continue until December 1, 1984. The project was prematurely terminated due to Hurricane Diana. The last day of fish censusing was August 26, 1984, after which the weather deteriorated because of the incoming hurricane.

Visual estimates were conducted at flood tides in order to avoid the poorer visibility caused by the outflux of estuaries during ebb tide. Midwater buoys at the control area consisted of floats identical to those deployed immediately above the FADs. Three identical floats (at FAD positions 2, 9 and 17), one on each of the three ground anchor lines, were attached to the tire anchors during the control periods for each pier's anchoring system (Fig. 2). These floats served two purposes---first to mark the identical location in the water column where FADs would be and, second, to see if these temporary objects would be attractive to fishes. The remaining 15 control sample locations were marked during each dive by a small hand-carried marker float (pelican float, Pelican Products) clipped temporarily to a tire anchor and suspended in location identical to the FADs.

Due to the time restrictions associated with scuba diving, only nine of the 18 FADs were visually censused on any given day. Therefore, every other FAD was censused during each dive; first the odd-numbered FADs and then the even-numbered FADs on the next dive day. All 18 FADs were censused once per week. At the beginning of each dive, water temperature and underwater vertical visibility were measured using a standard mercury thermometer and secchi disk, respectively, deployed from the boat.

During each dive, the fish associated with nine FADs, nine FAD tire anchors, and the four corner surface buoys and tire anchors were censused as follows. Two divers descended under the southeast corner surface buoy and recorded fish species, size range (fork lengths), and numbers of individuals for each species (Fig. 7). They then swam along the buoy line to the surface buoy tire anchor and ground line (Fig. 8) to the first FAD tire anchor (either #1 or #2) where benthic fishes associated with the tire anchor were censused as above. Divers then ascended the vertical FAD line and positioned themselves 10 feet (3 m) to 13 feet (4 m) on either side of the FAD, or less depending on visibility as they censused the fish around the FAD as above. Divers spent approximately two minutes at each FAD conducting the visual estimates. If unidentifiable species were encountered, a specimen was taken with a Hawaiian sling pole spear or hand nets and later identified in the laboratory. The same census procedures were used at the control site except that divers ascended beside a small temporary midwater buoy instead of a FAD.

The behaviors of fish associated with the FADs were also monitored biweekly. Again only 9 of the 18 FADs were observed on a given day. On each dive, the fish associated with each FAD were observed for 5 minutes. Notes on schooling, proximity to FADs, feeding activity (e.g. were fish feeding on FAD fouling organisms?), etc., were taken.

Structural damage and general fouling organism diversity and abundance were also recorded on a biweekly basis.

A 24-hour and two-week diel study was performed to observe any variation in residency within the experimental site over a 24-hour period. During the 24-hour diel study (8/17/84), both divers independently recorded the abundance and diversity of fish at the three substructures (FADs, tires and surface buoys). A total of four daylight and three night dives were made during the 24-hour diel study. The two- week diel study was performed because the 24-hour diel study did not take into account a complete lunar cycle. Therefore, dives were made at varying tides. During the two-week diel study (7/12/85-7/27/84), a total of five daylight and four night dives were logged, covering all hours of a day. All dives were made during a high tide. Again, both the abundance and diversity of fish were recorded at the three substructures. Underwater flashlights were used by both divers during all-night diving operations.

Fish Censusing Statistical Procedures

Fish censusing data concerning both study sites were analyzed using Statistical Analysis System (SAS) programs in conjunction with a VAX 11/780 computer located at the University of North Carolina at Wilmington. Mean values represent only those species observed by one or both divers. If only one diver observed a particular species, this value only was used in calculating the mean, hence a value of zero concerning the other diver was not included. The reason for this is that poor visibility would occasionally prohibit both divers from observing a particular species at the FADs.

The Wilcoxon rank sum test was used to test whether or not two populations were identical. The main reason for using this non-parametric test was that normality within both populations was not

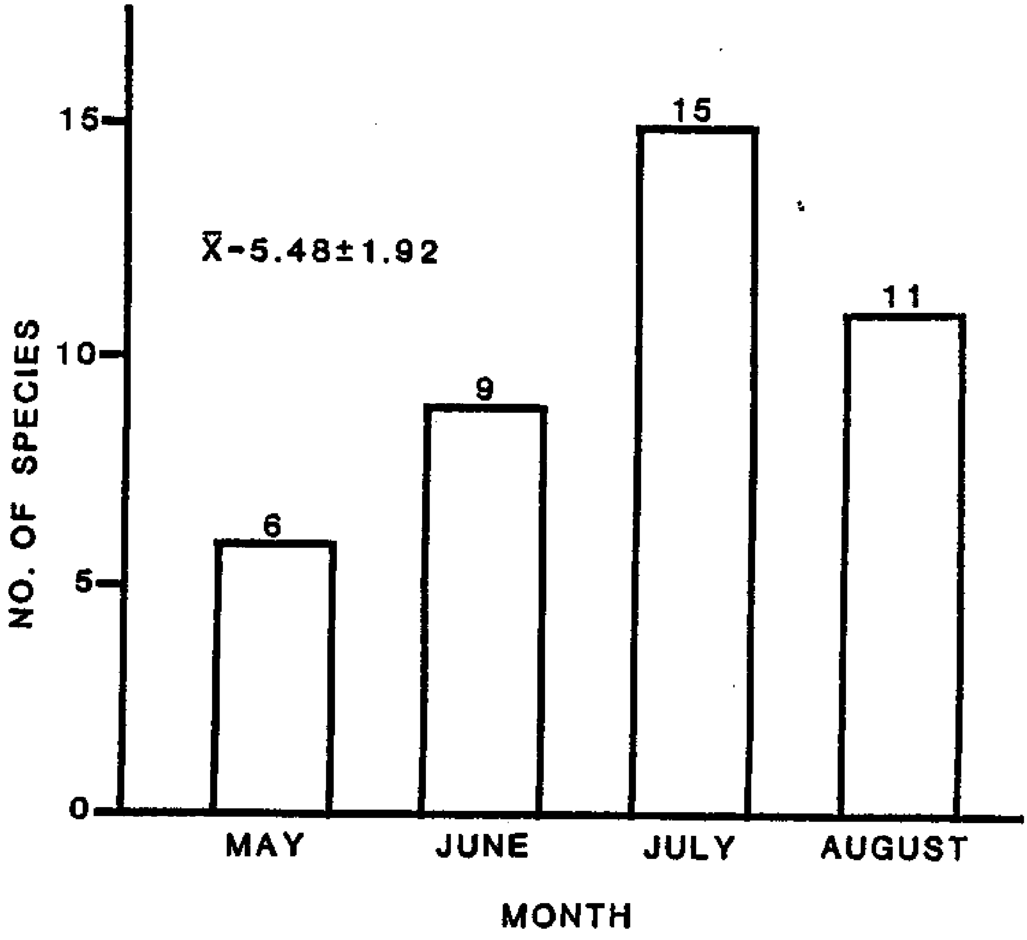


Fig. 7: Numbers of species recorded

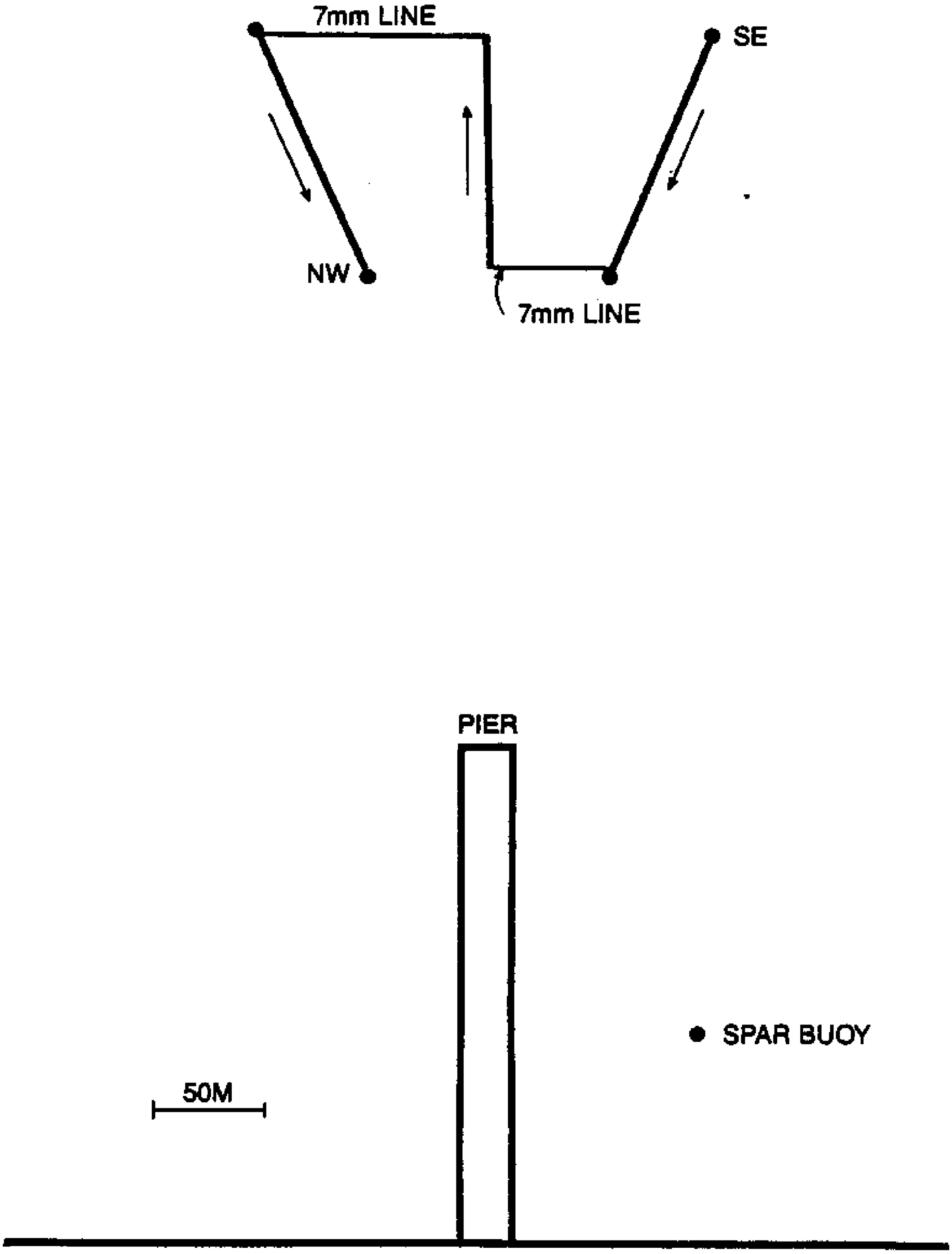


Fig. 8: Divers' direction of swim

assumed. Preliminary data analysis did not show normal distributions. In some cases, there were not enough observations of species to indicate any visible trend. Independent samples, which did exist, are assumed in this type of test. A 0.05 level means that the probability of these values occurring by chance is 5 in 100. Generally, a 0.05 level or lower indicates a statistically significant difference.

The analysis of variance (ANOVA) procedure was used to compare the means of several populations. This test was ideal for comparing the mean number of fish at varying water temperatures and visibility. However, because normality is assumed, a general linear model (GLM) also was used to observe whether or not there was any correlation between the mean number of fish with varying water temperature and visibility. ANOVA can only be used for unbalanced data, which existed in this case, in conjunction with only one treatment variable. A GLM analysis had to be used when two variables were used to investigate interactions between them in respect to the mean number of fishes. Again, for both ANOVA and GLM procedures, the 0.05 level was used which is generally accepted as indicating a statistically significant difference.

Results

-- Fish Fauna

The total fish fauna (Table 1) observed at the experimental reef included 35 species (21 families and 32 genera). Of the 35 species, 26 (16 families and 23 genera) were encountered solely at the midwater FADs during day and night observations (Table 1). Eighteen species (14 families and 18 genera) were sighted at the FAD anchors. Eight of these species were different from those observed at the midwater FADs (Table 1). Species observed at the surface buoys (Table 1) of the experimental site consisted of 14 species (7 families and 12 genera).

Blue runners (Caranx crysos) and butterfish (Peprilus tricanthus) were the most abundant species observed at the midwater FADs over the entire study (Table 2). Of the 26 species observed at the FADs, 10 are considered pelagics (Table 2). These 10 species represented 79 percent of the mean number of individuals/species observed at the FADs (Table 2). Three of the 10 pelagics would in addition be considered target species, representing 8 percent of the mean number of individuals/species observed at the FADs (Table 2).

There were 5.48 ± 1.92 (S.D.) species observed at the FADs during the entire study (Table 1). A total of 6 different species were observed in May with a maximum of 15 species observed in July (Table 1). Of the 17 species collected, the summer flounder (Paralichthys dentatus) was the largest (Table 3).

Table 1. Fish species observed at both the experimental and control sites over the entire study period.

Species	Experimental Site			Control Site		
.=pelagics(10)	FAD	Tire	Spar Buoy	Midwater buoys	Tire	Spar Buoy
Balistidae						
Aluterus scriptus (scrawled filefish)	*		*			
Monacanthus hispidus (planehead filefish)	*	*	*		*	*
Batrachoididae						
Opsanus tau (oyster toadfish)		*				
Blenniidae						
Hypsoblennius hentzi (feather blenny)	*	*				
1 *Hypleurochilus geminatus* (crested blenny)	*					
Bothidae						
Paralichthys dentatus (summer flounder)		*				
Carangidae						
.*Caranx crysos* (blue runner)	*	*	*			*
.*Chloroscombrus chrysurus* (Atlantic bumper)	*		*			
.*Decapterus punctatus* (round scad)	*	*	*			*
.*Seriola dumerili* (greater amberjack)	*		*			*
.*Seriola rivoliana* (almaco jack)	*		*			*
.*Seriola zonata* (banded rudderfish)	*		*			*

Species	Experimental Site			Control Site		
.*pelagics(10)	FAD	Tire	Spar Buoy	Midwater buoys	Tire	Spar Buoy
Echeneidae						
Remora remora (remora)	*					
Engraulidae						
Anchoa hepsetus (striped anchovy)	*					
Ephippidae						
Chaetodipterus faber (Atlantic spadefish)	*					
Gadidae						
1 Urophycis earlli (Carolina hake)	*					
Haemulidae						
Haemulon aurolineatum (Tomtate)		*			*	
Orthopristis chrysoptera) (pigfish)	*	*				
Lutjanidae						
1 Lutjanus griseus (gray snapper)	*					
Pomatomidae						
.Pomatomus saltatrix (bluefish)	*		*			
Rachycentridae						
.Rachycentron canadum (cobia)	*	*	*			*
Scianenidae						
Bairdiella chrysura (silver perch)					*	
Equetus umbrosus (cubbyu)					*	

Species	Experimental Site			Control Site		
.=pelagics(10)	FAD	Tire	Spar Buoy	Midwater buoys	Tire	Spar Buoy
Leiostomus xanthurus						
(spot)	*					
Micropogonias undulatus						
(Atlantic croaker)		*				
Scombridae						
.Scomberomorus maculatus						
(Spanish mackerel)	*					
Serranidae						
Centropristis philadelphica						
(rock sea bass)			*		*	
Centropristis striata						
(black sea bass)	*	*			*	
Diplectrum formosum						
(sand perch)					*	
Unknown	*					
Sparidae						
Archosargus probatocephalus						
(sheepshead)		*				
Diplodus holbrooki						
(spottail pinfish)	*					
Lagodon rhomboides						
(pinfish)	*	*	*		*	*
Stenotomus chrysops						
(scup)	*	*	*		*	
Stromateidae						
.Peprilus triacanthus						
(butterfish)	*	*			*	
Synodontidae						
Synodus foetens						
(inshore lizardfish)		*			*	

Species	Experimental Site			Control Site		
.=pelagics(10)	FAD	Tire	Spar Buoy	Midwater buoys	Tire	Spar Buoy
Tetraodontidae _Sphoeroides sp_ (puffer)		*				
Triglidae _Prionotus scitulus_ (leopard searobin)		*	*		*	

[1] Observed at the FADs during hurricane Diana assessment

Table 2. The mean number of individuals/species, observed at the midwater FADs over the entire study period (excluding hurricane assessment).

Species	Mean	Standard Deviation
Aluterus scriptus	1.43	1.21
Anchoa hepsetus	1.00	____
. *Caranx crysos*	12.33	12.32
Centropristis striata	1.59	1.10
Chaetodipterus faber	1.56	0.88
. *Chloroscombrus chrysurus*	2.08'	1.00
. *Decapterus punctatus*	2.98'	2.72
Diplodus holbrooki	1.17	0.41
Hypsoblennius hentzi	1.00	0.00
Lagodon rhomboides	1.26	0.61
Leiostomus xanthurus	1.00	0.00
Monacanthus hispidus	1.89	1.68
Orthopristis chrysoptera	4.00	1.15
.T *Pomatomus saltatrix*	5.33'	5.86
. *Peprilus triacanthus*	45.69'	137.12
.T *Rachycentron canadum*	1.00'	0.00
Remora remora	1.00	0.00
.T *Scomberomorus maculatus*	1.50'	1.00
. *Seriola dumerili*	1.00'	____
. *Seriola rivoliana*	1.92'	1.27
. *Seriola zonata*	1.15'	0.36
Stenotomus chrysops	2.00	0.00
Unknown Serranid	1.00	____

N=23 Pelagics=$\frac{74.98}{94.88}$=79% Target=$\frac{7.83}{94.88}$=8%

. - pelagic species
.T - target species

Table 3. Mean standard length of species collected at the experimental site.

Species	$\bar{x}$ SL(mm)	Range(mm)
Anchoa hepsetus	45.0	—
Bairdiella chrysura	160.0	—
Caranx crysos	115.0	—
Centropristis striata	98.0	—
Chloroscombrus chrysurus	37.0	—
Decapterus suncalus	165.0	—
Hypleurochilus geminatus	23.6	11-42
Hypsoblennius hentzi	43.0	20-60
Lagodon rhomboides	85.0	70-100
Monacanthus hispidus	22.8	17-38
Orthopristis chrysoptera	152.0	—
Paralichthys dentatus	197.0	—
Peprilus triacanthus	43.7	43-44
Prionotus scitulus	85.0	70-100
Seriola rivoliana	145.0	110-215
Seriola zonata	105.0	60-150
Stenotomus chrysops	52.5	45-60

Aggregation of Marine Fish Analysis

The most common family of fish at the FADs were the jacks (Carangidae) with seven species. Jacks are typical pelagic baitfish and sportfish species (e.g. greater amberjack). Four other pelagic species occurred at the FADs: bluefish, cobia, Spanish mackerel and butterfish. All 10 species of pelagic fish comprised an average of 80 percent of the total individuals observed. Approximately a third of these pelagics were jacks. However, pelagic target sportfish (bluefish, cobia and Spanish mackerel) comprised only 8 percent of the total fish species observed.

Fish were not observed in the upper section of the water column in the vicinity of the midwater floats within the control site. Twelve species (8 families and 11 genera) were observed at the FAD anchors at the control site. This was 10 species fewer than observed at the experimental FAD anchors (Table 1). The fish fauna at the surface buoys at the control site consisted of 9 species (4 families and 6 genera) (Table 1).

Of the 16 species (14 families and 15 genera) associated with the FAD anchors at both the experimental and control sites, the abundance of scup (*Stenotomus chrysops*) and summer flounder (*Paralichthys dentatus*) was significantly greater at the experimental site ($p<0.05$, Wilcoxon Rank Sum Test). In addition, there was no significant difference in the abundance between the 13 species (7 families and 11 genera) observed at the surface buoys between both the experimental and control study sites ($p>0.05$ Wilcoxon Rank Sum Test). Blue runners (*Caranx crysos*), the most common species observed at the spar buoys, showed no significant difference in their abundance between the spar buoys and FADs ($p>0.05$ Wilcoxon Rank Sum Test).

Water visibility and temperature at the experimental site averaged 15 feet (4.6 m) (range=2.0-7.0 m) and 73°F (22.8°C) (range=17.2-25.6°C) respectively. There was no significant correlation in the mean number of fish sighted at the midwater FADs at various water visibilities or temperatures ($p>0.05$ GLM and ANOVA). In addition, there was no interaction between both water visibility and temperature in respect to the mean number of fish observed at the midwater FADs ($p>0.05$ GLM and ANOVA).

Two diel studies were conducted to determine residency during light and dark periods at the midwater FADs. During a 24-hour diel study, 11 species (7 families and 10 genera) were observed, 5 of which were carangids (Table 5). Between both the two-week and 24-hour diel studies, the Atlantic bumper (*Chloroscombrus chrysurus*), pigfish (*Orthopristis chrysoptera*), spadefish (*Chaetodipterus faber*) and Spanish mackerel (*Scomberomorus maculatus*) were only sighted during the 24-hour diel study. There was no significant difference in the abundance between all 11 species observed during the 24-hour diel study in respect to night and day periods ($p>0.05$ Wilcoxon Rank Sum Test).

The planehead filefish (*Monacanthus hispidus*), black sea bass (*Centropristis striata*), pinfish (*Lagodon rhomboides*), blue runner (*Caranx crysos*), round scad (*Decapterus punctatus*) and the banded rudderfish (*Seriola zonata*), were the only species observed at the FADs consistently over the entire study period (Table 4). Blue runners, black sea bass and pinfish, however, were not initially observed until early June (Table 4). There was no significant correlation in the mean number of individuals concerning each of the 6 species observed at the FADs over the entire study period (p>0.05 GLM and ANOVA).

Five other species (4 families and 5 genera) showed possible season related trends. Scup (*Stenotomus chrysops*) were only observed in May while butterfish (*Peprilus triacanthus*) were observed in May through early June (Table 4). Almaco jacks (*Seriola rivoliana*) and scrawled filefish (*Aluterus scriptus*) were initially observed in the middle and latter part of June, respectively (Table 4). Almaco jacks were observed continuously through August, where as scrawled filefish were observed only through the end of July (Table 4). The spottail pinfish (*Diplodus holbrooki*) was observed from mid July through the end of August (Table 4). The remaining 12 species (11 families and 12 genera) were not observed often enough to see any visual trends.

Two diel studies were conducted to determine residency during light and dark periods at the FADs. During a 24-hour diel study, 10 species (7 families and 10 genera) were observed, 4 of which were carangids (Table 5). Between both the two-week and 24-hour diel studies, the Atlantic bumper (*Chloroscombrus chrysurus*), pigfish (*Orthopristis chrysoptera*), spadefish (*Chaetodipterus faber*) and Spanish mackerel (*Scomberomorus maculatus*) were only sighted during the 24-hour diel study. There was no significant difference in the abundance between all 10 species observed during the 24-hour diel study in respect to night and day periods (p>0.05 Wilcoxon Rank Sum Test).

Fourteen species (8 families and 12 genera), 5 of which were carangids, were observed during the two-week diel study (Table 5). Eight different species (7 families and 7 genera) were observed during the two-week diel study as compared to the 24-hour study (Table 5). Of the 14 species observed, only blue runner (*Caranx crysos*) showed a significant difference in their abundance between day and night periods, having a greater abundance during the day (p<0.05 Wilcoxon Rank Sum Test).

--Invertebrate Fauna

As early as 2 weeks after the FADs were deployed, both fouling and encrusting organisms were present on the FAD netting and rod buoys (see Figure 3) respectively, in relatively small numbers. After 1 to 1.5 months, the FADs had a thick, healthy coat of encrusting and fouling organisms. Two species of barnacles, *Chthamalus fragilis* and *Balanus amphitrite*, were present on the rod buoys, nose cones and fiberglass rods. The FAD netting was primarily fouled with hydroids and bryozoans (*Bugula* sp.). In addition, there was a great abundance of shrimp, (*Paleomonetes* spp. and *Hippolyte* spp.) amphipods (*Gammarus* sp.), crested blennies (*Hypleurochilus geminatus*) and spider crabs (*Libinia emarginata*) associated with the netting and fouling organisms.

Table 4. The mean number of individuals/species observed at the midwater FADs during each dive (excluding Diana assessment) (only at high tides).

	May		JUNE		
	19	23	1	5	9
Balistidae					
Aluterus scriptus (scrawled filefish)					
Monacantgus hispidus (planehead filefish)		1.00±——	1.00±0.00	4.00±2.19	4.86±2.67
Blennidae					
Hypsoblennius hentzi (feather blenny)					
Carangidae					
Caranx crysos (blue runner)				1.00±0.00	
Chloroscombrus chrysurus (Atlantic bumper)					
Decapterus punctatus (round scad)		5.00±1.41	6.11±4.31	3.88±3.04	
Seriola dumerili (greater amberjack)					
Seriola rivoliana (almaco jack)					
Seriola zonata (banded rudderfish)	1.00±0.00	1.00±0.00		1.00±0.00	
Echeneidae					
Remora remora (remora)					
Engraulidae					
Anchoa hepsetus (striped anchovy)					
Ephippidae					
Chaetodipterus faber (Atlantic spadefish)					
Haemulidae					
Orthopristis chrysoptera (pigfish)					
Pomatomidae					
Pomatomus saltatrix (bluefish)		5.33±5.86			
Rachycentridae					
Rachycentron canadum (cobia)					
Scianenidae					
Leiostomus xanthurus (spot)					
Scombridae					
Scomberomorus maculatus (Spanish mackerel)					

JUNE					JULY			
11	19	24	26	29	4	9	12	13
				1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00	3.25±2.06
3.50±0.71	1.00±0.00	1.20±0.45	2.00±1.41	3.00±0.00	1.25±0.50	1.00±____		
1.00±0.00								
		2.56±1.24	2.56±1.01	3.57±1.55	6.29±4.79	9.18±9.35	12.67±12.60	21.44±18.10
1.33±0.58						1.00±____	3.33±2.52	1.67±1.21
								1.00±____
							3.50±0.71	1.40±0.54
1.00±0.00	1.00±0.00		2.00±0.00	1.50±0.58	1.00±0.00			1.00±0.00
							1.00±0.00	
					2.50±0.71			
					1.00±0.00			

JULY							AUGUST	
14	15	22	23	24	25	27	15	17
			1.00±0.00	1.00±0.00	1.00±0.00			
		1.00±____					1.60±0.55	1.00±0.00
5.00±6.24	20.81±10.46	19.65±12.51	3.00±2.00	3.10±16.42	17.46±15.90	24.89±14.62	15.92±15.31	10.00±7.83
							5.00±____	1.50±____
	2.70±2.06	3.25±2.22		1.25±0.50		1.67±1.21		1.00±0.00
	1.60±0.89	2.17±1.47		1.00±0.00		1.33±0.58	1.00±____	4.50±0.71
1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00	2.00±____		1.25±0.50		
					1.00±____			
								5.00±____
						1.00±0.00		
					1.00±____			
								1.00±____

AUGUST 18	 26
1.00±0.00	1.00±0.00
6.86±6.39	4.42±2.91
	1.00±0.00
	1.50±1.00

	MAY		JUNE		
	19	23	1	5	9
Serranidae					
Centropristis striata (black sea bass)				1.00±0.00	1.00±0.00
Unknown					
Sparidae					
Diplodus holbrooki (spotted pinfish)					
Lagodon rhomboides (pinfish)				1.00±0.00	1.00±0.00
Stenotomus chrysops (scup)	2.00±____	2.00±0.00			
Stromateidae					
Peprilus triacanthus (butterfish)	17.75±21.79	103.20±221.32	2.50±0.71	1.00±0.00	

JUNE					JULY			
11	19	24	26	29	4	9	12	13
1.00±0.00			1.00±0.00		1.00±0.00	1.00±____		1.67±0.58
1.00±0.00	1.00±____				1.00±0.00	1.75±1.50	1.25±0.50	1.14±0.38

			JULY				AUGUST	
14	15	22	23	24	25	27	15	17
	1.00±0.00	1.00±0.00	1.00±0.00	1.00±___		1.00±0.00	1.54±0.88	3.44±1.81
1.00±0.00 1.00±0.00	1.00±___ 1.00±0.00	1.57±0.53	1.00±0.00	1.00±0.00 1.20±0.45	1.00±0.00 1.00±0.00	1.82±1.08		1.00±0.00

AUGUST	
18	26
1.00±0.00	
	2.00±0.00
1.00±0.00	1.00±0.00

Table 5. Mean no. of individuals/species observed during day and night observations of two diel studies.

Species	Diel Study			
	24 hr		2 week	
	Day	Night	Day	Night
Balistidae				
Aluterus scriptus (scrawled filefish)			2.80±2.05	1.00±0.00
Monacanthus hispidus (planehead filefish)	1.00±0.00	1.00±0.00	1.00±——	
Carangidae				
Caranx crysos (blue runner)	10.15±8.23	9.82±6.03	22.64±14.41	10.68±12.50
Chloroscombrus chrysurus (Atlantic bumper)	1.90±0.32	1.00±——		
Decapterus punctatus (round scad)	1.50±0.55		2.17±1.68	3.33±2.52
Seriola dumerili (greater amberjack)			1.00±——	
Seriola rivoliana (almaco jack)	3.33±2.08		1.62±0.97	3.50±0.71
Seriola zonata (banded rudderfish)			1.13±0.35	1.00±0.00
Echeneidae				
Remora remora (remora)				1.00±0.00
Engraulidae				
Anchoa hepsetus (striped anchovy)				1.00±——
Ephippidae				
Chaetodipterus faber (Atlantic spadefish)		1.00±0.00		
Haemulidae				
Orthopristis chrysoptera (pigfish)	4.33±0.82	2.00±——		
Rachycentridae				
Rachycentron canadum (cobia)			1.00±0.00	
Scianenidae				
Leiostomus xanthurus (spot)				1.00±——
Scombridae				
Scomberomorus maculatus (Spanish mackerel)	1.50±1.00			
Serranidae				
Centropristis striata (black sea bass)	2.41±1.43	1.00±——	1.11±0.32	1.00±0.00
Sparidae				
Diplodus holbrooki (spottail pinfish)			1.00±0.00	1.00±0.00
Lagodon rhomboides (pinfish)	1.22±0.43	1.20±0.45	1.41±0.72	1.07±0.26

Behavorial Observations

Objects placed in the midwater column provide fish with a visual stimulus for orientation in an otherwise void environment. The FADs appear to be used differently by each species. These uses include orientation, feeding and protection.

Butterfish (Peprilus triacanthus) were primarily observed in large schools of 60 to 200 individuals in varying sizes. Butterfish were usually found swimming near the upper, open-ended section of the FAD, occasionly straying 2 to 3 meters from the FAD. On rare occasions, due to the presence of the divers, butterfish moved into the FAD.

Blue runners (Caranx crysos) were not oriented to any specific section of the midwater FAD. Small numbers of blue runners, 1 to 35 individuals, were commonly observed swimming around the outside of the midwater FADs, occasionally exiting at the small opening at the nose cone. They appeared to enter the FAD when threatened by larger fish or by the approach of divers. Schools of blue runners were at times intermixed with a fewer number of round scad (Decapterus punctatus) and almaco jack (Seriola dumerili). Although blue runners typically remained close to the FADs, only straying 1 to 1.5 meters, on occasion, schools followed the divers from one midwater FAD to another, apparently following the diver's exhaust bubbles as the main attractant.

Several months after the deployment of the FADs, black sea bass (Centropristis striata) were observed in association with the FADs. They positioned themselves inside the FAD netting near the nose cone. They were never observed in pairs or small schools. Several times a black sea bass was observed actively pecking or nibbling on the fouling organisms attached to the FAD netting. No other species were observed inside the midwater FAD when a black sea bass was present. On numerous occasions, small schools of blue runners would attempt to swim into the FAD, only to veer away due to the territorial displays (flaring of fins) of a black sea bass. In addition, black sea bass were observed ascending the vertical line from the FAD anchor, feeding for a few minutes on the underside of the midwater FAD netting and then descending back to the FAD anchor by way of the vertical line.

The planehead filefish (Monacanthus hispidus) appeared to use the FAD primarily for protection. Solitary or small schools of individuals 1/2 to 3/4 inch (1 to 2 cm) in length, hovered close to the netting located near the fiberglass rods, rod buoys or the folds of the nylon netting at the mouth of the FAD. Once a healthy growth of fouling organisms were present, small planehead filefish were difficult to observe due to their cryptic coloration. Larger planehead filefish individuals (10 to 15 cm), which were not as abundant, were usually associated with the nose cone. On rare occasions, these larger individuals were observed feeding on the fouling organisms attached to the FAD netting and vertical line.

Single individuals or pairs of banded rudderfish (Seriola zonata) were apparently very territorial toward the FAD as no other species were observed when they were present. Banded rudderfish actively patrolled the area around the FADs, investigating and/or chasing off anything (e.g. fish, jellyfish (Stomolophus), divers) that came within close proximity of the FAD. This was evidenced by banded rudderfish straying as far as 5 meters away from the FAD to check out approaching divers. They appeared fearless of the divers. While the divers were present, banded rudderfish constantly approached, fled and re-approached the divers while simultaneously altering the intensity of their black bars.

Pinfish (Lagodon rhomboides) appeared to use the FADs primarily for feeding. Large individuals pecked and nibbled at the fouling organisms attached to the FAD netting. Large individuals, 10 to 20 cm in length, feeding on the inside netting of the FAD, showed aggressive behavior if other species attempted to move inside the FAD. One large individual was observed successfully deterring a school of 10 blue runners.

On rare occasions spadefish (Chaetodipterus faber) and remoras (Remora remora) were observed near the FAD netting. Spadefish oriented to the underside of the netting, rapidly descending along the vertical line and/or intensifying their black bars when frightened. Remoras always hovered under the underside of the netting, which was an expected orientation for this commensal species.

It is evident that the FADs served different functions in respect to the numerous species associated with these artificial units. Many of these species show strong signs of territoriality, which may in turn govern the diversity and abundance of fish associated at each midwater FAD.

Assessment of FAD Structural Integrity

As mentioned, when the FADs were initially deployed the units were positively buoyant and therefore positioned themselves vertically in the water column, with the open end positioned toward the surface. It was only after a month of submergence that the FADs became horizontally positioned due to the weight of fouling and encrusting organisms. However, after another month elapsed, the abundance of fouling and encrusting organisms overburdened the FAD floatation, causing them to sink. At this time, one additional midwater buoy was tied into eight FADs, repositioning each FAD vertically.

The PVC nose cones originally incorporated with the midwater FADs were not of adequate strength. After 1.5 months of submergence, the constant drag on the midwater FADs caused the nose cones to assume a slightly collapsed shape which in turn caused the entire midwater FAD to take on a more collapsed shape. In addition, when the midwater FADs were taken on board the ship, the weight of the netting due to the fouling and encrusting organisms was too great, causing the nose cones to crack. These problems were partially corrected with new fiberglass reinforced plastic nose cones. These new nose cones worked very well with only one cracking over the course of 2 months.

The weak link of the entire FAD system appears to lie in the nose cone-fiberglass rod connection. Silicone sealant was recommended as an adhesive. This proved to be inadequate. Four of the six lost FADs were due to the fiberglass rods pulling away from the nose cone. As the FADs were re-outfitted, silicone sealant was replaced by PVC cement. This proved to work well, but it is permanent and the FADs cannot be disassembled without cutting the rods.

The nose cone was shackled to a stainless steel trapeze ring which was tied into the vertical FAD lines (Fig. 4). Through the use of three different metals, galvanized steel, brass and stainless steel, major corrosion occurred within a short period of time. After three months, the galvanized shackles were replaced because they had worn thin, yet both the brass eyebolt and stainless steel trapeze ring held up well with very little corrosion. The least expensive solution to hinder the rate of corrosion would be to switch to a galvanized eyebolt and trapeze ring. An alternative solution would be to replace the galvanized shackles with brass. The FAD nylon netting held up very well. Various kinds of fishing tackle (e.g. down riggers, spoons, monofilament line) were commonly observed entangled within the netting. This tackle in turn produced holes varying from 1 to 5 inches (2 to 13 cm). Except for the initial tear, holes in the nylon netting did not increase in size from stress produced from wave surge, etc.

Although the study area was spared from the most severe environmental conditions resulting from Hurricane Diana (Sept. 12 to 13), heavy winds and wave surge took its toll on the artificial reef. An assessment of the aftermath of Hurricane Diana revealed that eight out of 15 midwater FADs were missing. Of the eight FADs missing, five had pulled away from their respective nose cones, two FADs broke away from the trapeze rings, and the nose cone of one FAD had completely collapsed. The seven FADs present were badly entangled in the FAD netting and the vertical FAD line. The nylon netting of these seven units had been pulled back away from their respective nose cones, assuming a collapsed position. In addition, numerous FAD anchors were flipped over and/or partially or completely buried in the substratum.

Catch Per Unit of Effort (CPUE) Analysis

The catch per unit of effort (CPUE) data were analyzed with the Statistical Package for the Social Sciences (SPSS) subprogram T-TEST (Nie, et al. 1975: 249-275). Briefly, this involved computing CPUE by dividing the number of each species caught by the total wet gear time (in minutes) on a case by case basis, and then comparing the piers' average CPUE statistics for each species. The figures shown in tables 1 through 6 are thus the mean figures for numbers of fish caught per minute of wet gear time.

During the year preceding deployment of the FADs, two-tailed t-tests were used to determine whether any statistically significant CPUE difference between piers existed under natural conditions. Following the deployment of the FADs, we hypothesized that significantly higher CPUE figures would be found at the pier with the FAD. In such cases, because we expect the mean force to be skewed in one direction (i.e., to be higher at the pier with the FAD), one-tailed t-tests were used to test statistical significance. The probability levels shown refer to the probability of the mean figures occurring by chance alone. A .01 level means that the probability of these values occurring by chance is 1 in 100; a .001 level means that the probability of these values occurring by chance is 1 in 1000. Generally, a .05 level (5 in 100) or lower indicates a statistically significant difference.

Tables 6 through 10 present the results of the comparisons of catch per unit of effort (CPUE) from Pier A and Pier B. Tables 6 and 7 present CPUE data collected during the fall of 1983, a year before the FAD was placed off either pier. These comparisons were necessary to determine whether or not higher average catches/unit of effort occurred at either pier under natural conditions. For table 7, we selected out those October 1983 cases because they overlapped in time with the 1984 experimental comparisons shown in table 6.

For the first two tables, the piers' average CPUE statistics for the eight species were compared using two-tailed T-tests. The probabilities shown demonstrate that few statistically significant differences exist between the two piers. Mean values which are significantly higher, include kingfish for the total, and king and Spanish mackerel for the cases within the October time period. In these cases, Pier A CPUE averages are higher.

Tables 8-10 compare the CPUE statistics from the two piers while using the FAD at one of the piers. Probability levels shown here are computed from one-tailed T-tests, instead of two-tailed. During the first time period (Table 8), while the FAD was anchored off Pier A significantly more Spanish mackerel were caught per minute of wet gear time from Pier A than from Pier B. However, the CPUE statistics for the two piers during the October time slot in 1983 (Table 7) show that Pier A tends to have more pelagics (king and Spanish mackerel) than Pier B under natural conditions. Table 9 shows that even when the FAD was moved to Pier B from mid-June to July, there were significantly more Spanish mackerel caught from Pier A than from Pier B. The higher

TABLE 6
CATCH PER UNIT OF EFFORT:
PIER A AND PIER B COMPARED WITHOUT FAD

October - December, 1983

Species	Average No. Caught/Minute of Wet Gear Time		
	Pier		
	Pier A (N=373)	Pier B (N=616)	
Bluefish	.0078 (sd=.037)	.0165 (sd=.262)	p=.524**
King Mackerel	.0002 (sd=.002)	.0000 (sd=.000)	p=.072
Spot	.0090 (sd=.073)	.0125 (sd=.069)	p=.448
*Sea Mullet	.0016 (sd=.010)	.0004 (sd=.004)	p=.007
Pompano	.0007 (sd=.009)	.0006 (sd=.008)	p=.800
Spanish Mackerel	.0003 (sd=.004)	.0014 (sd=.033)	p=.553
Sheepshead	.0000 (sd=.000)	.0001 (sd=.002)	p=.339
Flounder	.0078 (sd=.100)	.0011 (sd=.009)	p=.097

* Statistically significant.

**Probability levels refer to two-tailed students T-tests.

TABLE 7
CATCH PER UNIT OF EFFORT: PIER A AND PIER B COMPARED WITHOUT FAD

October, 1983

Species	Average No. Caught/Minute of Wet Gear Time		
	Pier		
	Pier A (N=133)	Pier B (N=268)	
Bluefish	.0025 (sd=.013)	.0061 (sd=.061)	p=.511
*King Mackerel	.0006 (sd=.003)	.0000 (sd=.000)	p=.012
Spot	.0164 (sd=.010)	.0189 (sd=.004)	p=.781
Sea Mullet	.0010 (sd=.001)	.0007 (sd=.000)	p=.584
Pompano	.0015 (sd=.001)	.0007 (sd=.006)	p=.429
*Spanish Mackerel	.0010 (sd=.007)	.0001 (sd=.001)	p=.025
Sheepshead	.0000 (sd=.000)	.0000 (sd=.001)	p=.331
Flounder	.0175 (sd=.167)	.0010 (sd=.011)	p=.109

TABLE 8
CATCH PER UNIT OF EFFORT: PIER A AND PIER B COMPARED WITH FAD AT PIER A

May 3, 1984 - June 14, 1984

Species	Average No. Caught/Minute of Wet Gear Time	
	Pier	
	Pier A (N=145)	Pier B (N=174)
Bluefish	.0060 (sd=.016)	.0052 (sd=.021)
	p=.339**	
King Mackerel	.0000 (sd.000)	.0000 (sd=.000)
	p=.5	
Spot	.0001 (sd=.001)	.0002 (sd=.001)
	p=.42	
Sea Mullet	.0000 (sd=.000)	.0024 (sd=.032)
	p=.181	
Pompano	.0000 (sd=.000)	.0000 (sd=.000)
	p=.5	
*Spanish Mackerel	.0020 (sd=.010)	.0004 (sd=.003)
	p=.019	
Sheepshead	.0000 (sd=.000)	.0000 (sd=.000)
	p=.5	
Flounder	.0002 (sd=.002)	.0001 (sd=.001)
	p=.37	

* Statistically significant.

**Probability levels refer to one-tailed student's t-tests.

TABLE 9
CATCH PER UNIT OF EFFORT: PIER A AND PIER B COMPARED WITH FAD AT PIER B

June 17, 1984 - July 30, 1984

Species	Average No. Caught/Minute of Wet Gear Time		
	Pier		
	Pier A (N=251)		Pier B (N=360)
Bluefish	.0007 (sd=.002)	p=.135	.0069 (sd=.089)
King Mackerel	.0001 (sd=.001)	p=.108	.0000 (sd=.000)
Spot	.0027 (sd=.018)	p=.075	.0055 (sd=.028)
Sea Mullet	.0006 (sd=.010)	p=.308	.0015 (sd=.026)
Pompano	.0000 (sd=.000)	p=.202	.0000 (sd=.000)
*Spanish Mackerel	.0007 (sd=.003)	p=.002	.0001 (sd=.001)
**Sheepshead	.0001 (sd=.001)	p=.0115	.0000 (sd=.000)
Flounder	.0012 (sd=.008)	p=.45	.0014 (sd=.017)

TABLE 10
CATCH PER UNIT OF EFFORT:
PIER A AND PIER B COMPARED WITH FAD AT CRYSTAL

July 31, 1984 - October 16, 1984

Species	Average No. Caught/Minute of Wet Gear Time		
	Pier		
	Pier A (N=199)		Pier B (N=415)
Bluefish	.0123 (sd=.080)	p=.119	.0428 (sd=.018)
King Mackerel	.0000 (sd=.000)	p=.074	.0000 (sd=.000)
Spot	.0266 (sd=.126)	p=.181	.0487 (sd=.331)
*Sea Mullet	.0041 (sd=.040)	p=.044	.0007 (sd=.006)
Pompano	.0006 (sd=.003)	p=.169	.0083 (sd=.069)
Spanish Mackerel	.0000 (sd=.000)	p=.204	.0004 (sd=.007)
Sheepshead	.0001 (sd=.002)	p=.118	.0000 (sd=.000)
Flounder	.0002 (sd=.001)	p=.247	.0120 (sd=.243)

CPUE figures for Spanish mackerel at Pier A cannot be attributed to the FAD.

While more Spanish mackerel/unit of effort tend to be caught from Pier A, Pier B CPUE figures for spot and bluefish are higher throughout the summer and autumn months (tables 9 and 10) than Pier A's figures, although not statistically significant. Finally, table 5 shows that the sea mullet CPUE was significantly higher at Pier A when the FAD was at Pier A during the third time period. Again, however, we cannot attribute this difference to the presence of the FAD, since significantly more kingfish are caught at Pier A under natural conditions (see Table 6). These findings suggest that the FAD does not affect CPUE.

Following comparisons of the total samples, we compared various subsamples within the larger sample on the basis of the section of the pier fishermen were located (end, middle, shore), the wind direction, wave height, and water temperature. Because the FADs were placed 750 feet from the end of the pier, we thought that fishermen fishing from the end of the pier would have the best chance of catching any fish attracted by the FAD. It would logically follow that comparisons between the end-of-pier cases from the two piers might yield different CPUE results that those for the entire sample.[1] In general, however, comparisons between the end-of-pier subsamples generated results similar to those of the entire sample. For example, Spanish mackerel CPUE figures were significantly higher at Pier A, with or without the FAD, and Pier B still had higher CPUE figures for spot and bluefish, although not signtificantly higher.

Nevertheless, there was one important difference between the end-of-pier subsample comparisons and those shown in tables 8-10 above. While there were more flounder/unit of effort caught from Pier B for the total sample during the third time period (table 10 -- FAD at Pier A), table 11 shows that the flounder CPUE figures for this time period change significantly when we compare only the end-of-pier fishermen. In addition, comparing the end-of-pier subsample values with those presented in Table 7, we can see that during the same time period a year earlier, under natural conditions, there was no significant difference between the two mean values for flounder.

[1] The end-of-pier subsample comparisons are important not only because they support the total sample comparisons, but also because the number of fishermen are more evenly distributed between the two piers, at least during the first two time periods. In Tables 1-5, it is clear that Pier B is used by around twice as many fishermen as Pier A, while significantly higher CPUE statistics almost always favor Pier A. It may be at Pier B because there are twice as many fishermen fishing for the same amount of fish, reducing each fisherman's chances by one-half that of Pier A fishermen. However, with the end-of-pier subsample, where the numbers of fishermen are closer to one another, the mean values for CPUE and the significant findings do not radically change, with the exception of flounder.

TABLE 11
FLOUNDER CPUE STATISTICS COMPARED FOR THREE SAMPLES

Sample	Average No. of Flounder Caught/ Minute of Wet Gear Time		
	Pier A		Pier B
1983 Sample (without FAD)	.0078 (sd=.100) (N=373)	p=.097	.0011 (sd=.262) (N=616)
July 31 - October 16 1984 Sample (FAD at Pier A)	.0002 (sd=.001) (N=199)	p=.247	.0120 (sd=.243) (N=415)
July 31 - October 16 1984 End-Of-Pier Sub-Sample (FAD at Pier A)	.0002 (sd=.001) (N=115)	p=.017)	.0000 (sd=.000) (N=203)

The increase in flounder with presence of the FAD may be due to the documented increase in bait fish attracted by the FAD, instead of a direct causal link between number of flounder and the FAD. However, we present these findings with a note of caution. Although the difference between the two means is not significant, Table 6 shows that the mean value for flounder/unit of effort was higher off Pier A during the fall of 1983, under natural conditions.

Finally, selecting out subsamples based on wave height and wind direction did not produce any noticeable departures from the findings presented above. There were a few isolated cases of statistical significance which did not appear in earlier comparisons, but these did not always coincide with the presence or absence of the FAD. On the basis of the computer analysis in general, we would have to conclude that the FAD, placed 750 feet from the end of the pier, had little if any effect on the fishermen's catch per unit of effort.

Conclusions and Discussion

In general, the results of the study were mixed. The FADs proved to be successful in aggregating baitfish in the nearshore environment. An average of 3.67±8.91 fish appeared on each FAD representing 35 different species. This compared with the control site which had no fish.

Schools of fish attracted to the FADs during our study were not as large as reported by Klima and Wickham (1971). The reason(s) for the difference is not clear because the artificial units used in both studies were similar in shape, size and were deployed at a similar depth. The natural habitat of both study sites may have varied greatly. In addition, the rapid recruitment of fish observed by Klima and Wickham (1971) did not occur in our study. Fish were not observed until after the FADs had been deployed for one week. This may emphasize the difference between the natural habitats between both studies. Fewer fish may be present where we deployed the FADs in comparison to Klima and Wickham's study site.

Numerous studies have shown that bottom and midwater artificial reefs increase the CPUE of several pelagic sport fish (Buchanan et al., 1974; Hammond et al., 1977; Wickham et al., 1973). These studies involved trolling over experimental and control study sites. Unfortunately trolling was not feasible in our study. Whether or not the CPUE may have been greater at our experimental site concerning pelagic sport fish using standard trolling methods needs to be investigated. Buchanan (1973) on the other hand found no significant different in the CPUE between an artificial reef and the natural habitat for both pelagic and bottom fishes.

The surface area of an artificial unit and its placement in the water column are important factors governing the diversity and abundance of fish attracted to the unit(s). The aggregation of pelagic fish near or beneath floating and moored objects is well documented (Gooding and Magnuson, 1967; Hunter and Mitchell, 1966, 1968). A greater abundance and diversity of fish have been shown to associate with midwater units rather than surface units (Klima and Wickham, 1971). In addition, a greater number of fish are associated with both simple and complex midwater units than surface structures (Klima and Wickham, 1971). Our results are similar to those of Klima and Wickham (1971); the diversity and abundance of fishes were much greater at the FADs than at the spar buoys. One exception to this concerns the blue runner (*Caranx crysos*) which did not exhibit a significant difference in their abundance between the FADs and spar buoys. The surface area of both the spar buoy and FAD differed greatly which might explain to some extent the difference in the abundance and diversity of fish observed at each structure.

Wickham and Russell (1974) proposed that fish leave artificial structures at night and that new recruitment occurs daily. Our results show no evidence to support this trend. Due to the frequent diving involved with the 24-hour diel study, it seemed likely that we observed the same fishes at the FADs rather than new recruits. However, blue runners (*Caranx crysos*) commonly moved from one FAD to another, using the diver as the attractant. A possible explanation of our results may be linked to the natural habitat where our FADs were deployed. There was no vertical relief or other structures for the fish to use as spatial references. A substantial migration would have been required of the fish in locating additional structures for orientation purposes (e.g. pier pilings, rock jetty).

The initial attraction of fish to midwater objects probably results from visually detecting the object in an otherwise void environment, providing spatial references (Wickham and Russell, 1974). This theory is supported by our study. Although the fish were capable of moving beyond sight of the FAD for a short period of time, they appeared to require almost constant visual contact. It is interesting to note though, that water visibility had no apparent effect on fish abundance in our study. In some instances, the attraction of sport pelagic fish appears to involve specific behavioral mechanisms (Wickham et al., 1973). Our study showed no evidence of any species specific mechanisms.

Territorial behavior may have played an important role in governing the abundance and diversity of fish associated with each FAD. The surface area of each FAD was apparently small enough to enable a single individual, especially rudderfish (Seriola zonata), to successfully deter all fish that attempted to approach the FAD. Possibly, if the surface area of the FAD was increased, territorial behavior may have had less of an effect on the diversity and abundance of fish associated with the FADs.

The simple design of the FADs and their relative ease of deployment and retrieval make these units feasible by individual fisherman and fishing clubs. It is evident though, that the FADs do require some maintenance (e.g. adding additional floatation, checking for corrosion) which can be performed easily by scuba divers. Relatively few pelagic target sportfish species were seen by divers. One reason for this may include skittishness of pelagic species near divers, making the fish difficult to spot in waters with limited visibility. Another more likely explanation was a general lack of pelagic sportfish in nearshore water near Wrightsville Beach, N.C., in the summer of 1984. Supporting this conclusion are the very low CPUE statistics. For example, between June 17 and July 30, 1984, a fisherman would have to fish at Pier A 166.6 hours of wet gear time to catch a king mackerel, 23.8 hours to catch a bluefish and 23.8 hours to catch a Spanish mackerel while at Pier B which was FAD enhanced the same fishermen would wait 2.41 hours to catch a bluefish, 166.6 hours to catch a Spanish mackerel and he would not have caught a king mackerel.

The FAD units were not successful in improving fishing success at the fishing piers. Factors attributed to the poor showing may include the general poor fishing in the inshore area during 1984 described above. Generally, the fall fishing season produces far more catch of pelagics on the piers. However, Hurricane Diana effectively interrupted the study on September 13, which may have caused us to miss this important season. Perhaps most important was the distance the units were placed from the piers (750 feet). As described, this was a demand placed on us by the pier owners because of their fear of complaints by fishermen who may have lost gear or fish. It may be unrealistic to expect fish to move this distance and become accessible for catch by fishermen on the piers. If FAD enhancement is attempted by pier owners in the future it is recommended that the units be moved closer to the pier to just out of casting distance (perhaps 150 feet). Loss of gear problems could be addressed by other methods such as a clearly recognizable buoying system and warning signs placed conspicuously on the piers.

A third objective was to determine whether the FAD units would be durable enough to hold up in the nearshore environment where currents and wave action expectedly create more stress on the system. Generally the units performed well. Six of the original 18 units were lost and 3 were replaced. Four were lost because the fiberglass rods slipped out of the nose cone. The rods were originally glued into the nose cone with a silicone sealant. After the failure the manufacturer recommended PVC cement. This worked well and should prevent this problem in the future. A fifth FAD was lost due to fraying of the vertical line at the nose cone juncture. This problem was solved when the shackle system was substituted. The sixth was lost because of galvanic corrosion. This can be corrected through the proper choice of compatible materials. Eight of the remaining fifteen units were lost on September 13, 1984, during Hurricane Diana, a category 2 hurricane with 100 mph sustained winds whose eye passed within twelve miles of the units. Major shoreline damage occurred in the Wrightsville beach area and it was surprising any of the units survived. The manufacturer has been using this episode in his marketing program.

The FADs were relatively easy to deploy. Once the anchoring system was constructed on land, the 18 units and two anchoring systems were deployed by a team of four using a 23-foot outboard in two and one-half days. At full retail prices, the total cost of the materials, excluding labor, and FAD units was $2,021. The 1984 price listed for 18 FAD units was $2,304. The manufacturer, however, donated the units to the project. Potentially, other homemade designs could be used. Each of the four surface buoys off each pier had its own schools of bait fish, indicating that a single buoy either floating at or below the surface may be effective in aggregating fishes.

Although permits may be difficult to obtain for placing bottom structures in the nearshore environment because of the potential for causing erosion problems, it appeared that bottom structures will also aggregate fishes. Within weeks after placement each concrete filled tire had black sea bass aggregating around it. The individual tires had only 10 inches of relief, which indicates that a more substantial structure would be quite successful in attracting black sea bass.

Aside from a FAD's ability or inability to aggregate fish, a further benefit which should not be overlooked is its marketing potential. Although publicity for the project was not sought, the local media discovered the project and wrote several articles about it. FAD enhancement could be used for advertising and marketing purposes to improve the competitive position of individual piers.

Further Research

The growth in marine recreational fishing participants has outpaced the growth rate of the U.S. population in recent decades by a factor of 2 1/2. (National Fisherman, July 1984). As more and more fishermen enter the fishery, fisheries-dependent businessmen and fisheries managers will need to develop new and innovative ways to keep their customers or constituency happy. Future research should continue to improve fishing at public and private access points such as fishing piers, fishing banks, jetties and bridges. Some questions which surfaced during the study deserve further scrutiny. They include:

1. Acoustic transmitter tagging of pelagics --- As midwater reefs and trolling alleys gain in popularity, more work needs to be done to determine the movement patterns of key target species near the attractors. Such information would help in FAD placement decisions near in-shore structures such as piers. It would also assist in spacing decisions for individuals units. The 60-foot (18 m) spacing distance between the individual FAD units chosen for this study was done by guess work. It was felt that 25-foot (7.6 m) underwater visibility was the maximum in this area and that fish would move from unit to unit by sight. This was obviously not tested. The mechanism that initially attracts fishes to the FADs is not known. Sight no doubt plays an important factor, but it is also likely that the low frequency sounds generated by currents impinging upon the midwater structures may be the initial attraction to fishes. Sight may play the main role in maintaining fishes in association with the FADs, but not necessarily in the initial attraction of fishes to FADs. If the low frequency sounds can be duplicated or synthesized and played back underwater, these artificial sounds might be used as initial enhancement mechanisms for artificial reefs.

2. Other FAD configurations should be tested --- The three six-FAD unit strings with the two end strings angled toward the pier were chosen because it was felt the end strings might act as leads toward the pier for fish migrating along the beach. This did not seem to happen because of the distance from the piers. Other designs should be tested and analyzed.

3. Controlled fishing over the units --- Because of time and funding limitations, no attempt was made to use controlled float fishing from boats over the FADs. Deep troll fishing was prohibited by a special declaration by the Marine Fisheries Commission in order to avoid boat fishermen taking fish and anchoring over and destroying the units. However, controlled fishing experiments over the units using float or surface trolling methods would/may be an effective way of determining pelagic availability since they may have avoided the divers. Also, a future use for FADs may be inshore trolling alleys or float fishing areas. Research is needed to determine fishing success by fishing over them.

4. The FADs were used in the study because they had been successfully tested in offshore waters and they were donated for the project. However, experimentation with other midwater designs should be

encouraged. Bottom structure in the nearshore zone appears to show promise particularly for sea bass. Coastal engineers should experiment with designs which can be placed in this environment without causing erosion. One possibility would be to attach the structure to the pier pilings which would be off the bottom and allow for sand transport below it.

5. Several assumptions were made by the pier owners about the motivations of their pier fishermen. A survey of pier fishermen regarding attitudes toward fish enhancement, loss of gear etc. should be conducted in order to help pier owners to make informed decisions about constructing FADs for their users.

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APPENDIX

PIER FISHING
INDIVIDUAL REPORT FORM

1. Date ______________________________
2. Time ______________________________
3. Fisherman # ____________
4. Section of Pier
    1. End
    2. Middle
    3. Shore side
5. Number of fishing rods used ________
6. Wet gear time (in minutes x rods used) _________
7. Number of fish caught

# Caught	Species	# Weighed	Average Weight
	Bluefish	_________	_______
	Spot	_________	_______
	Sea Mullet	_________	_______
	King Mackerel	_________	_______
	Pompano	_________	_______
	Spanish Mackerel	_________	_______
	Sheepshead	_________	_______
	Flounder	_________	_______
	Other	_________	_______
	Other	_________	_______