

ECOLOGY OF THE ASSOCIATION OF FISHES WITH FISH AGGREGATION DEVICES
(FADs): IMPORTANCE OF STRUCTURAL COMPLEXITY, WITH A DISCUSSION
OF THE ASSOCIATION OF FISHES WITH DRIFT MATERIALS

by

Rodney Alan Rountree

A thesis submitted to the faculty of the
Charleston Higher Education Consortium's
Graduate Program in Marine Biology
in partial fulfillment of the
requirements for the Degree of
Master of Science

COLLEGE OF CHARLESTON

September 1987

APPROVED BY:

Ann R. Nelson
MAJOR ADVISOR

3 September 1987
DATE

Charles K. Bevin
COMMITTEE

3 September 1987
DATE

Charles A. Gorman
COMMITTEE

3 Sept 87
DATE

Mark Bell
COMMITTEE

3 SEP 1987
DATE

Hardy Gorman
COMMITTEE

Sept. 3, 1987
DATE

DEAN OF GRADUATE STUDIES

DATE

Acknowledgments

I would like to thank my committee members C.A. Barans, M. Bell, C.K. Biernbaum, H.W. Freeman and G.R. Sedberry for their support and tireless review of this manuscript. My major advisor, G.R. Sedberry, is especially thanked for his patience and guidance. M. Bell, F.L. Folsom, S. Murphey and E.R. Hens of the South Carolina Wildlife and Marine Resources Department Recreational Fisheries Program provided materials and logistical support, without which this study would have been impossible. McIntosh Marine Inc. graciously donated four FADs for use in this study. The photographs used in my thesis were taken by M. Bell, who accompanied me on numerous scuba dives during the project. I would also like to thank J.W. Hayse and the other graduate students who helped me tote concrete blocks around on the bottom of the ocean. M.J. Clise of the South Carolina Marine Resources Research Institute provided valuable assistance with data processing. I thank Captains V. Taylor of the R/V Anita and J. LaRoach of the R/V Carolina Pride for their professional support of the numerous dive operations carried out during the course of my research. Special thanks go to my parents and family for their tremendous moral support during my years in college. This study was supported by the SCWMRD and by grants from the Slocum-Lunz Foundation, Inc., the Agricultural Society of South Carolina, and the South Carolina Sea Grant Consortium.

Table of Contents

	Page
Acknowledgements.....	ii
List of Figures.....	iv
List of Tables.....	xii
List of Appendices.....	xiii
Abstract.....	xiv
Introduction.....	1
Materials and Methods.....	12
Results.....	25
Discussion.....	82
Conclusions.....	116
Literature Cited.....	119
Appendices.....	129

List of Figures

Figure	Page
1. Experimental design and configuration of FAD type treatments used in this study. Numerals designate station numbers.....	13
2. Location of test site relative to bottom materials on Capers artificial reef and to the coast of South Carolina.....	15
3. Scale drawing of the FAD type treatment (A, B, and C), and the FAD type D structures, used in this study.....	16
4. Schematic showing movements of FADs during the course of the study. Numerals refer to station numbers (see Fig. 1) with numbers 1, 10 (after loss of 11), 12 and 22 designating the corners of the grid. Lines represent the approximate position of the rope grid lines on each date, while arrows indicate movements of the corner stations between dates. For example, station 22 moved from the position marked by the circle on 15 May to that marked by the cross on 6 June, then to the triangle on 6 August and finally, to the star on 21 October. The location of station 14 indicates a tendency for the grid to straighten out in a northern direction with station 22 lagging behind.....	26
5. Photographs of one of each of the FAD type treatment structures taken 115 days after deployment (6 September 1985). Arrows indicate the angle in the mooring line caused by the heavy drag on the float and sinking of the FAD. A) FAD type A with streamers still held up in the current and with little or no sinking in the water column. B) FAD type B with streamers beginning to hang down, and with some sinking of the FAD in the water column. C) FAD type C with dragging streamers and considerable sinking in the water column.....	28
6. Underwater photographs of selected species observed in this study, illustrating aspects of their behavior. A) <u>Aluterus scriptus</u> in the characteristic position of filefishes, orienting to, and hiding behind, the FAD. B) <u>Epinephalus morio</u> exhibiting an agonistic display to divers. The scaled flank of a black sea bass, hidden within the concrete block, can be seen under the red grouper's anal fin. C) Small school of <u>Decapterus punctatus</u> associated with the anchor of a FAD. A typical sized <u>Centropristis ocyurus</u> can be seen resting at the lower edge, near the cross-piece, of the concrete block.	

- D) photograph of fishes associated with the streamers of a FAD type C structure on day 159. Three filefish (1 in upper left corner and 2 in the lower middle of the photograph) can be seen orienting to the streamers where they are feeding on fouling organisms. Small black sea bass, like the one in this photograph, utilized the FADs only when they had become so heavily fouled that they were dragging on the bottom. E) One of the large black sea bass which often wedged themselves tightly into the concrete block. F) A stone crab, Menippe mercenaria, nearly fills one chamber of a concrete block. The arrow points to a Polinices sp. snail on which the crab was feeding under the crab's left cheliped. A typical sized sand perch can be observed just above the crab..... 33
7. Dendrogram resulting from inverse cluster analysis using the Jaccard similarity index based on presence/absence of species at structure types A, B, C, D and E combined for species with at least a 5 % frequency (N=106)..... 40
8. Nodal constancy, fidelity, and abundance for all species with a frequency of greater than 4 % grouped by FAD type treatment within day treatments. Note that a X in a cell indicates a significant fidelity..... 41
9. Dice plots of mean number of species, number of individuals and numbers of selected species observed per station by FAD type treatments. The horizontal line indicates the mean, the black bar represents one standard error and the white bar indicates one standard deviation above and below the mean. The range in observed values is shown by the vertical line (refer to Table 1 for sample sizes). Note that the response to FAD type treatment differed among species..... 45
10. Mean No. species/station for each FAD type treatment by day treatment. Note that FAD type treatment B had consistently lower means than FAD type A..... 47

11. Dice plots of mean number of species, number of individuals and number of selected species observed per station by day treatment. The mean is represented by the horizontal bar, the vertical black bar represents one standard error around the mean and the white bar represents one standard deviation about the mean. The vertical line represents the range of observed values. (refer to Table 1 for sample sizes). Means for day 91 were significantly lower than adjoining days in A, B, C, D, and H (see text)..... 48
12. Frequency histograms with FAD type treatment A, B, C and pooled types, on the x-axis. I) Total number of individuals/station. II) Total number of Decapterus punctatus/station. III) Number of D. punctatus/school based on 62 stations ($N_a = 31$, $N_b = 28$, $N_c = 23$, $N = 81$). IV) Total number of Caranx crysos/station..... 50
13. Contour plots of the 2-dimensional distribution of fish around structures of each FAD type treatment (A-C) and around a composite FAD based on data from all three treatments pooled (D). Contours represent the percent presence of individuals in m^2 cells around the structure as viewed perpendicular to the current axis.
- A). FAD type A: A total area of $65 m^2$ was utilized with an average of $10.86 (\pm 7.22) m^2/station$ ($N = 35$ non-zero records).
- B). FAD type B: A total area of $94 m^2$ was utilized with a mean of $12.14 (\pm 9.64) m^2/station$ ($N = 28$ non-zero records).
- C). FAD type C: A total area of $97 m^2$ was utilized with a mean of $14.04 (\pm 8.65) m^2/station$ ($N = 25$ non-zero stations).
- D). Pooled FAD types: A total area of $119 m^2$ was utilized with a mean of $12.17 (\pm 8.46) m^2/station$ ($N = 88$ non-zero stations)..... 52

14. Contour plots of the 2-dimensional distribution of fish (excluding Decapterus punctatus) around structures of each FAD type treatment (A-C) and around a composite FAD based on data from all three treatments pooled (D). Contours represent the percent presence of individuals in m² cells around the structure as viewed perpendicular to the current axis.
- A). FAD type A: A total area of 39 m² was utilized with an average of 7.06 (\pm 4.21) m²/station (n=35).
- B). FAD type B: A total area of 50 m² was utilized with an average of 7.70 (\pm 6.20) m²/station (n=28).
- C). FAD type C: A total area of 65 m² was utilized with an average of 10.08 (\pm 6.34) m²/station (n=24).
- D). Pooled FAD types: A total area of 65 m² was utilized with an average of 8.13 (\pm 5.61) m²/station (n=87). 54
15. Contour plots of the 2-dimensional distribution of fish (excluding D. punctatus) around structures of each FAD type treatment (A-C) and around a composite FAD based on data from all three treatments pooled (D). Contours represent the mean number of individuals/m²/station (assuming all individuals lie in a plane parallel to the axis of the current). Note the distribution was densest around the anchor and within 1 m of the FAD..... 56
16. Photographs of one of each of the FAD type treatment structures taken 17 days after deployment. A) FAD type A with few or no Decapterus punctatus present. Here Seriola zonata (with bars) and Caranx bartholomaei can be seen swimming close to the float. B) FAD type B at which on the order of 100 D. punctatus were observed. C) FAD type C at which on the order of 1000 D. punctatus were observed and at which Seriola zonata was absent.... 58
17. Photograph of a FAD type B station taken on day 55 showing the position of a school of round scad relative to the FAD. The school's behavior has been disturbed by divers, but the bowl shaped configuration and up current position of the school are still apparent..... 62

18. Contour plots of the 2-dimensional distribution of Decapterus punctatus around structures of each FAD type treatment (A-C) and around a composite FAD based on data from all three treatments pooled (D). Contours represent the percent presence of individuals in m^2 cells around the structure as viewed perpendicular to the current axis.
- A). FAD type A: A total area of $59 m^2$ was utilized with an average of $7.80 (\pm 5.49) m^2/station$ (n=25).
- B). FAD type B: A total area of $88 m^2$ was utilized with an average of $10.05 (\pm 6.29) m^2/station$ (n=20).
- C). FAD type C: A total area of $96 m^2$ was utilized with an average of $13.56 (\pm 3.86) m^2/station$ (n=16).
- D). Pooled FAD types: A total area of $117 m^2$ was utilized with an average of $10.05 (\pm 5.81) m^2/station$ (n=61)..... 64
19. Contour plots of the 2-dimensional distribution of D. punctatus around structures of each FAD type treatment (A-C) and around a composite FAD based on data from all three treatments pooled (D). Contours represent the average number of round scad/ $m^2/station$ assuming all fish lie in a plane perpendicular to the current axis... 65
20. Contour plots of the 2-dimensional distribution of D. punctatus around structures pooled from all three FAD type treatments by size school.
- A). Schools of 1-99 round scad utilizing a total area of $59 m^2$ with an average of $6.45 (\pm 3.72) m^2/station$ (n=31).
- B). Schools of 100-999 round scad utilized a total area of $69 m^2$ with an average of $8.45 (\pm 4.54) m^2/station$ (n=20).
- C). Schools of > 1000 round scad utilized a total area of $87 m^2$ with an average of $12.71 (\pm 5.46) m^2/station$ (n=17)..... 67

21. Contour plots of the distribution of C. crysos around structures by FAD type treatment (A-C) and for pooled data from all FAD type treatments (D). Contours represent the percent presence of C. crysos within m² cells around the structure.
- A). FAD type A: A total area of 20 m² was utilized with an average of 6.47 (\pm 4.56) m²/station (n=19).
- B). FAD type B: A total area of 19 m² was utilized with an average of 7.42 (\pm 4.52) m²/station (n=12).
- C). FAD type C: A total area of 38 m² was utilized with an average of 11.37 (\pm 3.66) m²/station (n=8).
- D). Pooled FAD types: A total area of 7.7 (\pm 4.68)m²/station (n=39)..... 69
22. Contour plots of the 2-dimensional distribution of Caranx crysos around structures of each FAD type treatment (A-C) and around a composite FAD based on data from all three treatments pooled (D). Contours represent the average number of blue runner/m²/station assuming all fish lie in a plane perpendicular to the current axis..... 71
23. Photographs of a FAD type D station taken 39 days after deployment (8 July 1985).
- A. Type D FAD with school of Seriola sp. in the foreground. The relative size of the FAD can be judged by comparison with the diver (on left) conducting a census.
- B. Anchor made of 4 concrete blocks used to moor the type D FADs. A large black sea bass (top arrow), 2 bank sea bass (on top and on right edge of front block), and 4 sand perch (other arrows) are evident in the photograph, illustrating the tendency for more species and number of fishes to be associated with these anchors than the anchors of other FAD type treatment structures (compare with fig. 6b, c, e and f)..... 76
24. Jaccard similarity among species observed at the FAD type treatment station (N=89). Similarity indices were standardized by station total; the similarity, therefore, reduces to percent co-occurrence..... 77

25. Visual field of a fusiform fish. Lines l and l' represent the back edge of the field of view at 150° and the angle of preferred visual orientation at 135° , respectively. These lines inscribe a zone of reaction within which a threat can be detected and visually monitored continuously. Lines r and r' inscribe the right zone of reaction. A frontal zone of binocular vision and a posterior blind zone (inscribed by l and r) of about 60° are also present (adapted from Hall *et al.*, 1986)..... 97
26. Visual field of a school of fish, oriented in one direction, formed by the overlapping visual fields of individual fish, represented by an individual in the school's center and the extreme right and left hand individuals. A). School with all members located on a plane perpendicular to the orientation axis, here down current. B) School curved with its convex end facing the point of orientation. The shaded area is the blind zone common to all members of the school. Striped areas are reaction zones of each individual. As in Fig. 25, l and l' define the left reaction zone, r and r' define the right reaction zone, and l and r define the blind zone. The prefixes a , b , and c , designate with the lines of vision of fish A, B, and C, respectively (i.e. a_1 is the edge of the left line of sight of fish A). Similarly the dashed curves (av , bc and cv) represent the limit of vision for each fish given 6 m visibility. The blind zone of the school is defined by ar and cl . An approaching predator is shown at 10 m (P_1), 6 m (P_2), and at 2 m (P_3). It sights fish B first at P_2 and its visual range is indicated by the dotted curve (pv)..... 99
27. Effect of a FAD on the visual fields of a predator and a school of fish assuming 6 m visibility.
- A). FAD located 4 m behind fish B within the schools blind zone. At P_1 a predator is within visual range of fish B but can not see it because of the FAD. Fish A and C are out of visual range. As it approaches closer more fish are occluded by the FAD, so that fewer and fewer lateral fish in the school can be seen. At P_2 a predator can see all members of the school but is itself sighted by fish C.
- B). FAD located 2 m behind fish B within the right zone of reaction of fish A and the left zone of reaction of fish C. In this position the school of fish can maintain visual orientation to the FAD, but the structure occludes the vision of fish A and C along lines a_1 and c_1 . This increases the school's

effective blind zone to the edge of lines ar' and cl' . At P_1 fish B is not visible to the predator, but the predator can move to P_2 before being sighted by fish C.

- C). FAD located 1.5 m behind fish B. This is the optimum position for visual orientation to the FAD by the school and does not cause occlusion of sight along cl and ar 103

List of Tables

Table		Page
1.	Sample sizes for FAD type by day number.....	20
2.	Species list of fishes, including information of occurrence in association with the FAD and/or the anchor and of the life history stage(s) observed.....	29
3.	Percent frequency for each species by FAD type treatment and for pooled FAD types. Ranks are based on pooled data.....	36
4.	Mean number and standard deviation of individuals per station by FAD type treatment for the 14 most common species observed.....	37
5.	Relative abundances of each species by FAD type treatment and pooled FAD type treatments.....	38
6.	Total number of species occurring for each FAD type by day.....	43
7.	Frequency of species occurring around single and multiple concrete blocks after loss of the FAD.....	44

List of Appendices

Appendix	Page
A	Computer package for calculating the density and frequency distribution of fishes about the FADs..... 129
	A.1. Flow chart showing the basic operations of program DISTPOS.F77..... 130
	A.2. Schematic showing the basic operations of program DISTPOS.F77..... 131
	A.3. Program: DISTPOS.F77..... 132
	A.4. Program: POSMEAN.F77..... 148
	A.5. Programs Graph.Type.F77, Graph.Day.F77 and Graph.Tot.F77 for graphing frequency and density distributions of fishes about FADs compiled over types or day factors, or over all factors combined..... 157
B	Means and standard deviations for each FAD type and day combination, for FAD type, Day and pooled data for select variables and species..... 168
	B.1. Mean number of individuals of <u>D. punctatus</u> in each fish school based on counts from the 62 stations with non-zero numbers. The numbers in parentheses are the sample size for each mean (n_1 = number of schools) and the number of non-zero stations (n_2)..... 169
	B.2. Means and standard deviation for the number of species, total number of individuals, total number excluding <u>D. punctatus</u> , and selected species per station by day and FAD type..... 170
C	Data for FAD type D (McIntosh units), including species frequencies and means..... 174
	C.1. Percent frequency of species observed at FAD type D structures..... 175
	C.2. Mean number of individuals per station for FAD type D structures for each census day. Days given are the number of days elapsed from time of deployment (days elapsed for treatment structures are given in parenthesis for comparison)..... 176

Abstract

The hypothesis that the standing crop of fishes associated with a FAD is a function of the degree of protection provided by the structure was tested by comparing recruitment to three types of mid-water FADs. Since the structural complexity of the FAD was considered to be directly related to the shelter available to the associated fishes, three FAD types with increasing orders of structural complexity were used as treatments. Each treatment was replicated six times and the eighteen FADs were deployed at 30 m intervals along a rope grid in 14 m of water off Charleston, South Carolina. A total of 20 families and 36 species of fishes were observed at 121 stations censused in eight surveys from May through November 1985. The fauna associated with the FADs was very similar to published reports of fauna associated with Sargassum spp. and jellyfish, suggesting similar origins and causes. Decapterus punctatus was the most frequently occurring (70 %) and abundant species (X = 576 individuals/station). Other common species included Caranx crysos, Diplectrum formosum, Caranx bartholomaei, Centropristis striata and Monacanthus hispidus. The number of species (X = 3.8), total number of individuals (X = 592) and number of Decapterus punctatus per station were significantly different among FAD type treatments (P = 0.0087, 0.0163, 0.0467, respectively). Fewer species of demersal fishes were attracted to concrete anchors after the loss of the FAD than to anchors with the FAD intact, suggesting a correlation of some demersal species with the occurrence of pelagic fishes at the FADs. Observations of fish behavior and quantitative analysis of spatial distributions of fishes

around the structures revealed that Decapterus punctatus occupied a position progressively farther up current of the FAD with increasing number of individuals per school. Decapterus punctatus made direct use of shelter only when present in small numbers or when disturbed by diver activity. I propose a model suggesting a visual mechanism that provides an advantage to schooling fish in avoiding predator attacks, and that Decapterus punctatus takes up a position around a FAD which enhances the school's ability to detect and avoid approaching predators.

Additionally, associations with drifting objects may allow a prey fish, which has habituated to an object, to escape predation by capitalizing on a reflexive avoidance of the object by a pursuing predator.

Implications of the results and conclusions drawn from this study demonstrate the feasibility and value of using designed and replicated artificial reef structures in experimental designs for the in situ study of marine habitat ecology. The importance of the interpretation of data obtained from such studies in light of behavioral observations is emphasized.

Introduction

Associations of fishes with seaweeds and many kinds of flotsam have been widely reported in the literature (Mortensen, 1917; Uda, 1933; Gooding and Magnuson, 1967; Hunter and Mitchell, 1967; Hunter, 1968; Dooley, 1972; Yesaki, 1977; Brock, 1986). Fishermen have exploited this behavior by seeking out and actively fishing around flotsam, seaweeds, and whales (Gooding and Magnuson, 1967; Yesaki, 1977). Early Japanese researchers categorized the tuna fishery by distinguishing catch success and biting characteristics among tuna schools associated with birds, whales, sharks, carcasses, flotsam, and non-associated schools in an attempt to assist the fishery in locating catchable tuna (Uda, 1933; Uda and Tukusi, 1934). More recently the importance of flotsam in commercial tuna fisheries was discussed by Greenblatt (1979) and Park (1984).

Unfortunately, fisheries around flotsam and similar natural sources of fish aggregations all depended on chance encounters by fishermen. To improve their chances of finding fish, fishermen learned that they could make their own "flotsam" and numerous economically important fisheries developed around the world (Hardenberg, 1950; Westenberg, 1953; Kojima, 1956; 1960a; Soemarto, 1960; Brandt, 1960; Galea, 1961; Inamura *et al.*, 1965; Kojima, 1966a; 1966b; Iwasa, 1981; Matsumoto *et al.*, 1981; de Sylva, 1982; Myatt and Myatt, 1982; Shomura and Matsumoto, 1982; Samples and Sproul, 1983; Floyd and Pauly, 1984; Klemm, 1984; Floyd, 1985; Samples and Schug, 1985; Samples and Sproul, 1985; Myatt, 1985). Today these man-made-flotsam have become known as fish aggregation devices

(usually referred to as FADs or F.A.D.s) because they act to aggregate fishes which would otherwise be scattered over large expanses of water.

FADs were first introduced into the United States in the 1970s (Myatt and Myatt, 1982), where two fundamentally different fisheries have developed. Various types of floating raft-like FADs have been experimented with in up to 1829 m (1000 fm) of water where pelagic fishes such as tuna and dolphin have been taken with great success (Matsumoto et al., 1981; Shomura and Matsumoto, 1982; Samples and Sproul, 1983; Klemm, 1984; Samples and Schug, 1985; Samples and Sproul, 1985). The South Carolina Wildlife and Marine Resources Department Artificial Reef Development Program has pioneered the use of small mid-water FADs in the state's shallow coastal waters. The nearshore South Carolina recreational fishery targets coastal pelagic fishes such as king mackerel, Scomberomorus cavalla, and is operated in 14 m - 30 m of water from 5 km to 50 km offshore. The concept of deploying up to several hundred small FADs in long "trolling allies" was pioneered in South Carolina (Hammond et al., 1977; Myatt, 1978; Myatt and Myatt, 1982; Anonymous, 1985; Myatt, 1985). Trolling allies are used as primary artificial reefs or to supplement and enhance bottom reef materials (M. Bell, Artificial Reef Coordinator, SCWMRD, Charleston, South Carolina, Personal Communication). One of the goals of my study was to evaluate the effectiveness of the mid-water FADs used in the South Carolina recreational fishery, to identify fauna associated with these FADs, and to identify changes in the effectiveness of the FADs over time, so that the fishery could be more efficiently managed.

With the growing importance of flotsam and FADs to commercial fisheries, researchers began to question the causes of associations of fishes with drifting materials. Gooding and Magnuson (1967) found six hypothetical causes reported in early literature: objects provide shelter from predators, fishes feed on algae fouling the objects, objects provide shade from harmful sunlight, objects provide a substrate on which to lay eggs, and objects cast shadows within which zooplankton are more visible. Gooding and Magnuson (1967) presented the additional hypothesis that floating objects act as cleaning stations. To this list of hypotheses can be added Westenberg's (1953) suggestions that fishes are attracted to sound produced by floating objects and that orientation to a visual stimulus may play a role. Hunter and Mitchell (1967) suggested that floating objects serve as a supernormal schooling companion and Hastings et al. (1976) suggested that floating objects provided a substrate for displaced benthic and nearshore fishes.

The most widely held hypothesis is that fishes utilize floating materials in some manner which gives them protection from predators. Protection might be obtained in several ways: through direct shelter provided by the materials or structure (Gooding and Magnuson, 1967; Hunter and Mitchell, 1967; Mitchell and Hunter, 1970; Dooley, 1972; Wickham et al., 1973; Wickham and Russell, 1974; Hastings et al., 1976; Kulczychi et al., 1981; and Murray et al., 1985); through camouflage and mimicry (Mortensen, 1917; Breder, 1942; 1946; 1949; Randall and Randall, 1960); or through an unexplained mechanism of interference with a predator's ability to capture prey (Gooding and Magnuson, 1967; Mitchell and Hunter, 1970; Wickham et al., 1973; Wickham and Russell, 1974). It

has also been suggested that floating objects provide protection by making the silhouette of associated fishes difficult to see against the dark backdrop of the structure (Anonymous, 1984; M. Bell, SCWMRD, Personal Communication), or by protecting a school's blind zone from approach by predators (Soemarto, 1960). Most of these observations (with the exception of a few special cases of mimicry, Breder, 1942; 1946; 1949; Randall and Randall, 1960) are speculations based on circumstantial evidence without supporting data or arguments. A few authors have remained skeptical of the importance of shelter to the maintenance of the association of fishes with drift materials or FADs (Mortensen, 1917; Westenberg, 1953; Brandt, 1960; and Klemm, 1984).

Circumstantial evidence for the protection hypothesis includes reports that fauna associated with drift materials are often dominated by juveniles (Hunter and Mitchell, 1967; 1968; Hunter, 1968; Dooley, 1972; Klemm, 1984; Floyd, 1985); that some fishes tend to move farther away from the structure with size (Kojima, 1960a; Dooley, 1972; Matsumoto et al., 1981; Brock, 1985); that some fishes may change color to blend in with the background coloration of floating objects (Gooding and Magnuson, 1967); and, that darker colored species tend to be more closely associated with materials than lighter colored species (Murray and Hjort, 1912; Hunter and Mitchell, 1967; Hunter, 1968; Mitchell and Hunter, 1970; Helfman, 1981). Again, it should be pointed out that, with the exception of observations on the dominance of juveniles, these reports are based on general observations and are not supported with quantitative data.

Field observations on the behavior exhibited by associated fishes in the presence of predators does lend some support to the protection hypothesis. In general, fright behavior of associated fishes can be summarized as follows: when a predator approached a group of fishes aggregated around a floating object, most of the prey fishes formed a compact group underneath or close to the object. Many species attempted to keep the object between themselves and the predator, while some smaller individuals or species took direct advantage of available cover (Gooding and Magnuson, 1967; Hunter and Mitchell, 1967; Mitchell and Hunter, 1970). In some cases, if the school was large compared to the structure, some individuals would break away and swim rapidly off on the approach of a predator (Gooding and Magnuson, 1967; Wickham et al., 1973; Wickham and Russell, 1974; McIlwain and Lukens, 1978).

The tendency of fishes to crowd around drift objects or FADs in response to a threat indicates that some sort of protection is gained by this behavior; however, descriptions of predator behavior around FADs provide conflicting evidence on the ability of predators to prey on FAD associated fishes. Schools of baitfishes associated with FADs have been observed to be preyed upon by Spanish mackerel, king mackerel, little tunny, bluefish (Wickham, 1972; Wickham and Russell, 1974) and by tuna (Anonymous, 1980; Matsumoto et al., 1981). Some investigators have reported that some predator species may not successfully capture fishes associated with objects, citing infrequent visual observations of predation (Gooding and Magnuson, 1967; Mitchell and Hunter, 1970; Wickham et al., 1973; Wickham and Russell, 1974). Gooding and Magnuson (1967) reported that most piscivores could not, or did not, successfully prey

on raft-associated fishes which maintained a position close to the structure, but sometimes did capture individuals farther from the structure. To compound the confusion, amberjacks and dolphin have frequently been observed to prey on fishes taking shelter directly under, or near to, FADs or drifting objects (Gooding and Magnuson, 1967; Hunter and Mitchell, 1967; Hunter, 1968; Potthoff, 1969) and these species have been considered exceptions to the general trend for predators not to prey on fishes closely associated with a structure (Gooding and Magnuson, 1967). The conflicting observations of predator behavior around FADs suggests that the low incidence of predation observed by some authors may be due to inadequate observation frequency rather than predator avoidance of the FAD. Mitchell and Hunter (1970) followed up on these general observations by carrying out laboratory experiments on fishes associated with drifting kelp. The presence of the seaweed was found to significantly reduce predator success and, perhaps, to reduce the amount of energy expended by fish in predator avoidance (Mitchell and Hunter, 1970). Observations of predator behavior around flotsam indicates that some species may not successfully prey on fishes closely associated with drifting objects, but whether the predator actively avoids the FAD or whether the FAD simply hinders the predator's ability to capture prey is not clear.

Behavioral observations and the findings of Mitchell and Hunter (1970) suggest, then, that objects provide protection from predators in some unknown manner. If shelter were important, then the size or type material of an object should influence the attraction of fishes. However, observations based on fisheries were conflicting. Westenberg

(1953) reported that fishes were attracted to objects regardless of object size, while Wolf (1974) reported no difference in catches among three types of drifting fish traps (used as FADs). Inoue et al. (1968), however, reported that Japanese fishermen had long associated vertically floating driftwoods with better catches of tuna than other drifting materials. This idea of the importance of vertical profile has been echoed by more recent researchers who stress the importance of surfaces protruding vertically from the structures (Waldvogel, 1978; Matsumoto et al., 1981). Kojima (1966a) found no relationship to object size in a study of dolphin, Coryphaena hippurus, catches around tsukegi and such drift materials as logs, seaweeds and animal carcasses. Yatomi et al. (1979) pointed out that, although fishes showed strong preferences for FAD material type, this behavior was greatly modified by the depth of FAD placement. Recently, in an examination of 370 tuna purse seine collections in the Korean fishery, Park (1984) suggested that more complex flotsam attracted more tuna, although he could not find a relationship between catch and the "length of flotsam". A few workers have gone as far as to say that fishes were attracted to virtually anything which floats and that the size or type of object makes little difference (Hunter, 1968; Brock, 1986).

In an effort to define the nature of this protection from predators, researchers have looked for correlations between the number of fish and the amount of shelter provided by the material. Ida et al. (1967a) found no relationship between the number of fishes associated with seaweeds and seaweed weight under natural conditions, but did find a positive relationship under experimental conditions. They suggested

that under natural conditions many of the larger fishes might have been more difficult to catch with larger seaweed rafts; that uncontrolled seasonal changes in fish abundance may have distorted the relationship and that a season-independent comparison of the number of fish per size of seaweed clump might show a correlation. It was reported, however, that the number of fish attracted to Sargassum ringgoldianum differed from that attracted to S. patens and they suggested the difference might be due to thallus size (Ida et al., 1967a).

Hunter and Mitchell (1967) came to a different conclusion in a study of fishes associated with flotsam off Costa Rica. They reported that the number of fishes in a collection was correlated to the volume of the object and that the size of the object also had an effect on the presence or absence of larger or adult fishes, although they did not demonstrate statistical significance of these correlations. In a later study Hunter and Mitchell (1968) concluded that these observations more probably reflected differences in the successional stage of the fish community associated with the object (Hunter and Mitchell, 1968).

More recently, Dooley (1972) could not demonstrate a significant relationship between the total biomass of fishes and the biomass of sargassum, but he suggested that the lack of significance might have been due to the large variance produced by less numerous species. He did report a "significant" positive correlation for Histrio histrio ($p < 0.1$, $r = 0.31$) and for Stephanolepis (=Monacanthus) hispidus ($p < 0.1$, $r = 0.21$). Kulczychi et al. (1981) reported a low correlation of fish abundance with drift-algal biomass between sampling dates ($r < 0.5$) and found a significant ($p < 0.05$) relationship between the direction of

change of the abundances of Gobiosoma robustum and Syngnathus scovelli and the wet weight of algae (i.e., an increase in algae biomass followed by an increase in fish abundance). No such relationship was found for the other 53 species collected (Kulczychi et al., 1981).

Studies attempting to find some relationship between the number of fish attracted and the type of FADs used in various fisheries, or the biomass, volume, weight or quantity of seaweeds and flotsam, were hampered by the unpredictable occurrence of drift materials and by the influence of uncontrolled environmental factors such as location, water depth, and drift history. In order to eliminate some of these uncontrolled factors, some researchers have attempted to determine the effects of structure size, shape and color on the number of fishes attracted to FADs under experimental field conditions (Hunter and Mitchell, 1967; Klima and Wickham, 1971; Wickham et al., 1973; Wickham and Russell, 1974).

The earliest attempt to experimentally determine any difference in the attraction of fishes among kinds of objects was conducted by Senta (1966). He set out objects of various types from artificial seaweeds to larger FAD-like objects over various times of the day and observed fish accumulation over a three-hour period. No relationship among the number or kinds of fishes and the type of object was found (Senta, 1966). Hunter and Mitchell (1968) later compared the effectiveness of nine types of FADs, which varied in shape, vertical displacement and surface area, in a two-year study. Fishes associated with these structures were captured at three-day intervals with a miniature purse seine (sample sizes varied from 4 to 15 for each unit). It was concluded that vertical

displacement did not effect the number of fish captured, but that larger catches tended to be made around objects with greater surface area. They also reported that the best catches were made around a three dimensional object shaped like a tent (Hunter and Mitchell, 1968). Unfortunately, their conclusions are tenuous because structure types were not replicated and all types were not used during both years of the study.

Klima and Wickham (1971) soon followed up on the work of Hunter and Mitchell (1968) and compared simple and complex structures modeled after Hunter and Mitchell's (1968) tent shaped structure. Three-dimensional wooden pyramid frames were used for both type FADs, but each were constructed differently. Three units of each FAD type were used, but these were not replicates because the structures were not moored at equal distances apart, and more importantly, one unit of each type was placed at the surface while the others were placed in mid-water. Klima and Wickham (1971) found that the simple structures usually attracted much greater numbers of fish than complex structures. However, because factors such as the location of the structures and depth of water were not controlled, and because treatment replication was not adequate, inferences made about the effect of structure complexity on fish attraction should be viewed with caution.

In fact, in later studies with similar structures, no difference in the attraction of fishes was found among structure types (Wickham, 1972; Wickham et al., 1973; Wickham and Russell, 1974). One study, however, did report significantly different catches of recreational gamefishes among single structures, multiple structures and control areas based on

trolling success (Wickham et al., 1973). Here the single structures were similar to the pyramid structures used in earlier studies, but the multiple structures were of a completely different design consisting of five conical structures spaced at 20 m intervals, so again poorly controlled treatments make interpretation of the results difficult.

In another study mid-water FADs were placed in a fresh water reservoir (Smith et al., 1980) in which smaller FADs had previously been studied (Reeves et al., 1977). Smith et al. (1980) reasoned that optimum size units were not used in the earlier study, accounting for the low abundance of fish observed. It was reported that higher concentrations of fish were found around their larger structures than were observed around the smaller structures used by Reeves et al. (1977). Helfman (1979) repeatedly sampled three FAD types differing in surface area and concluded that the total number and density of fishes were positively correlated with surface area. However, he does not report that the number of fishes differed significantly among FAD types. Since Helfman (1979) did not use replicated FAD types and variation among days was apparently not statistically considered, these results should be considered with caution.

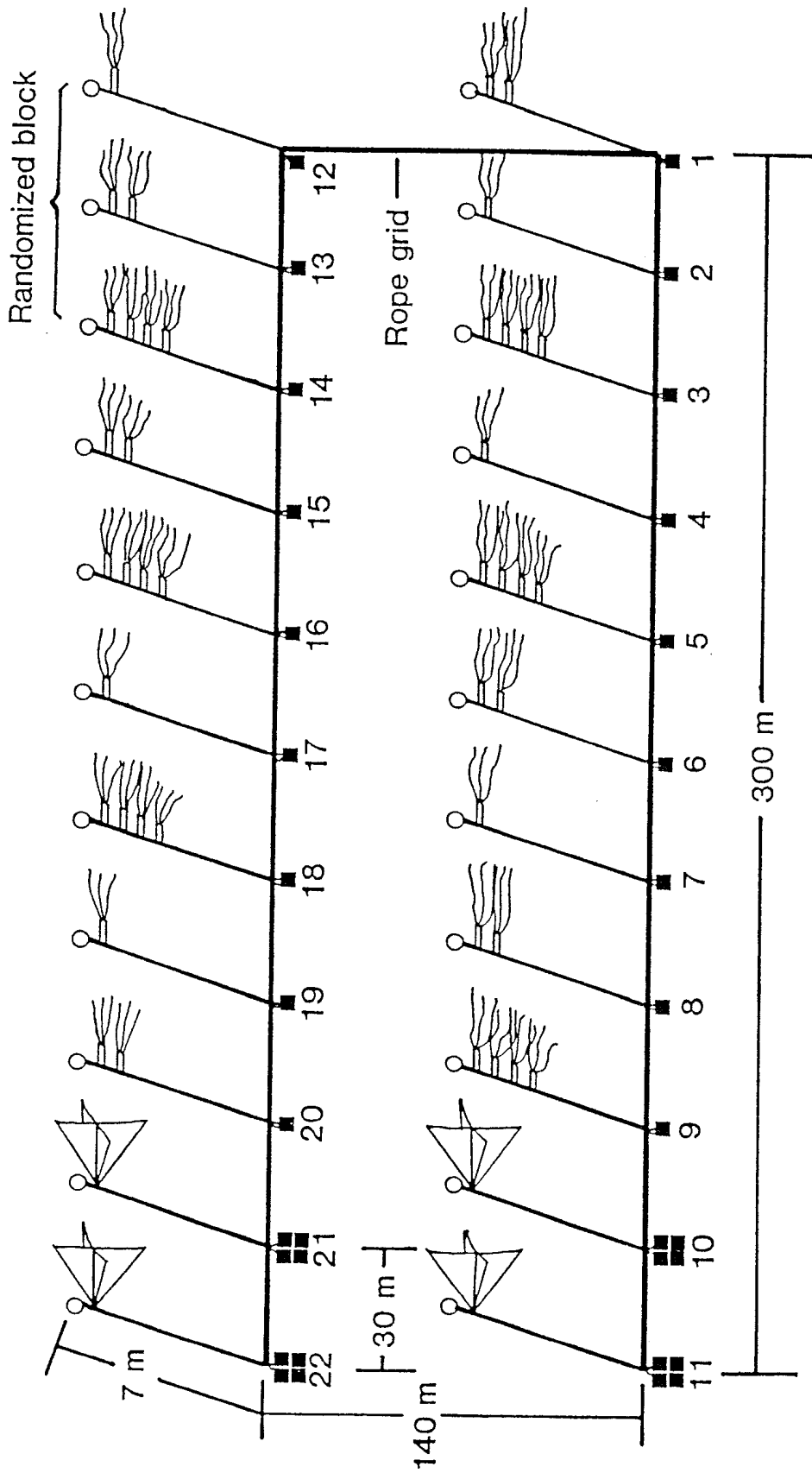
Past experimental studies have all suffered primarily from a lack of adequate treatment replication and small sample sizes because of the inherent difficulties of offshore experiments with FADs. For this reason, the primary goal of this study was to test, in a manner conducive to statistical analysis, the hypothesis that the standing crop of fishes associated with a FAD is a function of the amount of cover provided by the structure.

Materials And Methods

The experimental design was set up to test the hypothesis that the standing crop of fishes associated with a FAD is a function of the degree of protection from predation provided by the structure. The structural complexity of the FAD was considered to be directly related to the protective cover available to the associated fishes. Three FAD types with increasing orders of complexity were used as treatments. Each FAD type treatment was replicated six times, so that a total of 18 FADs were used. To increase the sample size, and to examine faunal changes with time, the FADs were visually censused eight times over a period of seven months. The experimental design, therefore, included a day factor where each treatment level represented the age of the FAD expressed as the number of days elapsed from the time of deployment to the time of the census.

FADs were placed in a randomized block configuration with six blocks containing one of each FAD type treatment (Fig. 1). This design was used to account for variation due to a number of related factors involving location effects and temporal effects. Variation in the number of fish per station due to FAD location can result from specific location effects (e.g., differences in topography, water depth, habitat, etc.) or from differences in the likelihood of fish encountering a FAD due to its position relative to other FADs. For example, if FADs are placed in a long line connected with a rope, units located towards the middle of the line might have higher numbers of fish if fish move from one unit to another by following the rope line.

Figure 1. Experimental design and configuration of FAD type treatments used in this study. Numerals designate station numbers.

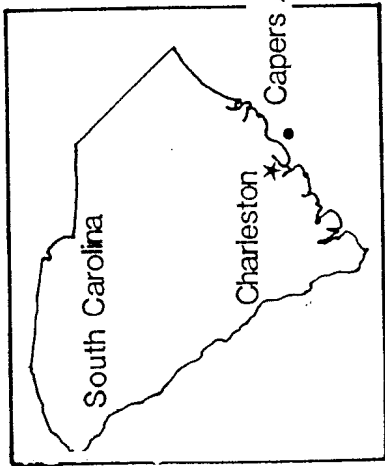


Because several hours elapsed between the time the first and last FADs were censused, temporal sources of variation arose from the order in which the FADs were censused. These sources might be hypothesized to include tidal effects, diel behavior effects, and behavioral effects of fishes invoked by the presence of the divers. Fishes might follow divers from one station to the next so that the last FAD censused would have abnormally high numbers. Grouping the treatments randomly within blocks effectively controls for both the spatial and temporal sources of variation; however, the randomized block design was also used for other reasons. It helps assure a proper balance between interdispersion of treatments and randomization (Hurlbert, 1984). It also assures the most efficient collection of data if sampling is interrupted before all replicates can be censused.

The study site was located in 14 m of water about 23 km northeast of Charleston, South Carolina, within the permitted grounds of Capers Artificial Reef (32°45.20' N, 79°34.15' W; Fig. 2). Although the site was located on the artificial reef grounds, the nearest bottom relief was located more than 1.0 km southeast (except for 18 FADs abandoned from earlier experimental trials, which were located about 250 m southeast of the study area), so the study area was not biased by a proximity to artificial reef materials. The site was characterized by a very flat sandy bottom which was devoid of relief and invertebrates characteristic of live bottom communities (e.g., sponges and soft corals) that occur throughout the region.

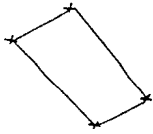
The structures used in this study were composed of three parts: the FAD, the mooring line and the anchor (Fig. 3). FADs consisted of a

Figure 2. Location of test site relative to bottom materials on Capers artificial reef and to the coast of South Carolina.



Capers Artificial Reef


Test site



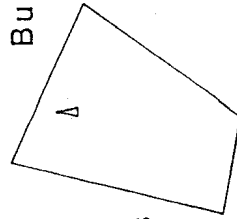
Abandoned test site



N ↑

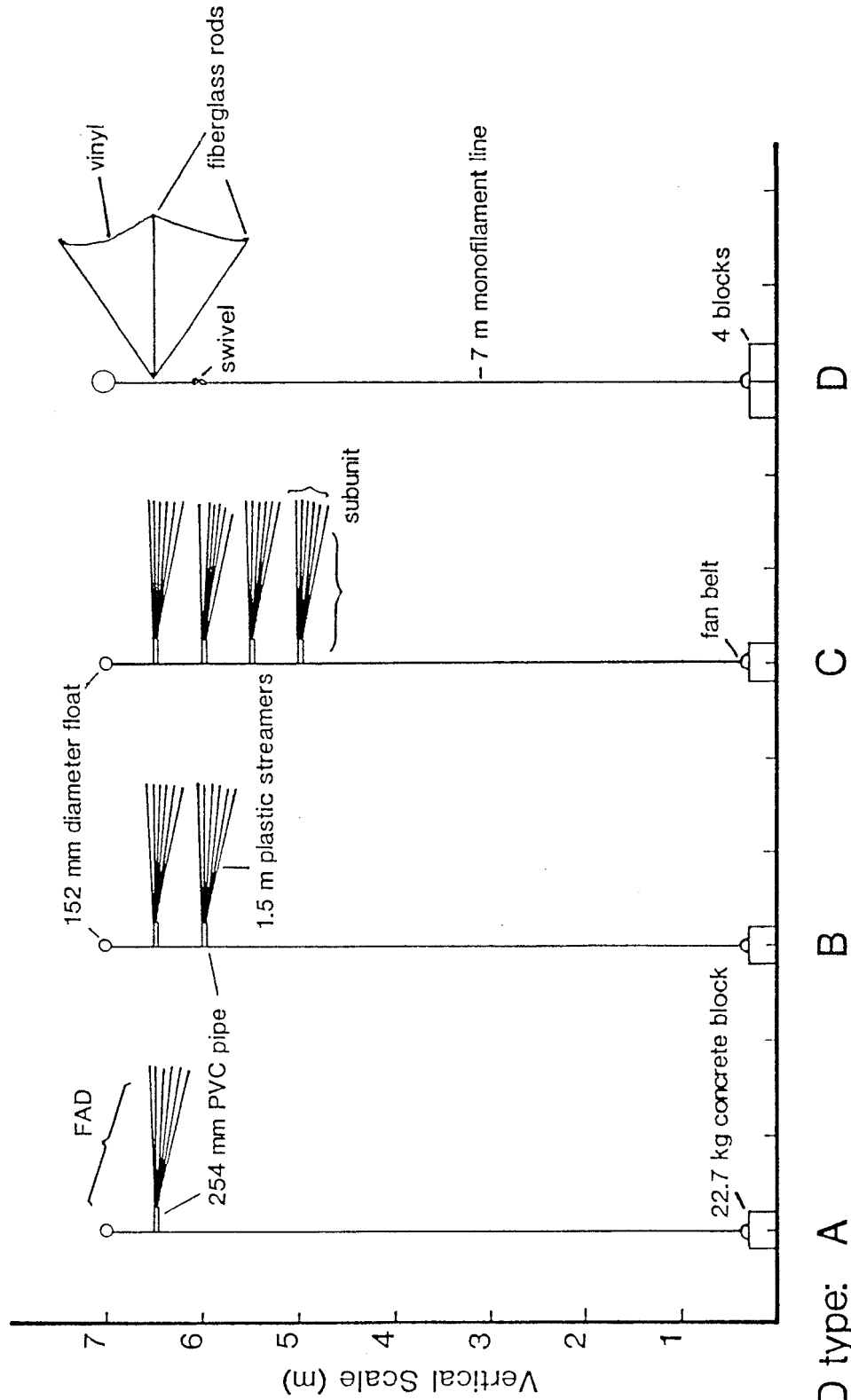
Scale  100 m

Buoy Lat. $32^{\circ} 44.47' N$
Long. $79^{\circ} 34.46' W$



Capers Artificial Reef
bottom materials

Figure 3. Scale drawing of the FAD type treatment (A, B, and C), and the FAD type D structures, used in this study.



FAD type: A

B

C

D

Horizontal Scale (m)

float and a set of subunits. The different levels of complexity used for each FAD type treatment were made by varying the number of subunits comprising the FAD; FAD type A had one subunit, type B had two subunits and type C had four subunits. The subunits consisted of a 254 mm length of 57 mm diameter PVC pipe through which the monofilament was run and to which were attached twelve 1.5 m black plastic straps (13 mm width), referred to as streamers (Fig. 3). Each FAD was buoyed by a 152 mm diameter float (9 kg lift at the surface) and was anchored with a single 22.7 kg concrete block. In order to minimize variation in subunit depth in the water column, subunits were placed beginning 0.5 m below the float and at 0.5 m intervals thereafter. The maximum depth-of-profile for a FAD was two meters in the case of the type C FADs. The monofilament mooring line (181 kg) was attached to the concrete block by a fan belt to reduce chafing.

A fourth FAD type, designated type D, was also used in this study, but was not included in the experimental design and was not considered a treatment. Four of these units were donated by McIntosh Marine, Incorporated, to be compared with the general type structure used as experimental FADs (types A, B and C). Each of the type D FADs consisted of a 1.8 m high parasol made of vinyl plastic with fiberglass rods used as supporting ribs. The fiberglass rods were flexible and were designed to depress under strong current conditions, thereby reducing drag on the mooring line. A larger float (254 mm diameter) was used for the buoy and four 22.7 kg concrete blocks were used to anchor each unit.

The randomized block configuration of the experimental design was constructed with a rope grid on which the FADs were placed at 30 m

intervals (Fig. 1). The structures and grid system were deployed from the R/V Anita on 15 May 1985 using a long-line method described below. Once on station at the study area, temporary marker floats were placed at the sites where the two parallel grid lines were to begin. The first FAD was then attached to the end of a reel of rope and thrown overboard near a marker float. The vessel was then allowed to drift with the line reeling rapidly off into the water. As the line paid off the reel, FADs were attached, at the fan belt with cable ties, to loops previously tied into the line at 30 m intervals. It took only a few minutes to set each grid line with this method. Because the type D FADs were too large to deploy in this manner, concrete blocks were deployed on the ends of the lines and the FADs were added by divers on 27 May 1985. The first and last units on each grid line were deployed with a small temporary surface buoy attached so that Loran-C coordinates could be recorded. A 140 m line connecting the north ends of each grid line was added by divers on a later date (Fig. 1).

The FADs were visually censused after the structures had been located with the aid of Loran-C coordinates and a search by a team of scuba divers. To census a unit I would follow the grid line until a FAD came into view. At that point I would stop and record the time, type unit and visibility. The spatial distribution within the water column up current and down current of the structure was then recorded for individuals and schools of each species. It was important to get this information before the fishes began to react to the presence of the divers. Once the positions had been recorded, I could then move closer to make positive identifications and count the number of individuals of

each species. Estimates of fish sizes, reported herein, are given to provide the reader with semi-quantitative information for comparative purposes. Typically the grid was censused in two dives with one leg (11 units including the type D FADs) covered in about 50 minutes. The time spent at each unit ranged from one to ten minutes.

A total of 121 counts was made in eight censuses over a seven month period from May through November, 1985. Eighty-nine counts were on FAD types A, B and C. The remaining counts were made on structure type D and on damaged treatment type FADs which could not be used in the statistical analysis. Damaged FADs were classified into two general types. Type E structures consisted of the concrete anchors remaining after the loss of the FAD while type G structures consisted of otherwise damaged type A, B and C FADs. Structure types D and E were used to provide additional insight into fish use of structures because they represented opposite structural extremes. Type D structures were more massive and had more complex anchors than the treatment type FADs. The type E structures, which consisted only of an anchor, were used as a control against the presence of a FAD. Comparisons of the occurrence of fishes on type E structures, which lacked FADs, to treatment type structures helped to clarify the importance of the FAD in attracting fishes. Only FAD types A, B, and C structures were considered treatments, other structures were used solely for general comparisons. Actual sample sizes for each FAD type by day are provided in Table 1.

Table 1. Sample sizes for FAD type by day number.

FAD Type	Days elapsed from FAD deployment										Type Totals
	8	23	55	91	100	115	159	194	194	194	
A	5	3	5	5	3	5	5	5	4	35	
B	5	3	5	4	2	4	5	5	1	29	
C	6	3	4	2	2	2	3	3	3	25	
D	0	2	3	3	1	3	0	0	0	12	
E	0	0	1	1	2	2	4	4	4	14	
Month:	May	June	July	Aug.	Aug.	Sept.	Oct.	Oct.	Nov.		

Statistical analysis of the treatment effects were performed on untransformed and transformed variates for comparison, using the Generalized Linear Models (GLM) procedure of the Statistical Analysis System (SAS) available from SAS Institute Inc., of Cary, North Carolina. A rank transformation of the variates was used for two reasons. Counts of fishes were not expected to be normally distributed with different species exhibiting different distributions and requiring different transformations which may not completely normalize the data. Rank transformations are appropriate for many types of distributions and statistical tests performed on ranked data have been shown to be very powerful and robust procedures (Conover and Iman, 1976; Conover, 1980). The second reason was to reduce the effect of variation introduced by differences in my ability to census fish between sampling days. Comparisons of statistical analysis performed on rank transformed data and on untransformed data were also used as an aid in the determination of the appropriateness of the tests as suggested by Conover and Iman (1976).

The experimental design used in this study calls for a statistical analysis using a three-way model-I anova (Sokal and Rohlf, 1981) in which there are three FAD type treatments, eight day treatments and six FAD type treatment blocks. The rank transformation was made by ranking variates within FAD type treatment blocks, so that rank values ranged from one to three.

Because many of the blocks contained missing cells, due to the loss of FADs and incomplete sampling, inferences based on the statistical analysis of the randomized block design were questionable. For this

reason, analysis was performed on a two-way anova with FAD type and day factors, ignoring blocks. This more conservative test was compared to the above test and used to support or further weaken the statistical inferences made. Rank transformations for this test were made by ranking the data within day.

Finally, analysis of the FAD type treatment effect was made by performing an anova and the Kruskal-Wallis test on data for each day separately. This was done because it was felt that uncontrolled factors operating between days might mask any FAD type effect if the data were pooled. One example of such a factor would be interactions between species where one species is replaced from a "preferred" FAD type by a more competitive species. A significant FAD type effect for a given day would be an indication for the need of a closer examination of the data or the acquisition of more data before a conclusion can be reached.

These statistical tests were performed on the number of species observed per station, the total number of individuals per station and the total number of individuals per station excluding Decapterus punctatus (because of the numerical dominance of D. punctatus). The tests were also performed for selected species. All tests were compared in an effort to determine the validity of their results. If all tests agreed well, only the most conservative significance level was reported; however, conflicting results were reported whenever they occurred. The Scheffe test comparison of means was performed for all significant treatment effects. In addition, descriptive statistics, including analysis of frequency distributions by FAD type, were prepared for each of these variables.

The manner in which fish made use of the FADs was also suggested by a study of the behavior and spatial distribution of fishes around FADs. A series of FORTRAN programs were written (Appendix A) which calculated the frequency of occurrence of a species or species group within square meter cells distributed up current and down current of the FADs. Percent occurrence, average number of individuals, sum, sum of squares, and variances for each of these variables were also calculated for each square meter cell. In addition the average number and variance of cells occupied by fishes per station was computed (i.e., the average area occupied by fishes in the plane passing through the FAD and parallel to the current axis). These computations were made for select species and species groups for each FAD type treatment and for pooled data. These data were used to prepare contour plots of the distribution of fishes around the FADs by occurrence (or percent utilization) and density of individuals. The contour plots provided quantitative information on how closely fishes associated with the FADs and insight into how they derived benefit from the association.

Additionally, cluster and nodal analyses based on Jaccard and Bray-Curtis similarity indices (Clifford and Stephenson, 1975; Boesch, 1977) were used to characterize the fauna attracted to the FADs and to examine differences among FAD type and day treatments. Because unequal sample sizes were used, abundance values used in the Bray-Curtis similarity indices were standardized by station totals and hence were reduced to Sanders' (1960) dominance affinity or percent similarity (Boesch, 1977). Because of the large number of rare species, Jaccard and Bray-Curtis similarity indices were computed for data including only those species

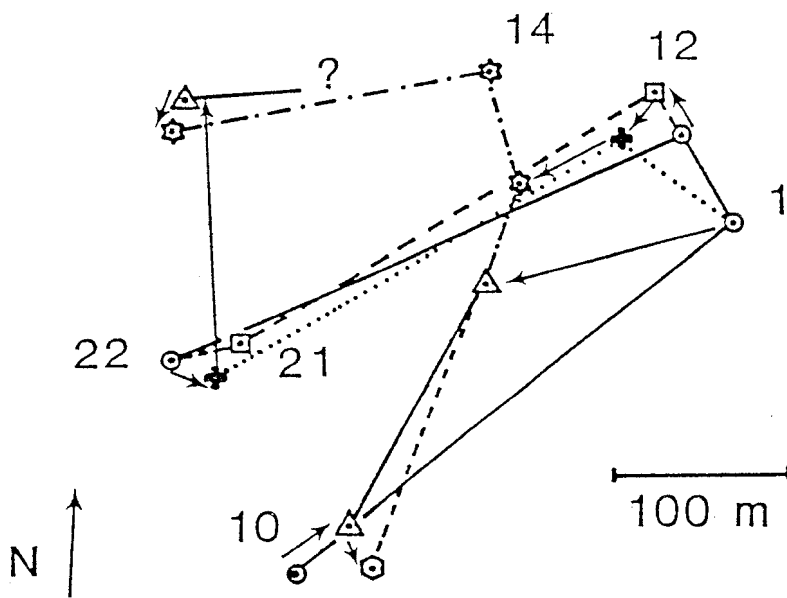
with a frequency of more than 4 %. Data for structure type A, B, C, D and E were included for this analysis. Cluster analysis based on the Jaccard similarity index was performed for data pooled for all FAD types combined (A, B, C, D, and E) to characterize the fauna observed during the study period (including species occurring in at least 4 % of the samples). Nodal analysis based on constancy, fidelity and abundance indices (Boesch, 1977) were based on data from the treatment type FADs only, including species occurring in at least 5 % of the samples. Fidelity (ratio of the constancy of a species in one group over its constancy over all collections) was subjected to a χ^2 goodness of fit test to determine if occurrence in a group was significantly different from occurrence over all collections (Boesch, 1977).

Results

Through the course of the study several physical changes in the experimental design occurred. The structures did not remain in their original locations, with some moving as much as 200 m by the end of the study (Fig. 4). Major movements of structures were noted after Hurricane Bob in July 1985, but, fortunately, the grid line remained intact enabling divers to find the structures. Besides making the grid line harder to locate prior to censusing, the movement of the FADs caused experimental bias in two ways. Some stations periodically moved within a few meters of adjacent stations so that both counts had to be excluded from analysis, reducing the sample size. Repositioning of stations by divers also biased stations by possibly driving off some fishes which might have remained in residence until the next census. Finally, stations which did not move during rough weather conditions would be less likely to loose associating fishes, which introduced bias among FAD type treatments and among day treatments.

In addition to station movement, many FADs were damaged or destroyed over time, resulting in a change in the structure type designation for that station. In most cases where the FAD was lost the anchor was left behind still attached to the grid line and it was designated a type E structure. One FAD type A, three FAD type B, two FAD type C, and all four FAD type D structures were lost by the end of the study. Three additional FADs, one of each FAD type treatment, had to be removed from analysis because of damage or proximity to one another. FAD type A structures had less drag in the current, which made them less

Figure 4. Schematic showing movements of FADs during the course of the study. Numerals refer to station numbers (see Fig. 1) with numbers 1, 10 (after loss of 11), 12 and 22 designating the corners of the grid. Lines represent the approximate position of the rope grid on each date, while arrows indicate movements of the corner stations between dates. For example, station 22 moved from the position marked by the circle on 15 May to that marked by the cross on 6 June, then to the triangle on 6 August and finally, to the star on 21 October. The location of station 14 indicates a tendency for the grid to straighten out in a northern direction with station 22 lagging behind.



- 15 May
- 22 May
-+ 6 June
- △—△-?-△ 6 August
- △—△---☆ 6 September
- ☆---△---☆ 21 October

susceptible to weather conditions and loss. By the end of the study six of the 18 FAD type treatment structures were physically lost with a total of nine stations missing or biased on the last census day.

The experimental design was also affected by differences in the amount of fouling organisms among the three FAD type treatments. By day 100 (6 August) the depth of a FAD was determined by the weight of fouling present and the variable of FAD depth was no longer controlled (Fig. 5). The type C FADs, with nearly 4 times the surface area of the type A FADs, were most strongly affected and became so heavily fouled that the plastic streamers began to drag on the bottom in September. This heavy fouling increased the current drag on the type C structures and decreased their life span.

Twenty families of fishes and 36 species were observed on the 121 stations censused (Table 2). The most frequently observed families were the Carangidae with seven species and the Serranidae with six species. In addition, the octopus, Octopus vulgaris, and three species of crabs, Menippe mercenaria, Portunus sp. and an unidentified majid, were observed. Ten species of fishes associated only with the FAD itself and 23 species associated only with the anchor. The round scad (Decapterus punctatus), yellow jack (Caranx bartholomaei), and planehead filefish (Monacanthus hispidus) associated with both the anchor and the FAD (Table 2). Four of the top ten species by percent occurrence, Decapterus punctatus, Caranx crysos, Monacanthus hispidus and Caranx bartholomaei (ranked 1, 4, 5, and 6, respectively), associated primarily with the FAD. The other six top ten species associated with the anchor and consisted of the serranids, Diplectrum formosum, Centropristis striata,

Figure 5. Photographs of one of each of the FAD type treatment structures taken 115 days after deployment (6 September 1985). Arrows indicate the angle in the mooring line caused by the heavy drag on the float and sinking of the FAD. A) FAD type A with streamers still held up in the current and with little or no sinking in the water column. B) FAD type B with streamers beginning to hang down, and with some sinking of the FAD in the water column. C) FAD type C with dragging streamers and considerable sinking in the water column.

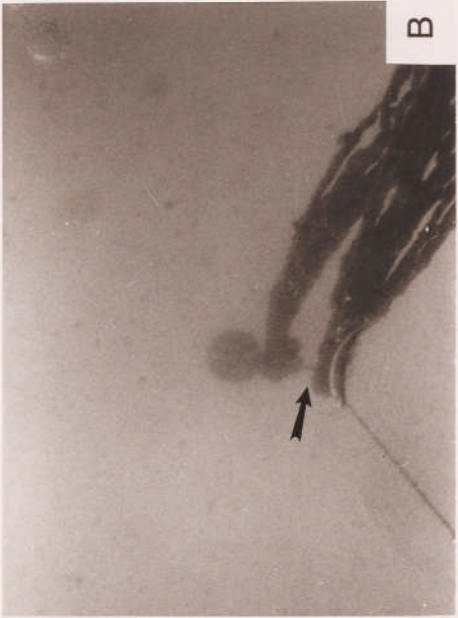


Table 2. Species list including information of occurrence in association with the FAD and/or the anchor and of the life history stage(s) observed.

Family Species	Associated with Anchor	Associated with FAD	Juvenile	Adult or Sub-adult
Anguillidae				
<u>Anguilla rostrata</u>	*			*
Clupeidae				
<u>Sardinella aurita</u>		*		*
Batrachoididae				
<u>Opsanus tau</u>	*			*
Antennariidae				
<u>Antennarius sp.</u>	*			*
Gadidae				
<u>Urophycis sp.</u>	*			*
Syngnathidae				
<u>Hippocampus erectus</u>	*			*
<u>Syngnathus sp.</u>	*			*
Serranidae				
<u>Centropristis ocyurus</u>	*		*	
<u>Centropristis striata</u>	*		*	
<u>Diplectrum formosum</u>	*		*	
<u>Epinephelus morio</u>	*		*	
<u>Mycteroperca microlepis</u>	*		*	
<u>Serranus subligarius</u>	*		*	
Grammistidae				
<u>Rypticus sp.</u>	*		*	
Priacanthidae				
<u>Priacanthus cruentatus</u>	*		*	
Rachycentridae				
<u>Rachycentron canadum</u>		*		*

Table 2. Continued.

Family Species	Associated with Anchor	Associated with FAD	Juvenile	Adult or Sub-adult
<u>Carangidae</u>				
<u>Caranx bartholomaei</u>	*	*	*	
<u>Caranx crysos</u>		*	*	
<u>Caranx ruber</u>		*	*	
<u>Decapterus punctatus</u>	*	*	*	*
<u>Seriola zonata</u>		*	*	
<u>Seriola sp.</u>		*	*	
<u>Trachurus lathami</u>		*		*
<u>Lutjanidae</u>				
<u>Lutjanus sp.</u>	*		*	
<u>Haemulidae</u>				
<u>Haemulon aurolineatum</u>	*		*	
<u>Sparidae</u>				
<u>Archosargus probatocephalus</u>	*			*
<u>Stenotomus chrysops</u>	*			*
<u>Sciaenidae</u>				
<u>Equetus acuminatus</u>	*		*	
<u>Ephippidae</u>				
<u>Chaetodipterus faber</u>		*		*
<u>Pomacanthidae</u>				
<u>Holacanthus sp.</u>	*		*	
<u>Labridae</u>				
<u>Halichoeres sp.</u>	*		*	
<u>Blenniidae</u>				
<u>Hypleurochilus geminatus</u>	*		*	*

Table 2. Continued.

Family Species	Associated with Anchor	Associated with FAD	Juvenile	Adult or Sub-adult
Ballistidae				
<u>Aluterus monoceros</u>		*		*
<u>Aluterus scriptus</u>		*		*
<u>Monacanthus hispidus</u>	*	*	*	
Diodontidae				
<u>Chilomycterus schoepfi</u>	*			*

and Centropristis ocyurus, the two invertebrates, Menippe mercenaria and Octopus vulgaris, and the blenny, Hypleurochilus geminatus.

Most of the fishes attracted to the structures were juveniles (Table 2). The only common species which were represented largely by sub-adult and adult individuals were the round scad, Decapterus punctatus, and the scup, Stenotomus chrysops. Seven species, including Aluterus scriptus and Aluterus monoceros, were represented by a single adult. Both Aluterus spp. swam very close to the float and the top subunit of the FAD, keeping it between themselves and the divers by constantly rotating around it (Fig. 6a). The demersal species, Diplectrum formosum, Centropristis striata, Halichoeres sp. and Hypleurochilus geminatus, were predominantly juveniles, but a few sub-adult or adult individuals were observed. The only adult gamefish observed were the Atlantic spadefish (Chaetodipterus faber) and the sheephead (Archosargus probatocephalus). Three sub-adult cobia (Rachycentron canadum; about 60 cm T.L. to 100 cm T.L.) were the only large piscivores observed. These cobia appeared to be visitors (as defined by Gooding and Magnuson, 1967) at one station on day 159 (22 October 1985). Evidence of frequent visits by piscivores was suggested, however, by the large wounds with clear teeth marks which were observed on numerous individuals of Decapterus punctatus, Seriola sp., Caranx bartholomaei, and Caranx crysos.

Three pelagic species, Caranx bartholomaei, Decapterus punctatus, Seriola sp., and the demersal species Stenotomus chrysops, occasionally followed divers from one station to the next. Decapterus punctatus followed less than one minute behind the divers on a few occasions, and

Figure 6. Underwater photographs of selected species observed in this study, illustrating aspects of their behavior. A) Aluterus scriptus in the characteristic position of filefishes, orienting to, and hiding behind, the FAD. B) Epinephalus morio exhibiting an agonistic display to divers. The scaled flank of a black sea bass, hidden within the concrete block, can be seen under the red grouper's anal fin. C) Small school of Decapterus punctatus associated with the anchor of a FAD. A typical sized Centropristis ocyurus can be seen resting at the lower edge, near the cross-piece, of the concrete block. D) photograph of fishes associated with the streamers of a FAD type C structure on day 159. Three filefish (1 in upper left corner and 2 in the lower middle of the photograph) can be seen orienting to the streamers where they are feeding on fouling organisms. Small black sea bass, like the one in this photograph, utilized the FADs only when they had become so heavily fouled that they were dragging on the bottom. E) One of the large black sea bass which often wedged themselves tightly into the concrete block. F) A stone crab, Menippe mercenaria, nearly fills one chamber of a concrete block. The arrow points to a Polinices sp. snail on which the crab was feeding under the crab's left cheliped. A typical sized sand perch can be observed just above the crab.



swam parallel to them, just within the diver's vision, on one occasion. Schools of Seriola sp. sometimes followed immediately behind the divers, while on a few occasions very young individuals of Caranx bartholomaei (about 40 mm T.L.) were observed to swim within centimeters of my face as I moved from station to station. The scup, Stenotomus chrysops, followed divers but lagged behind by as much as a minute. Decapterus punctatus and S. chrysops actively fed on debris and organisms kicked up by the divers and apparently followed this trail.

Several individuals of a few species were observed to remain at a station for extended periods of time. A single red grouper, Epinephalus morio (about 100 mm T.L.), was first observed on day 91 at station number 7. It remained at that station until day 115 but moved to the adjacent station number 8 between day 115 and 159. It was not observed on day 194, but because of the extremely poor visibility, its absence cannot be certain. This juvenile grouper, therefore, remained in residence for a minimum of 68 days. The red grouper was very strongly associated with the concrete anchor and could not be frightened away by divers who persistently tried to chase it out into the open to be photographed (Fig. 6b). A juvenile Lutjanus sp. snapper may have remained at the same station over a 25 day period, but this is less certain. An individual of Antennarius sp. (frogfish) was observed over a 16 day period on two adjacent stations.

Juvenile gag, Mycteroperca microlepis, were observed to swim away down the grid line as divers approached a station along the opposite side, but they invariably returned in a few minutes time despite the divers' presence. Individuals of Monacanthus hispidus, Syngnathus sp.,

and Centropristis striata apparently oriented to the rope line when more than a meter away from the nearest structure.

The round scad, Decapterus punctatus, was the most frequently observed species, occurring at 70 % of the FAD type treatment stations (Table 3). An average of 576 individuals/station was observed, making it the top ranked species by mean number (Table 4). Decapterus punctatus was overwhelmingly dominant and accounted for 98 % of the total number of individuals at the FAD type treatment stations (Table 5). Round scad often formed more than one school per station (Appendix B.2) with an average of 634 fish/school (Appendix B.1). Individuals were visually estimated to range in size from about 70 mm T.L. to about 150 mm T.L., averaging around 120 mm T.L.

The sand perch, Diplectrum formosum, and black sea bass, Centropristis striata, were the second and third most common species (Table 3). Diplectrum formosum occurred at 56 % of the stations (Table 3) and was ranked third by mean number per station (Table 4) and relative abundance (Table 5). Most individuals were juveniles ranging from about 40 mm T.L. to 150 mm T.L. and averaging around 100 mm T.L. The smaller sand perch were especially common in May and June, but were present throughout the summer, while the few sub-adult individuals occurred in the fall. Centropristis striata occurred at 50 % of the stations (Table 3); however, since more than one individual per station was rarely observed, it was ranked seventh by mean number per station (Table 4) and eighth by relative abundance (Table 5).

Table 3. Percent frequency for each species by FAD type treatment and for pooled FAD types. Ranks are based on pooled data.

Species	FAD Type A	FAD Type B	FAD Type C	Pooled	Pooled Rank
<u>Decapterus punctatus</u>	71.4	72.4	64.0	67.7	1
<u>Diplectrum formosum</u> *	71.9	58.3	31.8	56.4	2
<u>Centropristis striata</u> *	59.4	33.3	54.5	50.0	3
<u>Caranx crysos</u>	54.3	41.4	32.0	43.8	4
<u>Monacanthus hispidus</u>	37.1	34.5	52.0	40.4	5
<u>Caranx bartholmaei</u>	31.4	20.7	36.0	29.2	6
<u>Menippe mercenaria</u> *	37.5	25.0	13.6	26.9	7
<u>Centropristis ocyurus</u> *	25.0	12.5	13.6	19.2	8
<u>Octopus vulgaris</u> *	15.6	25.0	4.5	15.4	9
<u>Hyleurochilus geminatus</u> *	12.5	16.7	13.6	14.1	10
<u>Seriola sp.</u>	11.4	10.3	12.0	11.2	11
<u>Seriola zonata</u>	11.4	6.9	4.0	7.9	12
<u>Caranx ruber</u>	2.9	6.9	12.0	6.7	12
<u>Stenotomus chrysops</u>	8.6	3.4	4.0	5.6	14
<u>Lutjanus sp.</u>	5.7	10.3	0.0	5.6	14
<u>Epinephelus morio</u>	8.6	3.4	0.0	4.4	16
<u>Chaetodipterus faber</u>	0.0	3.4	12.0	4.4	16
<u>Halichoeres sp.</u> *	9.4	0.0	0.0	3.8	18
<u>Portunus sp.</u> *	0.0	4.2	4.5	2.5	19
<u>Syngnathus sp.</u>	2.9	0.0	4.0	2.2	19
<u>Serranus subligarius</u> *	3.1	0.0	0.0	1.3	19
<u>Opsanus tau</u> *	3.1	0.0	0.0	1.3	19
<u>Urophycis sp.</u> *	0.0	0.0	4.5	1.3	19
<u>Equetus acuminatus</u>	0.0	4.2	0.0	1.3	19
<u>Anguilla rostrata</u>	2.9	0.0	0.0	1.1	19
<u>Mycteroperca microlepis</u>	0.0	0.0	4.0	1.1	19
<u>Priacanthus cruentatus</u>	0.0	0.0	4.0	1.1	19
<u>Rachycentron canadum</u>	0.0	3.4	0.0	1.1	19
<u>Haemulon aurolineatum</u>	0.0	3.4	0.0	1.1	19
<u>Aluterus sp.</u>	2.9	0.0	0.0	1.1	19
<u>Aluterus scriptus</u>	0.0	3.4	0.0	1.1	19
<u>Aluterus monoceros</u>	2.9	0.0	0.0	1.1	19
<u>Hippocampus erectus</u>	2.9	0.0	0.0	1.1	19
<u>Chilamycterus schoepfi</u>	2.9	0.0	0.0	1.1	19
<u>Sardinella aurita</u>	2.9	0.0	0.0	1.1	19
<u>Antennarius sp.</u>	0.0	0.0	4.0	1.1	19
<u>Archosargus probatocephalus</u>	0.0	0.0	4.0	1.1	19
Crab A	0.0	3.4	0.0	1.1	19
Sample size	35	29	25	89	
Sample size (*)	32	24	22	78	

Table 4. Mean number and standard deviation of individuals per station by FAD type treatment for the 14 most common species.

Species	FAD Type A	FAD type B	FAD Type C	Pooled	Rank
<u>Decapterus punctatus</u>	171 + 325	771 + 1564	901 + 1560	576 + 1267	1
<u>Caranx crysos</u>	8.4 + 14.3	4.9 + 9.7	7.8 + 14.6	7.1 + 13.0	2
<u>Diplectrum formosum</u>	2.1 + 2.5	2.5 + 4.5	1.6 + 3.2	2.1 + 3.4	3
<u>Caranx bartholmaei</u>	1.4 + 3.6	0.7 + 1.8	3.4 + 7.0	1.7 + 4.5	4
<u>Stenotomus chrysops</u>	0.7 + 3.5	2.1 + 10.2	2.3 + 10.7	1.6 + 8.2	5
<u>Seriola sp.</u>	0.9 + 3.1	0.9 + 3.8	2.0 + 8.1	1.2 + 5.1	6
<u>Monacanthus hispidus</u>	1.5 + 5.1	0.6 + 1.1	1.2 + 1.8	1.1 + 3.4	7
<u>Centropristis striata</u>	0.7 + 0.5	0.4 + 0.7	0.7 + 0.6	0.6 + 0.6	8
<u>Hypoleurochilus geminatus</u>	0.3 + 0.8	0.3 + 1.1	0.2 + 0.8	0.3 + 0.9	9
<u>Menippe mercenaria</u>	0.4 + 0.6	0.3 + 0.4	0.1 + 0.4	0.3 + 0.5	9
<u>Centropristis ocyurus</u>	0.4 + 0.8	0.1 + 0.3	0.1 + 0.4	0.2 + 0.6	11
<u>Octopus vulgaris</u>	0.2 + 0.4	0.3 + 0.6	0.1 + 0.2	0.2 + 0.4	11
<u>Seriola zonata</u>	0.1 + 0.4	0.7 + 0.3	0.1 + 0.4	0.1 + 0.4	13
<u>Caranx ruber</u>	0.0 + 0.2	0.1 + 0.3	0.1 + 0.3	0.1 + 0.3	13

Table 5. Relative abundances of each species by FAD type treatment and pooled FAD type treatments.

FAD type: Species	A		B		C		Pooled	
	Total No.	% Abundance	Total No.	% Abundance	Total No.	% Abundance	Total No.	% Abundance
<u>Decapterus punctatus</u>	13828	95.85	22356	98.35	22532	97.85	58716	97.56
<u>Caranx crysos</u>	293	2.03	141	0.62	195	0.85	629	1.05
<u>Diplectrum formosum</u>	67	0.46	61	0.27	36	0.16	164	0.27
<u>Caranx bartholomaei</u>	49	0.34	20	0.09	84	0.36	153	0.25
<u>Stenotomus chrysops</u>	22	0.15	50	0.22	50	0.22	122	0.20
<u>Seriola sp.</u>	33	0.23	26	0.11	50	0.22	109	0.18
<u>Monacanthus hispidus</u>	51	0.35	18	0.08	30	0.13	99	0.16
<u>Centropristis striata</u>	20	0.14	10	0.04	14	0.06	44	0.07
<u>Hypleurochilus geminatus</u>	9	0.06	9	0.04	6	0.03	24	0.04
<u>Menippe mercenaria</u>	13	0.09	6	0.03	3	0.01	22	0.04
<u>Centropristis ocyurus</u>	12	0.08	3	0.01	3	0.01	18	0.03
<u>Octopus vulgaris</u>	5	0.03	7	0.03	1	0.00	13	0.02
<u>Chaetodipterus faber</u>	0	0.00	6	0.03	4	0.02	10	0.02
<u>Seriola zonata</u>	5	0.03	2	0.01	2	0.01	9	0.01
<u>Caranx ruber</u>	1	0.01	2	0.01	3	0.01	6	0.01
<u>Lutjanus sp.</u>	2	0.01	4	0.02	0	0.00	6	0.01
<u>Archosargus probatocephalus</u>	0	0.00	0	0.00	4	0.02	4	0.01
<u>Epinephelus morio</u>	3	0.02	1	0.00	0	0.00	4	0.01
<u>Halichoeres sp.</u>	4	0.03	0	0.00	0	0.00	4	0.01
<u>Priacanthus cruentatus</u>	0	0.00	0	0.00	4	0.02	4	0.01
Other	9	0.06	9	0.04	5	0.02	23	0.04
Total (excluding- <u>D. punctatus</u>)	598	4.15	375	1.65	494	2.15	1467	2.44
Total	14426		22731		23026		60183	

The blue runner, Caranx crysos, occurred at 44 % of the stations and was ranked second by mean number with an average of 7 fish/station (Table 4). This species made up about 1 % of the total number of individuals observed (Table 5), but accounted for 43 % of the total number of fish excluding Decapterus punctatus. The blue runner was 4 times as abundant as the sand perch and the yellow jack (Caranx bartholomaei), making it a very dominant species (although secondarily to the round scad). With Decapterus punctatus removed, Caranx crysos together with Diplectrum formosum, Caranx bartholomaei, Stenotomus chrysops, Monacanthus hispidus and Seriola sp. made up 86 % of the total abundance of fishes.

Inverse cluster analysis of the frequency occurrence of species at structure types A, B, C, D, and E combined, using the Jaccard similarity index, resulted in three species groups (Fig. 7). Inverse cluster analysis on species abundance using the Bray-Curtis similarity index resulted in similar groups and is not shown. Group-I includes eight of the ten most frequently occurring species (Table 3). This group was further divided into subgroups A and B with group-IA most common in early summer (Fig. 8). Group-IB species occurred fairly constantly over much of the study period and FAD type treatments (Fig. 8). Group-II species were a heterogeneous assemblage that occurred mainly from mid-summer to early fall and were more abundant at type D structures (especially Equetus acuminatus, Stenotomus chrysops and Seriola sp., see Appendix C). Group-III species contained two of the ten most frequently occurring species, Caranx bartholomaei and Octopus vulgaris (Table 3), which were most common and abundant in the fall (Fig. 8). The three

Figure 7. Dendrogram resulting from inverse cluster analysis using the Jaccard similarity index based on presence/absence of species at structure types A, B, C, D and E combined for species with at least a 5 % frequency (N=106).

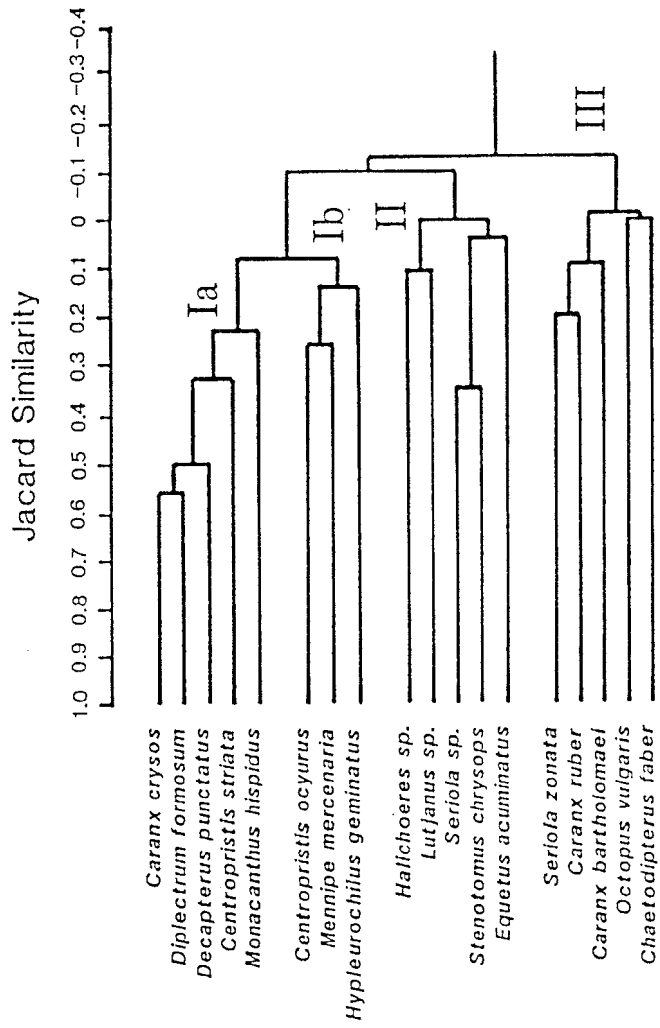
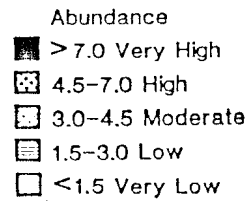
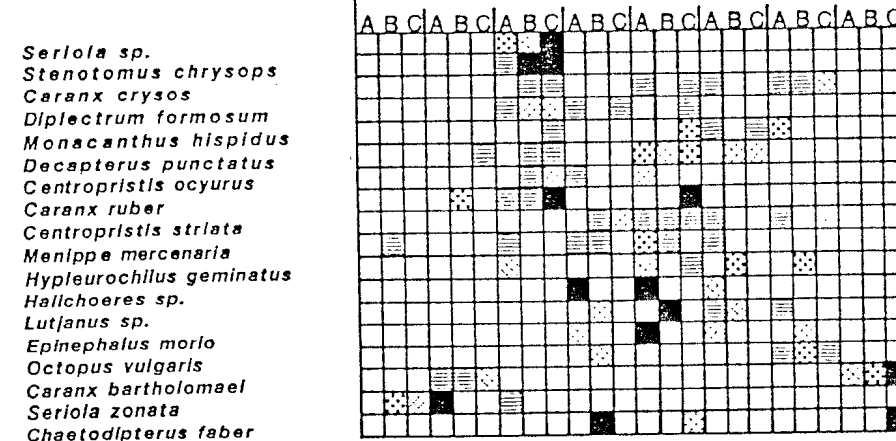
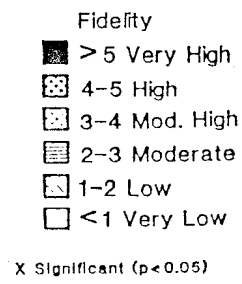
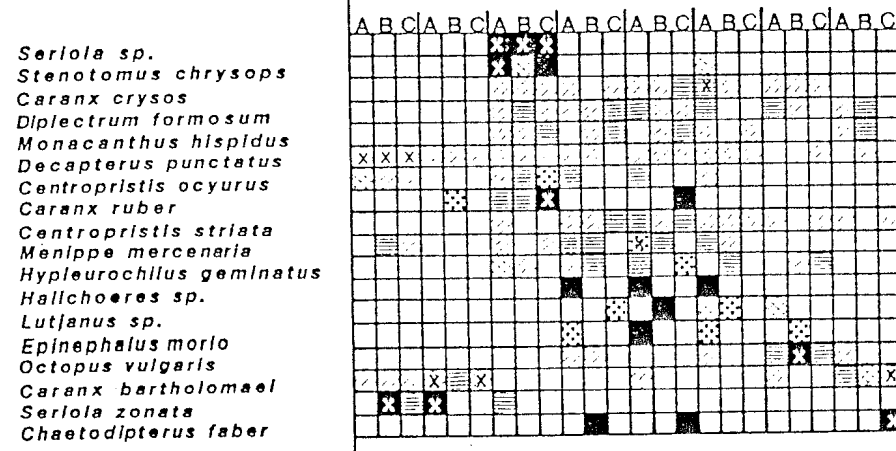
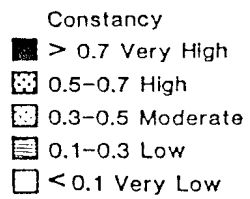
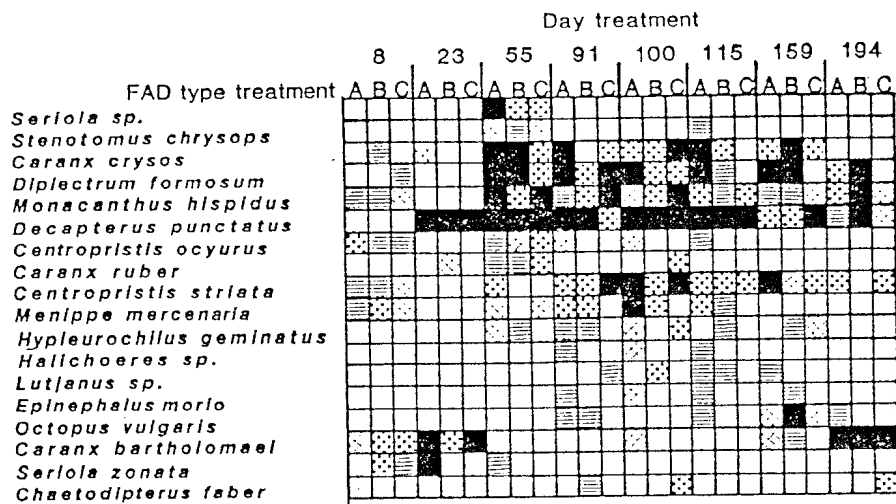


Figure 8. Nodal constancy, fidelity, and abundance for all species with a frequency of greater than 4 % grouped by FAD type treatment within day treatments. Note that a X in a cell indicates a significant fidelity.



pelagic species Seriola zonata, Caranx ruber and C. bartholomaei were united by frequent co-occurrence early in the study (May-June) before they disappeared in July. Caranx bartholomaei, however, reappeared in the late fall and was united with the other fall species, Octopus vulgaris and Chaetodipterus faber. The species in group-III also show a tendency to exhibit a high fidelity to a station type or day for which group-I fishes show low fidelity (Fig. 8).

The total number of species observed for each FAD type treatment ranged from 26 for type A to 22 for type C (Table 6). For all FAD type treatments combined, peak total numbers of species occurred on days 55 and 115. Differences in the total number of species among FAD type treatments were due to differences in the number of rare species observed. Of the eight species unique to type A FADs, only Halichoeres sp. occurred more than once. The total number of species observed for type D FADs was similar to that for the treatment types, while the total number of species for type E stations was much lower (Table 6). Only seven species were observed at the type E stations, which lacked FADs, with Diplectrum formosum and Octopus vulgaris the only common species (Table 7). In contrast 25 species were observed to associate with the concrete blocks anchoring FADs (Table 2).

Although the total number of species for each FAD type treatment probably differed mainly because of unequal sample sizes, the number of species per station was strongly affected by FAD type treatment. An overall average of 3.8 species/station was observed (Appendix B.2), while FAD type A had the highest, and FAD type B had the lowest, mean number of species per station among the FAD type treatments (Fig. 9a).

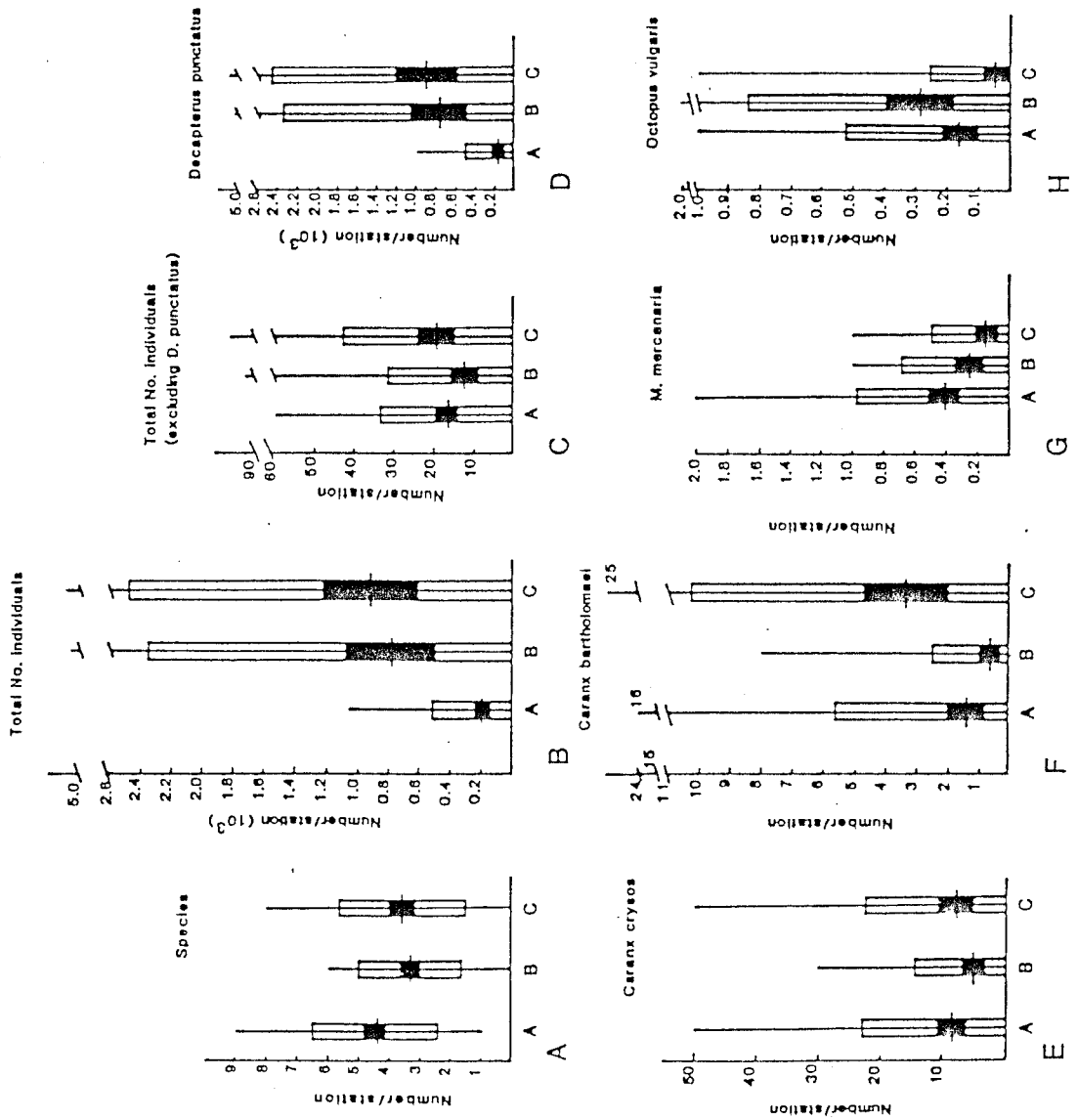
Table 6. Total number of species occurring for each FAD type by day.

Day	Pooled					Pooled All types
	Type A	Type B	Type C	Type ABC	Type D	
8	8	8	8	12	-	12
23	5	3	2	6	4	6
55	16	10	13	18	11	19
91	12	9	6	14	13	19
100	11	7	9	15	10	19
115	13	11	3	17	9	20
159	8	10	7	12	-	13
194	6	4	6	8	-	8
Total	26	23	22	38	23	40

Table 7. Frequency of Species occurring around single and multiple concrete blocks after loss of the FAD.

Species	Single Block	4-Block	Combined	Percent Occurrence
Zero species	5	1	6	42.9
<u>Diplectrum formosum</u>	3	2	5	35.7
<u>Octopus vulgaris</u>	3	1	4	28.1
<u>Centropristis striata</u>	0	2	2	14.3
<u>Halichoeres sp.</u>	1	1	2	14.3
<u>Equetus acuminatus</u>	0	1	1	7.1
<u>Centropristis ocyurus</u>	0	1	1	7.1
<u>Menippe mercenaria</u>	1	0	1	7.1
No. Species	4	6	7	
Sample size	11	3	14	

Figure 9. Dice plots of mean numbers of species, number of individuals and numbers of selected species observed per station by FAD type treatment. The horizontal line indicates the mean, the black bar represents one standard error and the white bar indicates one standard deviation above and below the mean. The range in observed values is shown by the vertical line (refer to Table 1 for sample sizes). Note that the response to FAD type treatment differed among species.



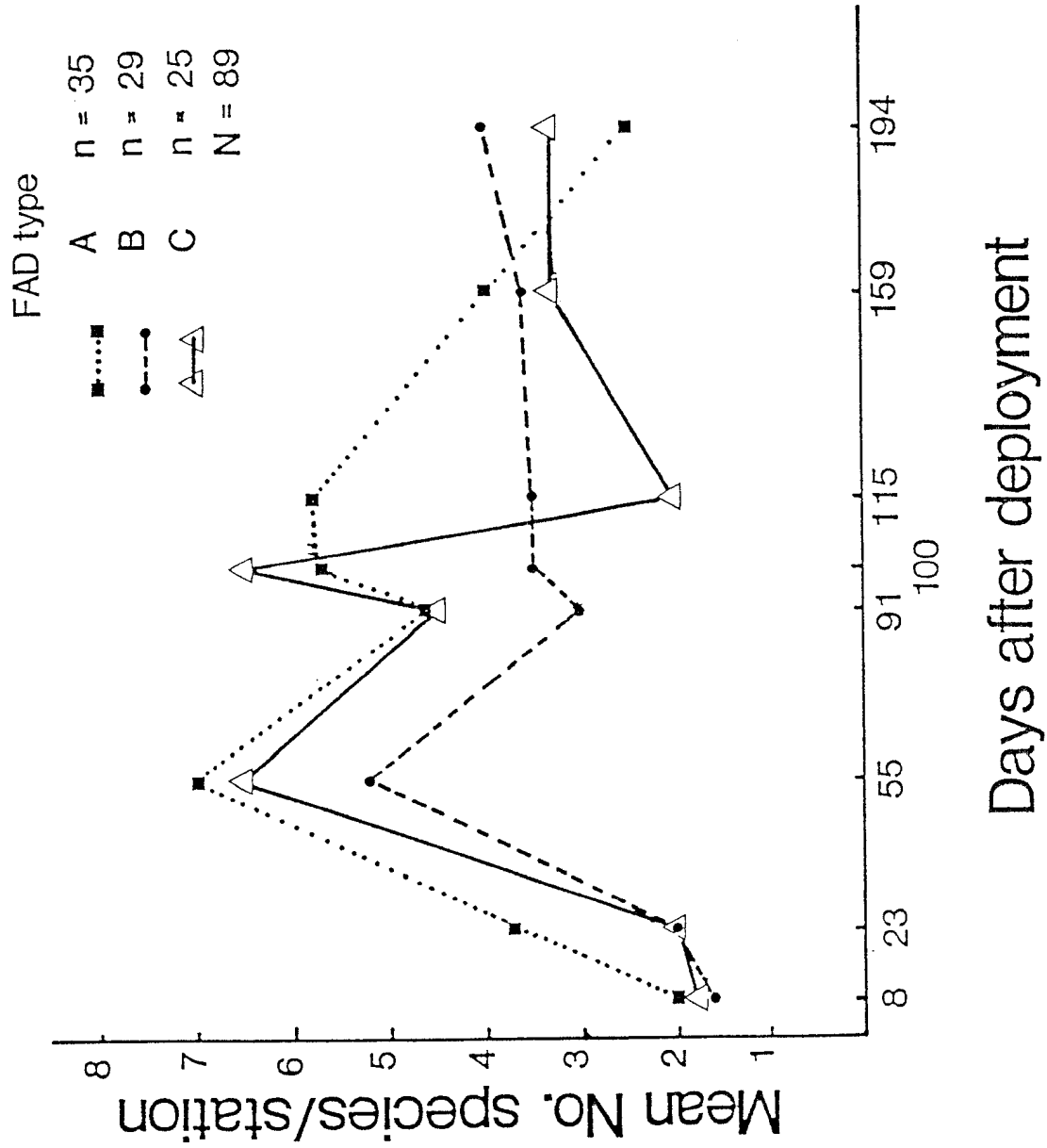
FAD type treatment

FAD type treatment A had consistently higher mean number of species per station than the other treatments throughout the study (Fig. 10), while means for FAD types B and C were more equivalent. The FAD type treatment effect was not significant using the 2-way anova on data ranked within days, though the probability was low ($p=0.0573$). All other anovas indicated a highly significant effect, with the 2-way anova on unranked data the most conservative ($p=0.0087$). Scheffe tests based on ranked and unranked data all showed FAD type A to be significantly different from type B ($p<0.05$), but conflicted with respect to the significance of the other FAD type paired comparisons.

The number of species per station showed a strong temporal trend rising from a low mean on day 8 to a peak on day 55 followed by a decline to day 194 (Fig. 11a). The day treatment effect was highly significant based on the 2-way anova on unranked data ($p=0.0087$), but was nonsignificant for data ranked within day ($p=0.0564$). The Scheffe test indicated that the peak means (day 55, 100 and 115) were significantly different from days 8, 23 and 91 while day 55 was also different from day 159 and 194 (Fig. 11a).

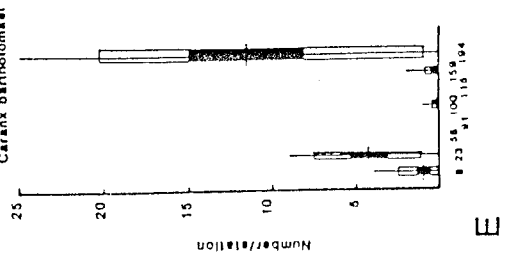
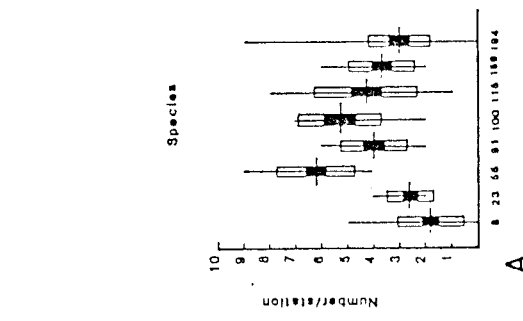
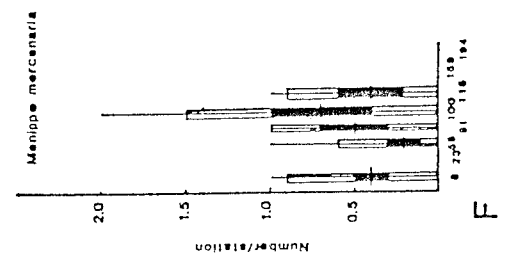
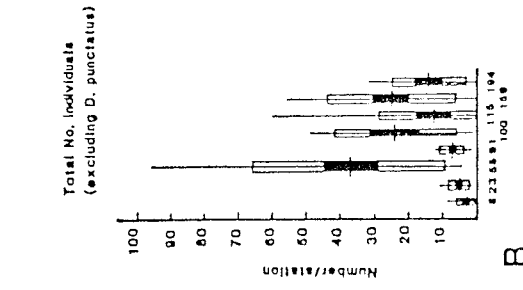
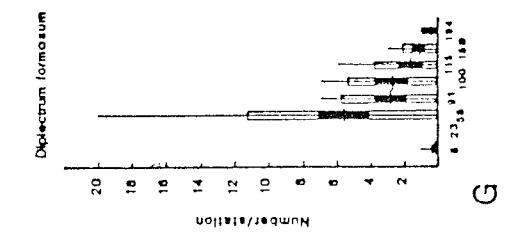
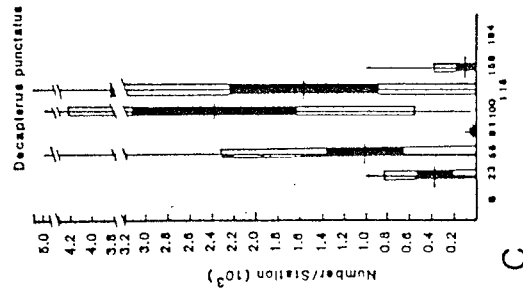
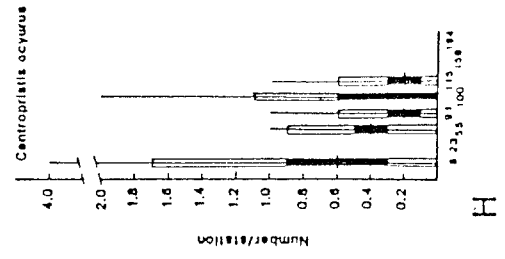
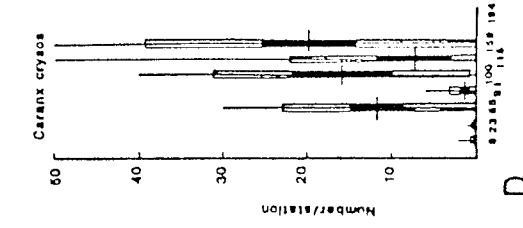
An apparent trend of increasing total number of individuals of all species per station from FAD type A to C was observed (Fig. 8b), with an overall average of 676 (± 1489) individuals/station (592 \pm 1266 with one outlier removed, Table 4). The mean number of individuals per station for FAD types B and C were 4 and 5 times greater than the mean for FAD type A. The mean number of individuals per station for FAD type A were lower than for types B and C for five days and higher than them for two days (Appendix B.2). In addition, mean number of individuals per station

Figure 10. Mean No. species/station for each FAD type treatment by day treatment. Note that FAD type treatment B had consistently lower means than FAD type A.



Days after deployment

Figure 11. Dice plots of mean number of species, number of individuals and numbers of selected species observed per station by day treatment. The mean is represented by the horizontal bar, the vertical black bar represents one standard error around the mean and the white bar represents one standard deviation about the mean. The vertical line represents the range of observed values. (refer to Table 1 for sample sizes). Means for day 91 were significantly lower than adjoining days in A, B, C, D, and H (see text).



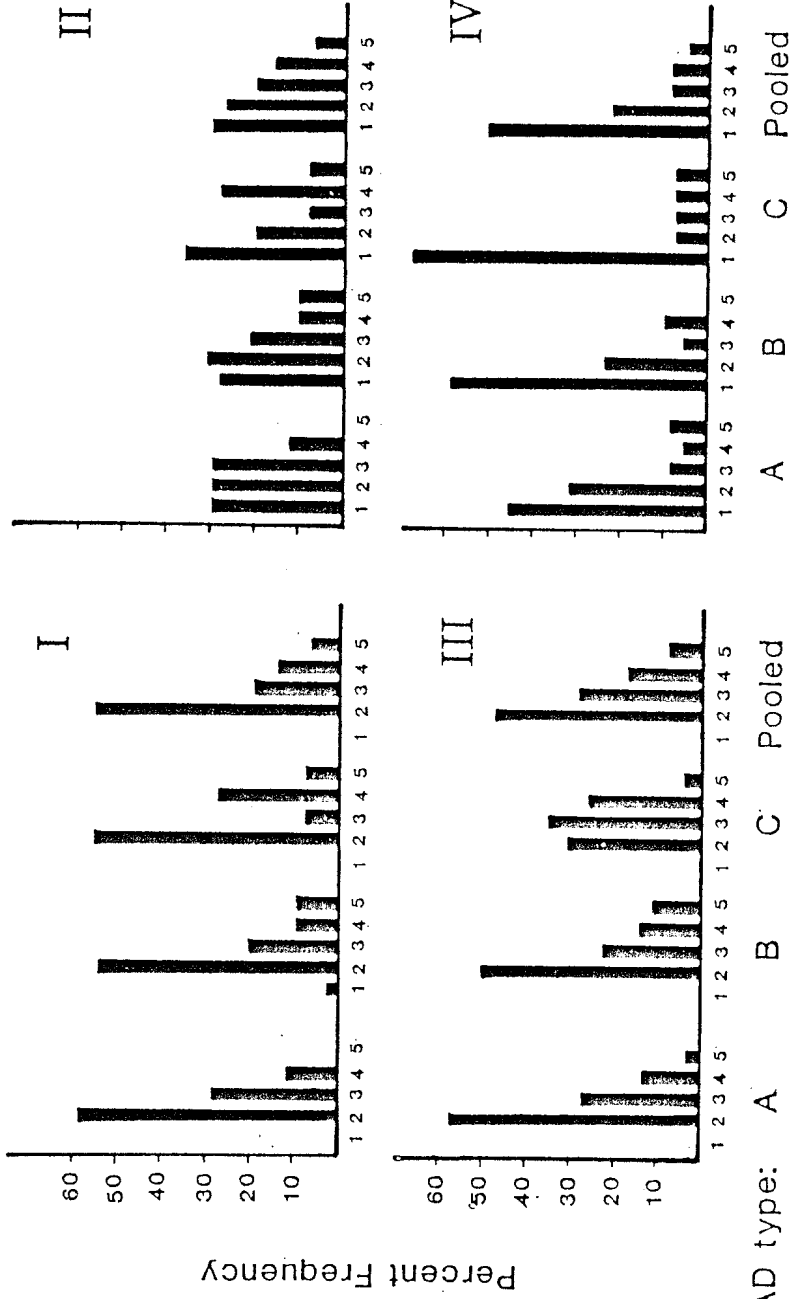
Day Treatments

for type C were usually higher than for type B (Appendix B.2). There was good agreement among the anova tests, with the 2-way anova on data ranked within day, the most conservative test, indicating a significant FAD type treatment effect ($p=0.0163$). The Scheffe a-posteriori test on unranked data distinguished FAD type A from C while the same test on ranked data resulted in significant differences between A and C and between B and C type FADs ($p<0.05$). The most conservative conclusion was that FAD type A attracted significantly fewer individuals per station than FAD type C and FAD type B probably attracted fewer individuals per station than FAD type C.

An explanation for the apparent significant difference between FAD types B and C and non-significant difference between A and B was suggested by the frequency distribution of the total number of individuals per station for each FAD type treatment (Fig. 12a). A trend of reduction of the frequency of counts of 100-999 individuals per station from types A to C was apparent. The distributions for FAD types A and B were similar except for the presence of the 5000⁺ counts in B, which account for its relatively high mean. The distribution for type C FADs, however, was very different, with a reduced occurrence of 100-999 individuals per station and an increased occurrence of 1000-4999 individuals per station (Fig. 12a). Counts ranging from 1000 to 4999 individuals per station were nearly 3 times as frequent at type C stations than type B station.

The total number of individuals per station of all species exhibited a strong temporal trend, increasing from a low of 2.8 individuals/station on day 8 (May) to a peak of 2407 individuals/station on day 100 (August)

Figure 12. Frequency histograms with FAD type treatment A, B, C and pooled types, on the x-axis. I) Total number of individuals/station. II) Total number of Decapterus punctatus/station. III) Number of D. punctatus/school based on 62 stations ($N_a = 31$, $N_b = 28$, $N_c = 23$, $N = 81$). IV) Total number of Caranx crysos/station.



Class Key:

FAD types I II	For IV
No. of Fish	No. of Fish
1 = 0	= 0
2 = 1-99	= 1-10
3 = 100-999	= 11-20
4 = 1000-4999	= 21-30
5 = ≥5000	= >30

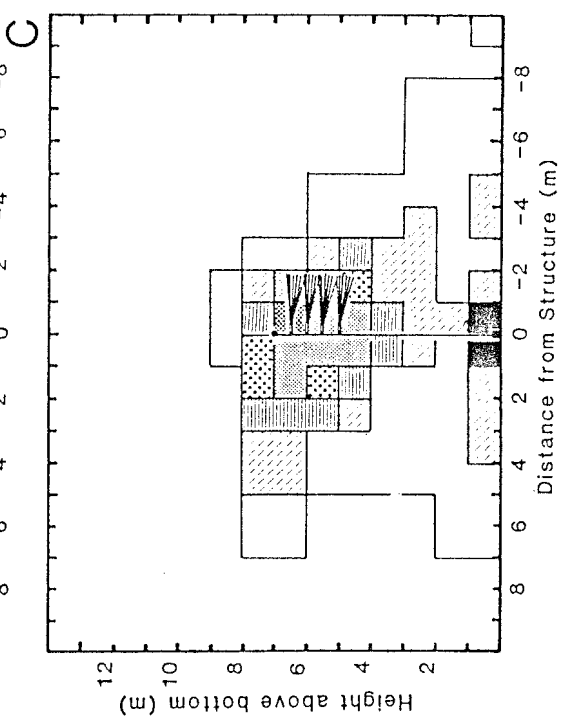
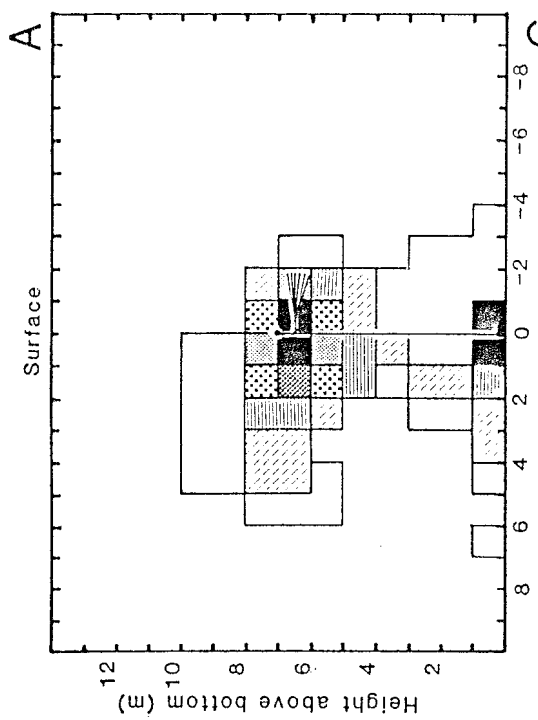
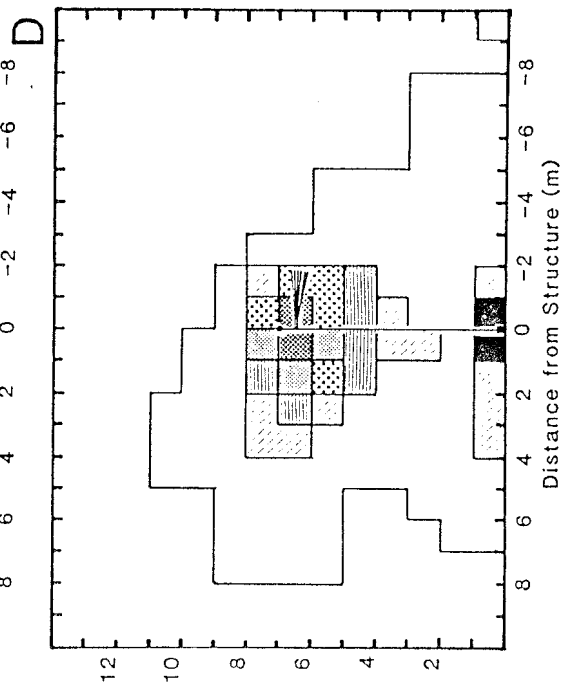
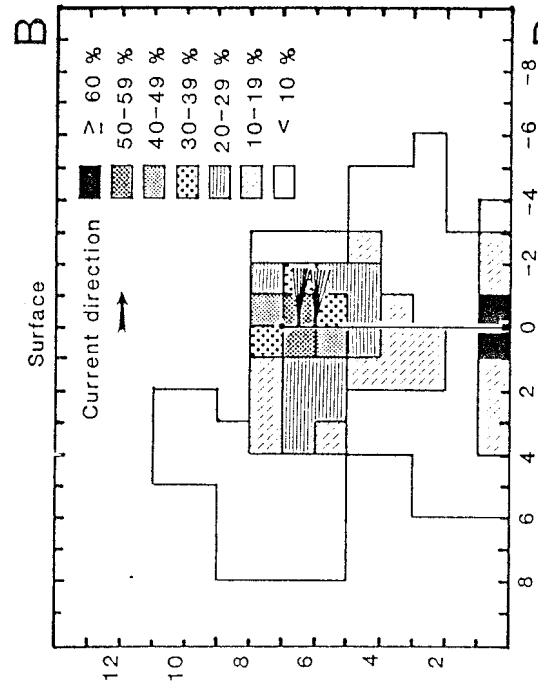
and then rapidly dropping to 15 individuals/station on day 194 (November; Appendix B.2). A very strong drop in the mean number per station was observed on day 91. The day treatment had a significant effect ($p=0.0300$) on the number of individuals based on analysis of data ranked within days (very highly significant for unranked data, $p=0.0001$). The Scheffe test on ranked data was non-significant while the same test on unranked data resulted in a significant difference ($p<0.05$) for some pairs. Day 100 (the highest mean, Appendix B.2) was different from all other days except for days 55 and 115, while day 8 was different from days 100 and 115.

Fishes tended to be distributed more to the up-current side of both the anchor and FAD and to a lesser extent to the mooring line (Fig. 13). They were most frequently located within 1 m² up current and down current of the anchor and the float and first subunit of the FAD (Fig. 13d). However, in contour plots of the density distribution of fishes (not shown), higher mean number of individuals/m² was observed 2-4 m up current of the FAD, indicating that more fishes occurred less often farther up current. Fishes occupied an increasingly larger area from FAD type A to C (Fig. 13a-c), with an average of 11 m² occupied around type A structures and 14 m² occupied around type C structures. A trend of increasing vertical range from FAD type A to C, corresponding to the increase in vertical profile of the FAD, was also observed (Fig. 13a-c).

The average total number of individuals of all species per station, excluding Decapterus punctatus, did not follow the same trend as the total number including D. punctatus (Fig. 9c). FAD type C had the highest mean number of individuals per station while FAD type B had the

Figure 13. Contour plots of the 2-dimensional distribution of fish around structures of each FAD type treatment (A-C) and around a composite FAD based on data from all three treatments pooled (D). Contours represent the percent presence of individuals in m^2 cells around the structure as viewed perpendicular to the current axis.

- A). FAD type A: A total area of $65 m^2$ was utilized with an average of $10.86 (\pm 7.22) m^2/station$ ($N = 35$ non-zero records).
- B). FAD type B: A total area of $94 m^2$ was utilized with a mean of $12.14 (\pm 9.64) m^2/station$ ($N = 28$ non-zero records).
- C). FAD type C: A total area of $97 m^2$ was utilized with a mean of $14.04 (\pm 8.65) m^2/station$ ($N = 25$ non-zero stations).
- D). Pooled FAD types: A total area of $119 m^2$ was utilized with a mean of $12.17 (\pm 8.46) m^2/station$ ($N = 88$ non-zero stations).

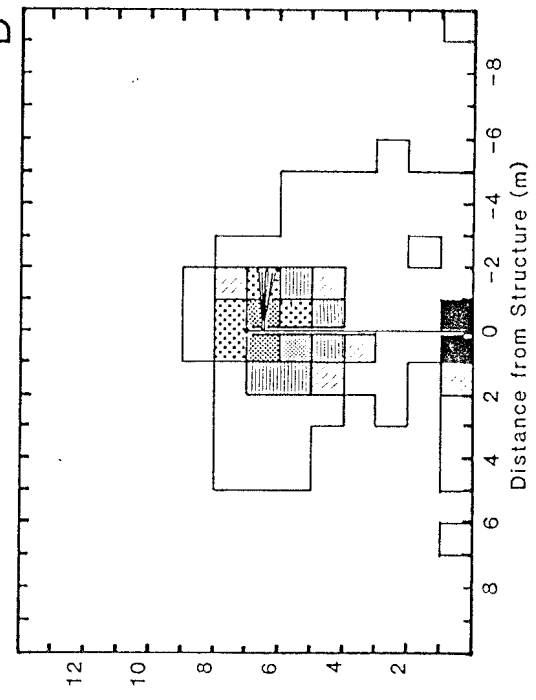
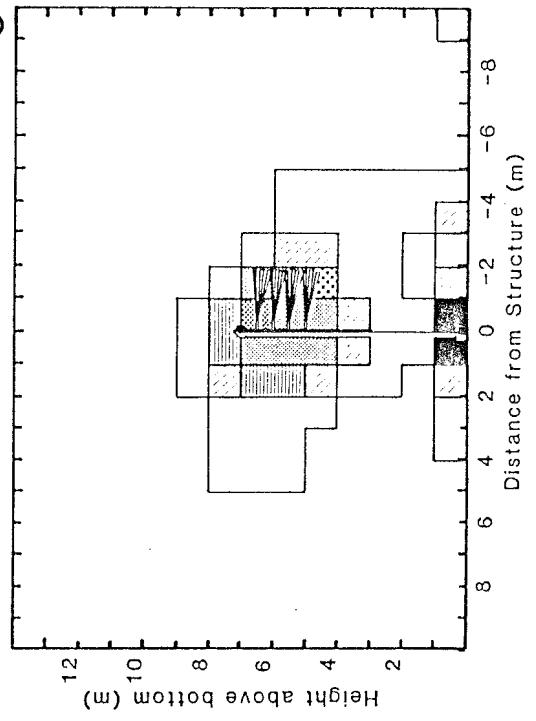
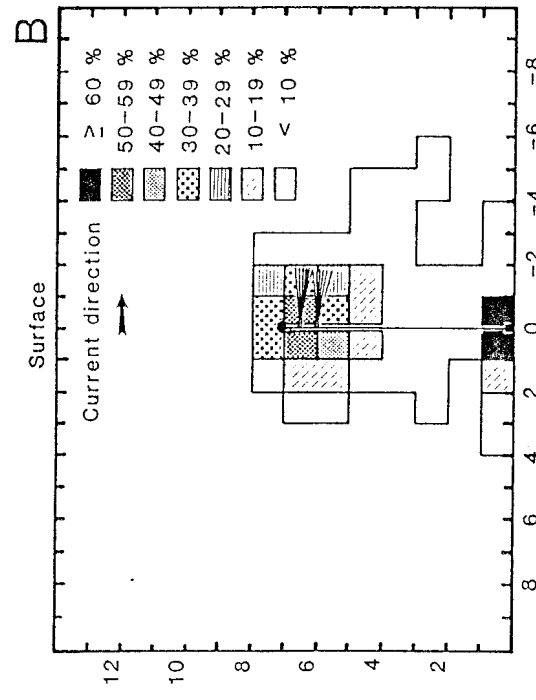
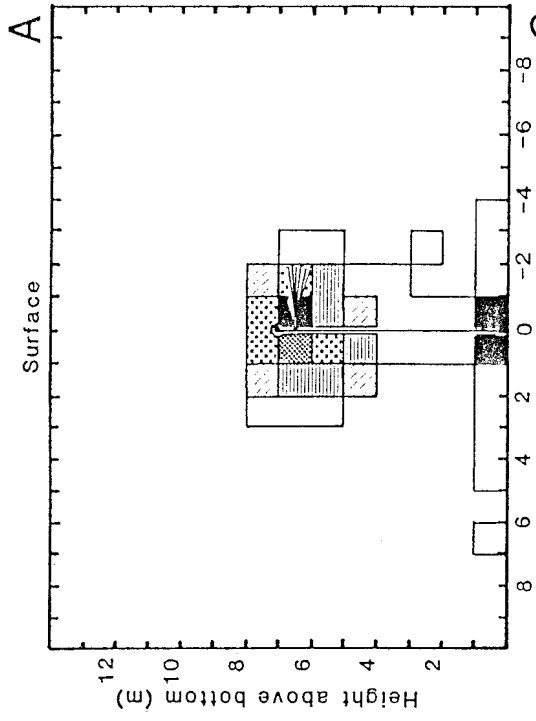


lowest. FAD type C had the highest mean six out of the eight days with a peak of 51.3 individuals/station on day 55 (Appendix B.2). FAD type B had consistently lower means and had the lowest means among the three FAD types for six days (Appendix B.2). Although conflicting anova results were obtained, differences among the FAD type treatments were not enough to show a significant FAD type treatment effect. Only the 3-way anova on data ranked within FAD type treatment blocks resulted in a significant FAD type effect ($p=0.0437$). This indication of a significant FAD type treatment effect was supported by a significant FAD type effect for day 115 ($p<0.05$, Kruskal-Wallis), but this support was weakened by a non-significant anova on unranked data for that day.

A very highly significant day treatment effect on the total number of individuals per station was observed for both the 3-way and 2-way anova on unranked data ($p=0.0001$). However, the 2-way anova on ranked data was non-significant, although it had a low probability ($p=0.0663$). The mean number of individuals per station rose sharply from a low of 2.8 individuals/station on day 8 to a peak of 37.4 individuals/station on day 55 (Fig. 11b). It dropped sharply on day 91, then rose sharply on day 100 after which time it fluctuated widely. The Scheffe means test using unranked data resulted in a significant difference between day 55 (the peak mean) and the three lowest means (day 8, 23, and 91, $p<0.05$).

Although the total number of individuals (excluding Decapterus punctatus) per station was not significantly different among FAD type treatments, a strong difference in the distribution of fishes about the different type FADs was exhibited (Fig. 14a-c). In general, fishes

- Figure 14. Contour plots of the 2-dimensional distribution of fish (excluding Decapterus punctatus) around structures of each FAD type treatment (A-C) and around a composite FAD based on data from all three treatments pooled (D). Contours represent the percent presence of individuals in m^2 cells around the structure as viewed perpendicular to the current axis.
- A). FAD type A: A total area of $39 m^2$ was utilized with an average of $7.06 (\pm 4.21) m^2/station$ ($n=35$).
 - B). FAD type B: A total area of $50 m^2$ was utilized with an average of $7.70 (\pm 6.20) m^2/station$ ($n=28$).
 - C). FAD type C: A total area of $65 m^2$ was utilized with an average of $10.08 (\pm 6.34) m^2/station$ ($n=24$).
 - D). Pooled FAD types: A total area of $65 m^2$ was utilized with an average of $8.13 (\pm 5.61) m^2/station$ ($n=87$).

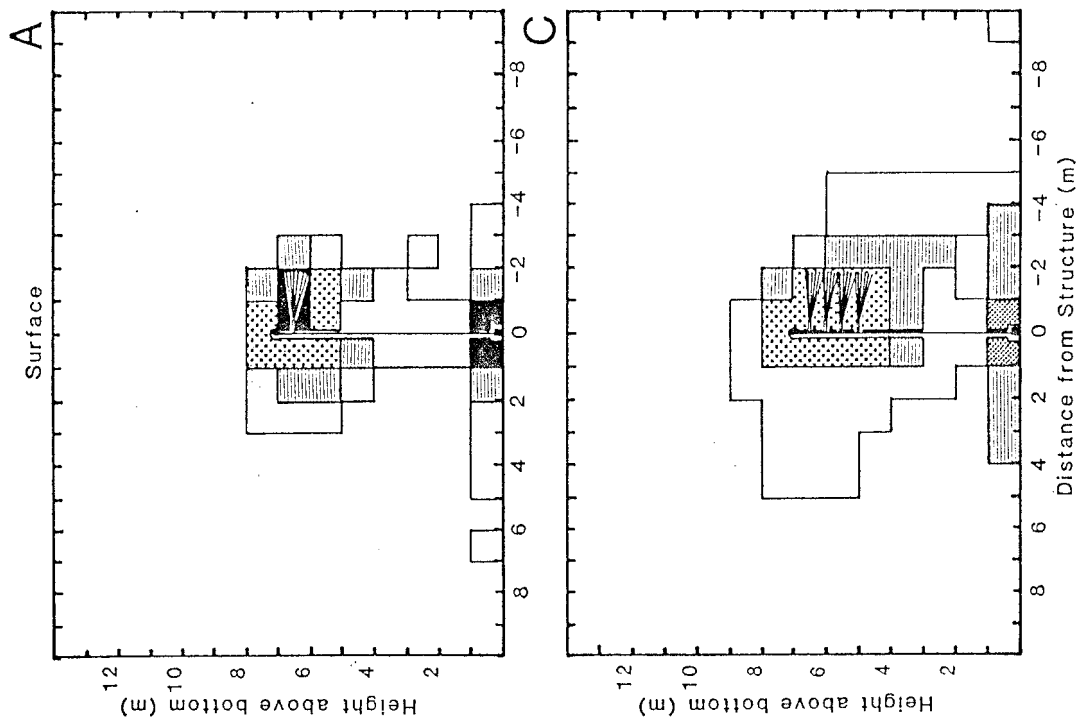
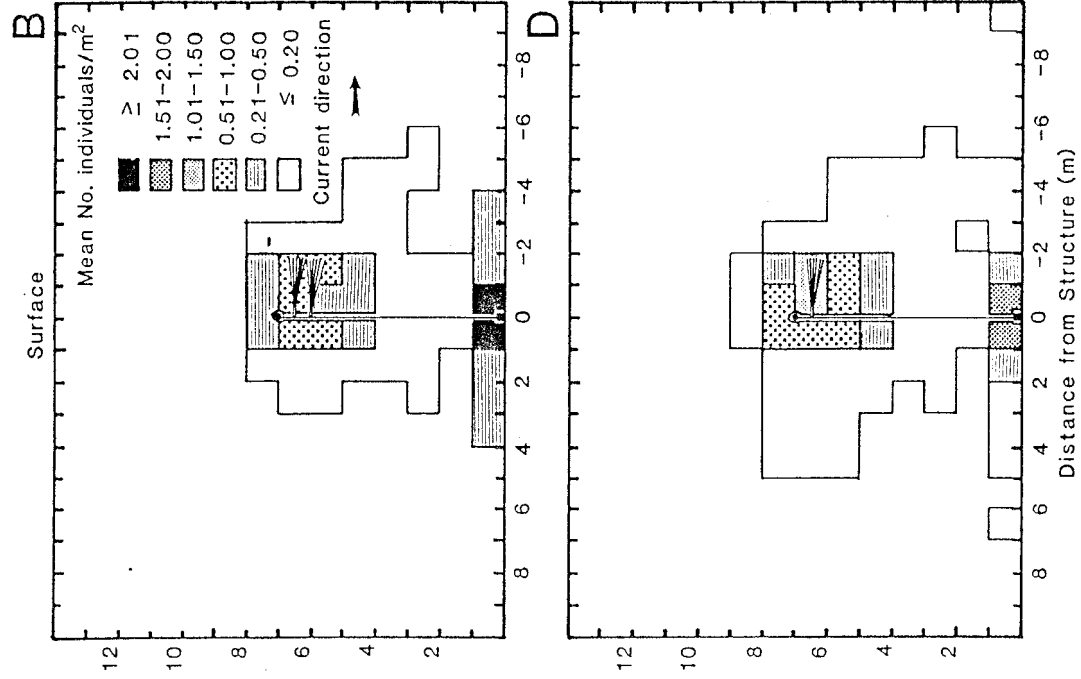


occupied an average area of 8.1 m²/station and occurred most frequently (79 % of the stations) within an area 1 m² up current and down current of the anchor, followed by an area 1 m² up current and down current of the float and first subunit of the FAD (54-58 % of the stations, Fig. 14d). A trend of increasing area occupied from FAD type A (7.1 m²/station) to FAD type C (10.1 m²/station) was observed (Fig. 14a and 14c, respectively). This was a reflection of the increase in the vertical distribution of fish occurrence around the FADs corresponding to the vertical profile of the FAD. In general, all species considered together (excluding D. punctatus) were distributed fairly evenly up current and down current of the FAD, with a slight tendency to occur more frequently down current (Fig. 14d).

The distribution of the mean number of fish per square meter block around the FAD shows a more pronounced tendency of increasing vertical range from FAD type A to C (Fig. 15a-c). The distribution also shows that more fish occur down current of the FAD (Fig. 15d). A comparison of the distributions of the percent occurrence and mean number of individuals within the 1 m² cells around the structures reveals that higher numbers of fish occur more frequently directly around the FAD subunits (at their up current ends) and that the fish spread out to make the most use of the available cover.

Much of the variance observed in the total number of fish per station and the total number of fish per station excluding D. punctatus, was due to the varying contributions of different species over time. Therefore, the relationships of the number of individuals per station for some of the most frequently occurring species are examined below.

Figure 15. Contour plots of the 2-dimensional distribution of fish (excluding D. punctatus) around structures of each FAD type treatment (A-C) and around a composite FAD based on data from all three treatments pooled (D). Contours represent the mean number of individuals/m²/station (assuming all individuals lie in a plane parallel to the axis of the current). Note the distribution was densest around the anchor and within 1 m of the FAD.

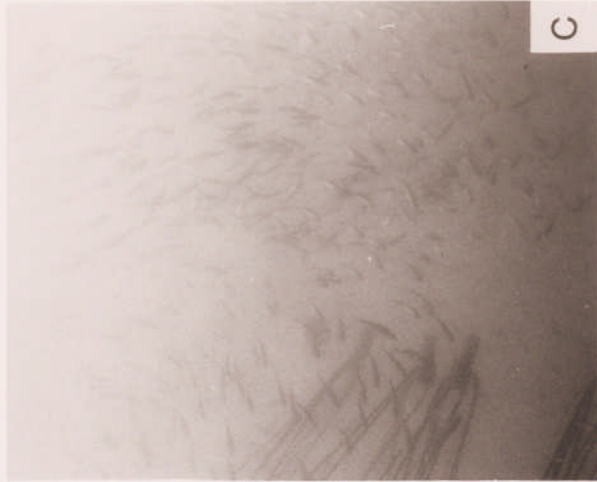


Decapterus punctatus

The abundance of Decapterus punctatus increased with the complexity of the FAD with the lowest mean number of D. punctatus occurring at FAD type A and highest at FAD type C (Fig. 9d). FAD type A had lower mean values than the other types on five of the seven days for which the species was present (Appendix B.2). This difference in the number of scad per station among the FAD treatment types was especially evident during several dives made early in the study (May and June). During one of these dives made 17 days after deployment of the FADs (31 May), few scad were observed on FAD type A stations (Fig. 16a), whereas on the order of 100 scad occurred on FAD type B stations (Fig. 16b) and on the order of 1000 scad occurred on FAD type C stations (Fig. 16c). This difference in the abundance of scad among the FAD types was found to be significant ($p=0.0349$, Kruskal-Wallis) during a census conducted on day 23 (6 June).

Although difference in the abundance of D. punctatus among the FAD types were not as obvious later in the study, a significant FAD type treatment effect was observed with good agreement among the anova tests performed. The most conservative test was the 2-way anova on data ranked within days which reported a significant FAD type effect ($p=0.0467$). FAD type A was found to be significantly different from C in all a-posteriori tests ($p<0.05$), but tests performed on ranked and unranked data resulted in conflicting probabilities for differences between A and B and between B and C type FADs. Differences among these pairs were conservatively held to be non-significant.

Figure 16. Photographs of one of each of the FAD type treatment structures taken 17 days after deployment. A) FAD type A with few or no Decapterus punctatus present. Here Seriola zonata (with bars) and Caranx bartholomaei can be seen swimming close to the float. B) FAD type B at which on the order of 100 D. punctatus were observed. C) FAD type C at which on the order of 1000 D. punctatus were observed and at which Seriola zonata was absent.



Further evidence of differences among FAD types was observed in an analysis of the frequency distributions of the total number of round scad per station by FAD type treatment. A trend of increasing occurrence of large counts and decreasing occurrence of smaller counts of round scad per station from FAD type A to FAD type C was observed (Fig. 12b). FAD type C exhibited a pronounced decrease in the frequency of counts of 100-999 scad/station and a pronounced increase in the frequency of counts of 1000-4999 scad/station compared to FAD types A and B. FAD type A was distinguished by a maximum count of 1050 scad/station (with an outlier removed) while FAD types B and C each had maximums above 5000 scad/station. FAD type B differed from FAD type A mainly in the occurrence of some counts above 4999 scad/station, which had the effect of inflating the mean for FAD type B and making it appear more equivalent to the mean for FAD type C. FAD type C, however, differed strongly from FAD types A and B in that standing crops of 1000-4999 scad/station were predominant, while standing crops of 1-99 scad/station were most frequently observed for FAD type A and B.

Since D. punctatus often occurred in more than one school per station, the effect of the FAD type treatment on schooling was examined. The mean number of schools per station was not significantly different among FAD type treatments (Appendix B.2), but the frequencies of the number of schools per station differed strongly among FAD types. Overall, a single school occurred at 49 % of the stations, two schools at 19 % of the stations and three schools at 2 % of the stations. Single schools strongly dominated at FAD type A (57 %) and FAD type B (51 %) with two schools occurring at 14 % and 17 % of FAD type A and B

stations, respectively. Single schools, however, were only slightly more frequent than two schools at FAD type C stations (36 % and 26 %, respectively). Although differences in the number of schools of D. punctatus per station among FAD type treatments were not significant, the number of schools were found to be dependent on the total number of round scad at the station ($X^2=4.770$, $p<0.05$). There was a tendency, then, for round scad to segregate into more than one school with increasing total number of individuals per station so that the higher the number of round scad per station, the more likely there would be two schools present.

The average number of round scad per school was not significantly different among the FAD type treatments except for day 23 ($p=0.0144$, Kruskal-Wallis). However, a trend of decreasing frequency with increasing number of individuals per school was observed for FAD types A and B but not for FAD type C (Fig. 12c). Schools of 100-999 individuals were most frequently observed for FAD type C stations (Fig. 12c), with an average of 980 (± 1486) individuals/school. Schools observed at FAD types A and B were most frequently composed of 1-99 scad (Fig. 12c), with an average of 201 scad/school at FAD type A stations and 798 scad/school at FAD type B stations (See appendix B.1 for more information on mean school sizes).

To summarize the frequency data: 1) FAD type C stations were characterized by a predominant occurrence of standing crops of D. punctatus of 1000-4999 fish/station, which were frequently broken down into two schools, for which 100-999 fish/school occurred most frequently; 2) FAD types A and B stations were characterized by a predominant

occurrence of a standing crop of 1-99 fish/station made up of a single school. The occasional occurrence of larger numbers of round scad at FAD type B stations inflated the value of the mean number of round scad per station for this type, making it appear to have had a similar attraction to scad as that of FAD type C stations. In fact, FAD type treatments A and B have a similar attraction while the FAD type C treatment was greatly different.

Additional support for the effect of FAD type treatment on attraction of Decapterus punctatus was provided by the nodal analysis. Decapterus punctatus exhibited very high constancy for all FAD type treatments throughout the summer and early fall except for FAD type treatment C on day 91 (Fig. 8). Throughout the study period a low fidelity to FAD treatment type was exhibited (Fig. 8). Also note that within days, FAD types B and C often exhibited low to moderate abundances while FAD type A exhibited very low abundance on all days except day 100 (Fig. 8). In general then, the FAD type treatment had little effect on the presence/absence of Decapterus punctatus, but strongly affected its abundance.

An examination of the distribution of round scad in the water column surrounding the FAD was helpful in understanding the effect of the FAD type treatment on their behavior. When separate schools were observed at a station, they usually maintained their identity even in the presence of the divers, although the schools sometimes joined into one large school after being disturbed. Separate schools appeared to exhibit different behavior, with the larger school often observed to actively feed in the water column (Fig. 17) with the school's center usually

Figure 17. Photograph of a FAD type B station taken on day 55 showing the position of a school of round scad relative to the FAD. The school has been disturbed by divers, but the bowl shaped configuration and up current position of the school are still apparent.



located about 2 m up current and level with the FAD (Fig. 18d). A second, smaller school, apparently rested in an inactive state near the bottom a few meters up current of the anchor (Fig. 18d), or occasionally closely around the anchor (Fig. 6c).

Several different trends in the distribution of round scad around FADs among the FAD type treatments were noted. The area utilized increased from 7.8 m²/station for FAD type treatment A to 13.6 m²/station for FAD type treatment C (Fig. 18a-c). The increase in area was partly due to an increase in the number of fish present, hence the area occupied, but was also due to a tendency for fish to utilize a vertical range corresponding to the vertical profile of the FAD (Fig. 18a-c). Bias due to the sinking of the FAD type treatment C stations also contributed to this vertical expansion, but a comparison of the distribution of round scad around each FAD type treatment for each day indicated that the bias was not severe. The trend of increasing vertical range of the center of distribution of Decapterus punctatus was pronounced for the distribution of the mean number of fish per square meter around the FAD (Fig. 19a-c). The densest contour zones expanded vertically, moving deeper in the water column from FAD type treatment A to C. A comparison of the frequency contour plot and density contour plot indicated that larger numbers of scad occurred several meters up current of the FADs, but only infrequently, while small numbers of individuals occurred frequently in direct association with the subunits (Fig 18 and 19, respectively).

The positions occupied by small, medium and large schools of Decapterus punctatus suggested that they utilized the FADs for protection

- Figure 18. Contour plots of the 2-dimensional distribution of Decapterus punctatus around structures of each FAD type treatment (A-C) and around a composite FAD based on data from all three treatments pooled (D). Contours represent the percent presence of individuals in m^2 cells around the structure as viewed perpendicular to the current axis.
- A). FAD type A: A total area of $59 m^2$ was utilized with an average of $7.80 (\pm 5.49) m^2/station$ ($n=25$).
 - B). FAD type B: A total area of $88 m^2$ was utilized with an average of $10.05 (\pm 6.29) m^2/station$ ($n=20$).
 - C). FAD type C: A total area of $96 m^2$ was utilized with an average of $13.56 (\pm 3.86) m^2/station$ ($n=16$).
 - D). Pooled FAD types: A total area of $117 m^2$ was utilized with an average of $10.05 (\pm 5.81) m^2/station$ ($n=61$).

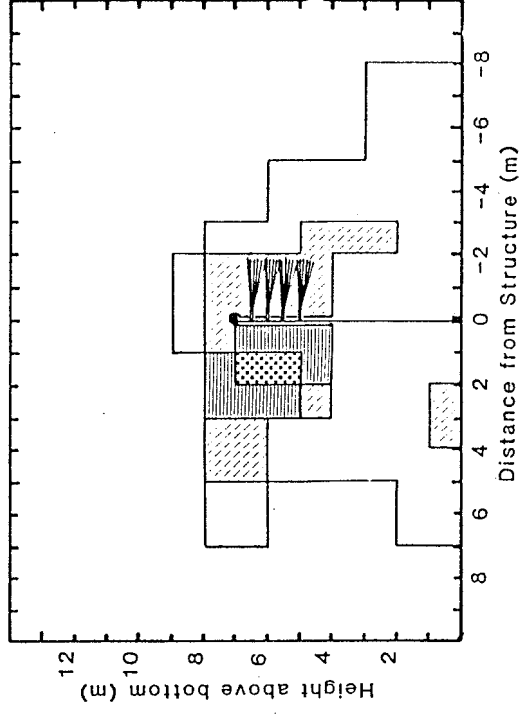
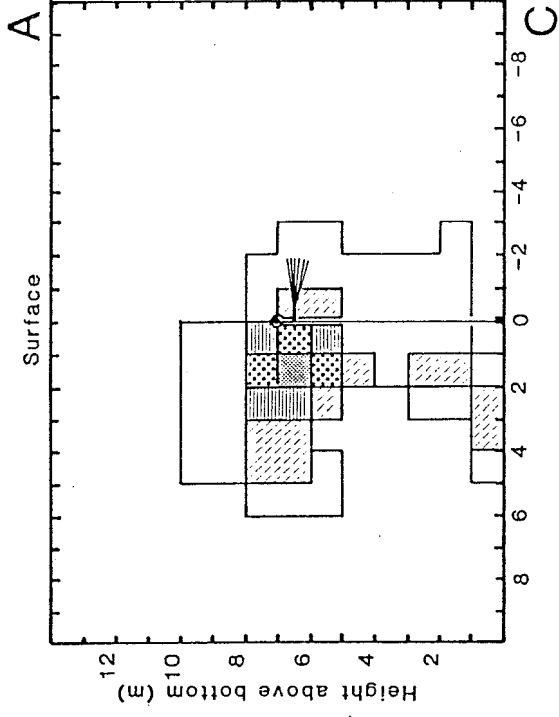
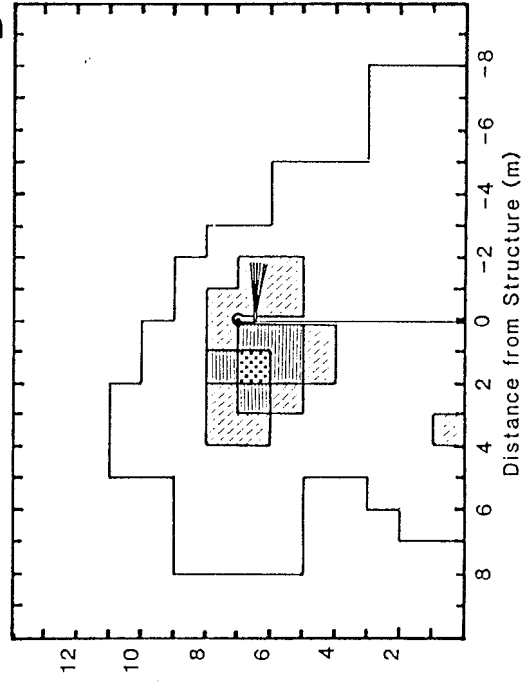
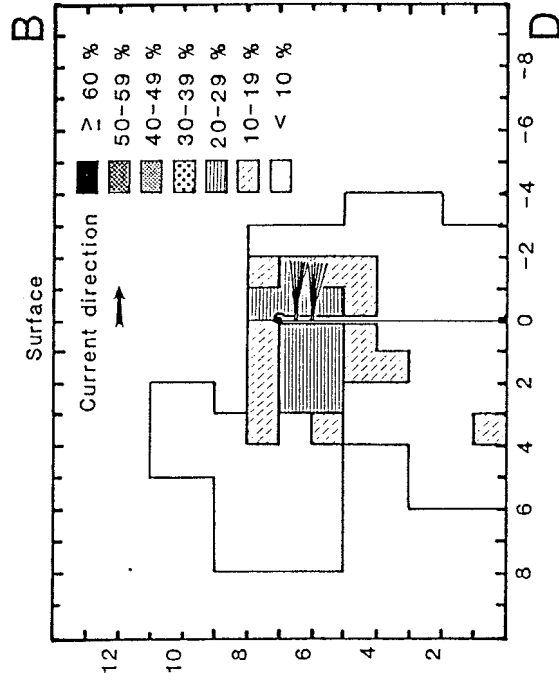
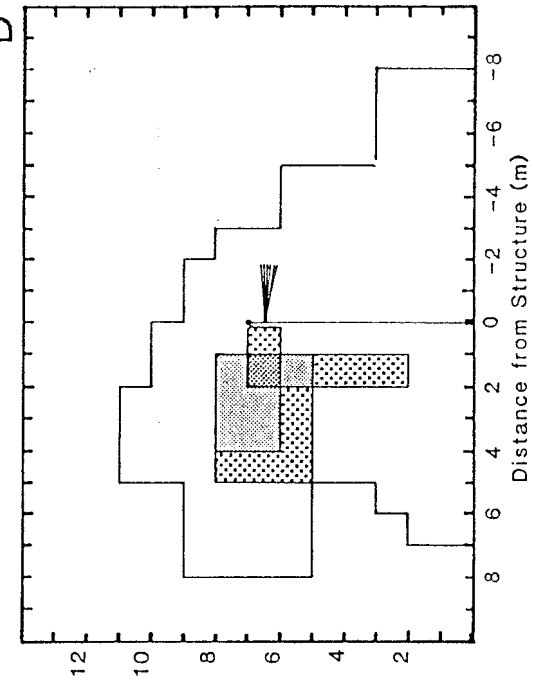
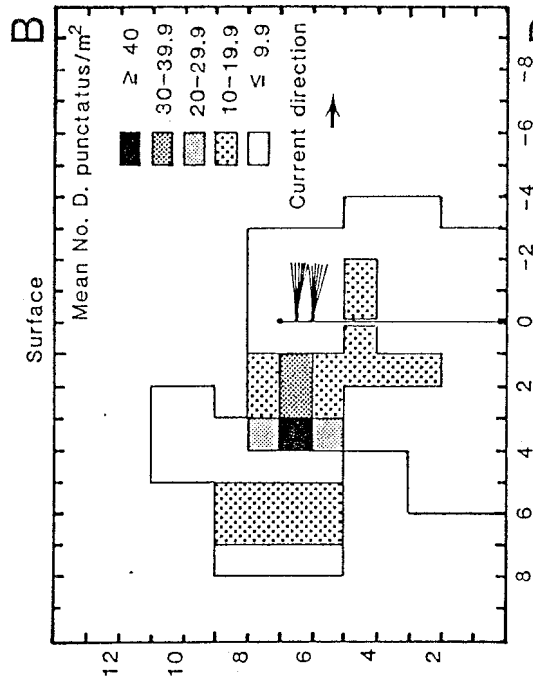
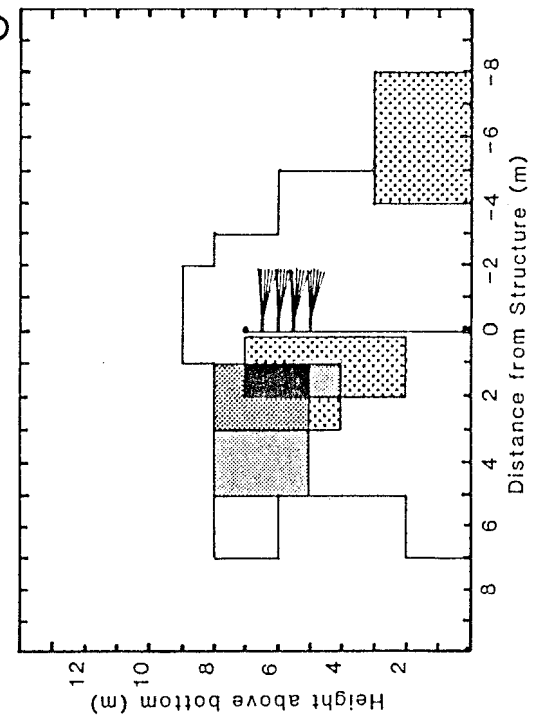
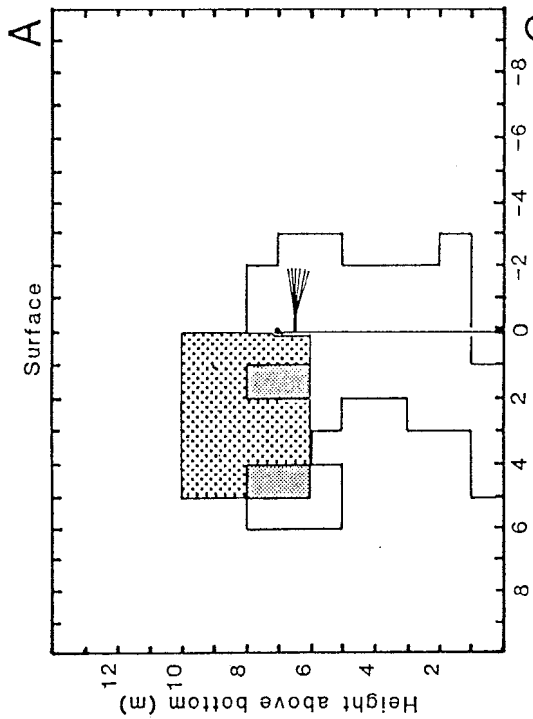


Figure 19. Contour plots of the 2-dimensional distribution of D. punctatus around structures of each FAD type treatment (A-C) and around a composite FAD based on data from all three treatments pooled (D). Contours represent the average number of round scad/m²/station assuming all fish lie in a plane perpendicular to the current axis.



in different ways. Smaller schools (1-99 individuals) tended to be distributed closely around the FAD with a peak occurrence in the first meter up current of the subunits (Fig. 20a). As the school increased in number, the center of distribution shifted farther up current of the FAD and expanded vertically (Fig. 20a-c).

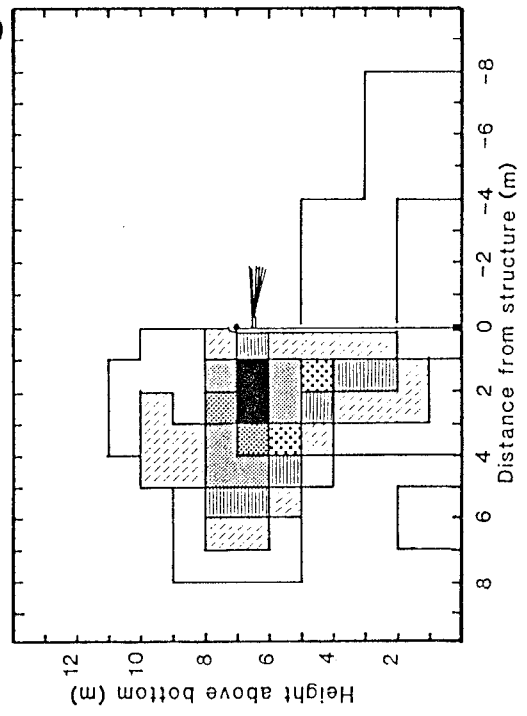
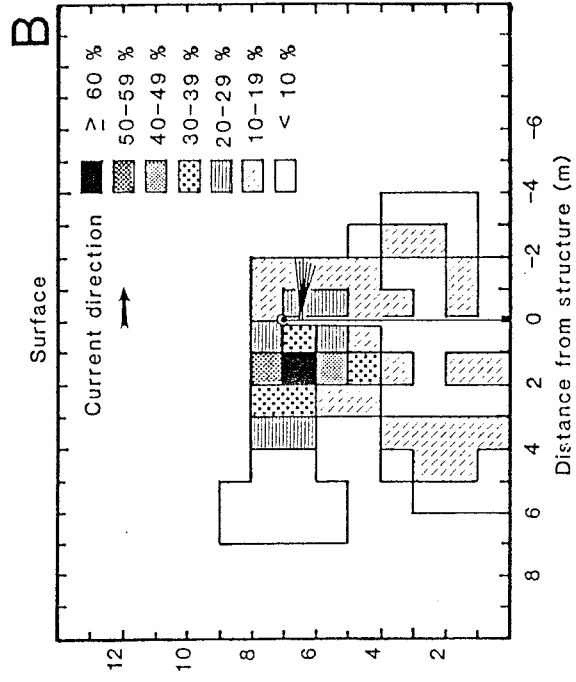
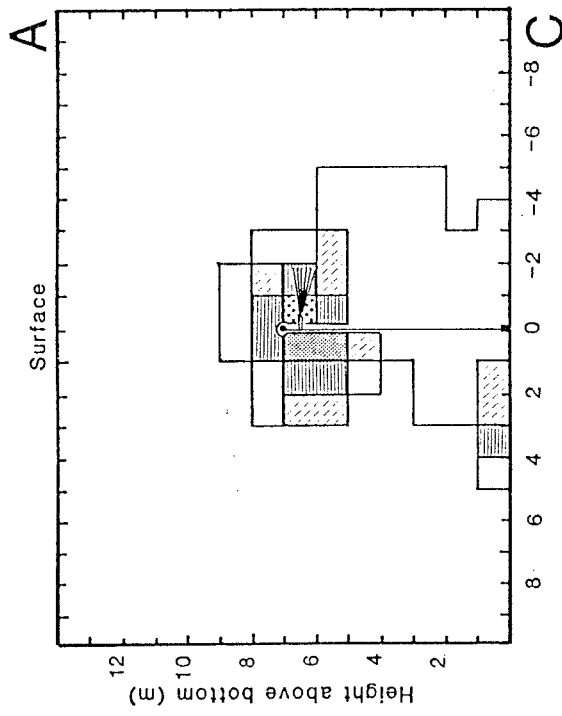
The number of D. punctatus per station was strongly dependent on the day treatment. The most conservative anova was the 2-way anova on data ranked within days which indicated a highly significant day treatment effect ($p=0.0045$). Decapterus punctatus exhibited a high constancy and low fidelity over much of the study, but had a significantly low fidelity on day 8, at which time the species was completely absent (Fig. 8). In fact, Decapterus punctatus occurred at all stations from June through September (day 23-115), except for day 91, at which time it occurred at 82 % of the stations. The frequency of D. punctatus declined rapidly in the fall to a low of 38 % of the stations in November (day 194). Although the constancy was high for much of the study and fidelity was low, abundances were greatest on days 100 and 115 (Fig. 8). The mean number of round scad per station rose from zero on day 8 to 1009 fish/station on day 55, then dropped to 27 fish/station on day 91 before reaching a peak of 2383 fish/station on day 100 (Fig. 11c). Day 91 was significantly different from days 55 and 100 (Scheffe, $p<0.05$). Days 8 and 23 were significantly different from day 100 as were days 159 and 194 ($p<0.05$).

Figure 20. Contour plots of the 2-dimensional distribution of D. punctatus around structures pooled from all three FAD type treatments by size school.

A). Schools of 1-99 round scad utilizing a total area of 59 m² with an average of 6.45 (\pm 3.72) m²/station (n=31).

B). Schools of 100-999 round scad utilized a total area of 69 m² with an average of 8.45 (\pm 4.54) m²/station (n=20).

C). Schools of > 1000 round scad utilized a total area of 87 m² with an average of 12.71 (\pm 5.46) m²/station (n=17).

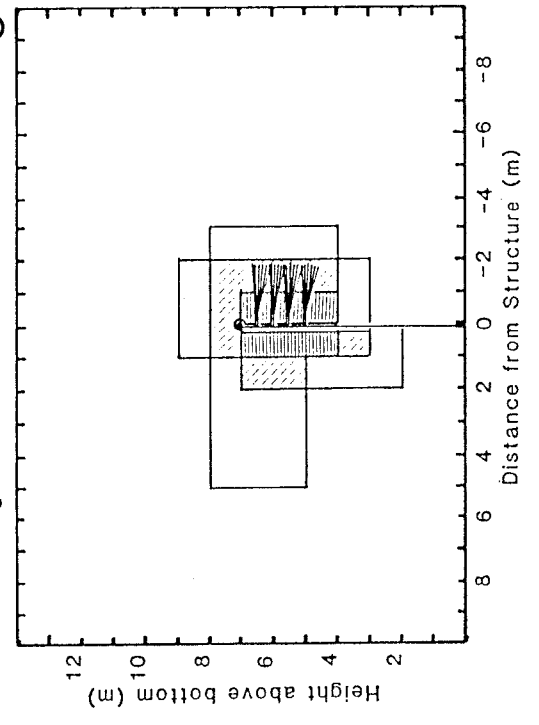
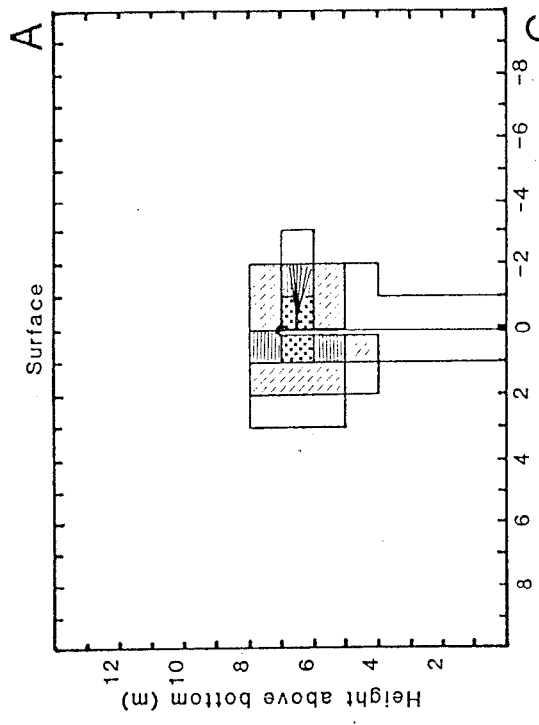
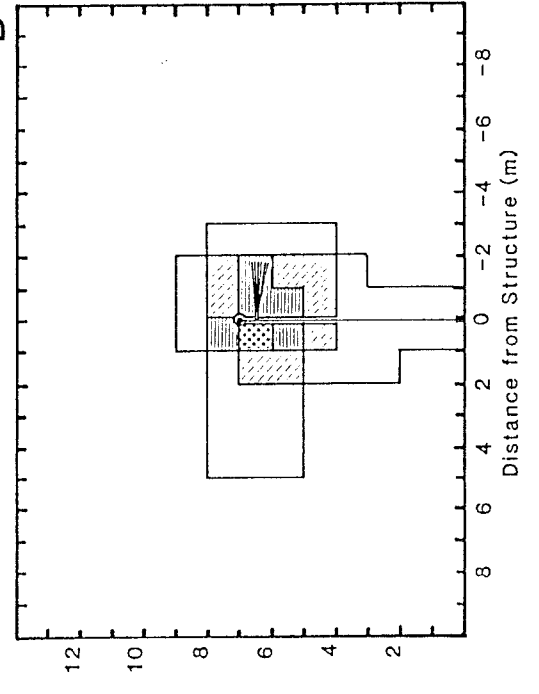
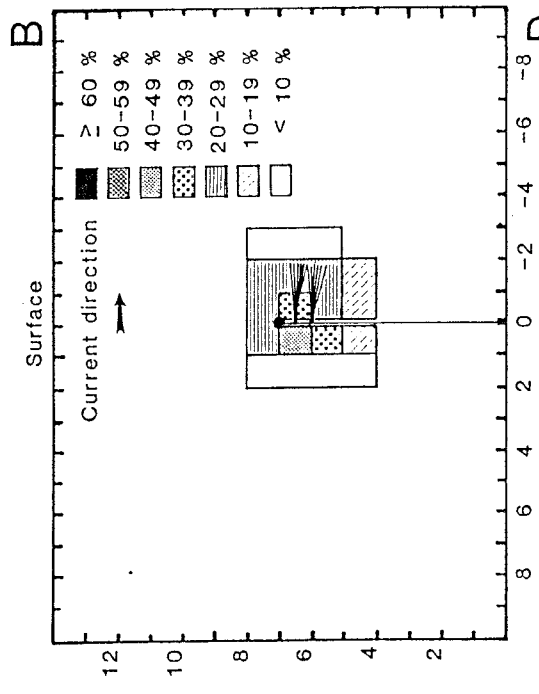


Caranx crysos

Although fewer blue runner occurred on FAD type B stations (Fig. 9e) than on the other stations, there was no significant FAD type treatment effect except for day 115 (Kruskal-Wallis, $p=0.0211$). However, nodal analysis and the analysis of frequency suggested some differences among FAD type treatments. The blue runner occurred at 54 % of FAD type treatment A stations, 41 % of FAD type treatment B stations and 32 % of FAD type treatment C stations. It exhibited a significant fidelity for FAD type treatment A on day 115 (Fig. 8), but a moderately high abundance index for FAD type C on day 159 (Fig. 8). As with Decapterus punctatus, there was a significant trend for larger numbers of individuals to occur more frequently, increasing from FAD type A to FAD type C ($p<0.025$). A standing crop of 1-10 blue runner occurred most frequently at FAD types A and B, but occurred only 8 % of the time at FAD type C station (Fig. 12d). Apparently Caranx crysos was more frequently attracted to FAD type A stations, but occurred in greater abundance at FAD type C stations.

Blue runner were more closely associated with the FAD than was Decapterus punctatus, with a peak occurrence located one meter up current and down current of the float (Fig. 21d). Although this species was noticeably disturbed by the approach of divers, it exhibited a strong behavioral attachment to the FAD and could not be frightened away. The blue runner was very mobile and was frequently observed to double back behind the FAD for a moment before resuming a position up current of the FAD. The distribution of blue runner around the FAD differed among the FAD type treatments (Fig. 21a-c). A trend of vertical elongation of the

- Figure 21. Contour plots of the distribution of C. crysos around structures by FAD type treatment (A-C) and for pooled data from all FAD type treatments (D). Contours represent the percent presence of C. crysos within m² cells around the structure.
- A). FAD type A: A total area of 20 m² was utilized with an average of 6.47 (\pm 4.56) m²/station (n=19).
 - B). FAD type B: A total area of 19 m² was utilized with an average of 7.42 (\pm 4.52) m²/station (n=12).
 - C). FAD type C: A total area of 38 m² was utilized with an average of 11.37 (\pm 3.66) m²/station (n=8).
 - D). Pooled FAD types: A total area of 7.7 (\pm 4.68) m²/station (n=39).

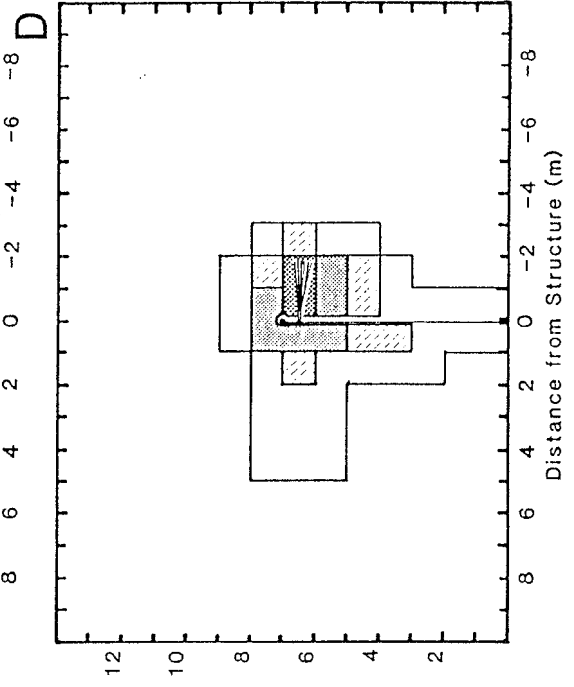
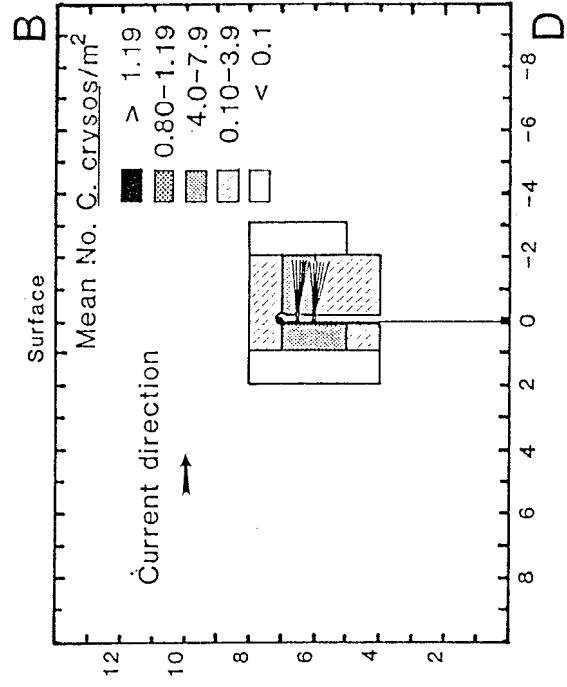
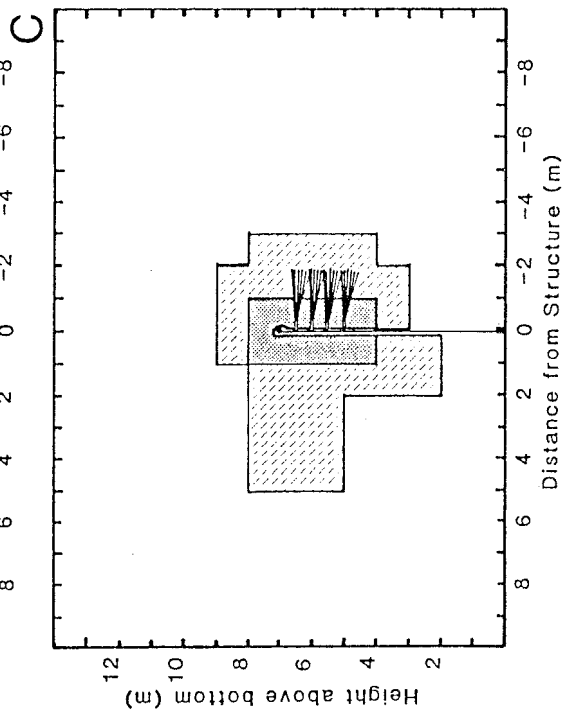
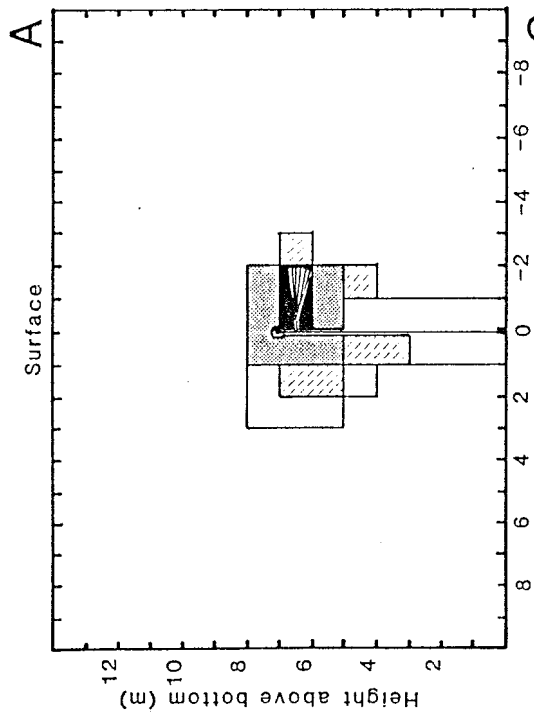


center of the distribution corresponding with the vertical elongation of the FAD profile from FAD type A to C was observed (Fig. 21a-c). Unlike that of Decapterus punctatus, however, there was no concurrent shift up current.

Caranx crysos was most densely distributed immediately around the FAD (Fig. 22), with a trend similar to that of its frequency (Fig. 21). However, there was a tendency for higher mean numbers of C. crysos to occur in the area just downstream of the FAD (Fig. 22d). For FAD type treatment A, the densest region occupied was the 2 m² area located directly around the subunit (Fig. 22a), while in FAD type treatments B and C, the densest regions were located more up current of the subunit and of the entire FAD (actual cell means, not shown, were highest in the first meter up current of the FAD; Fig. 22b-c).

A significant day treatment effect on the number of blue runner per station was observed. The blue runner exhibited a high constancy and low fidelity from mid-summer (July) through mid-fall (November), but had highest abundance indices on day 159 (Fig. 8). The most conservative statistical test was the 2-way anova on data ranked within days in which a highly significant day treatment effect was found ($p=0.0031$). Day treatment means were variable, but generally rose from a low near zero on day 8 to a peak of 19.8 fish/station on day 159 before dropping to zero on day 194 (Fig. 11d). The mean for day 91 was unexpectedly low. Analysis of unranked data found the three lowest day means (8, 23, and 91) significantly different from the peak value of day 159 (Scheffe, $p<0.05$).

Figure 22. Contour plots of the 2-dimensional distribution of Caranx crysos around structures of each FAD type treatment (A-C) and around a composite FAD based on data from all three treatments pooled (D). Contours represent the average number of blue runner/m²/station assuming all fish lie in a plane perpendicular to the current axis.



Caranx bartholomaei

Caranx bartholomaei may have been more highly attracted to FAD type C stations than other FAD types, although statistical tests conflicted. A significant FAD type effect on the number of yellow jack, Caranx bartholomaei, per station was not found for any anova in which all days were included. However, since Caranx bartholomaei occurred commonly on only three days and was rare on a fourth day (see below), analysis of variance was also performed on data including only the three days when the species was common. When C. bartholomaei was common, a significant FAD type effect was found for unranked data with the 2-way anova ($p=0.0474$, $n=46$), but not for ranked data. A Scheffe test on this data indicated that FAD type treatment C differed from FAD type treatment B. This was supported by the fact that the mean number of yellow jack per station was highest for FAD type treatment C and lowest for FAD type treatment B (Fig. 9f). In fact, FAD type treatment C had higher mean values on all three days when the species was common (Appendix B.2).

Nodal analysis also showed that Caranx bartholomaei had a significantly high fidelity to FAD type treatment C on day 194 (Fig. 8). Abundance indices for C. bartholomaei were moderately high and very high for FAD type treatment C on days 23 and 194, respectively (Fig. 8). On day 194 the effect of FAD type treatment was emphasized by increasing fidelity and abundance from FAD type A to FAD type C (Fig. 8). Analysis of frequency also supported this trend as more than five individuals occurred twice as frequently at FAD type C stations as either of the other FAD type stations.

Behaviorally, the yellow jack was very strongly associated with the FAD. Individuals of this species were most frequently observed swimming a few inches from the float and among the subunits of the FAD (Fig. 16a). C. bartholomaei could not be frightened away from the FAD, and remained with the float even if it was rapidly jerked down in the water by the divers. There was a slight tendency for the spatial distribution of yellow jack to expand vertically around the FAD, corresponding to the vertical profile of the FAD, but they occurred predominantly just below the float for all FAD types (Figure not shown).

The day treatment effect was highly significant on the number of Caranx bartholomaei per station with the most conservative test being the 2-way anova on data ranked within days ($p=0.0026$). The mean number rose from 1.0 fish/station on day 8 to 4.3 fish/station on day 23, then dropped to zero (Fig. 11e). Except for the 0.1 fish/station on day 100, yellow jack did not occur from July through September. They reappeared in October and were significantly most abundant in late November on day 194 (Scheffe, $p<0.05$). The few individuals observed at 14 % of the stations on day 100 were very young juveniles (30 mm - 50 mm T.L.), while the species averaged around 150 mm T.L. in all other observations. Yellow jack occurred at 89 % of the stations on day 23 and 88 % of the stations on day 194 and exhibited highest constancy for day 194 (Fig. 8).

Other pelagic species

Some evidence suggesting treatment effects on several other pelagic species were found. The number of planehead filefish, Monacanthus hispidus, did not appear to be significantly affected by FAD type treatment or day treatment. The FAD type treatment effect was, however,

found to be significant for data ranked within FAD type treatment blocks ($p=0.0095$) and the day treatment was significant for the number of filefish per station ranked within days ($p=0.0409$). In addition, Monacanthus hispidus exhibited a higher constancy and fidelity for FAD type treatment C stations and was highly constant over most of the summer and fall (Fig. 8).

Monacanthus hispidus occurred most frequently among the plastic strapping of the FAD subunits (19 % of the stations in 1 m² area directly below and down current of the float) where it was often observed to actively feed on the fouling organisms (Fig. 6d). Although this species occurred nearly as often around the concrete anchor (13.5 % of the stations) as around the subunits, the average number of M. hispidus/m² in this area was very low compared to the area around the subunits (0.07 fish/m², 0.36 fish/m², respectively). As might be expected, M. hispidus occupied increasingly greater areas around the structure from FAD type A to FAD type C, with an average of 1.9 m²/station at FAD type A, 2.7 m²/station at FAD type B and 3.2 m²/station at FAD type C.

Two carangids were also suspected to be attracted more by one FAD type than another. The unidentified amberjack, Seriola sp., was present only on day 55 for the FAD type treatment stations (Appendix B.2), but was also observed on day 91 at the type D structures (Appendix C). Amberjack exhibited a higher constancy for FAD type A but it had a higher abundance index for FAD type C (Fig. 8), with twice the mean number of individuals per station for FAD type C stations than types A and B (12.5, 6.6, and 5.2 fish/station, respectively). This species was probably more highly attracted to the type D stations (with an average

of 15 fish/station) than the FAD type treatments (with an overall average of 8 fish/station) on day 55 (Fig. 23a).

The banded rudder fish, Seriola zonata, was one of the first species to be attracted to the FADs, with the first individuals observed just hours after deployment. They occurred in low numbers on days 8, 23, and 55 and were most common on day 23 (Appendix B.2). A significantly high fidelity to FAD type treatment B on day 8 and to FAD type Treatment A on day 23 was noted (Fig. 8). Higher abundances for FAD type treatments B and C were found for day 8 while the highest abundance occurred for FAD type A on day 23 (Fig. 8). A significant FAD type effect was found for day 23 when the species occurred at all the FAD type A stations and none of the other stations ($p < 0.0211$, Kruskal-wallis). Observations on day 17 and 23 suggested that the banded rudderfish occurred only at those stations where Decapterus punctatus occurred in low numbers or was absent (Fig. 16a). In fact it co-occurred with Decapterus punctatus only 6 % of the time (Fig. 24). This suggestion was supported by the shift from higher fidelity and abundance for FAD type treatments B and C on day 8 when Decapterus punctatus was absent, to very high fidelity and abundance at FAD type treatment A stations on day 23 when D. punctatus was numerous at types B and C and was present in low numbers at type A stations (Fig. 8).

Demersal species

Several of the common demersal species exhibited apparent treatment effects. There was some suggestion that Chaetodipterus faber and Archosargus probatocephalus preferred FAD type C stations and that Stenotomus chrysops was most abundant at FAD type D stations (See

- Figure 23. Photographs of a FAD type D station taken 39 days after deployment (8 July 1985).
- A. Type D FAD with school of Seriola sp. in the foreground. The relative size of the FAD can be judged by comparison with the diver (on left) conducting a census.
 - B. Anchor made of 4 concrete blocks used to moor the type D FADs. A large black sea bass (top arrow), 2 bank sea bass (on top and on right edge of front block), and 4 sand perch (other arrows) are evident in the photograph, illustrating the tendency for more species and number of fishes to be associated with these anchors than the anchors of other FAD type treatment structures (compare with fig. 6b, c, e and f).

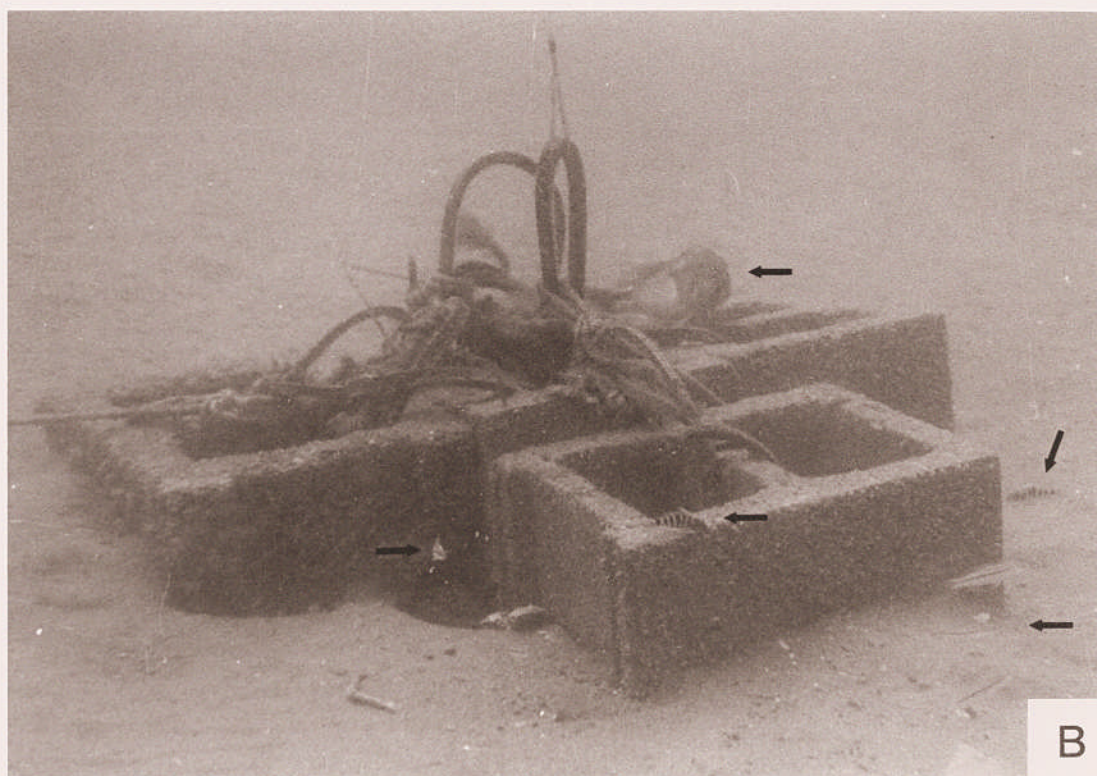


Figure 24. Jaccard similarity among species observed at the FAD type treatment station (N=89). Similarity indices were standardized by station total; the similarity, therefore, reduces to percent co-occurrence.

Appendix B.2 for S. chrysops data) but these species occurred too infrequently for statistical analysis. Although the number of individuals per station of the sand perch, Diplectrum formosum, was not significantly affected by FAD type treatment, the presence or absence of sand perch did depend on FAD type treatment ($p < 0.025$). Sand perch occurred at 72 % of FAD type A station, 58 % of FAD type B stations and 32 % of FAD type C stations (Table 3). The mean number of sand perch per station was slightly higher for FAD type B, with an average of 2.1 fish/station for all types combined (Table 4). The average number of sand perch was higher for type D stations than for the FAD type treatments (Appendix B.2, Fig. 23b).

Differences in the number of sand perch per station among days were highly significant based on the analysis of unranked data ($p = 0.0004$), but were not significant for data ranked in days. The mean number of sand perch was lowest for day 8 and highest for day 55, after which time a steady decline to a second lowest value on day 194 was observed (Fig. 11g). Day 55 was significantly different from days 8, 159 and 194, which had the three lowest mean values ($p < 0.05$, Scheffe).

The black sea bass, Centropristis striata, occurred in smaller numbers per station and least frequently at FAD type B stations (Tables 4 and 3, respectively). The FAD type treatment effect was not significant, however, except for data ranked within FAD type treatment blocks ($p = 0.0418$). The presence of the FAD may have been indirectly important in attracting this species since it occurred in only 14 % of the type E stations (Table 7). Further, black sea bass were not observed at any of the single block type E stations and occurred only in those

consisting of four concrete blocks (Table 7). Black sea bass occurred more frequently (67 %), and with a higher mean number of fish per station (1.6 fish/station; appendix B.2) at type D stations than at the treatment stations. Up to four individuals were observed at the type D stations (with the four concrete blocks), while a maximum of two individuals were observed rarely (6 % of the stations) at the FAD type treatment stations.

The importance of the anchors as cover to black sea bass was apparent in their behavior. Black sea bass occurred most commonly within one meter of the anchor (45 % of the stations), but exhibited a tendency to make more frequent use of the area down current than up current of the anchor. Smaller individuals (<150 mm T.L.) were positively attracted to divers and were frequently observed in the sand surrounding the anchor, while larger individuals invariably sought cover within the concrete block (Fig. 6e). Larger fish were apparently indifferent to the divers' presence and would submit to handling rather than vacate the anchor. When divers physically removed an individual from the block (by grasping it by the tail and pulling), that individual would invariably return at the first opportunity.

The bank sea bass, Centropristis ocyurus, appeared to favor FAD type treatment A stations, for which it exhibited its highest abundance and a significantly high fidelity on day 8 when the species was most common (Fig. 8). Analysis of variance conflicted with a significant FAD type treatment effect observed for data ranked within day ($p=0.0141$) and a non-significant effect for other anovas. A general trend of decreasing numbers of C. ocyurus from a high on day 8 to a low of zero on days 159 and 194 was also observed (Fig. 11h).

The two invertebrates, Menippe mercenaria and Octopus vulgaris, also exhibited some differences among FAD type treatments and day treatments. The stone crab, M. mercenaria, occurred most frequently at FAD type A stations and least frequently at FAD type C stations (Table 3), although this was not significant. The mean number of crabs per station also decreased from FAD type A to FAD type C (Fig. 9g). The FAD type treatment effect on the number of crabs per station was probably significant, but results were conflicting. Data ranked within days did not show a significant effect, although a highly significant effect was observed for unranked data ($p=0.0003$), and a significant effect was found for data ranked within FAD type treatment blocks ($p=0.0493$). Nodal analysis also revealed a significantly high fidelity and a high abundance for FAD type A on day 100 (Fig. 8). The day treatment effect was also significant, with the most conservative test being the 3-way anova on unranked data ($p=0.0488$). The highest mean numbers of stone crab per station occurred on day 100, while crabs were not present on day 159 and 194 (Fig. 11f).

The stone crab was never observed outside of the concrete block (Fig. 6f), but some evidence suggests that it spent some time foraging in the sand around the anchor. The crab was observed to feed on Polinices sp. snails (Fig. 6f) and occasionally on the sunray venus clam, Macrocalistima nimbosa. On a few occasions live individuals of Polinices sp. or M. nimbosa were observed apparently stored in the unoccupied second chamber of the concrete block, while the crab was feeding on another individual in the other chamber.

The octopus, Octopus vulgaris, occurred most frequently (Table 3) and in highest mean numbers (Fig. 9h) at FAD type B stations and was rare at FAD type C stations. It exhibited a significantly high fidelity for FAD type B on day 159 (Fig. 8). The FAD type treatment effect, however, was not found to be significant. The octopus was one of the few species observed at the type E stations (Table 7), indicating that the FAD was not important directly in the association and some other factor must be responsible for its higher occurrence on FAD type B stations. The number of octopus per station was significantly affected by the day treatment factor, with the most conservative test the 3-way anova on unranked data ($p=0.0044$). Octopus were much more frequent on day 159 (October) than other days, occurring at 62 % of the stations.

Discussion

Generally, the total of 36 species of fishes observed in this study was similar to the total number of species reported in previous studies of FADs and flotsam, although the number excluding the demersal fishes would be low (Gooding and Magnuson, 1967; Hunter and Mitchell, 1967; 1968; Dooley, 1972; Hammond et al., 1977; Murray et al., 1985). Gooding and Magnuson (1967) reported a total of 35 species of fishes around a drifting raft combined from several drift locations in the Pacific ocean. Hunter and Mitchell (1968) observed 21 species around experimental FADs during a two year study in the Pacific waters off Costa Rica, but observed 32 species around flotsam in the same area (1967). Workman et al. (1985) reported 20 species and 11 families of fishes around FADs off the island of St. Croix, U.S. V.I.. Hammond et al. (1977) reported observing, or collecting, 15 species of fishes while conducting experimental fishing around mid-water FADs originally located within a few kilometers of my study site (Capers Artificial Reef). I observed only five of the same species reported by Hammond et al. (1977). Recently, Murray et al. (1985) reported 35 species of 21 families around FADs located in shallow waters off Wilmington, North Carolina. Eighteen of these species were also observed in my study in South Carolina. Twenty-three species associated with the FAD anchors in South Carolina (Table 2) compared to eight species reported by Murray et al. (1985) in North Carolina, with five species common to both studies.

There was a pronounced difference in the faunal composition of the FAD-associated fishes observed in my study compared to that reported by

Murray et al. (1985). Murray et al. (1985) observed few Decapterus punctatus and reported Caranx crysos, Peprilus triacanthus and Chloroscombrus chrysurus to be the most abundant species. The lack of D. punctatus and abundance of P. triacanthus and C. chrysurus is probably best attributed to placement of the FADs in very shallow (7 m) water less than one kilometer from shore in North Carolina (Murray et al., 1985) compared to placement in 14 m of water about 10 km directly offshore in South Carolina.

There were strong differences in the fauna observed associated with the FADs (Fig. 7) and the fauna of sandy bottom in the South Atlantic Bight. I observed only four of the 14 numerically dominant demersal fishes reported collected in the 9 m - 18 m depth zone on sandy bottoms in the South Atlantic Bight in the summer months (Wenner et al., 1979). I did observe the three dominant species Stenotomus aculeatus (=chrysops), Monacanthus hispidus and Diplectrum formosum, reported by Wenner et al. (1979) from the same depth zone on sandy bottom, as important components of the fauna associated with the FADs (Tables 3, 4 and 5). Although these three species are also characteristic of areas with some type of hard substrate, other demersal species observed at the FADs (such as Centropristis striata, Mycteroperca microlepis, Chaetodipterus faber and Archosargus probatocephalus) are not as clearly associated with sandy bottoms and are more characteristic of live-bottom (sponge-coral) areas (Barans and Burrell, 1976; Wenner et al., 1979; 1980; Wenner, 1983) and of shallow water artificial reefs (Buchanan, 1973; Buchanan et al., 1974; Parker et al., 1979; Steimle and Ogren, 1982; Lindquist et al., 1985). Pelagic species associated with the FADs

were more representative of dominant species taken over sandy bottom, but Chloroscombrus chrysurus was notably absent and Sardinella anchovia (=aurita) was represented by a single individual at the FADs (Wenner et al., 1979; 1980). It appears that the fauna associated with the FADs was more characteristic of communities associated with hard substrate and live-bottom than of truly sand bottom communities.

The association of fishes with FADs may result from a pre-adaptation of many pelagic fishes to associate with many kinds of drifting materials and living organisms such as Sargassum spp. and jellyfishes. Hunter and Mitchell (1967) suggested that the various associations of fishes with flotsam and with other living animals (e.g., jellyfish, sharks, whales, turtles, etc.) may be related behaviors. Russian researchers carried this idea further and discussed the importance of association with floating debris, drift weeds, Sargassum spp., whales, etc. to epipelagic and neustonic fishes (Besednov, 1960; Parin, 1968; Zaitsev, 1971). After an extensive review of literature on the associations of fishes with FADs, jellyfishes, Sargassum spp. and flotsam, I have come to the conclusion that these associations are very closely related behaviors. Many of the species of fishes known to associate with jellyfish (see review by Mansueti, 1963) can also be found in lists of fishes associated with Sargassum spp., and other drifting seaweeds, and in lists of fishes associated with FADs and flotsam. I will not attempt to provide a review of all the cases of species which are common to species lists among the types of associations, but I will discuss the various associations of species reported with FADs, herein.

A strong similarity of the FAD associated fish fauna to fish fauna of Sargassum spp. is apparent. Numbers of species observed associated with Sargassum spp. and other seaweeds tend to be somewhat higher than the number associated with FADs in South Carolina (See Dooley, 1972 for a review of published accounts). Dooley (1972) reported 54 species and 23 families of fishes associated with Sargassum spp. in the Florida Current. Pelagic species observed associating with FADs in this study known to associate with Sargassum spp. include: Caranx bartholomaei, Caranx ruber, Decapterus punctatus (Dooley, 1972), Caranx crysos (Berry, 1959; Dooley, 1972; Bortone et al., 1977; Johnson, 1978a), Aluterus spp., Monacanthus hispidus (Weis, 1968; Fine, 1970; Dooley, 1972; Bortone et al., 1977; Johnson, 1978b), Seriola sp. and Seriola zonata (Dooley, 1972; Bortone et al., 1977; Johnson, 1978a). I observed seven of the 21 species Dooley (1972) reported as closely associated with Sargassum spp.. In fact, all seven species of carangids observed around FADs in my study are considered moderate to close associates of Sargassum spp. and 10 of the 13 species of fishes (excluding Sardinella aurita, Rachycentron canadum, and Chaetodipterus faber) observed associating with FADs in my study (Table 2) are known to be moderate to close associates with Sargassum spp. (Dooley, 1972).

Many of the species of fishes which were observed at the FADs are also known to associate with jellyfish. Mansueti (1963) reviewed the literature of fish-jellyfish associations and cites records of most of the pelagic species I observed around FADs as associating with jellyfish. Since Mansueti's (1963) review, Caranx crysos (Bohlke and Chaplin, 1968), Caranx sp. (Phillips et al., 1969; Phillips, 1971), Caranx bartholomaei

(Rountree, 1983), Monacanthus hispidus (Phillips et al., 1969; Phillips, 1971; Rountree, 1983) and Seriola zonata (Johnson, 1978a) have also been reported as associating with jellyfish. It is notable that Peprilus triacanthus and Chloroscombrus chrysurus, which were two of the most abundant species observed by Murray et al. (1985) in North Carolina, are well known associates of jellyfishes (Smith, 1907; Buhler, 1930; Hildebrand, 1954; Mansueti, 1963; Hoese et al., 1964; Phillips et al., 1969; Horn, 1970; Phillips, 1971; Rountree, 1983; Tolley, 1987). I have collected juveniles of these species associated with Stomolophus meleagris (Rountree, 1983) and I have observed adults associated with a makeshift FAD in the general area where Murray et al. (1985) conducted their study. The size ranges of P. triacanthus and C. chrysurus reported by Murray et al. (1985) are slightly larger than observed sizes of jellyfish associates of these two species (Phillips et al., 1969; Horn, 1970; Rountree, unpublished undergraduate thesis available through Randall Library, University of North Carolina at Wilmington, Wilmington, North Carolina). It is possible that the association of P. triacanthus and C. chrysurus with FADs is related to the symbiosis of young juveniles with jellyfish.

The low number and frequency of species observed on the concrete blocks after the loss of the FAD (i.e. type E stations, Tables 6 and 7) indicates that the concrete blocks anchoring FADs may have been more attractive to fishes than concrete blocks by themselves. Only Diplectrum formosum and Octopus vulgaris occurred commonly at the type E structures (Table 7). Centropristis striata occurred at only 14 % of the type E structures (Table 7), but occurred at 50 % of the FAD type treatment

structures (Table 3). Several demersal fishes did appear to occur with different frequencies or abundances among FAD types, indicating possible indirect effects (Fig. 8,9 and Table 3,4). Archosargus probatocephalus, Mycteroperca microlepis and, to a lesser extent, Chaetodipterus faber and Centropristis striata were probably attracted to FAD type C structures in the fall because of the proximity of the FADs to the bottom (Fig. 5). However, I made no observations of behavior which would support the hypothesis that demersal fishes are attracted to the FAD itself when it is suspended more than 3 m off the bottom (except, perhaps, Chaetodipterus faber). I do not believe that the bottom fishes were directly affected by the FAD type treatment, or even the presence of the FAD itself, as they did not orient to, or associate with the FAD itself.

Aggregations of schooling fishes, such as Decapterus punctatus, Caranx crysos, Caranx bartholomaei and Seriola sp. associated with the mid-water FAD may have influenced the abundance and occurrence of demersal fishes near the FAD anchor. Stenotomus chrysops co-occurred strongly with Seriola sp., and Centropristis striata co-occurred strongly with Decapterus punctatus and Caranx crysos (Fig. 7, 24). Diplectrum formosum occurred frequently with D. punctatus (Fig. 24), but occurred most frequently where D. punctatus was least abundant (FAD type A) and least frequently where D. punctatus was most abundant (FAD type C, Table 3, Fig. 8). Schools of resident fishes have been shown to increase secondary productivity of certain benthic communities by a transfer of nutrients obtained while feeding in other habitats to the benthic communities through the accumulation of organic materials in fecal

deposits (Bray and Miller, 1985; Meyer and Schultz, 1985a; 1985b).

Decapterus punctatus, Caranx bartholomaei, and Caranx crysos, by feeding on plankton and depositing feces on the bottom near the FADs, may increase the attractiveness of the FAD anchors to the demersal species and may be responsible for the observed differences in frequency and abundance of demersal fishes among FAD types and between the FAD anchors and type E structures.

Competition for shelter within the anchors was apparently strong among demersal fishes and invertebrates. Fish occurred more frequently at the anchor than the FAD (Fig. 13 and 14). Densities of fishes were highest at the anchor and immediately around the FAD, if Decapterus punctatus is excluded (Fig. 15). Overall, there was a density of 1.51 - 2.0 fish/m² around the anchor with D. punctatus removed (Fig. 15), suggesting the possibility of competition for space. The octopus, stone crab and black sea bass exhibited a strong behavioral association with the concrete blocks used for anchors and each appeared to use the chambers of the blocks as shelter (Fig. 6). The octopus and stone crab did not co-occur together at the same structure and the octopus and black sea bass occurred together infrequently (Fig. 24). The stone crab, however, co-occurred together with the black sea bass frequently (Fig. 24). Additionally, black sea bass usually occurred solitarily at the treatment type FADs which were anchored with a single concrete block, but up to four individuals occurred at the type D FADs which were moored with four concrete blocks (Appendix C.2), suggesting strong intra-specific competition for space.

Observations during this study indicate that the average number of species per station were significantly different among the three FAD type treatments (Figs. 9 and 10). However, the effect of FAD type on the mean number of species is difficult to interpret because the mean number of species did not vary together with the FAD type (i.e. an increase in FAD complexity did not lead to an increase in the average number of species, or conversely a decrease in mean number of species). In fact, FAD type B has the lowest mean number of species per station (Figs. 9, 10), rather than an intermediate mean. Interpretation of the effect of FAD type on mean number of species per station is confounded by the combination of pelagic and demersal fishes in the species number since the demersal species are not assumed to be directly affected by the FAD.

The mean of 3.8 species per station for pooled data is comparable to means reported by other researchers (Murray et al., 1985; Workmen et al., 1985). Workmen et al. (1985) reported means of 1.6 - 2.0 species per FAD for three FAD types based on repetitive counts over a five day period. Mean number of species varied with time of day and location of deployment. Murray et al. (1985) reported an overall mean of 5.48 species but the sample size and units used (number per FAD, per census, per month?) were not clear. Hunter and Mitchell (1967) collected from 1 to 7 species/FAD around various objects under different locations, seasons and soak periods.

The total number of fish at a station was significantly different among FAD type treatments (Fig. 9b), which was mainly a reflection of the numerical dominance of Decapterus punctatus (Fig. 9d, Table 5). The influence of the contribution of D. punctatus to the total number of

fish per station is emphasized by the lack of a significant difference of the total number of fish excluding D. punctatus among FAD types (Fig. 9c). There is little information in the literature for comparison with my data on the total number of fish per station. Hunter and Mitchell (1968) reported average total numbers of fish ranging from 4 to 647 per structure (n = 4 - 15). Klima and Wickham (1971) estimated that FADs off Panama City, Florida attracted from 1/2 to 5 metric tons of mixed species of bait fishes on a daily basis (mostly Decapterus punctatus, Sardinella anchovia (=aurita), and Harengula pensacolatae).

During July, 1969 Klima and Wickham (1971) reported averages ranging from 230 to 269,000 fish per FAD. Simple FADs were found to attract larger numbers of fishes than complex FADs, although only two replicates of each FAD type were used (Klima and Wickham, 1971). Wickham and Russell (1974) later reported a total catch of 14,147 kg of fishes around FADs fished with a purse seine 4 to 8 times a day for nine nonconsecutive days in July. Decapterus punctatus accounted for 6,842 kg and Sardinella anchovia (=aurita) accounted for 7,305 kg out of the total catch (Wickham and Russell, 1974). More recently, Workman et al. (1985) reported averages of from 92.5 to 179.2 fish per FAD for three types of structures. Unfortunately, the FADs were not replicated within location and repetitive counts made within a day were treated as replicates (i.e. increasing the sample size) and were averaged together making the effect of FAD type uncertain.

Decapterus punctatus, the most common and abundant species observed at the FADs (Tables 3 and 4), is one of the most abundant coastal pelagic species in the South Atlantic Bight (Wenner et al., 1979; 1980; Hales,

1984; 1987). Decapterus punctatus has been described as a close associate of Sargassum spp. (Dooley, 1972) and as one of the most abundant species observed around FADs in the Gulf of Mexico (Klima and Wickham, 1971; Wickham, 1972; Wickham et al., 1973; Ogren, 1974; Wickham and Russell, 1974). Hammond et al. (1977) also observed D. punctatus as common around FADs in South Carolina. Murray et al. (1985), however, reported D. punctatus as infrequent and occurring in low abundance around FADs during the summer in 7 m of water off North Carolina. The absence of D. punctatus around FADs in North Carolina was probably due to the proximity to shore of the study site as the species has been observed in abundance around FADs placed in deeper water nearby (D. Lindquist, UNCW, Wilmington, N.C., Personal Communication).

The genus Decapterus includes many species most sought around the world in fisheries utilizing FADs (Hardenberg, 1950; Westenberg, 1953; Soemarto, 1960; Brandt, 1960; Ogren, 1974; Wickham, 1972; Matsumoto et al., 1981). The genus is often collected with drift weeds and other flotsam (Hirosaki, 1960b; Hunter and Mitchell, 1967; Dooley, 1972). There may be a tendency for smaller juveniles to associate with drift weeds such as Sargassum spp. and for larger individuals to associate with FADs. Dooley (1972) collected D. punctatus ranging from 39 mm to 54 mm S.L., averaging 50 mm S.L. with Sargassum spp. in the Florida Current, while I observed individuals ranging from 70 mm to 150 mm T.L. and averaging 120 mm T.L. around FADs in South Carolina. Hirosaki (1960b) collected a 13 mm and 16 mm specimen of Decapterus sp. with drift weed from Japan. Gooding and Magnuson (1967) collected individuals from 120 mm to 250 mm F.L. from the deep oceanic waters off Hawaii and in the

equatorial Central Pacific. Hunter and Mitchell (1967) reported Decapterus sp. as the 5th most abundant species collected with flotsam, and as the 4th most abundant species collected around FADs (Hunter and Mitchell, 1968) from the Pacific coast of Central America. Individuals collected with flotsam ranged from 17 mm to 100 mm S.L., while individuals collected around FADs ranged from 30 mm to 230 mm S.L. (Hunter and Mitchell, 1967; 1968). The apparent trend of small juveniles to associate with floating seaweeds and larger individuals to associate with FADs points to a link between the association with drift weeds and with FADs. Perhaps the association of juveniles with drift weeds may condition the fishes to associate with floating objects and is the origin of the tendency to associate with FADs. Unfortunately, not enough is known of the behavior and biology of juvenile Decapterus spp. to evaluate the ecological importance of these associations.

Decapterus punctatus was significantly affected by FAD type treatment (Fig. 9) with highest means occurring at FAD type C stations (Table 4). An analysis of the frequency of abundance classes of the total number of D. punctatus for each FAD type revealed that FAD type C attracted a disproportionately greater frequency of the abundance class of 1000-4999 fish/FAD (Fig. 12). An analysis of the frequency of abundance classes of the number of Decapterus punctatus per school for each FAD type indicated that the increased abundance at FAD type C was due to an increased occurrence of schools of 100 to 999 fish per FAD for FAD type C as compared to FAD type A and B (Fig. 12). Since D. punctatus is a schooling species the frequency analysis led me to suspect that the type C FADs supported a different size school than the other FAD types.

Further, the tendency for D. punctatus to break up into two or more schools with increasing numbers, with a smaller school resting near the bottom and a larger school actively feeding in the water column, suggests that a limited size school can be supported by a given FAD and that additional numbers can be supported by a segregation of position and behavior (see discussion below).

Although the abundance of D. punctatus differed among FAD types, its behavior did not immediately suggest a correlation of abundance to shelter because the fish usually occupied a position some distance up current of the FAD (Fig. 17). The up current position of the school raises the questions of how the school maintains its orientation to the FAD and why it moves so far from the shelter of the FAD. The up current position of Decapterus spp. has been observed and commented upon by several authors (Hardenberg, 1950; Westenberg, 1953; Soemarto, 1960; Hunter and Mitchell, 1967; Klima and Wickham, 1971; Wickham et al., 1973; Wickham and Russell, 1974). Westenberg (1953) suggested that Decapterus spp. maintained an up current position through acoustic orientation to the FAD. Klima and Wickham (1971) on the other hand, observed that small groups of Decapterus punctatus often broke away from the main school and swam behind and around the FAD and suggested that orientation to the FAD was maintained by periodic visual contact by some members of the school.

The contour plots provided herein are the first quantitative description of the spatial distribution of Decapterus punctatus and other fishes associated with FADs, although Holland and his colleagues provide some quantitative information for two species of tuna (Holland,

1985; Holland, Chang and Ferguson, 1985). Some researchers, however, have provided general observations of spatial zonation for some species (Hardenberg, 1950; Westenberg, 1953; Hirosaki, 1960a; Kojima, 1960b; Soemarto, 1960; Inamura et al., 1965; Gooding and Magnuson, 1967; Hunter and Mitchell, 1967; Ida et al., 1967b; Hunter, 1968; Hunter and Mitchell, 1968; Mitchell and Hunter, 1970; Klima and Wickham, 1971; Wickham and Russell, 1974; Wolf, 1974; Hastings et al., 1976; Reeves et al., 1977; Helfman, 1979; Yatomi et al., 1979; Smith et al., 1980; Klemm, 1984; Holland, 1985; Holland, Chang and Ferguson, 1985). The contour plot of the percent occurrence of D. punctatus for data pooled from all three FAD type treatments shows that the species occurred most often just up current of the FAD (Fig. 18). Contour plots for each FAD type treatment reveal a strong tendency for D. punctatus to increase its vertical range to match the profile of the FAD (Fig. 18). This trend is repeated with more emphasis in the density contours (Fig. 19). The peak density contours are up current of the FAD and there is an elongation of the contours corresponding with the FAD's profile (Fig. 19). The elongation is caused by the increased abundance of Decapterus punctatus at the larger FADs, but note that the densest contours line up with the profile of the FADs rather well (Fig. 19). The consistency of the profile matching in the contour plots, and behavior observed in the field, led me to suspect a visual nature to the association. Perhaps Decapterus punctatus uses the structure to hide the school's profile or silhouette from a distant predator, as has been suggested previously (Anonymous, 1984; M. Bell, Personal Communication), such that there is an optimum

school size for a given FAD size as the frequency analysis suggested (Fig. 12).

The trend for Decapterus punctatus to move farther up current with increasing school size supports the idea that schooling behavior is of great importance in the association of Decapterus punctatus with FADs and flotsam (Fig. 20). Schools of 1-99 fish occurred most frequently closely around the FAD with a peak occurrence just up current of the FAD. Schools of 100-999 fish occurred most frequently 1m - 2 m up current of the FAD, while schools of 1000 or more fish occurred most frequently 2 m - 4 m up current of the FAD (Fig. 20). Apparently, when D. punctatus is present in small numbers, they utilize the FADs directly for shelter, but as the number of fish in the school increases, they venture farther from the structure. The reason for this trend is not immediately clear, but feeding behavior may be important. Schools positioned up current of the FAD were actively feeding on plankton and formed a bowl shaped configuration with its apex, and most individuals, facing into the current (Fig. 17). Decapterus punctatus is known to be a planktivore and feeds largely on copepods (Dooley, 1972; Hales, 1984; 1987). Perhaps the FAD interferes with feeding activities when large numbers of individuals are crowded around the structure. Moving up current of the FAD would eliminate the interference, but a position several meters up current would not be necessary.

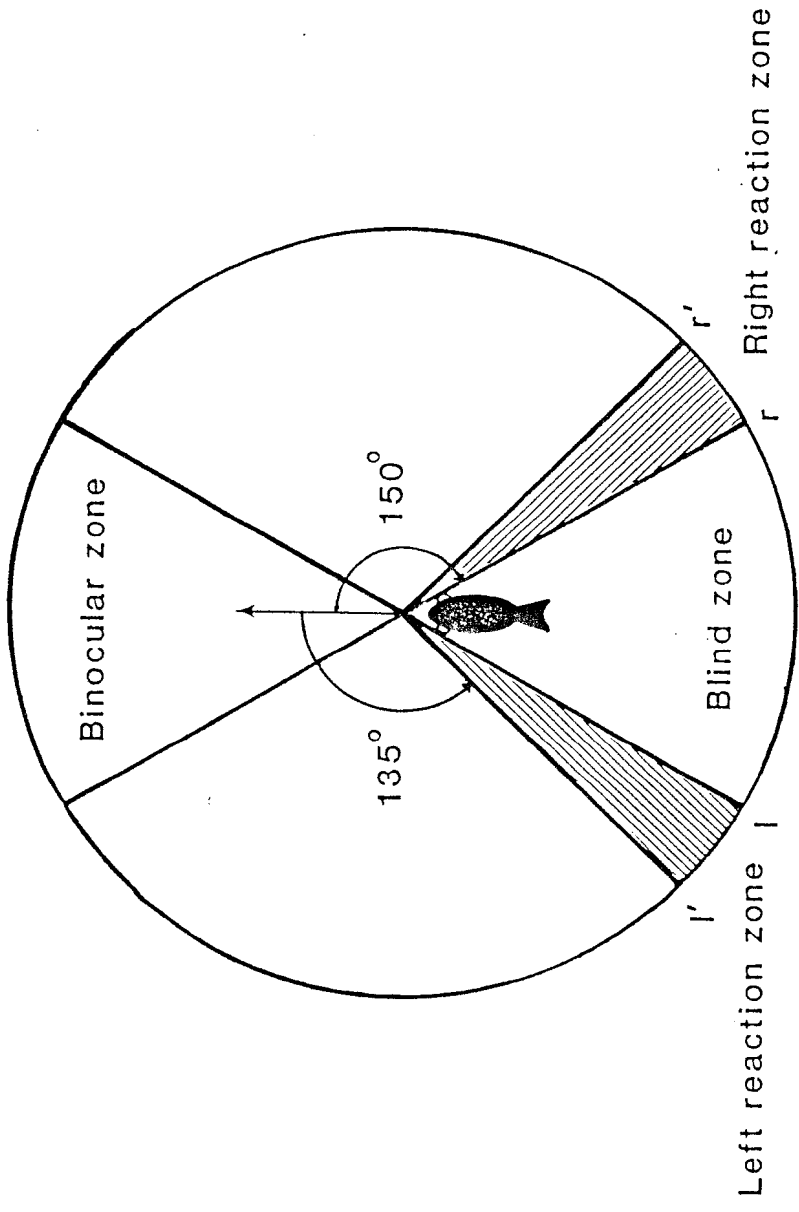
Another explanation for the up current position was provided by Soemarto (1960) who suggested that Decapterus spp. may maintain a position up current of a FAD to protect its downstream blind zone. This idea suggested to me that the FAD physically prevents a predator from

approaching the school from down current. Such behavior would explain the apparent profile matching suggested by the contour plots (Fig. 18, 19). Soemarto's (1960) reference to a school's blind zone seems to be the only one in the literature, so to develop a model of the visual field of a school of fish some information on vision in fishes is necessary.

Many fishes have a wide field of view and it has been reported that most roundfish can see a field of about 150° on either side of their bodies (Walls, 1942 cited in Wardle, 1986; Protasov, 1966; Hall et al., 1986; Wardle, 1986). An individual fish's field of view is composed of right and left 150° zones of monocular vision which overlap to form a 60° zone of binocular vision directly to the fish's front, leaving a 60° blind zone to the fish's rear (Fig. 25). In a recent study of the fountain effect in schooling fishes, Hall et al. (1986) found that individuals within the school react to an approaching object independently by turning away from it at an angle of 135° rather than the expected 150° . It was suggested that the lesser angle is maintained because at greater angles the fish's own swimming motions would interfere with its observations of the approaching predator (Hall et al., 1986). I have interpreted this behavior as indicating the presence of right and left zones of reaction in which the 135° line is the limit at which continuous visual orientation is possible and the 150° line is the limit of vision (Fig. 25).

With Soemarto's (1960) comments in mind and the observations of spatial orientation I observed, I have extrapolated on the work of Hall and his colleagues to develop a model of schooling in fishes (Hall et

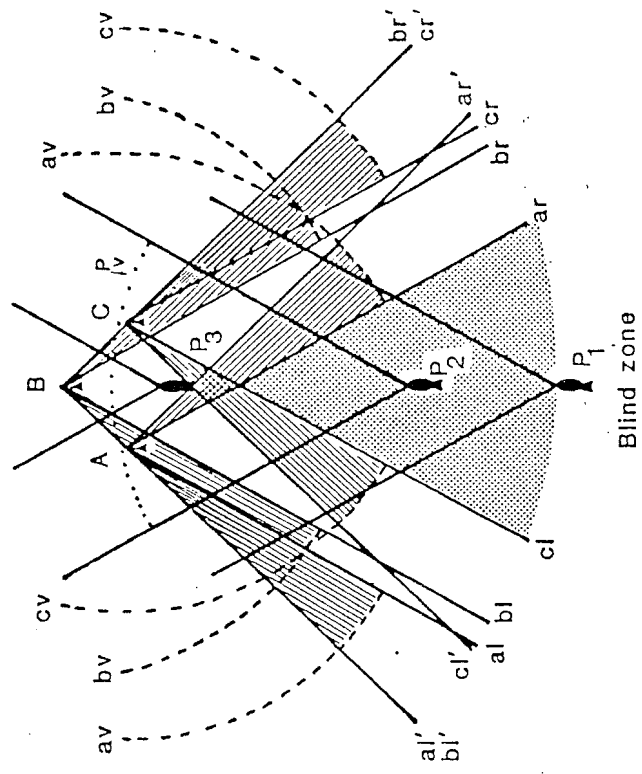
Figure 25. Visual field of a fusiform fish. Lines l and l' represent the back edge of the field of view at 150° and the angle of preferred visual orientation at 135° , respectively. These lines inscribe a zone of reaction within which a threat can be detected and visually monitored continuously. Lines r and r' inscribe the right zone of reaction. A frontal zone of binocular vision and a posterior blind zone (inscribed by l and r) of about 60° are also present (adapted from Hall et al., 1986).



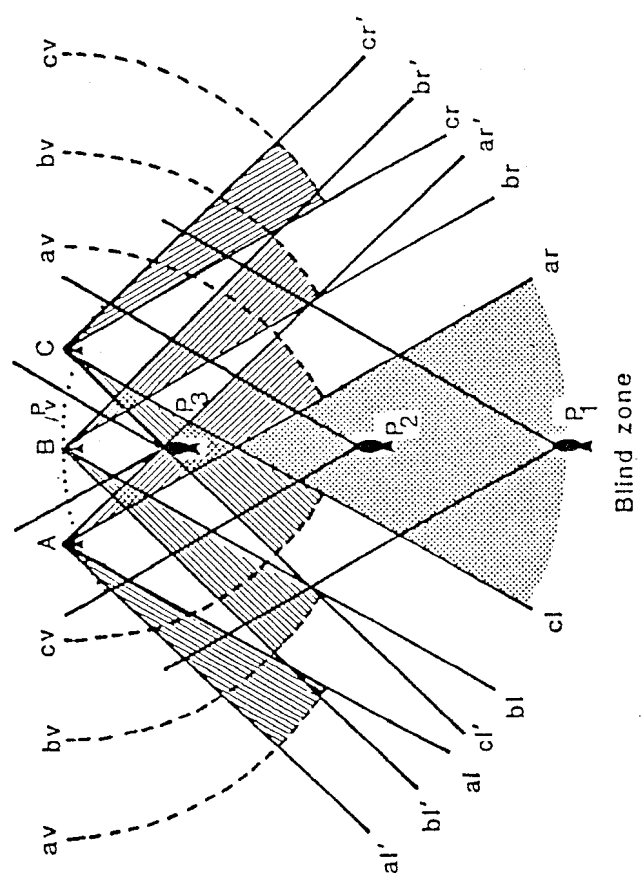
al., 1986). The visual fields of fish A, B and C representing a 4 m long school of fish facing up current are shown in Figure 26. The zones of reaction and blind zones of each fish overlaps that of its neighbor's so that a blind zone common to all members of the school (stippled area) is formed by the intersection of the left line of sight of fish C (cl) and the right line of sight of fish A (ar in Fig. 26). The school's blind zone takes up considerably less area than that of an individual fish and begins some distance down current of the school. Right away it is apparent that schooling fishes facing into a current while feeding have a tremendous visual advantage over solitary fishes since an approaching predator would be sighted by some members of the school while still several meters down current. It has been suggested that the absence of planktivorous fishes in the water column over sand bottoms during the day is due to the threat of predators since planktivorous fishes directing their attentions at the water column would be vulnerable to attack by predators (Hobson, 1968; 1979; Hobson and Chess, 1986). The importance of an early warning defence system in schooling planktivorous fishes is evident under such conditions.

In the model of the visual field of a school of fish the location of the blind zone is a function of the distance between fish A and fish C so that the blind zone is pushed farther down current with increasing school size (Fig. 26). The model provides an explanation for the observations of some researchers that larger schools of fish appear to be able to detect an approaching predator sooner than smaller schools, since the larger the school the farther down current the blind zone is located and, hence, the earlier a predator would move into the school's

Figure 26. Visual field of a school of fish, oriented in one direction, formed by the overlapping visual fields of individual fish, represented by an individual in the school's center and the extreme right and left hand individuals. A) School with all members located on a plane perpendicular to the orientation axis, here down current. B) School curved with its convex end facing the point of orientation. The shaded area is the blind zone common to all members of the school. Striped areas are reaction zones of each individual. As in Fig. 25, l and l' define the left reaction zone, r and r' define the right reaction zone, and l and r define the blind zone. The prefixes a , b , and c , designate with the lines of vision of fish A, B, and C, respectively (i.e. al is the edge of the left line of sight of fish A). Similarly the dashed curves (av , bc and cv) represent the limit of vision for each fish given 6 m visibility. The blind zone of the school is defined by ar and cl . An approaching predator is shown at 10 m (P_1), 6 m (P_2), and at 2 m (P_3). It sights fish B first at P_2 and its visual range is indicated by the dotted curve (pv).



II



I

field of view (Magurran, Oultan and Pitcher, 1985 cited in Milinski, 1986; Milinski, 1986; Pitcher, 1986). The model also predicts that an approach from directly behind the middle of the school would be optimal, allowing the predator its closest approach before being sighted (Fig. 26).

The visual advantage gained by schooling fishes would be most obvious for species in which avoidance behavior could be induced in individuals not directly aware of a threat by observations of a neighbor's behavior. In many cases, however, it is thought that individuals in a school act independently and that induction of a fright response depends on the level of panic exhibited by the inducing fish (Hall et al., 1986). In other words, a sudden dart of some individuals away from a strong threat would be more likely to induce sudden avoidance responses of neighboring individuals (perhaps initiating a flash expansion of the school, Partridge, 1982), while a cautious retreat away from a possible threat would be less likely to induce a response in neighboring individuals. Indeed, Hall et al. (1986) found that the fountain effect resulted from independent responses of individuals nearest a slowly approaching threat. As the threat moves closer to the school more and more individuals move away creating the flowing effect for which the behavior was named. It is likely, however, that, once a large percentage of the individuals in a school begin moving, others would follow in order to maintain contact with the school even if they are unaware of the threat themselves. Interfish threat communication would be advantageous but not necessary to this model.

If a predator approached from directly behind fish B, it would be sighted by both lateral individuals at the same time (P_3 in Fig. 26) and the school would form a variation of the fountain effect in which it splits and re-assembles behind the predator. Splitting is thought to be uncommon, however, because it places some individuals in danger when the school rejoins (Pitcher, 1986). It is also possible that individuals toward the center of the school might be more likely to be separated from the school and would be more vulnerable to attack. If the predator approached from behind fish A, however, the fountain effect would be initiated by fish C after sighting the predator while it was still within the blind zone of fish A and B (Fig. 26). Individuals between fish C and B would follow fish C as the predator entered their reaction zones in approaching fish A. Fish A would likely follow the rest of the school despite the fact that it would not have been aware of the predator (at least until it oriented to the direction of movement of the school, at which time the predator would come into its field of view). It would be advantageous, under these conditions, for the predator to attack from directly behind the middle of the school in order to remain within the blind zone longer, increasing its element of surprise, and to increase its chance of splitting the school.

The binocular field of vision of an approaching predator plays an important role in this model (Fig. 26). As the predator moves closer to the school from behind fish B, individuals positioned laterally in the school fall outside of the predator's zone of binocular vision (area within bold lines) at point P_3 (Fig. 26). Since it would require a rapid change in direction, with a resulting loss of momentum and speed,

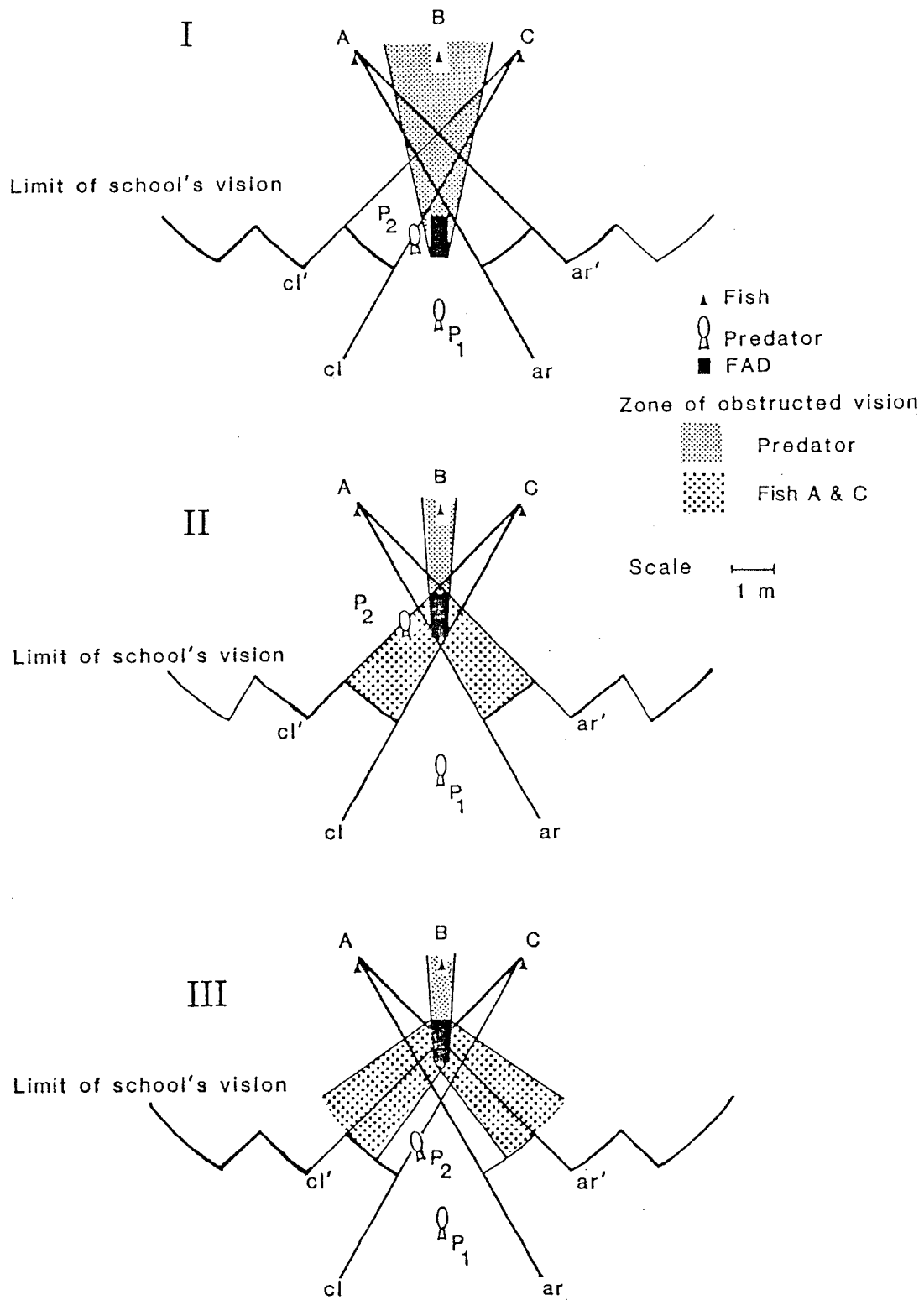
for a predator to turn and focus on lateral individuals (which would necessarily have already sighted the predator), lateral fishes falling outside of the predator's zone of binocular vision would be relatively safe from attack. The predator, then, is forced to progressively home in on smaller and smaller groups of individuals in the school in order to stay within the blind zone as long as possible.

If the model of the visual field of schooling fishes proves to be correct, then the position of the school relative to the FAD would be of critical importance to predator avoidance. In Figure 27 the same 4 m school illustrated in Figure 26 is shown at three different locations up current of a 1 m long FAD. A predator is shown 6 m down current of fish B at point P_1 and at the point when first visible to the school at P_2 . The lightly stippled area is the area of a predator's visual field occluded by the FAD when the predator is 6 m down current of fish B (P_1). At P_1 the predator can only see the lateral individuals in the school and the FAD serves to occlude the vision of the predator and to physically block its approach from behind the middle of the school (Fig. 27). The predator would then tend to move laterally to attack fish A or C, and to move around the FAD. In moving laterally, however, the predator moves into the field of view of the school earlier (point P_2) than if it had approached from directly behind fish B (Fig. 27). If the school performs a fountain maneuver to escape the predator, it would not only wind up behind the predator but behind the FAD where they could take advantage of the shelter of the structure.

If a 4 m school were located 4 m up current of a FAD, the FAD would lie within the school's blind zone (Fig. 27a). With the FAD within the

Figure 27. Effect of a FAD on the visual fields of a predator and a school of fish assuming 6 m visibility.

- A). FAD located 4 m behind fish B within the school's blind zone. At P_1 a predator is within visual range of fish B but can not see it because of the FAD. Fish A and C are out of visual range. As it approaches closer more fish are occluded by the FAD, so that fewer and fewer lateral fish in the school can be seen. At P_2 a predator can see all members of the school but is itself sighted by fish C.
- B). FAD located 2 m behind fish B within the right zone of reaction of fish A and the left zone of reaction of fish C. In this position the school of fish can maintain visual orientation to the FAD, but the structure occludes the vision of fish A and C along lines al and cl . This increases the school's effective blind zone to the edge of lines ar' and cl' . At P_1 fish B is not visible to the predator, but the predator can move to P_2 before being sighted by fish C.
- C). FAD located 1.5 m behind fish B. This is the optimum position for visual orientation to the FAD by the school and does not cause occlusion of sight along cl and ar .



school's blind zone, visual orientation to the structure would not be possible except by direct movement of the fish which would in turn interfere with feeding activities. A predator could also move around the FAD while still within the school's blind zone negating or reducing the advantage of associating with a FAD (Fig. 27a). A 4 m long school positioned 2 m up current of a FAD could easily maintain visual orientation to the FAD since the structure would fall within the zones of reaction of fish A and fish C (Fig. 27b). However, in this location the FAD occludes the field of view of fish A and fish C, thereby increasing the size of the school's blind zone (shown by bold stipples), so that the predator can approach more closely than it could normally approach the school (Fig. 27b). The position of the FAD located at a point just within the zones of reaction of the lateral fish is a disadvantageous position for the school and should be avoided. A FAD positioned 1.5 m down current of a 4 m school would be optimal (Fig. 27c). Here the FAD is well within the school's visual field allowing visual orientation. Note, however, that the view of fish A and C is not obstructed along their zones of reaction and the FAD does not interfere with the school's ability to detect an approaching predator.

The model predicts that a school of fish facing up current while feeding should position itself to allow continuous visual orientation to the FAD and such that the FAD does not interfere with the school's ability to detect an approaching predator (Fig. 27). Since a school's blind zone is located increasingly farther down current with increasing school size, it follows that schools should take up a position increasing farther up current of a FAD with increasing numbers of individuals. The

model, then, correctly predicts the observation that Decapterus punctatus moves increasingly farther up current of a FAD with increasing school size (Fig. 29).

Although my model assumes a static condition of schooling fishes, it offers insight into the possible advantages of schooling and the association of fishes with floating objects and FADs. I will discuss only one additional variation of this model until further research can verify the general model. Schools of D. punctatus often assumed a strongly arced configuration (Fig. 17). In Figure 26b a 4 m long school is arced to form a perfect semicircle. In an arced configuration, interfish spacing is the same as in a straight school, but lateral vision of individuals within the school is less obstructed by neighboring fish. The distance necessary for each individual to swim in order to bunch up or reach shelter when frightened would also be minimized. Note also that fish A and fish C would lie just within the reaction zone of fish B, where their positions could be constantly monitored by fish B (Fig. 26b).

Under conditions of limited visibility, the arced school configuration would have a much reduced blind zone (compare area beyond curves av, bv, and cv in Fig. 26a and 26b). Avoidance of predators would also be enhanced under limited visibility. A predator approaching the school from down current of fish B would first sight fish A and fish C at point P₂, at which time fish B would still be beyond the predator's visual range, indicated by curve pv (Fig. 26b). Sighting lateral fish first could cause the predator to move laterally and to move into the school's visual field earlier. Additionally, an arced school

configuration results in a more down current blind zone so that fish B would be farther up current of the FAD in an arced school as opposed to a straight school (Fig. 26). The model predicts, therefore, that an arced school configuration is more advantageous than a straight-line school.

Observations of the effect of FAD type treatment on the number of schools and number of individuals per school of Decapterus punctatus may be partially explained by the schooling model. Since FAD type A had only a 0.5 m vertical profile it offers less of a visual obstruction to potential predators than FAD type C, which had a 2.0 m vertical profile (Fig. 3). Differences in vertical profile might account for the significantly different abundances of D. punctatus among FAD types (Fig. 9). Indeed, FAD type A structures most frequently attracted schools of fewer than 100 individuals while FAD type C structure most frequently attracted schools of 100-999 individuals (Fig. 12c). A limit to the number of individuals per school of D. punctatus which can effectively use a FAD was also suggested by the dependence of the number of schools per structure on the total number of D. punctatus present. As the number of feeding individuals in an aggregation increases above a limited value set by the size of the FAD, some individuals (perhaps those already satiated) might split off from the school and move to the bottom to rest, accounting for the frequently observed second school of D. punctatus (Fig. 19).

Although my model of the visual field of a school of fish is highly speculative, it does predict some important aspects of schooling behavior and agrees with observations of the spatial distribution of D. punctatus

about the FADs reported, herein. I believe it is also a readily testable model both in laboratory and field studies. In situ studies of predator interactions with schooling fishes are especially promising with the use of FADs and underwater remote video. It would even be possible to substitute divers for natural predators and to observe the response of schools associated with FADs to the approach of a diver. The evolution of the visual mechanism of predator avoidance described by the model would be closely tied to the evolution of schooling behavior and may result partially from the selective pressures acting on planktivorous species which are vulnerable to predators while feeding in the water column (Hobson, 1968; 1979; Hobson and Chess, 1986). The additional advantages of associating with structure suggested by the model might also be partially responsible for the evolution of the association of fishes with flotsam, Sargassum spp. and jellyfishes. The association of many species, especially of D. punctatus, with FADs probably has its origins in their association with flotsam, Sargassum spp. and jellyfish.

Murray et al. (1985) reported S. zonata occurred at FADs throughout the summer and noted it exhibited a strong interspecific territoriality. Seriola zonata, however, did not occur after July in South Carolina (Fig. 8). It was most abundant at FAD type C stations until late May and early June when D. punctatus became abundant, after which time S. zonata was found only at FAD type A stations where D. punctatus occurred in low numbers (Fig. 8). When D. punctatus occurred in low numbers at a station they occupied a position around the FAD similar to that occupied by S. zonata (Fig. 16a, 20a), but when in larger numbers D. punctatus was located some distance up current of the FAD (Fig. 20). If both species

feed on similar zooplankton resources, it would be disadvantageous for S. zonata to occupy a position down current of a large school of D. punctatus. Competition for food between these two species may account for the absence of S. zonata during August. The low abundance and infrequent occurrence of D. punctatus and frequent occurrence of S. zonata observed by Murray et al. (1985) supports the idea that these two species are competitors at FADs.

The blue runner, Caranx crysos, the second most abundant species observed (Tables 4 and 5), has been commonly reported to associate with FADs (Klima and Wickham, 1971; Wickham et al., 1973; Wickham and Russell, 1974; Murray et al., 1985). Juvenile C. crysos have also been described as Sargassum spp. associates (Berry, 1959; Dooley, 1972; Bortone et al., 1977; Johnson, 1978a). Dooley (1972) reported that blue runner occurred in relatively low abundance with Sargassum spp. from March through June, in high abundance in June and July and were uncommon after November, agreeing well with the seasonality observed around FADs in South Carolina (Fig. 11d, Appendix B.2). Murray et al. (1985) reported that the blue runner did not appear around FADs in North Carolina until early June, while I observed small numbers as early as late May (Fig. 11d, appendix B.2). According to existing literature, larvae and juveniles of C. crysos occur with strongest affinity within the Gulf stream and offshore waters of the southeastern United States and remain offshore until reaching a size of from 80 mm to 100 mm S.L. (McKenney et al., 1958; Berry, 1959; Johnson, 1978a; Goodwin and Finocane, 1985). Fish over 80 mm S.L. begin moving into the inshore waters in July and may move back offshore after November (Berry, 1959; Johnson, 1978a). The sudden

disappearance of C. crysos around FADs in November (Fig. 11d, appendix B.2) was probably a result of such offshore migration.

Caranx crysos physically associated more closely with the FADs than did Decapterus punctatus (Fig. 21 and 22). It usually occurred in small schools of 10 or fewer individuals (Fig. 12d). The blue runner occurred most frequently within 1 m of the FAD float (Fig. 21), but was most densely distributed 1 m - 2 m down current of the FAD float directly around the FAD subunit (Fig. 22). Again, as with D. punctatus, there was a strong tendency for the school to match the profile of the FAD when positioned up current (Fig. 21, 22). Murray et al. (1985) also reported that C. crysos rarely stayed far from FADs and usually remained within 1 m - 1.5 m of the FAD. When C. crysos was present in small numbers (ten or less) they usually occupied a position directly around the float or streamers (see Fig. 3) of the subunits, but larger schools of 20 to 50 or more individuals usually occurred about 1 m up current of the FAD, which is in agreement with the schooling model. I have observed blue runner actively feeding on plankton while facing into the current and the species has been reported to feed on planktonic copepods and other zooplankton (McKenney et al., 1958; Dooley, 1972). The blue runner may, therefore, use the visual field of a school in the same manner as proposed for Decapterus punctatus.

Apparently, C. bartholomaei has not been reported to associate with FADs in past studies, probably because FAD studies in the western Atlantic and Gulf of Mexico have been carried out during the summer months (Klima and Wickham, 1971; Wickham et al., 1973; Wickham and Russell, 1974; Murray et al., 1985). Young juveniles, however, have been

reported as associates of jellyfish (Fowler, 1945; Berry, 1959; Mansueti, 1963; Johnson, 1978a; Rountree, 1983) and with Sargassum spp. (Berry, 1959; Fine, 1970; Bortone et al., 1977; Johnson, 1978a). I collected a 51 mm S.L. specimen associated with the jellyfish Stomolophus meleagris in July, 1982 from inshore waters off North Carolina (Rountree, 1983). Murray et al. (1985) did not report C. bartholomaei around FADs off North Carolina during May and June, although I observed the species in small numbers during May and June off South Carolina (Fig. 11e, Appendix B.2).

Very little is known of the ecology of the species but the larvae and juveniles are thought to occur mainly in association with offshore currents with adults uncommonly found in inshore waters (Berry, 1959; Johnson, 1978a). Dooley (1972) collected individuals with Sargassum spp. in the Gulf stream ranging from 10 mm - 77 mm S.L.. The occurrence of the very young juveniles in August appeared to correspond with the presence of large amounts of Sargassum spp. in the surface waters of the study area during that time (Fig. 11e). The fact that young juveniles are known to associate with Sargassum spp. and larger juveniles and subadults were observed to associate with FADs, suggests that the association with FADs is a carry over from an earlier association of the young juveniles with Sargassum spp..

The yellow jack occurred most frequently and in greatest numbers when Caranx crysos and Decapterus punctatus were less abundant (Fig. 8). The yellow jack co-occurred together with D. punctatus only 20 % of the time and with C. crysos only 7 % of the time (Fig. 24), suggesting competition between C. bartholomaei and these species. Although I am

unaware of any published reports on feeding by C. bartholomaei, I have observed the species actively feeding on plankton while associated with FADs. Competition for planktonic food resources may account for the low co-occurrence of C. bartholomaei with C. crysos and D. punctatus. The close similarity in the spatial distributions of C. bartholomaei and C. crysos, and the low co-occurrence of these two species (Fig. 24), suggests to me that the two Caranx spp. are strong competitors.

Although the model of schooling in fishes suggests that schooling fishes associate with FADs in order to gain an additional visual advantage over predators, it does not suggest an advantage of crowding around an object once a predator has been detected. The benefit derived by non-schooling species associating with FADs is also unexplained. Many solitary species, and species occurring in small aggregations, were observed closely associating with the FADs. The contour plots of the frequency and density of fishes (with D. punctatus excluded) showed the highest contours immediately around the FAD, parallel to the streamers and around the anchors (Figs. 14 and 15). Aluterus spp. exhibited a well defined use of the FAD for shelter (Fig. 6), in which they used the FAD as a shield between themselves and an approaching diver.

Insight into a possible advantage of association with FADs and flotsam can be found in observations on schooling behavior and predatory tactics discussed by Radakov (1973). It was noted that many predators herd schooled fish to the surface or into shallow water where restricted movements impair avoidance maneuvers and minimize the advantage of schooling. Zaitsev (1971) also discussed problems in predator avoidance faced by schooling and solitary fishes living near the surface layer of

the ocean. Many solitary predators are known to hunt by rushing into a school of fish, not so much in an attempt to snatch a fish, but rather to confuse the school and drive off some individuals which could then be chased down and captured (Radakov, 1973). Floating objects might function, then, to aid schooling fishes to maintain the school integrity by preventing predators from splintering the school by repeated lunges into it.

Association of fishes with floating objects may tend to inhibit or reduce the effectiveness of predatory tactics. Predators might be reluctant to lunge into a school associated with a floating object for fear of collision. A simple reflex response to a visual stimulus might cause the predator to veer slightly or slow down momentarily, allowing the prey to escape. Such a reflexive avoidance of an object might account for the frequent reports of poor predator success on fishes crowding closely around FADs (Gooding and Magnuson, 1967; Mitchell and Hunter, 1970; Wickham et al., 1973; Wickham and Russell, 1974). Habituation to a specific object might enable the prey fish to avoid the same reflex response, thereby, gaining an advantage over the predator. The importance of habituation may account for the apparent reluctance of fishes to leave an object for which they have established an association for a new object placed nearby (Hunter and Mitchell, 1967).

Characteristics that optimize the number of fishes which can crowd around the object should have an important influence on the standing crop of fishes. Long vertically oriented objects would allow a larger school to crowd around the object than short thick objects, or long horizontally oriented objects. Some support for this idea comes from

reports that vertically floating objects such as logs are thought to be more effective than horizontally floating objects in FAD/flotsam fisheries (Inoue et al., 1968; Waldavogel, 1978; Matsumoto et al., 1981). This mechanism of utilizing an object to prevent predators from disrupting a schooling formation through a reflexive avoidance response by the predator may also explain why the FAD type treatment C structures attracted more fishes than the other FAD types (Fig. 9). The mechanism is equally applicable to non-schooling and schooling fishes.

Several observations on the performance of the FADs in this study may prove useful to recreational fisheries. The extensive movement of the structures (Fig. 4) indicates that similar structures used in construction of trolling allies in South Carolina probably scatter over a wide area fairly quickly. Most of the species observed in the study (Table 2) did not occur in sizes large enough to directly contribute to the recreational fishery, except for the sheepshead and Atlantic spadefish. However, FADs are used mainly to attract baitfishes which, in turn, are thought to attract the important pelagic gamefishes into the general area. Trolling allies in South Carolina usually consist of around 100 FADs placed in 0.8 km - 1.6 km long rows (M. Bell, personal communication). The mean number of fishes observed per structure during the peak period of August (Fig. 11, Appendix B.2) can be used to extrapolate an estimated standing crop of 58,000 to 452,000 fishes on nearby trolling allies, depending on the type FAD used. I have little doubt that such large aggregations of baitfishes would have an important impact on pelagic predators. It should be noted, however, that the abundance of D. punctatus at the FADs was lowest during the spring and

fall peak fishing seasons (Fig. 11). At these times the FADs may not have attracted sufficient numbers of baitfishes to significantly attract important game species, such as Scomberomorus cavalla.

Fouling on the type C FADs was heavy enough to drastically reduce their life spans relative to the type A FADs. Increasing the float size would require an increase in the anchor weight and an increase in deployment costs. The best possible use of the FADs would probably be to use them in conjunction with such bottom materials as culvert pipe, ships and other traditional and prefabricated artificial reef materials (M. Bell, Personal Communication). Findings in this study also suggest that FADs should be designed with increased vertical profile to optimize attraction of round scad and other baitfishes.

Some problems encountered in this study can be avoided. Since the abundance of fishes varied strongly over time, the extreme variation in the number of fishes per FAD observed in this study could be reduced by sampling over a shorter time period. The time period chosen to make the study should coincide with the peak abundance of target species. Sampling over a shorter time period would also reduce the bias due to loss of structures and differential fouling rates among structure types. Station loss and movement might be reduced by securing the ends of the rope grid lines with "deadheads" (anchors use to secure telephone poles and towers). These anchors can be easily set by a team of divers in sandy bottoms (a 1.8 m long anchor can be set in about five minutes by two divers) and should effectively stabilize any "permanent" grid line. After the FADs and grid lines have been deployed from the surface vessel,

divers could secure one end of the grid line and then take out the slack in the line before securing the opposite end.

Although many problems were experienced in this study, the value of using controlled experimental designs in the study of marine habitat ecology was clearly evident. Implications of results and conclusions drawn from this study demonstrate the need for more controlled field studies on the use of structure by fishes. Variation in the numbers of fishes due to the population dynamics of individual species (observed as temporal variation in numbers), weather conditions, local topography, currents and species interactions can mask any treatment effect or alter a species' apparent response to a treatment. The use of treatment replications in an experimental design is the best way to statistically account for uncontrolled factors in the analysis of a treatment effect. The use of FADs in research is especially valuable in the study of pelagic fish behavior and ecology because FADs aggregate otherwise widely scattered fishes and provide scientists with a dependable point of observation of pelagic species which are otherwise difficult to study.

Conclusions

1. The number of species, total number of individuals and number of Decapterus punctatus per station were significantly affected by the type of FAD structure. The amount of vertical profile was probably the most important structural characteristic affecting the abundance of fishes.
2. The abundance of demersal species attracted to the anchors may have been influenced by the abundance of pelagic schooling fishes at the FAD.
3. The associations of fishes with flotsam, drifting seaweeds (such as Sargassum spp.) and jellyfishes are closely related behaviors and probably have similar origins and causes.
4. The association of fishes with FADs may result from a pre-adaptation of many pelagic fishes to associate with many kinds of drifting materials.
5. The spatial distribution of fishes about FADs were quantitatively described. Schools of Decapterus punctatus occupy a position up current of the FAD and tend to conform their profile to match the profile of the FAD. Decapterus punctatus occupies a position increasingly farther up current with increasing school size.
6. I propose a model of the visual field of a school of fish. The model predicts:
 - A. A school of planktivorous fishes feeding in open water has a visual advantage over solitary planktivores, since the schooling fishes' visual fields overlap in such a way as to reduce the

likelihood of a predator being able to approach from behind the school without being detected.

- B. Larger schools of fish should be able to detect an approaching predator sooner than smaller schools because the predator would move out of the school's blind zone and be sighted by some individuals in the school at a point farther behind the school.
 - C. Association with a FAD provides schools with additional advantages:
 - 1) A FAD serves to partially occlude the vision of a predator approaching a school of fish from down current.
 - 2) A FAD would tend to cause the predator to move into the field of view of the school earlier than it might have in the FAD's absence.
 - 3) A FAD enhances a school's predator avoidance tactics, such as the fountain effect, by providing shelter to the school and a physical barrier to the predator.
 - D. The model also predicts that the position of the school relative to the FAD depends on the physical size of the school and location of its blind zone. Since the blind zone is located farther down current with increasing school size, the school should move up current with increasing size to take advantage of optimal FAD position.
7. Association of fishes with drifting materials may provide some protection from predation by allowing fishes habituated to an object to capitalize on a reflexive avoidance of an object by an attacking predator.

8. FADs effectively aggregate large concentrations of baitfishes during the summer months, but would probably be more effectively utilized in fisheries by clustering them together within small areas, rather than by forming long trolling alleys.

Literature Cited

- Anonymous. 1980. Report on fish aggregation devices workshop. U.S. Dept. Commerce NOAA, NMFS Honolulu Laboratory, Southwest Fisheries Center. 17p.
- Anonymous. 1984. Further development of fish aggregation devices. Saltwater Conversation 1984(3):20-22.
- Anonymous. 1985. Artificial reef news: mid-water fish attractors create trolling alleys, saltwater fishing clubs getting involved. Saltwater Conversation 1985(1):17-19.
- Barans, C.A., and V.G. Burrell, Jr. 1976. Preliminary findings of trawling on the continental shelf off the southeastern United States during four seasons (1973-1975). South Carolina Marine Resources Center, Tech. Report No. 13. 16p.
- Berry, F.H. 1959. Young jack crevalles (Caranx species) of the southeastern Atlantic coast of the United States. Fishery Bull. Fish Wildl. Serv. U.S. 59(152):417-535.
- Besednov, L.N. 1960. Some data on the ichthyofauna of the Pacific Ocean flotsam. Trudy Inst. Okeanol. 41:192-197. (Trans. from Russian by W. van Campen Bureau of Commercial Fisheries, Honolulu, Hawaii).
- Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. U.S. Environmental Protection Agency Ecological Research Series EPA-600/3-77-033. 113p.
- Bohlke, J.E., and C.C.G. Chaplin. 1968. Fishes of the Bahamas and adjacent tropical waters. Livingston Publ. Co., Wynnewood, Pa. 771p.
- Bortone, S.A., P.A. Hastings and S.B. Collard. 1977. The pelagic-Sargassum ichthyofauna of the eastern Gulf of Mexico. Northeast Gulf Sci. 1(2):60-67.
- Brandt, A., von. 1960. Fishing methods in world sardine fisheries. In: Proceedings of world scientific meetings on the biology of sardines and related species. Ed. Rosa, H., Jr. and G. Murphy. Rome. Vol. II. Subject Synopsis No. 3:563-623.
- Bray, R.N., and A.C. Miller. 1985. Planktivorous fishes: their potential as nutrient importers to artificial reefs. Bull. Mar. Sci. 37(1):396.
- Breder, C.M., Jr. 1942. On the behavior of young Oligoplites saurus (Bloch and Schneider). Copeia 1942(4):267.
- Breder, C.M., Jr. 1946. An analysis of the deceptive resemblances of fishes to plant parts, with critical remarks on protective

- coloration, mimicry and adaptation. Bull. Bingham Oceanogr. Collect. Yale Univ. 10(2):1-49.
- Breder, C.M., Jr. 1949. On the behavior of young Lobotes surinamensis. Copeia 1949(4):237-242.
- Brock, R.E. 1985. Preliminary study of the feeding habits of pelagic fish around Hawaiian fish aggregation devices or can fish aggregation devices enhance local fisheries productivity? Bull. Mar. Sci. 37(1):40-49.
- Brock, R.E. 1986. Accent on fisheries enhancement. pp. 44-57 In. : 1986 World Record Game Fishes. The International Game Fish Association, For Lauderdale, Florida.
- Buhler, H. 1930. Die Verduugsorgane der Stromateidae (Teleost). Seitschr. f. Murphol. v. Okolog. d. Teere. 19:59-115.
- Buchanan, C.C. 1973. Effects of an artificial habitat on the marine sport fishery and economy of Murrells Inlet, South Carolina. Mar. Fish. Rev. 35(9):15-22.
- Buchanan, C.C., R.B. Stone and P.O. Parker, Jr. 1974. Effects of artificial reefs on a marine sport fishery off South Carolina. Mar. Fish. Rev. 36(11):32-38.
- Clifford, H.T., and W. Stephenson. 1975. An introduction to numerical classification. Academic Press, N.Y. 229p.
- Conover, W.J. 1980. Practical nonparametric statistics, second edition. New York: John Wiley and Sons, Inc.
- Conover, W.J., and R.L. Iman. 1976. On some alternative procedures using ranks for the analysis of experimental designs. Communications in Statistics. A5(14):1348-1368.
- de Sylva, D.P. 1982. Potential for increasing artisanal fisheries production from floating artificial habitats in the Caribbean. Proc. Gulf Carib. Fish Inst. 34:156-167.
- Dooley, J.K. 1972. Fishes associated with the pelagic sargassum complex, with a discussion of the sargassum community. Contributions in Marine Science (Publication of the Institute of Marine Science) Texas University 16(March):1-32.
- Fine, M.L. 1970. Faunal variation on pelagic sargassum. Mar. Biol. 7(2):112-122.
- Floyd, J.M. 1985. Recent trends in Philippine tuna fishery. Am. Inst. Fish. Res. Biologists Briefs 14(4):6-7.
- Floyd, J.M., and D. Pauly. 1984. Smaller size tuna around the Philippines

- can fish aggregating devices be blamed? Infofish Marketing Digest No. 5/84 p. 25-27.
- Fowler, H.W. 1945. A study of the fishes of the southern Piedmont and Coastal Plain. Acad. Nat. Sci. Phila. Monogr. 7. 408p.
- Galea, J.A. 1961. The "kannizzati fishery." Proc. Gen. Fish. Council. Medit. 6:85-91.
- Gooding, R.M. and J.J. Magnuson. 1967. Significance of a drifting object to pelagic fishes. Pacific Sci. 21(4):486-479.
- Goodwin, J.M. and J.H. Finucane. 1985. Reproductive biology of blue runner (Caranx crysos) from the eastern Gulf of Mexico. Northeast Gulf Sci. 7(2):139-146.
- Greenblatt, P.R. 1979. Associations of tuna with flotsam in the eastern tropical Pacific. Fish. Bull. 77(1):147-155.
- Hales, L.S., Jr. 1984. Aspects of the life history of the round scad, Decapterus punctatus, (Pisces: Perciformes: Carangidae) in the South Atlantic Bight. M.S. Thesis. College of Charleston, Charleston, South Carolina. 95p.
- Hales, L.S. 1987. Distribution, abundance, reproduction, food habits, age, and growth of the round scad, Decapterus punctatus, in the South Atlantic Bight. Fish. Bull. 85(2):251-268.
- Hall, S.J., C.S. Wardle and D.N. MacLennan. 1986. Predator evasion in a fish school: test of a model for the fountain effect. Mar. Biol. 91:143-148.
- Hammond, D.L., D.D. Myatt and D.M. Cupka. 1977. Evaluation of midwater structures as a potential tool in the management of the fisheries resources on South Carolina's artificial fishing reefs. South Carolina Marine Resources Center, Tech. Report No. 15. 19p.
- Hardenberg, J.D.F. 1950. Development of pelagic fisheries. Proc. Indo-Pac. Fish. Council., Singapore, 1949, No. 1, sec. IV:138-143.
- Hastings, R.W., L.H. Ogren and M.T. Mabry. 1976. Observations of the fish fauna associated with offshore platforms in the northeastern Gulf of Mexico. Fish. Bull. 74(2):387-402.
- Helfman, G.S. 1979. Fish attraction to floating objects in lakes. In: Response of fish to habitat structure in standing water. North Central Division AFS Special Publication No. 6. pp. 49-57.
- Helfman, G.S. 1981. The advantage to fishes of hovering in shade. Copeia 1981(2):392-400.

- Hildebrand, H.H. 1954. A study of the fauna of the brown shrimp (Penaus aztecus Ives) grounds in the western Gulf of Mexico. Univ. Tex. Pub. Inst. Mar. Sci. 3(2):233-366.
- Hirosaki, Y. 1960a. Observations and experiments on the behavior of fishes toward floating objects in aquarium (prelim. report). J. Fac. Sci. Hokkaido Univ. Ser. 6. 14(3):320-327.
- Hirosaki, Y. 1960b. Some ecological observations of fishes in Sagami Bay appearing together with the drifting seaweeds. J. Fac. Sci. Hokkaido Univ. Ser. 6. 14(3):435-442.
- Hobson, E.S. 1968. Predatory behavior of some shore fishes in the Gulf of California. U.S. Bur. Sport Fish. Wildl. Res. Rept. 73:1-92.
- Hobson, E.S. 1979. Interactions between piscivorous fishes and their prey. pp. 231-242. In: H. Clepper (ed.) Predator-Prey systems in Fisheries Management. Sport Fishing Institute, Washington, D.C.
- Hobson, E.S., and S.R. Chess. 1986. Relationships among fishes and their prey in a nearshore sand community off southern California. Environ. Biol. Fishes. 17(3):201-226.
- Hoese, H.D., B.J. Copeland and J.M. Miller. 1964. Seasonal occurrence of Cyanea medusae in the Gulf of Mexico at Port Aransas, Texas. Texas J. Sci. 16(3):391-393.
- Holland, K. 1985. Acoustic tracking of tuna. Am. Inst. Fish. Res. Biologists 14(3):4-5.
- Holland, K., R. Chang and S. Ferguson. 1985. Progress report on tuna tracking. South Pacific Commission (SPC) Fisheries Newsletter No. 32-March 1985:19-23.
- Horn, M.H. 1970. Systematics and biology of the stromateoid fishes of the genus Peprilus. Bull. Mus. Comp. Zool. 140(5):165-261.
- Hunter, J.R. 1968. Fishes beneath flotsam. Sea Frontiers 14:280-288.
- Hunter, J.R., and C.T. Mitchell. 1967. Association of fishes with flotsam in the offshore waters of Central America. Fish. Bull. 66:13-29.
- Hunter, J.R., and C.T. Mitchell. 1968. Field experiments on the attraction of pelagic fish to floating objects. S. Cons. Perm. in Explor. Mer. 31(3):427-434.
- Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecol. Monogr. 54(2):187-211.
- Ida, H., Y. Hiyama and T. Kusaka. 1967a. Study of fishes gathering around floating seaweed. I. Abundance and species composition. Bull. Jap. Soc. Sci. Fish. 33(10):923-929.

- Ida, H., Y. Hiyama and T. Kusaka. 1967b. Study of fishes gathering around floating seaweed. II. Behavior and feeding habit. Bull. Jap. Soc. Sci. Fish. 33(10):930-936.
- Inamura, Y., M. Inoue, M. Ogura, and S. Takeuchi. 1965. Fishing of dolphin, Coryphaena hippurus, by bamboo raft in the southwest coast of Japan Sea. J. Tokyo Univ. Fish. 51:81-86.
- Inoue, M., R. Amano, Y. Iwasaki and M. Yamantio. 1968. Studies on environments alluring skipjack and other tunas. II. On the driftwoods accompanied by skipjack and tunas. Bull. Jap. Soc. Sci. Fish. 34(4):283-387.
- Iwasa, K. 1981. The effectiveness of artificial fish aggregating devices (Payao) on the high seas (a progress report). Jap. Mar. Fish. Resource Res. Center. No. 21, p. 32-39. Otsu, T. Trans. for Southwest Fisheries Center Honolulu Laboratory, NMFS, NOAA, Honolulu, Hawaii 96812, Aug. 1982. Trans. No. 68.
- Johnson, G.D. 1978a. Development of fishes of the Mid-Atlantic Bight. IV. Carangidae through Ephippidae. U.S. Fish. Wildl. Serv., Biol. Servs. Prog., FWS/OBS-72/12, 314p.
- Johnson, G.D. 1978b. Development of fishes of the Mid-Atlantic Bight. VI. Stromateidae through Ogcocephalidae. U.S. Fish. Wildl. Serv., Biol. Servs. Prog., FWS/OBS-78/12, 416p.
- Klemm, R. 1984. Big island tuna conference: more questions than answers. MAKAI: "towards the Sea". University of Hawaii Sea Grant Program 6(8):1-4.
- Klima, E.F., and D.A. Wickham. 1971. Attraction of coastal pelagic fish with artificial structures. Tran. Am. Fish. Soc. 100(1):86-99.
- Kojima, S. 1956. Fishing for dolphins in the western part of the Japan Sea. II. Why do fishes take shelter under floating materials. Bull. Jap. Soc. Sci. Fish. 21(10):1049-1052.
- Kojima, S. 1960a. Fishing for dolphins in the western part of the Sea of Japan. V. Species of fishes attracted to bamboo rafts. Bull. Jap. Soc. Sci. Fish. 26(4):279-382. Trans. W.G. Van Campen. 1962. Southwest Fisheries Center, NMFS, NOAA, Honolulu, HI.
- Kojima, S. 1960b. Fishing for dolphin in the western part of the Sea of Japan. VI. Behaviors of fish gathering around bamboo rafts. Bull. Jap. Soc. Sci. Fish. 26(4):383-388.
- Kojima, S. 1966a. Studies on fishing conditions of the dolphin, Coryphaena hippurus, in the western regions of the Sea of Japan. XI. School of dolphins accompanying various kinds of floatages. Bull. Jap. Soc. Sci. Fish. 32(8):647-651.

- Kojima, S. 1966b. Studies on fishing conditions of the dolphin, Coryphaena hippurus, in the western regions of the Sea of Japan. XII. The size of a dolphin school. Bull. Jap. Soc. Sci. Fish. 32(8):652-654.
- Kulczychi, G.R., R.W. Virnstein and W.F. Nelsen. 1981. The relationship between fish abundance and algal biomass in a seagrass-drift algae community. Estuarine Coastal Shelf Sci. 12:341-347.
- Lindquist, D.G., M.V. Ogburn, W.B. Stanley, H.L. Troutman and S.M. Pereira. 1985. Fish utilization patterns on temperate rubble-mound jetties in North Carolina. Bull. Mar. Sci. 37(1):244-251.
- McKenney, T.W., E.C. Alexander, and G.L. Voss. 1958. Early development and larval distribution of the carangid fish, Caranx crysos (Mitchill). Bull. Mar. Sci. Gulf Caribb. 8(2):167-200.
- McIlwain, J.D., and R.R. Lukens. 1978. Artificial reef enhancement utilizing midwater attraction structures. In: Aska, D.Y. (ed). Artificial reefs in Florida. State Univ. System of Florida, Sea Grant Program. Report No. 24. 68p.
- Magurran, A.E., W. Oulton and T.J. Pitcher. 1985. Vigilant behaviour and shoal size in minnows. Zeitschrift fur Tierpsychologie 67:167-178.
- Mansueti, R. 1963. Symbiotic behavior between small fishes and jellyfishes, with new data on that between the stromateid, Peprilus alepidotus, and the scyphomedusa, Chrysaora quinquecirrha. Copeia 1963(1):40-80.
- Matsumoto, W.M., T.K. Kazama and D.C. Aasted. 1981. Anchored fish aggregating devices in Hawaiian waters. Mar. Fish. Rev. 43(9):1-13.
- Meyer, J.L., and E.T. Schultz. 1985a. Tissue condition and growth rate of corals associated with schooling fish. Limnol. Oceanogr. 30:157-166.
- Meyer, J.L., and E.T. Schultz. 1985b. Migrating haemulid fishes as a source of nutrients and organic matter on coral reefs. Limnol. Oceanogr. 30:146-156.
- Milinski, M. 1986. Constraints placed by predators on feeding behaviour, Chapter 9 In: Pitcher, T.J. (ed). The behavior of teleost fishes. Baltimore, Maryland: The Johns Hopkins University Press. 583p.
- Mitchell, C.T., and J.R. Hunter. 1970. Fishes associated with drifting kelp, Macrocystis pyrifera, off the coast of southern California and northern Baja California. Calif. Fish and Game 56(4):288-297.
- Mortensen, T. 1917. Observations on protective adaptation and habits, mainly in marine animals. In: Papers from Dr. Th. Mortensen's Pacific

- Expedition 1914-1916. Vidensk. Medd. Dansk Naturhist. Forem. 69:57-96, ill.
- Murray, J., and J. Hjort. 1912. The depth of the ocean: a general account of the modern science of oceanography based largely on the scientific researches on the Norwegian steamer Michael Sars in the North Atlantic. Macmillan and Co. Ltd., London.
- Murray, J., D. Lindquist, D. Griffith and J. Howe. 1985. The use of midwater fish aggregation devices to attract marine fishes at two North Carolina fishing piers. Working paper 85-1, UNC Sea Grant College Program, 105 1911 Building, North Carolina State University, Raleigh, NC 27650. 53p.
- Myatt, D. 1978. The "trolling alley" fishing system. In: Aska, D.Y. (ed.) Artificial reefs in Florida. State University System of Florida, Sea Grant Program. Report No. 24 68p.
- Myatt, D.O. 1985. Midwater fish attractors. Chapter 10, p. 303-315 In: Artificial reefs: marine and freshwater applications. D'Itri, F.M. (ed), Lewis Publishers, Inc. (Chelsea, Michigan: 1985) 589p.
- Myatt, D.O., and E. Myatt. 1982. Midwater fish attractors. pp. 54-71 In: 1982 World Record Game Fish. The International Game Fish Association, Fort Lauderdale, Florida.
- Ogren, L.H. 1974. Midwater structures for enhancing recreational fishing. p. 65-67 In: Proceedings of an International Conference on artificial reefs. Houston, Texas. March 20-22, 1974. Eds. L. Colunga and R. Stone.
- Parin, N.V. 1968. Ichthyofauna of the epipelagic zone. M. Raveh (Transl.), Israel Program for Scientific Translations, IPST No. 5738, United States Department of the Interior, Washington, D.C. 206p.
- Park, S.-W. 1984. On the tuna schools associated with the drift objects or animals in the western equatorial Pacific waters. Bull. Korean Fish. Soc. 17(1):47-54.
- Parker, R.O. Jr., R.B. Stone and C.C. Buchanan. 1979. Artificial reefs off Murrells inlet, South Carolina. Mar. Fish. Rev. 41(9):12-24.
- Partridge, B.L. 1982. Structure and function of fish schools. Sci. Am. 245:114-123.
- Phillips, P.J. 1971. The pelagic Cnidaria of the Gulf of Mexico: zoogeography, ecology and systematics. Ph.D. Dissertation. Texas A & M Univ. 212p.
- Phillips, P.J., W.D. Burke and E.J. Koener. 1969. Observations on the trophic significance of jellyfishes in Mississippi Sound with

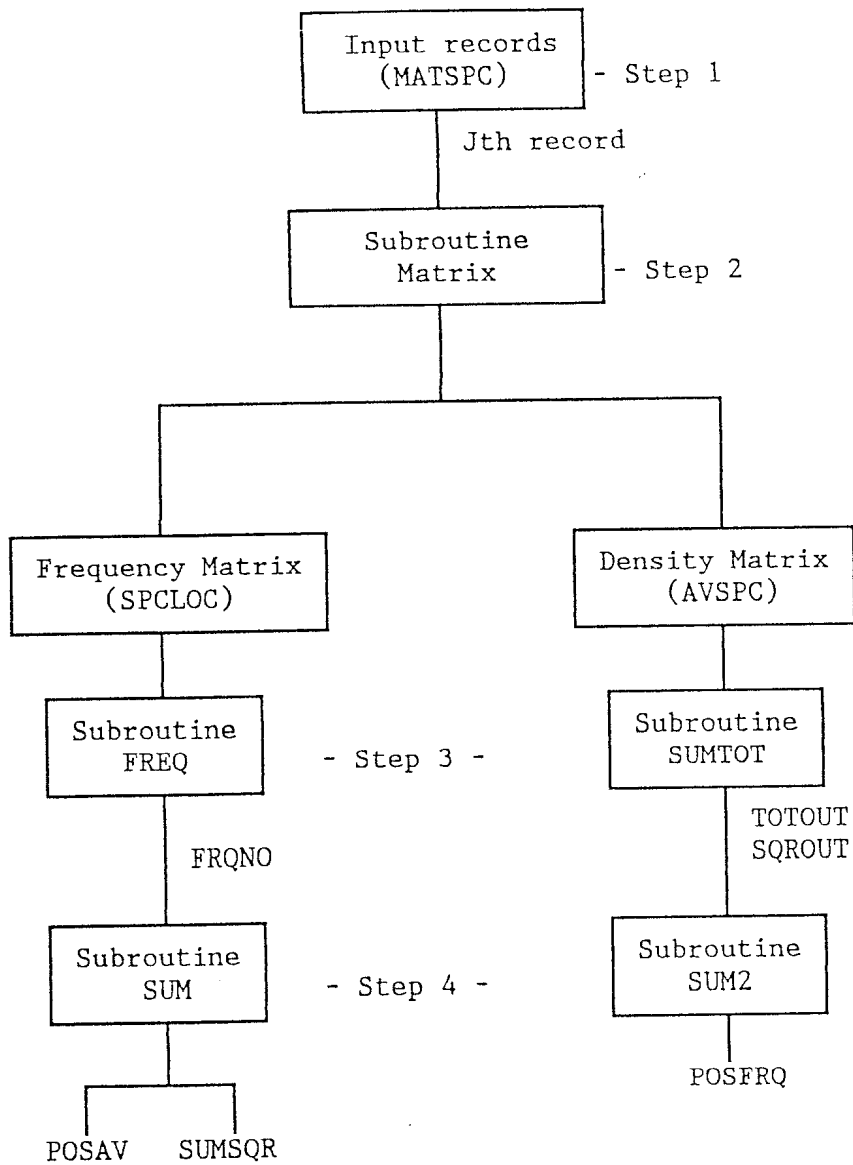
- quantitative data on the associative behavior of small fishes with medusae. *Tran. Amer. Fish. Soc.* 98(4):703-712.
- Pitcher, T.J. 1986. Functions of shoaling behaviour in teleosts, Chapter 12. pp. 294-337, In: Pitcher, T.J. (Ed). *The behavior of teleost fishes*. Baltimore, Maryland: The Johns Hopkins Univ. Press. 553p.
- Potthoff, T. 1969. Searching for tuna. *Comm. Fish. Rev.* 31(2):35-37.
- Protasov, V.R. 1966. Vision and near orientation of fish. M. Raveh (Transl.), Israel Program for Scientific Translation, IPST No. 5738, United States Department of the Interior, Washington, D.C. 175p.
- Radakov, D.V. 1973. *Schooling in the ecology of fishes*. John Wiley and Sons (Israel Program for Scientific Translations). 173p.
- Randall, J.E. and H.A. Randall. 1960. Examples of mimicry and protective resemblance in tropical marine fishes. *Bull. Mar. Sci. Gulf and Caribb.* 10(4):444-480.
- Reeves, W.C., G.R. Hooper and B.W. Smith. 1977. Preliminary observations of fish attraction to artificial midwater structures in freshwater. *Proc. Annu. Conf. Southeast. Asso. Fish. Wildl. Agencies* 31:471-476.
- Rountree, R. 1983. The ecology of *Stomolophus meleagris* and its fish symbionts. *J. Elisha Mitch. Sci. Soc.* 99(4):172. (Abstract)
- Samples, K.C., and D.M. Schug. 1985. The economic impact of fish aggregation devices on Hawaii's charter boat fishing fleet: Part 2. Predictions of long-run effects. *Sea Grant Quart. Univ. Hawaii Sea Grant Program* 7(2):1-6.
- Samples, K.C., and J.T. Sproul. 1983. Fish aggregating devices and open-access commercial fisheries: A theoretical inquiry. Third International Artificial Reef Conference, Occidental College, Newport Beach, Calif. Nov. 4-6, 1983. Dept. Agricultural and Resource Economics University of Hawaii-Manoa, Honolulu, Hawaii.
- Samples, K.C., and J.T. Sproul. 1985. Fish aggregating devices and open-access commercial fisheries: a theoretical inquiry. *Bull. Mar. Sci.* 37(1):305-317.
- Sanders, H.L. 1960. Benthic studies in Buzzards Bay. III. The structure of the soft-bottom community. *Limn. Oceanogr.* 5:138-153.
- Senta, T. 1966. Experimental studies on the significance of drifting seaweeds for juvenile fishes. I. Experiments with artificial drifting seaweeds. *Bull. Jap. Soc. Sci. Fish.* 32(8):639-643.
- Shomura, R.S., and W.M. Matsumoto. 1982. Structured flotsam as fish aggregating devices. NOAA Technical Memorandum NMFS October 1982 9p.

- Smith, B.W., G.R. Hooper and C.S. Lawson. 1980. Observation of fish attraction to improved artificial midwater structures in freshwater. Proc. Annu. Conf. Southeast. Assoc. Fish Wildl. Agencies 34:404-409.
- Smith, H.M. 1907. The fishes of North Carolina. N.C. Geol. Econom. Surv. 2:1-453, 21pls.
- Soemarto. 1960. Fish behavior with special reference to pelagic shoaling species: Lajang (Decapterus spp.). 8th Proc. Indo-Pacific Fish. Counc. Sec. III:89-93.
- Sokal, R.R., and F.J. Rohlf. 1981. Biometry. 2nd Ed. W.H. Freeman and Co., San Francisco, CA. 859p.
- Steimle, F.W. Jr., and L. Ogren. 1982. Food of fish collected on artificial reefs in the New York Bight and off Charleston, South Carolina. Mar. Fish. Rev. 44(6-7):49-52.
- Tolley, S.G. 1987. Association of young Chloroscombrus chrysurus (Pisces: Carangidae) with the jellyfish Aurelia aurita. Copeia 1987(1):216-219.
- Uda, M. 1933. Types of skipjack schools and their fishing qualities: the shoals of "katuwo" and their angling. Bull. Jap. Soc. Sci. Fish. 2:107-111. Transl. by W.G. Van Campen, 1952, In. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 83:68-78.
- Uda, M., and Z. Tukusi. 1934. Local variations in the composition of skipjack (Katsuwonus pelamis) schools. Bull. Jap. Soc. Sci. Fish. 83:51-67.
- Waldvogel, J. 1978. Fishing artificial floating objects. California Sea Grant Marine Advisory Programs Newsletter July 1978. p. 1-2.
- Walls, G.L. 1942. The vertebrate eye and its adaptive radiation. Bull. of the Cranbrook Institute of Science 19:375-376.
- Wardle, C.S. 1986. Fish behavior and fishing gears. Chapter 18, pp. 463-495 In: Pitcher, T.J. (ed). The behavior of teleost fishes. Baltimore, Maryland: The Johns Hopkins University Press. 553p.
- Weis, J.S. 1968. Fauna associated with pelagic sargassum in the Gulf Stream. Am. Midl. Nat. 80(2):554-558.
- Wenner, C.A. 1983. Species associations and day-night variability of trawl-caught fishes from the inshore sponge-coral habitat, South Atlantic Bight. Fish. Bull. 81(3):537-552.
- Wenner, C.A., C.A. Barans, B.W. Stender, and F.H. Berry. 1979. Results of MARMAP otter trawl investigations in the South Atlantic Bight. III. Summer, 1974. South Carolina Marine Resources Center Tech. Report No. 41. 62p.

- Wenner, C.A., C.A. Barans, B.W. Stender, and F.H. Berry. 1980. Result of MARMAP otter trawl investigations in the South Atlantic Bight. V. Summer, 1975. South Carolina Marine Resources Center Tech. Report No. 45. 57p.
- Westenberg, J. 1953. Acoustical aspects of some Indonesian fisheries. *J. Cons. Int. Explor. Mer.* 18:311-325.
- Wickham, D. 1972. Developments in Mid-water reefs. In: Proceedings of Sport Fishing Seminar. November 18-19, 1971, Jekyll Is., Ga., Wilmington, N.C., Coastal Plains Center Marine Development Services, Seminar Series 1. P. 7-10.
- Wickham, D.A., and G.M. Russell. 1974. An evaluation of mid-water artificial structures for attracting coastal pelagic fishes. *Fish. Bull.* 72:181-191.
- Wickham, D.A., J.W. Watson Jr., and L.H. Ogren. 1973. The efficiency of midwater artificial structures for attracting pelagic sport fish. *Trans. Am. fish. Soc.* 102(3):563-572.
- Wolf, R.S. 1974. Minor miscellaneous exploratory/experimental fishing activities in the Caribbean and adjacent waters. *Mar. Fish. Rev.* 36(9):78-87.
- Workman, I.K., A.M. Landry, Jr., J.W. Watson, Jr. and J.W. Blackwell. 1985. A midwater attraction device study conducted from hydrolab. *Bull. Mar. Sci.* 37(1):377-386.
- Yatomi, H.M., M. Inoue, A. Miyashita and H. Machida. 1979. Studies on domestication and extensive breeding of skipjack, tunas and other fishes. 2. On the gathering and scattering behavior of fishes observed in summer at the artificial floating fish reef at Mera Bay. *J. Fac. Mar. Sci. Technol. Tokai Univ.* (12):223-234.
- Yesaki, M. 1977. Innovations in harvest of pelagic resources. *Mar. Fish. Rev.* 39(9):14-23.
- Zaitsev, Yu. P. 1971. Marine neustonology. A. Mercado (Transl.). K.A. Vinogradov (ed). Israel Program for Scientific Translations, IPST NO. 5976, United States Department of the Interior, Washington, D.C. 207p.

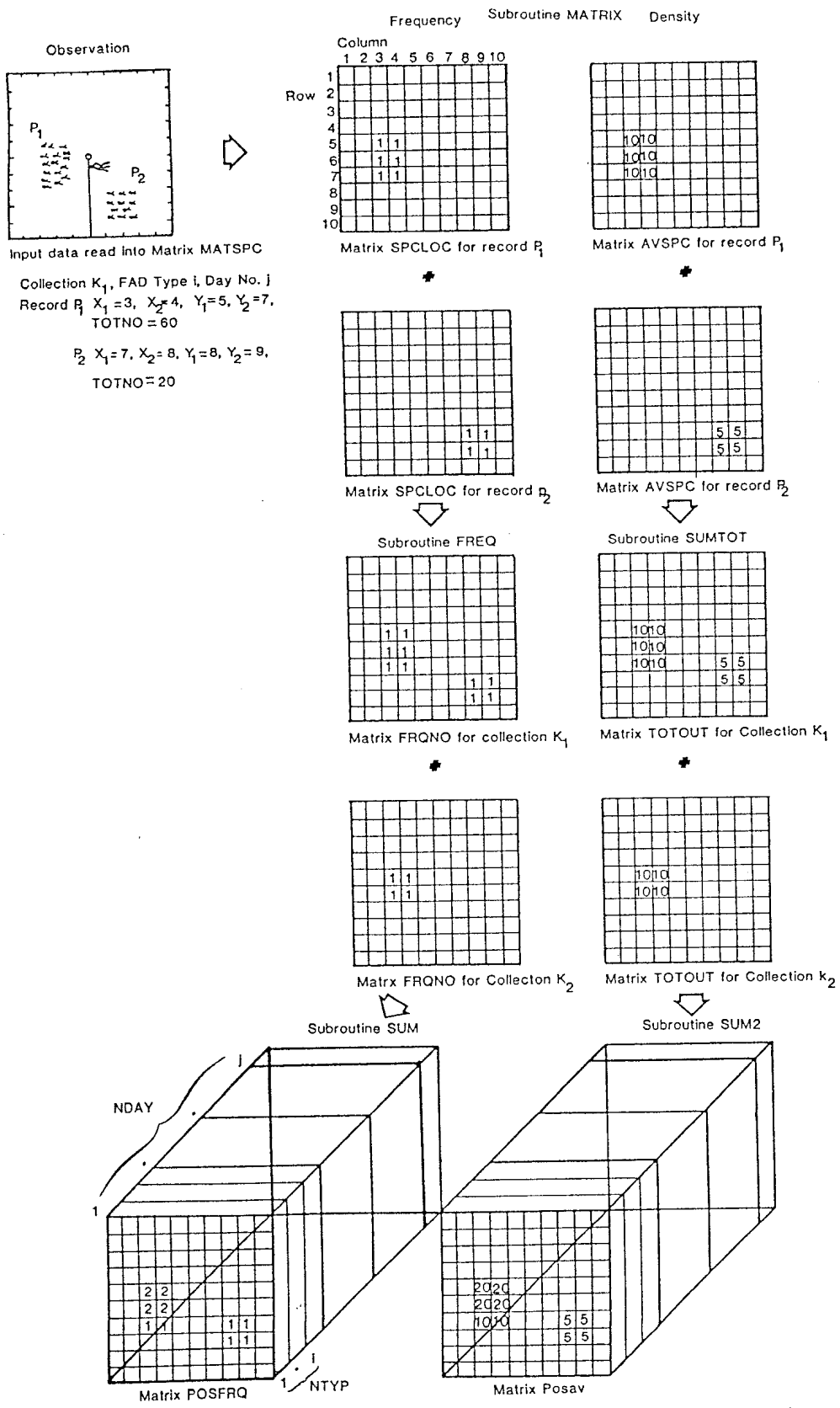
Appendix A. Computer programs for calculating the density and frequency distributions of fishes about the FADs.

Appendix A.1 Flow chart of principle functions of Distpos.F77



- Step 1: Reads each input record and assigns to proper NTYP and NDAY level.
- Step 2: Assigns frequency and number of individuals within cells of a row x column matrix for the Jth record.
- Step 3: Sums all records over the Kth collection number and outputs a row x column matrix for frequency (FRQNO) and density (TOTOUT).
- Step 4: Sums matrices for all collections within the NTYP₁ and NDAY₁ level of matrix POSFRQ, POSAV and SUMSQR with dimensions NROW x NCOL x NTYP x NDAY.

Appendix A.2. Schematic showing the basic operations of program
Distpos.F77.



Appendix A.3. Program Dispos.F77


```

C *****
C *
C * PROGRAM:  DISTPOS.F77
C *
C * WRITTEN BY RODNEY ROUNTREE          DATE:  10 OCTOBER 1986
C *
C * PURPOSE:
C *
C * THIS PROGRAM FINDS THE FREQUENCY OF OCCURRENCE, SUM OF THE NUMBER OF
C * INDIVIDUALS, AND SQUARE OF THE SUM OF INDIVIDUALS OCCURRING IN SQUARE
C * UNIT CELLS IN AN AREA REPRESENTED BY A TWO DIMENSIONAL MATRIX DIVIDED
C * INTO ROW BY COLUMN CELLS.  IT IS USEFUL FOR QUANTIFYING THE SPATIAL
C * DISTRIBUTION OF AN ORGANISM WITHIN A TWO DIMENSIONAL FIELD WHICH CAN
C * THEN BE COMPILED FOR ANY COMBINATION OF TWO FACTORS.  FOR EXAMPLE,
C * THE SPATIAL DISTRIBUTION OF BARNACLES RELATIVE TO THE CENTER OF A
C * ROCK CAN BE COMPILED FOR ALL ROCKS OBSERVED, FOR ONE PARTICULAR ROCK
C * OVER SEVERAL MONTHS, OR FOR A PARTICULAR MONTH FOR ALL ROCKS.
C * THE AREA OCCUPIED IS DEFINED BY A RANGE IN ROW (Y-AXIS) AND COLUMN
C * (X-AXIS) SUBSCRIPTS.  THIS AREA IS BROKEN UP INTO COMPONENT CELLS,
C * AND A FREQUENCY OF ONE IS ADDED TO THE CORRESPONDING CELLS OF A TWO
C * DIMENSIONAL MATRIX.  THE PROGRAM FURTHER ALLOWS THE COMPILATION OF
C * THIS INFORMATION OVER TWO FACTORS, SUCH AS LOCATION AND MONTH, BY
C * INSERTING THE TWO DIMENSIONAL MATRIX AS LEVELS WITHIN A FOUR
C * DIMENSIONAL MATRIX WITH DIMENSIONS OF ROW, COLUMN, FACTOR 1, AND
C * FACTOR 2.
C *
C * FOR EXAMPLE, IF 100 INDIVIDUALS OCCUR IN BLOCKS RANGING FROM ROW 5
C * TO 10 AND COLUMN 5 TO 6, THEN THEY OCCUPY A TOTAL OF TEN SQUARE UNIT
C * AREA CELLS IN THAT RECORD.  A VALUE OF ONE IS ADDED TO EACH CELL IN
C * THE 2-D MATRIX WHICH HAS SUBSCRIPTS FALLING WITHIN THIS RANGE.
C * THE 2-D MATRIX WILL THEN BE ASSIGNED A POSITION WITHIN THE 4-D MATRIX
C * CORRESPONDING TO THE APPROPRIATE LEVEL OF EACH OF THE TWO FACTORS
C * (IF THE OBSERVATION WERE MADE AT LOCATION 2 DURING MONTH 5, IT WOULD
C * BE ASSIGNED TO THE 2ND AND 5TH LEVELS OF THE 3RD AND 4TH DIMENSIONS,
C * RESPECTIVELY).
C *
C * THE NUMBER OF INDIVIDUALS PER CELL AND SQUARE OF THIS NUMBER ARE ALSO
C * COMPILED IN TWO SEPARATE MATRICES.  IN THE ABOVE EXAMPLE RECORD
C * (OBSERVATION) A SECOND MATRIX WOULD CONTAIN VALUES OF 10 INDIVIDUALS
C * WITHIN EACH OF THE TEN CELLS IN WHICH FISH OCCURRED (A HOMOGENEOUS
C * DISTRIBUTION OF INDIVIDUALS IS ASSUMED).  A THIRD MATRIX CONTAINS
C * THE SQUARE OF THE NUMBER OF ORGANISMS PER CELL.  THESE MATRICES ARE
C * OUTPUT TO A FILE WHICH CAN BE INPUT INTO OTHER PROGRAMS TO FIND THE
C * MEAN NUMBER OF INDIVIDUALS, PERCENT OCCURRENCE AND STANDARD DEVIATION
C * FOR EACH CELL IN THE MATRIX.
C *
C * IF SPECIES OR SPECIES GROUPS OCCUR IN TWO OR MORE SEPARATE LOCATIONS
C * FOR AN OBSERVATION (ROW 5 - 6 COLUMN 2 - 3 AND ALSO ROW 8 - 9 AND
C * COLUMN 5 - 6, FOR EXAMPLE), THEN EACH GROUP IS RECORDED AS A SEPARATE
C * RECORD.  DISTRIBUTIONS FOR EACH RECORD ARE ADDED THROUGH MATRIX ADD-
C * ITION TO DEFINE THE SPATIAL DISTRIBUTION OF ORGANISMS AT A STATION
C * (COLLECTION).

```



```

C  **      OUTPUT: **
C  **      NOREC- NUMBER OF COLLECTIONS IN BY LEVELS OF NTPY1 AND **
C  **      NDAY1 **
C  **      BLOCNO- SUM OF THE NUMBER OF CELLS OCCUPIED PER COLLEC- **
C  **      TION FOR EACH NTPY1*NDAY1 BY LEVEL **
C  **      BLCSQR- SUM OF SQUARES OF BLOCNO **
C  **      POSFRQ- FINAL OUTPUT, 4-D MATRIX FORMED BY COMPILING **
C  **      2-D MATRICES OVER NTPY1 AND THEN OVER NDAY1 **
C  **      POSAV- SAME AS ABOVE BUT WITH FISH NUMBER **
C  **      SUMSQR- 4-D MATRIX CONTAINING THE SQUARE OF FISH NO. **
C  **      FRQOUT- 2-D FILE CONTAINING A RECORD FOR EACH CELL IN **
C  **      4-D MATRIX OF THE FREQUENCY OF FISH FOR THAT **
C  **      CELL FOR ALL NON-ZERO BLOCKS. ALSO CONTAINS **
C  **      INDEX VALUES INDICATING THE PROPER POSITION OF **
C  **      THE VALUE IN 4-D MATRIX SO THAT IT CAN BE **
C  **      RECONSTRUCTED. **
C  **      SUMOUT- SAME AS FRQOUT BUT WITH REAL VARIABLES FOR **
C  **      NUMBER OF FISH AND SQUARE OF THE NUMBER OF FISH **
C  **      PER CELL **
C  **      FILES: INPUT: FILCOD- FILE CONTAINING RECORDS SORTED BY **
C  **      COLLECTION NUMBER (NOTE - THE NUMBER **
C  **      OF RECORDS MAY NOT BE GREATER THAN THE **
C  **      PARAMETER SIZ1) **
C  **      OUTPUT: POSOUT.LST- LIST FILE CONTAINING ERROR MESSAGES **
C  **      AND A STATEMENT REPORTING THE OVERALL **
C  **      MEAN NUMBER OF CELLS OCCUPIED FOR POOLED **
C  **      DATA, THE SAMPLE SIZE, NUMBER OF BLOCKS **
C  **      FILLED IN THE OUTPUT MATRIX, AND THE **
C  **      NUMBER OF RECORDS PROCESSED. **
C  **      OUT- DATA FILE CONTAINING THE INFORMATION **
C  **      IN FRQOUT AND SUMOUT. **
C  **      SAMNO- DATA FILE CONTAINING THE NUMBER OF **
C  **      COLLECTIONS, SUM OF THE NUMBER OF CELLS **
C  **      OCCUPIED, SUM OF SQUARES, AND MEAN NUM- **
C  **      BER OF CELLS/COLLECTION, FOR EACH **
C  **      NTPY1*NDAY1 LEVEL. (NOTE: BECAUSE ZERO **
C  **      COLLECTIONS ARE NOT INPUT, THE SAMPLE **
C  **      SIZES AND MEANS MAY NOT BE YOUR "REAL" **
C  **      ONES, BUT THEY CAN BE RE-CALCULATED **
C  **      FROM THE SUM AND SUM OF SQUARES WITH **
C  **      THE CORRECT SAMPLE SIZE) **

```

```

C *****
C *****
C
C COMMON/NOBLOC/BLOCKS, BLOCNO(8,60), BLCSQR(8,6)
C COMMON/OUTPUT/ POSFRQ(14,25,6,8), POSAV(14,25,6,8), SUMSQR(14,25,6,8)
C
C INTEGER BLOCKS, BLOCNO, BLCSQR, CELLSQR, MENCEL, VARCEL, MENBLC, VARBLC
C
C INTEGER COUNT, NTPY1, NDAY1, NROW1, NCOL1, B, K, NOGRAF, CELLNO,
C # SS, TT, UU, WW, P, PP, I, TYMCO, TYFCO, TOTNO, EE, FF, GG,
C # XIPOS, XIIPOS, YIPOS, YIIPOS, INC, JNC, KNC, LNC, C, E, CC,
C # H, Q, SIZ1, NOALL, LEVEL, LEV, AA, BB, CCC, DD, COLLNO, COLCHC,
C # Z, Y, ZZ, ZY, GZ, ZP, YP, MIM
C
C INTEGER BINDE, KINDEX, DR, HEAD, LEAD
C
C THE FOLLOWING PARAMETERS DEFINE THE DIMENSION SIZES OF THE FOUR
C DIMENSIONAL MATRIX WHICH IS OUTPUT. SIZ1 DEFINES THE NUMBER OF
C RECORDS THAT CAN BE INPUT.
C
C PARAMETER (NROW1 = 14, NCOL1 = 25, NTPY1 = 6, NDAY1 = 8, SIZ1 = 1000)
C
C INPUT DATA:
C
C INTEGER MATSPC(SIZ1, 8)
C
C MATRICIES PASSED TO SUBROUTINES:
C
C INTEGER SFCLOC(NROW1,NCOL1), FRQNO(NROW1,NCOL1)
C REAL AVSPC(NROW1, NCOL1), TOTOUT(NROW1,NCOL1), SQRTOT(NROW1,NCOL1)
C
C INTEGER DAYLEV(NDAY1), NOREC(NDAY1,NTPY1), TYPE(NTPY1)
C
C OUTPUT TO DATA FILE:
C FOUR DIMENSIONAL MATRIX: (SEE COMMON/OUTPUT/)
C
C INTEGER POSFRQ
C REAL POSAV, SUMSQR
C
C ACTUAL OUTPUT MATRIX, CONTAINING ONLY NONZERO CELLS OF FOUR DIMENSION
C MATRIX, AND VALUES OF ITS SUBSCRIPT SO THAT IT CAN BE RECONSTRUCTED
C
C INTEGER FRQOUT(NROW1*NCOL1*NTPY1*NDAY1, 5)
C REAL SUMOUT(NROW1*NCOL1*NTPY1*NDAY1, 2)
C
C FILES:
C
C OPEN(9, FILE = 'FILCOD', STATUS = 'OLD', PAD = 'YES', RECFM = 'DS')
C OPEN(6, FILE = 'OUT', STATUS = 'FRESH')

```

```

      OPEN(7, FILE = 'POSOUT.LST', STATUS = 'FRESH',
#CARRIAGECONTROL = 'FORTRAN')
C
      OPEN(8, FILE = 'SAMNO', STATUS = 'FRESH')
C
C
C
C
      LOOP TO READ IN THE INPUT DATA SET INTO A 2-D MATRIX
C
C
      I = 0
C
      8 IF (.TRUE.) CONTINUE
          I = I + 1
          READ(9, 10, END = 11) COLLNO, TYPCOD, TYMCO, TOTNO, XIPOS, XIIPOS,
#              YIPOS, YIIFOS
      10 FORMAT(16, I2, I2, I5, I3, I3, I3, I3)
C
          MATSPC(1,1) = TYPCOD
          MATSPC(1,2) = TYMCO
          MATSPC(1,3) = TOTNO
          MATSPC(1,4) = XIPOS
          MATSPC(1,5) = XIIPOS
          MATSPC(1,6) = YIPOS
          MATSPC(1,7) = YIIFOS
          MATSPC(1,8) = COLLNO
C
C
          GO TO 8
      11 CONTINUE
          COUNT = I - 1
C
C
      MATRIX INITIALIZATIONS
C
      DO 35 AA = 1, NDAY1
          DO 36 BB = 1, NIYP1
              DO 37 CCC = 1, NROW1
                  DO 38 DD = 1, NCOL1
                      FOSFRQ(CCC, DD, BB, AA) = 0
                      POSAV(CCC,DD,BB,AA) = 0.0
                      SUMSQR(CCC,DD,BB,AA) = 0.0
      38          CONTINUE
      37          CONTINUE
      36          CONTINUE
      35          CONTINUE
C
      DO 850 IBLOC = 1, NDAY1
          DO 851 JBLOC = 1, NIYP1
              BLOCNO(IBLOC, JBLOC) = 0
              BLCSQR(IBLOC, JBLOC) = 0
      851          CONTINUE

```

```

850 CONTINUE
C
C THIS STEP ACTS LIKE A SORTER AND ASSIGNS EACH RECORD TO ITS PROPER LEVEL
C IN THE 4-D MATRIX SO THAT CELLS INDICATED IN THE RECORD CAN BE ADDED TO
C THE MATRIX
C
C IF THE NUMBER OF RECORDS IN THE INPUT DATA SET IS LESS THAN 10, THE
C PROGRAM ABORTS
C
C IF (COUNT .GE. 10) THEN
C
C NOALL = 0
C
C DO 39 EE = 1, NDAY1
C DO 40 FF = 1, NTYP1
C NOREC(EE,FF) = 0
40 CONTINUE
39 CONTINUE
C
C DO 41 GG = 1, NDAY1
C DAYLEV(GG) = 0
41 CONTINUE
C
C DO 444 GZ = 1, NTYP1
C TYPE(GZ) = 0
444 CONTINUE
C
C COLCHC = MATSPC(1,8)
C J = 0
C
C EACH RECORD IN THE DATA SET IS PASSED THROUGH THIS LOOP
C
C 636 IF (J .GE. COUNT) GO TO 366
C J = J + 1
C
C COLCHC IS A LOOP CONTROL VARIABLE USED TO IDENTIFY RECORDS WITH THE
C SAME COLLECTION NUMBER SO THAT THE 2-D MATRICES FOR RECORDS WITHIN
C COLLECTIONS CAN BE COMPILED INTO ONE 2-D MATRIX.
C
C IF (MATSPC(J,8) .EQ. COLCHC) THEN
C
C CALL MATRIX(MATSPC(J,6), MATSPC(J,7), MATSPC(J,4), MATSPC(J,5),
C # SPCLOC, AVSEC, MATSPC(J,3), NROW1, NCOL1, MATSPC(J,8))
C
C CALL FREQ(SPCLOC, NROW1, NCOL1, FRQNO)
C CALL SUMTOT(AVSEC, NROW1, NCOL1, TOTOUT)
C COLCHC = MATSPC(J,8)
C
C ELSE
C
C BLOCKS = 0

```

```

DO 81 Z = 1, NROW1
  DO 82 Y = 1, NCOL1
    IF (FRQNO(Z,Y) .GT. 1) THEN
      FRQNO(Z,Y) = 1
    ENDIF
  C
    IF (FRQNO(Z,Y) .GT. 0) THEN
      BLOCKS = BLOCKS + 1
      SQRTOT(Z,Y) = (TOTOUT(Z,Y) ** 2)
    ENDIF
82   CONTINUE
81   CONTINUE
C
C   THIS STEP CALCULATES THE NUMBER OF COLLECTIONS IN EACH LEVEL
C   BY DAY AND TYPE (NOREC), THE NUMBER OF CELLS FILLED IN THE
C   MATRIX FOR EACH COLLECTION (BLOCNO) AND THE SQUARE OF THE NUMBER
C   OF CELLS FILLED FOR EACH COLLECTION (BLCSQR)
C
C
C   NOREC(MATSPC(J-1,2), MATSPC(J-1,1)) = NOREC(MATSPC(J-1,2),
#     MATSPC(J-1,1)) + 1
C   BLOCNO(MATSPC(J-1,2),MATSPC(J-1,1)) = BLOCNO(MATSPC(J-1,2),
#     MATSPC(J-1,1)) + BLOCKS
C   BLCSQR(MATSPC(J-1,2),MATSPC(J-1,1)) = BLCSQR(MATSPC(J-1,2),
#     MATSPC(J-1,1)) + (BLOCKS**2)
C
C
C   ONCE RECORDS HAVE BEEN COMPILED OVER A COLLECTION NUMBER THEY
C   ARE THEN COMPILED OVER LEVELS IN NTYP1 AND NDAY1
C
C   CALL SUM(FRQNO, MATSPC(J-1,2), MATSPC(J-1,1), NROW1, NCOL1, NTYP1,
#     NDAY1)
C   CALL SUM2(TOTOUT, MATSPC(J-1,2), MATSPC(J-1,1), NROW1, NCOL1, NTYP1,
#     NDAY1, SQRTOT)
C
C   RE-INITIALIZATION OF INTERMEDIATE MATRICIES BEFORE COMPIATION OVER
C   THE NEXT COLLECTION NUMBER
C
C   DO 83 ZZ = 1, NROW1
     DO 84 ZY = 1, NCOL1
       FRQNO(ZZ,ZY) = 0
       TOTOUT(ZZ,ZY) = 0
       SQRTOT(ZZ,ZY) = 0
84   CONTINUE
83   CONTINUE
C
C
C   CALL MATRIX(MATSPC(J,6), MATSPC(J,7), MATSPC(J,4), MATSPC(J,5),
#     SPCLOC, AVSPC, MATSPC(J,3), NROW1, NCOL1, MATSPC(J,8))
C
C   CALL FREQ(SPCLOC, NROW1, NCOL1, FRQNO)
C   CALL SUMTOT(AVSPC, NROW1, NCOL1, TOTOUT)

```

```

        COLCHC = MATSFC(J,8)
C
C
        ENDIF
C
C
C
        GO TO 636
366 CONTINUE
C
C
C
        THIS CONDITIONAL IF STATEMENT PERFORMS THE COMPUTATIONS FOR THE LAST
        RECORD OF THE INPUT DATA SET IF ITS COLLECTION NUMBER IS THE SAME AS
        THE PRECEDING RECORD BECAUSE THE ABOVE LOOP IS EXITED BEFORE THIS
        CAN BE DONE IN THAT CASE.
C
        IF (COLCHC .EQ. MATSFC(COUNT-1,8)) THEN
            BLOCKS = 0
            DO 91 ZP = 1, NROW1
                DO 92 YP = 1, NCOL1
                    IF (FRQNO(ZP,YP) .GT. 1) THEN
                        FRQNO(ZP,YP) = 1
                    ENDIF
C
                    IF (FRQNO(ZP,YP) .GT. 0) THEN
                        BLOCKS = BLOCKS + 1
                        SQRTOT(ZP,YP) = (TOTOUT(ZP,YP) ** 2)
                    ENDIF
                92 CONTINUE
            91 CONTINUE
C
            CALL SUM(FRQNO, MATSFC(J,2), MATSFC(J,1), NROWJ, NCOL1, NTYP1,
                # NDAY1)
            CALL SUM2(TOTOUT, MATSFC(J,2), MATSFC(J,1), NROW1, NCOL1, NTYP1,
                # NDAY1, SQRTOT)
C
            NOREC(MATSFC(J,2), MATSFC(J,1)) = NOREC(MATSFC(J,2),
                # MATSFC(J,1)) + 1
            BLOCNO(MATSFC(J,2), MATSFC(J,1)) = BLOCNO(MATSFC(J,2),
                # MATSFC(J,1)) + BLOCKS
            BLCSQR(MATSFC(J,2),MATSFC(J,1)) = BLCSQR(MATSFC(J,2),
                # MATSFC(J,1)) + (BLOCKS**2)
C
C
            ENDIF
C
C
C
        COUNTING COLLECTIONS:
        DO 47 II = 1, NDAY1
            DO 48 JJ = 1, NTYP1

```



```

      DAYLEV(II) = DAYLEV(II) + NOREC(II,JJ)
      TYPE(JJ) = TYPE(JJ) + NOREC(II,JJ)
48      CONTINUE
47      CONTINUE
C
      DO 49 MIM = 1,NDAY1
          NOALL = NOALL + DAYLEV(MIM)
49      CONTINUE
C
C
C
      ELSE
          WRITE(7,120)
120      FORMAT(' THERE IS INSUFFICIENT DATA TO RUN THIS PROGRAM')
          GO TO 12
      ENDIF
C
C
C
C
      THIS LOOP AND MENCEL AND VARCEL PRODUCE THE NUMBER OF BLOCKS OCCUPIED
      BY FISH AND THE SUM OF THE SQUARE OF THE NUMBER OF BLOCKS OCCUPIED BY
      ORGANISMS IN EACH COLLECTION SO THAT THE MEAN NUMBER OF BLOCKS (MENBLC)
      AND VARIANCE (VARBLC) PER COLLECTION BY NTYPE*NDAY1 LEVELS IS OUTPUT
C
C
      CELLNO = 0
      CELLSQR = 0
      DO 852 IBL = 1, NDAY1
          DO 853 JBL = 1,NTYP1
C
          IF (NOREC(IBL,JBL) .LE. 1) THEN
              IF (NOREC(IBL,JBL) .EQ. 1) THEN
                  MENBLC = BLOCNO(IBL, JBL)
                  VARBLC = 0
              ELSE
                  MENBLC = 0
                  VARBLC = 0
              ENDIF
C
          ELSE
C
              MENBLC = NINT(REAL(BLOCNO(IBL,JBL))/REAL(NOREC(IBL,JBL)))
              VARBLC = NINT((REAL(BLCSQR(IBL,JBL))-(REAL(BLOCNO(IBL,JBL))**2)/
#              REAL(NOREC(IBL,JBL))))/REAL(NOREC(IBL,JBL)-1))
C
          ENDIF
C
          WRITE(8,558) IBL, JBL, NOREC(IBL,JBL), BLOCNO(IBL,JBL),
#          BLCSQR(IBL,JBL), MENBLC, VARBLC
558      FORMAT(I3, 1X, I3, 1X, I4, 1X, I4, 1X, I4, 1X, I4, 1X, I4)
C
C

```

```

      CELINO = CELINO + BLOCNO(IBL,JBL)
      CELLSQR = CELLSQR + BLCGSR(IBL, JBL)
C
853   CONTINUE
852   CONTINUE
C
C
C
C   HERE THE MEAN NUMBER AND VARIANCE OF BLOCKS OCCUPIED BY FISH PER
C   COLLECTION FOR ALL DATA POOLED TOGETHER IS OUTPUT
C
      MENCEL = NINT(REAL(CELINO)/REAL(NOALL))
      VARCEL = NINT((REAL(CELLSQR)-(REAL(CELINO)**2)/REAL(NOALL))
#         /REAL(NOALL-1))
C
      WRITE(7,67) MENCEL, VARCEL, NOALL, COUNT
67   FORMAT( /' THE OVERALL AVERAGE NUMBER OF CELL = ', I4, 'WITH A
#     VARIANCE OF ', I4, ' AND A SAMPLE SIZE OF N = ', I5/' A TOTAL OF ',
#     I5, ' RECORDS WERE PROCESSED. '/')
C
C
C   THIS STEP PRODUCES THE ACTUAL OUTPUT DATA FILE
C
C   THIS STEP CREATES A MATRIX CONTAINING A RECORD FOR EACH CELL IN THE FOUR
C   DIMENSIONAL MATRIX OF FREQUENCY, NUMBER OF FISH AND NUMBER OF FISH
C   SQUARE, WITH VALUES GREATER THAN ZERO.  EACH RECORD CONTAINS INDEX
C   VALUES INDICATING ITS PROPER POSITION IN A 4-D MATRIX, SO THAT THE
C   MATRIX CAN BE RECREATED IN LATER PROGRAMS.  ALL RECORDS ARE OUTPUT TO
C   FILE 'OUT'.
C
      LEVEL = 0
      DO 17 INC = 1, NDAY1
      DO 18 JNC = 1, NTFYF1
      DO 19 KNC = 1, NROW1
      DO 20 LNC = 1, NCOL1
      IF (POSFRQ(KNC,LNC,JNC,INC) .GT. 0) THEN
          LEVEL = LEVEL + 1
          FRQOUT(LEVEL,1) = KNC
          FRQOUT(LEVEL,2) = LNC
          FRQOUT(LEVEL,3) = JNC
          FRQOUT(LEVEL,4) = INC
          FRQOUT(LEVEL,5) = POSFRQ(KNC,LNC,JNC,INC)
          SUMOUT(LEVEL,1) = POSAV(KNC,LNC,JNC,INC)
          SUMOUT(LEVEL,2) = SUMSOR(KNC,LNC,JNC,INC)
      ENDIF
C
20   CONTINUE
19   CONTINUE
18   CONTINUE
17   CONTINUE
C
C

```

```

DO 88 LEV = 1, LEVEL
  WRITE(6,21) FRQOUT(LEV,1), FRQOUT(LEV,2), FRQOUT(LEV,3),
#   FRQOUT(LEV,4), FRQOUT(LEV,5), SUMOUT(LEV,1), SUMOUT(LEV,2)
21  FORMAT(4(1X, I2), 1X, I3, 1X, F9.2, 1X, F12.3)
88  CONTINUE

C
  WRITE(7,854) LEVEL
854 FORMAT(' THERE ARE ', I3, ' CELLS FILLED IN THE MATRIX'/'1')
C
12  CONTINUE
    STOP
    END

C
C
C
C
C
SUBROUTINE MATRIX(YI, YII, XI, XII, OUT, OUT2, FISHNO, NROW2, NCOL2
#   OBSNO)
C
C   PRODUCES AN OUTPUT MATRIX IN WHICH EACH CELL REPRESENTS A SQUARE
C   METER OF WATER AREA DEFINED BY ROW AND COLUMN INDICES (Y AND X
C   COORDINATE) WITHIN A 25 X 14 M AREA AROUND AN FAD. THE OUTPUT
C   MATRIX CONTAINS THE FREQUENCY AT WHICH FISH OCCURRED IN THE
C   COORESPONDING SQUARE METER AREA FOR A SINGLE RECORD.
C
C
C
C   ARGUMENTS:
C   INPUT:
C     YI - INITIAL VALUE OF DO LOOP DEFINED BY RANGE OF FISH
C         POSITION ALONG Y-AXIS
C     YII - END RANGE VALUE OF Y-AXIS POSITIONS
C     XI - INITIAL VALUE OF DO LOOP DEFINED BY RANGE OF FISH
C         POSITION ALONG X-AXIS
C     XII - FINAL VALUE ALONG X-AXIS
C     OBSNO - COLLECTION NUMBER
C
C   OUTPUT:
C     OUT: A TWO DIMENSIONAL MATRIX OF FISH FREQ. WITHIN BLOCKS
C     OUT2: A 2-D MATRIX FISH NO. PER SQUARE METER FOR BLOCKS IN
C           WHICH THEY OCCUR IN A GIVEN RECORD
C
COMMON/NOBLOC/ BLOCKS, BLOCNO(8,6), BLCSQR(8,6)
C
INTEGER BLOCKS, BLOCNO, BLCSQR
C
LOCAL DECLARATIONS
C
INTEGER XI, XII, YI, YII, NROW2, NCOL2, K2, M, FISHNO, T, S, L,
# N, NPOS, OBSNO
C

```

```

C      INTEGER OUT(NROW2, NCOL2)
      REAL OUT2(NROW2, NCOL2)
      REAL AVEFSH
C
      NPOS = 0
      DO 50 T = 1, NROW2
        DO 51 S = 1, NCOL2
          OUT(T,S) = 0
          OUT2(T,S) = 0
51      CONTINUE
50      CONTINUE
C
C      IF (YII .GT. NROW2) THEN
        WRITE(7,656) YII
656      FORMAT(' ERROR SUBSCRIPT YII = ', I3, ' IS OUT OF RANGE')
        GO TO 444
      ENDIF
C
      IF (XII .GT. NCOL2) THEN
        WRITE(7, 657) XII
657      FORMAT(' ERROR SUBSCRIPT XII = ', I3, ' IS OUT OF RANGE')
        GO TO 444
      ENDIF
C
C      OUTER DO LOOP TO FILL IN ELEMENTS FROM ROW YI TO ROW YII
C
      IF (YI .GT. YII .OR. XI .GT. XII) THEN
        WRITE(7,821) YI, YII, XI, XII
821      FORMAT(' ERROR CHECK X AND Y VALUES YI-YII = ',
#       I2, 1X, I2, ' XI-XII ', I2, 1X, I2)
        GO TO 444
      ENDIF
C
      DO 52 K2 = 1, NROW2
C
C      INNER LOOP TO FILL IN ELEMENTS FROM COLUMN XI TO XII
C
      DO 53 M = 1, NCOL2
        IF(K2 .GE. YI .AND. K2 .LE. YII .AND. M .GE. XI .AND. M .LE. XII)
#         THEN
          OUT(K2,M) = 1
          NPOS = NPOS + 1
        ELSE
          OUT(K2,M) = 0
        ENDIF
53      CONTINUE
52      CONTINUE
C
C      THIS IS THE TOTAL NUMBER OF SQUARE METER BLOCKS OCCUPIED BY
C      FISH IN THIS RECORD, THE NUMBER OF FISH PER CELL IS FOUND BY

```

```

C   DIVIDING THE TOTAL NUMBER OF FISH (FISHNO) BY THE NUMBER OF
C   CELLS OCCUPIED (NPOS)
C
C   IF (FISHNO .LE. 0 .OR. NPOS .LE. 0) THEN
C       WRITE(7,892) FISHNO, NPOS
892  FORMAT(' ERROR DIVISION OF OR BY ZERO, FISHNO = ', I5, ' NPOS = ' 13)
C       GO TO 444
C   ENDIF
C
C   AVEFSH = REAL(FISHNO)/REAL(NPOS)
C
C   DO 54 L = 1, NROW2
C       DO 55 N = 1, NCOL2
C
C           IF (L .GE. YI .AND. L .LE. YII .AND. N .GE. XI .AND. N .LE. XII)
C           # THEN
C               OUT2(L,N) = AVEFSH
C           ELSE
C               OUT2(L,N) = 0.0
C           ENDIF
C
C   55  CONTINUE
C   54  CONTINUE
C
C   444 CONTINUE
C
C   RETURN
C   END
C
C
C   SUBROUTINE FREQ(IN, ROWIN, COLIN, OUT)
C
C   THIS PRODUCES A 2-D MATRIX OF DATA FROM SUBROUTINE MATRIX POOLED OVER
C   A COLLECTION NUMBER.  THE FREQUENCY OF FISH OCCURRING WITHIN CELLS IN
C   THE MATRIX OVER A SINGLE COLLECTION NUMBER ARE THEN PASSED BACK TO THE
C   MAIN PROGRAM
C
C
C   INTEGER ROWIN, COLIN, TOTR, TOTC
C   INTEGER IN(ROWIN, COLIN), OUT(ROWIN, COLIN)
C
C   DO 77 TOTR = 1, ROWIN
C       DO 78 TOTC = 1, COLIN
C           OUT(TOTR,TOTC) = OUT(TOTR,TOTC) + IN(TOTR,TOTC)
C   78  CONTINUE
C   77  CONTINUE
C       RETURN
C   END
C
C
C
C

```

```

SUBROUTINE SUMTOT(IN2, ROWIN2, COLIN2, OUTOT)
C
C
C THIS PROGRAM SUMS THE 2-D MATRIX OUTPUT FROM SUBROUTINE MATRIX TO
C PRODUCE A 2-D MATRIX OF THE NUMBER OF FISH PER CELL FOR A GIVEN
C COLLECTION NUMBER WHICH IS THEN OUTPUT TO THE MAIN PROGRAM
C
C
C INTEGER ROWIN2, COLIN2, SUMR, SUMC
C REAL IN2(ROWIN2,COLIN2), OUTOT(ROWIN2,COLIN2)
C
C DO 79 SUMR = 1, ROWIN2
C   DO 80 SUMC = 1, COLIN2
C     OUTOT(SUMR,SUMC) = OUTOT(SUMR,SUMC) + IN2(SUMR,SUMC)
80 CONTINUE
79 CONTINUE
RETURN
END
C
C
C SUBROUTINE SUM(MAT2, DIDEX, FIDEX, NROW3, NCOL3, NTYP3, NDAY3)
C
C THIS ROUTINE PERFORMS AN ELEMENT BY ELEMENT ADDITION OF TWO
C MATRICIES FOR ROW AND COLUMNS ONLY. THE 2-D MATRIX OUTPUT FROM
C SUBROUTINE FREQ FOR EACH COLLECTION NUMBER ARE THEN ADDED UP AND
C THE TEMPORARY TWO LEVEL MATRIX IS ADDED TO THE CORRESPONDING ELEMENTS
C IN A PERMAMENT 4-D MATRIX AND OUTPUT.
C
C
C COMMON/OUTPUT/ POSFRQ(14,25,6,8), POSAV(14,25,6,8), SUMSQR(14,25,6,8)
C INTEGER NROW3, NCOL3, RR, COC, NTYP3, NDAY3, DIDEX, FIDEX
C
C INPUT MATRIX
C
C INTEGER MAT2(NROW3, NCOL3)
C
C OUTPUT MATRIX
C
C INTEGER POSFRQ
C REAL POSAV, SUMSQR
C
C DO 56 RR = 1, NROW3
C   DO 57 COC = 1, NCOL3
C     POSFRQ(RR, COC, FIDEX, DIDEX) = POSFRQ(RR, COC, FIDEX, DIDEX)
C     # + MAT2(RR, COC)
57 CONTINUE
56 CONTINUE
RETURN
END

```

```

C
C
C
SUBROUTINE SUM2(MAT4, D, F, NROW4, NCOL4, NTYP4, NDAY4, MAT5)
C
C THIS ROUTINE PERFORMS AN ELEMENT BY ELEMENT ADDITION OF TWO
C MATRICIES CONTAINING REAL VALUES FOR ROW AND COLUMNS ONLY.
C THE 2-D MATRIX OUTPUT FORM SUBROUTINE SUMTOT AND MAIN PROGRAM
C ARE SUMMED UP FOR EACH COLLECTION NUMBER AND THIS TEMPORARY 2-D
C MATRIX IS ADDED TO THE CORRESPONDING ELEMENTS IN A PERMANENT 4-D MATRIX
C
C
C COMMON/OUTPUT/ POSFRQ(14,25,6,8), POSAV(14,25,6,8), SUMSQR(14,25,6,8)
C
C INTEGER NROW4, NCOL4, R, COUN, NTYP4, NDAY4, F, D
C
C INTEGER POSFRQ
C REAL POSAV, SUMSQR
C REAL MAT4(NROW4, NCOL4), MAT5(NROW4, NCOL4)
C
C
C DO 58 R = 1, NROW4
C   DO 59 COUN = 1, NCOL4
C     POSAV(R, COUN, F, D) = POSAV(R, COUN, F, D) + MAT4(R, COUN)
C     SUMSQR(R, COUN, F, D) = SUMSQR(R, COUN, F, D) + MAT5(R, COUN)
59   CONTINUE
58 CONTINUE
C
C RETURN
C END
C

```

Appendix A.4. Program Posmean.F77


```

C
C *****
C *
C * PROGRAM: POSMEAN.F77
C *
C * WRITTEN BY RODNEY ROUNTREE DATE: 10 OCTOBER 1986
C *
C * PURPOSE: THIS PROGRAM PRODUCES AN OUTPUT FILE CONTAINING THE PER-
C * CENT FREQUENCY OF OCCURRENCE OF FISH WITHIN EACH ONE
C * SQUARE METER BLOCK AROUND A FAD. IT ALSO PRODUCES THE
C * MEAN NUMBER OF FISH AND VARIANCE OF FISH IN EACH BLOCK.
C *
C *-----*
C *
C * THERE ARE SIX DATA FILES OUTPUT FROM THIS PROGRAM AND TWO FILES INPUT
C * FROM DISTPOS.F77. EACH FILE CONTAINS THE INDICIES OF ROW AND COLUMN
C * REPRESENTING A SQUARE-METER CELL IN THE WATER COLUMN UP OR DOWN CUR-
C * RENT OF A FAD. INDICIES OF DAY NUMBER AND TYPE FAD NUMBER MAY ALSO
C * BE PRESENT. IN THE OUTPUT FILES EACH RECORD ALSO CONTAINS THE FRE-
C * QUENCY OCCUPIED, SUM OF THE NUMBER OF FISH AND SUM OF SQUARES.
C *
C * INPUT:
C *
C * INPUT.POS: THIS FILE CONTAINS DATA FOR EACH TYPE FAD WITHIN
C * DAY, SO IT HAS INDICIES FOR ROW, COLUMN, FAD TYPE
C * AND DAY. EACH RECORD ALSO CONTAINS THE FREQUENCY
C * OCCUPIED, SUM OF THE NUMBER OF FISH AND SUM OF
C * SQUARES.
C *
C * SAMNO: FILE CONTAINING THE NUMBER OF RECORDS (COLLECTIONS)
C * FOR EACH BY LEVEL AND DAY AND TYPE.
C * **SAMNO, AS OUTPUT FROM DISTPOS.F77, CONTAINS DATA
C * ONLY FOR NON-ZERO COLLECTIONS. YOU MAY WISH TO
C * MODIFY IT BY DEFINING YOUR SAMPLE SIZES TO INCLUDE
C * ZERO COUNTS BEFORE RUNNING THIS PROGRAM.
C *
C * OUTPUT:
C *
C * POSMEAN: THIS FILE CONTAINS DATA FOR EACH FAD TYPE WITHIN EACH
C * DAY SO IT HAS INDICIES FOR ROW, COLUMN, FAD TYPE AND
C * DAY.
C *
C * DAYMEAN: THIS FILE CONTAINS DATA FOR EACH FAD TYPE WITHIN EACH
C * DAY SO IT HAS INDICIES FOR ROW, COLUMN, FAD TYPE AND
C * DAY.
C *
C * TYPEMEAN: THIS FILE CONTAINS DATA COMPILED FOR EACH FAD TYPE FOR
C * ALL DAYS COMBINED. IT HAS INDICIES FOR ROW, COLUMN
C * AND FAD TYPE.
C *
C * ALLTOT: THIS FILE CONTAINS DATA COMPILED OVER ALL OBSERVATIONS
C * IT HAS INDICIES FOR ROW AND COLUMN ONLY.

```

```

C *
C *      ARCTOT:      THIS FILE CONTAINS DATA COMPILED OVER ALL OBSERVATIONS *
C *                  FOR FAD TYPES 1-TYPCON ONLY. IT HAS INDICIES FOR ROW *
C *                  AND COLUMN ONLY. **THE PARAMETER TYPCON ALLOWS YOU *
C *                  TO COMPUT DATA FOR A SUBSET OF NTYP. *
C *
C *      DAYABC:      THIS FILE CONTAINS DATA COMPILED OVER FAD TYPES *
C *                  1-TYPCON FOR EACH DAY. IT HAS INDICIES FOR ROW, *
C *                  COLUMN AND DAY. *
C *
C *****
C
C
C
C
C      INTEGER NROW, NCOL, NTYP, NDAY, TYPCON, SIZE
C      PARAMETER(NROW = 14, NCOL=25, NTYP=6, NDAY=8, TYPCON=3, SIZE=5000)
C
C      (NOTE ** THE PARAMETER TYPCON ALLOWS YOU TO COMPILE DATA OVER A SUBSET
C      OF THE NTYP LEVELS SEPARATLY, PROVIDED THE DATA ARE ORDERED PROPERLY.
C      SIZE DEFINES THE MAXIMUM NUMBER OF RECORDS WHICH CAN BE INPUT, FOR THE
C      4-D MATRIX DEFINED BY THE ABOVE VARIABLES, THE MAXIMUM NUMBER OF RECORDS
C      POSSIBLE WOULD BE 16800, IF ALL CELLS WERE FILLED.
C
C
C      INTEGER NUM(NDAY,NTYP), DAY(NDAY), FAD(NTYP), ABC(NDAY)
C
C      INTEGER Y, X, TYP, TYM, FRQ, COUNT, IQ, XL, YL, ZED, YED, I,
C      #   SAMNO, TOTNUM, NUMBER, T, D
C
C      REAL SUM, SQR
C      REAL RELNUM(SIZE,3)
C      REAL TOTSUM(NROW, NCOL, 2), TOTSQR(NROW,NCOL,2),
C      #   TOTPER(NROW,NCOL,2), TOTMEN(NROW,NCOL,2), TOTVAR(NROW,NCOL,2)
C
C      REAL DAYSUM(NROW,NCOL,NDAY), DAYSQR(NROW,NCOL,NDAY),
C      #   DAYPER(NROW,NCOL,NDAY), DAYMEN(NROW,NCOL,NDAY),
C      #   DAYVAR(NROW,NCOL,NDAY)
C
C      REAL ABCSUM(NROW,NCOL,NDAY), ABCSQR(NROW,NCOL,NDAY),
C      #   ABCPER(NROW,NCOL,NDAY), ABCHEN(NROW,NCOL,NDAY),
C      #   ABCVAR(NROW,NCOL,NDAY)
C
C      REAL TYFSUM(NROW,NCOL,NTYP), TYFSQR(NROW,NCOL,NTYP),
C      #   TYPPER(NROW,NCOL,NTYP), TYPMEN(NROW,NCOL,NTYP),
C      #   TYPVAR(NROW,NCOL,NTYP)
C
C      INTEGER TOTFRQ(NROW,NCOL,2), DAYFRQ(NROW,NCOL,NDAY),
C      #   TYPFREQ(NROW,NCOL,NTYP), ABCFRQ(NROW,NCOL,NDAY)
C
C
C      OPEN(5, FILE = 'INPUT.POS', STATUS = 'OLD', PAD = 'YES', RECFM = 'DS')
C      OPEN(6, FILE = 'POSMEAN', STATUS = 'FRESH')

```

```

OPEN(7, FILE = 'DAYMEAN', STATUS = 'FRESH')
OPEN(8, FILE = 'TYIMEAN', STATUS = 'FRESH')
OPEN(9, FILE = 'ALLTOT', STATUS = 'FRESH')
OPEN(10, FILE = 'ABCTOT', STATUS = 'FRESH')
OPEN(11, FILE = 'DAYABC', STATUS = 'FRESH')
OPEN(13, FILE = 'SAMNO', STATUS = 'OLD', PAD = 'YES', RECFM = 'DS')
C
C
DO 190 T = 1, NTYP
  DO 191 D = 1, NDAY
    NUM(D,T) = 0
191  CONTINUE
190  CONTINUE
C
DO 19 IN=1,NDAY
  DAY(IN) = 0
  ABC(IN) = 0
C
DO 21 IJ=1,NROW
  DO 22 JI=1,NCOL
    DAYFRQ(IJ,JI,IN) = 0
    DAYSUM(IJ,JI,IN) = 0
    DAYSQR(IJ,JI,IN) = 0
    DAYPER(IJ,JI,IN) = 0
    DAYMEN(IJ,JI,IN) = 0
    DAYVAR(IJ,JI,IN) = 0
22  CONTINUE
21  CONTINUE
19  CONTINUE
C
DO 40 INT = 1,NTYP
  FAD(INT) = 0
  DO 41 JNT = 1,NROW
    DO 42 KNT = 1,NCOL
      TYFFRQ(JNT,KNT,INT) = 0
      TYFSUM(JNT,KNT,INT) = 0
      TYFSQR(JNT,KNT,INT) = 0
      TYFPER(JNT,KNT,INT) = 0
      TYFMEN(JNT,KNT,INT) = 0
      TYFVAR(JNT,KNT,INT) = 0
C
      IF (INT .LE. TYPCON) THEN
        ABCFRQ(JNT,KNT,INT) = 0
        ABCSUM(JNT,KNT,INT) = 0
        ABCSQR(JNT,KNT,INT) = 0
        ABCPER(JNT,KNT,INT) = 0
        ABCMEN(JNT,KNT,INT) = 0
        ABCVAR(JNT,KNT,INT) = 0
      ENDIF
42  CONTINUE
41  CONTINUE
40  CONTINUE

```

```

C
DO 43 KNJ = 1,2
  DO 44 INJ = 1,NROW
    DO 45 JIN = 1,NCOL
      TOTFRQ(INJ,JIN,KNJ) = 0
      TOTSUM(INJ,JIN,KNJ) = 0
      TOTSQL(INJ,JIN,KNJ) = 0
      TOTPER(INJ,JIN,KNJ) = 0
      TOTMEN(INJ,JIN,KNJ) = 0
      TOTVAR(INJ,JIN,KNJ) = 0
45    CONTINUE
44  CONTINUE
43  CONTINE
C
C
  IQ = 0
87  IF (.TRUE.) CONTINUE
    IQ = IQ + 1
    READ(13,88,END=89) XL, YL, SAMNO
88  FORMAT(I3, 1X, I3, 1X, I4)
C
    NUM(XL,YL) = SAMNO
C
    GO TO 87
89  CONTINUE
C
C
  TOTNUM = 0
  NUMBER = 0
C
  DO 99 ZED = 1, NDAY
    DO 100 YED = 1, NTPY
      DAY(ZED) = NUM(ZED,YED) + DAY(ZED)
      FAD(YED) = NUM(ZED,YED) + FAD(YED)
      TOTNUM = TOTNUM + NUM(ZED,YED)
C
      IF (YED .LE. TYPCON) THEN
        ABC(ZED) = ABC(ZED) + NUM(ZED,YED)
        NUMBER = NUMBER + NUM(ZED,YED)
      ENDIF
C
100  CONTINUE
99  CONTINUE
C
C
  I = 0
9   IF (.TRUE.) CONTINUE
    I = I + 1
    READ(5, 10, END = 11) Y, X, TYP, TYM, FRQ, SUM, SQR
10  FORMAT(4(I3, I2), 1X, I3, 1X, F9.2, 1X, F12.3)
C
    IF (NUM(TYM,TYP) .GT. 1) THEN

```

```

      IF (FRQ .GT. 0) THEN
        RELNUM(I,1) = REAL(FRQ)/REAL(NUM(TYM,TYP))
        RELNUM(I,2) = SUM/REAL(NUM(TYM,TYP))
        RELNUM(I,3) = (SQR - (SUM**2)/REAL(NUM(TYM,TYP)))/
#       REAL(NUM(TYM,TYP)-1)
      ELSE
        RELNUM(I,1) = 0
        RELNUM(I,2) = 0
        RELNUM(I,3) = 0
      ENDIF
C
      ELSE
        RELNUM(I,1) = REAL(FRQ)
        RELNUM(I,2) = SUM
        RELNUM(I,3) = 0
      ENDIF
C
C
      WRITE(6, 55) Y, X, TYP, TYM, FRQ, SUM, SQR, RELNUM(I,1), RELNUM(I,2),
#       RELNUM(I,3), NUM(TYM,TYP)
55     FORMAT(4(1X, I2), 1X, I3, 1X, F9.2, 4(1X, F12.3), 1X, I2)
C
C
      DAYFRQ(Y,X,TYM) = DAYFRQ(Y,X,TYM) + FRQ
      DAYSUM(Y,X,TYM) = DAYSUM(Y,X,TYM) + SUM
      DAYSQR(Y,X,TYM) = DAYSQR(Y,X,TYM) + SQR
C
      TYPFREQ(Y,X,TYP) = TYPFREQ(Y,X,TYP) + FRQ
      TYPSUM(Y,X,TYP) = TYPSUM(Y,X,TYP) + SUM
      TYPSQR(Y,X,TYP) = TYPSQR(Y,X,TYP) + SQR
C
      TOTFRQ(Y,X,2) = TOTFRQ(Y,X,2) + FRQ
      TOTSUM(Y,X,2) = TOTSUM(Y,X,2) + SUM
      TYPSQR(Y,X,2) = TYPSQR(Y,X,2) + SQR
C
      IF (TYP .LE. TYPCON) THEN
        TOTFRQ(Y,X,1) = TOTFRQ(Y,X,1) + FRQ
        TOTSUM(Y,X,1) = TOTSUM(Y,X,1) + SUM
        TOTSQR(Y,X,1) = TOTSQR(Y,X,1) + SQR
        ABCFRQ(Y,X,TYM) = ABCFRQ(Y,X,TYM) + FRQ
        ABCSUM(Y,X,TYM) = ABCSUM(Y,X,TYM) + SUM
        ABCSQR(Y,X,TYM) = ABCSQR(Y,X,TYM) + SQR
      ENDIF
C
      GO TO 9
11     CONTINUE
      COUNT = I - 1
C
C
C
      DO 30 IR = 1,NROW
        DO 31 JC = 1,NCOL

```

```

      IF (TOTNUM .GT. 1) THEN
        IF (TOTFRQ(IR,JC,2) .GT. 0) THEN
          TOTPER(IR,JC,2) = REAL(TOTFRQ(IR,JC,2))/REAL(TOTNUM)
          TOTMEN(IR,JC,2) = TOTSUM(IR,JC,2)/REAL(TOTNUM)
          TOTVAR(IR,JC,2) = (TOTSQR(IR,JC,2)-((TOTSUM(IR,JC,2)**2)/
# REAL(TOTNUM)))/REAL(TOTNUM-1)
        ELSE
          TOTPER(IR,JC,2) = 0
          TOTMEN(IR,JC,2) = 0
          TOTVAR(IR,JC,2) = 0
        ENDIF
      C
    ELSE
      TOTPER(IR,JC,2) = REAL(TOTFRQ(IR,JC,2))
      TOTMEN(IR,JC,2) = TOTSUM(IR,JC,2)
      TOTVAR(IR,JC,2) = 0
    ENDIF
  C
  C
    IF (TOTFRQ(IR,JC,2) .NE. 0) THEN
      WRITE(9, 66) IR, JC, TOTFRQ(IR,JC,2), TOTSUM(IR,JC,2),
# TOTSQR(IR,JC,2), TOTPER(IR,JC,2), TOTMEN(IR,JC,2),
# TOTVAR(IR,JC,2), TOTNUM
66   FORMAT(I2, I2, I3, F9.2, 4(F12.3), 1X, I4)
    ENDIF
  C
  C
    TOTPER(IR,JC,1) = REAL(TOTFRQ(IR,JC,1))/REAL(NUMBER)
    TOTMEN(IR,JC,1) = TOTSUM(IR,JC,1)/REAL(NUMBER)
    TOTVAR(IR,JC,1) = (TOTSQR(IR,JC,1)-((TOTSUM(IR,JC,1)**2)/
# REAL(NUMBER)))/REAL(NUMBER-1)
  C
    IF (TOTFRQ(IR,JC,1) .NE. 0) THEN
      WRITE(10, 66) IR, JC, TOTFRQ(IR,JC,1), TOTSUM(IR,JC,1),
# TOTSQR(IR,JC,1), TOTPER(IR,JC,1), TOTMEN(IR,JC,1),
# TOTVAR(IR,JC,1), NUMBER
    ENDIF
  C
  C
31   CONTINUE
30   CONTINUE
  C
  C
DO 32 I1 = 1, NDAY
  DO 33 I2 = 1, NROW
    DO 34 I3 = 1, NCOL
      IF (DAY(I1) .GT. 1) THEN
        IF (DAYFRQ(I2,I3,I1) .GT. 0) THEN
          DAYPER(I2,I3,I1) = REAL(DAYFRQ(I2,I3,I1))/REAL(DAY(I1))
          DAYMEN(I2,I3,I1) = DAYSUM(I2,I3,I1)/REAL(DAY(I1))
          DAYVAR(I2,I3,I1) = (DAYSUM(I2,I3,I1)-((DAYSUM(I2,I3,I1)**2)/
# REAL(DAY(I1))))/REAL(DAY(I1)-1)

```

```

ELSE
    DAYPER(I2,I3,I1) = 0
    DAYMEN(I2,I3,I1) = 0
    DAYVAR(I2,I3,I1) = 0
ENDIF
ELSE
    DAYPER(I2,I3,I1) = REAL(DAYFRQ(I2,I3,I1))
    DAYMEN(I2,I3,I1) = DAYSUM(I2,I3,I1)
    DAYVAR(I2,I3,I1) = 0
ENDIF
C
IF (DAYFRQ(I2,I3,I1) .NE. 0) THEN
    WRITE(7,67) I2, I3, I1, DAYFRQ(I2,I3,I1), DAYSUM(I2,I3,I1),
#       DAYSQR(I2,I3,I1), DAYPER(I2,I3,I1), DAYMEN(I2,I3,I1),
#       DAYVAR(I2,I3,I1), DAY(I1)
67    FORMAT(3(I2), I3, F9.2, 4(F12.3), 1X, I2)
ENDIF
C
IF (ABC(I1) .GT. 1) THEN
    IF (ABCFRQ(I2,I3,I1) .GT. 0) THEN
        ABCPER(I2,I3,I1) = REAL(ABCFRQ(I2,I3,I1))/REAL(ABC(I1))
        ABCMEN(I2,I3,I1) = ABCSUM(I2,I3,I1)/REAL(ABC(I1))
        ABCVAR(I2,I3,I1) = (ABCSQR(I2,I3,I1)-((ABCSUM(I2,I3,I1)**2)/
#           REAL(ABC(I1))))/REAL(ABC(I1)-1)
    ELSE
        ABCPER(I2,I3,I1) = 0
        ABCMEN(I2,I3,I1) = 0
        ABCVAR(I2,I3,I1) = 0
    ENDIF
C
ELSE
    ABCPER(I2,I3,I1) = REAL(ABCFRQ(I2,I3,I1))
    ABCMEN(I2,I3,I1) = ABCSUM(I2,I3,I1)
    ABCVAR(I2,I3,I1) = 0
ENDIF
C
IF (ABCFRQ(I2,I3,I1) .NE. 0) THEN
    WRITE(11,67) I2, I3, I1, ABCFRQ(I2,I3,I1), ABCSUM(I2,I3,I1),
#       ABCSQR(I2,I3,I1), ABCPER(I2,I3,I1), ABCMEN(I2,I3,I1),
#       ABCVAR(I2,I3,I1), ABC(I1)
ENDIF
C
34    CONTINUE
33    CONTINUE
32    CONTINUE
C
DO 35 JJ = 1, NTFP
    DO 36 JJJ = 1, NROW
        DO 37 JOE = 1, NCOL
            IF (FAD(JJ) .GT. 1) THEN
                IF (TYPFRQ(JJJ,JOE,JJ) .GT. 0) THEN

```

```

        TYPPER(JJJ,JOE,JJ) = REAL(TYFFRQ(JJJ,JOE,JJ))/REAL(FAD(JJ))
        TYPMEN(JJJ,JOE,JJ) = TYPSUM(JJJ,JOE,JJ)/REAL(FAD(JJ))
        TYPVAR(JJJ,JOE,JJ) = (TYPSQR(JJJ,JOE,JJ)-((TYPSUM(JJJ,JOE,
#         JJ)**2)/REAL(FAD(JJ))))/REAL(FAD(JJ)-1)
        ELSE
            TYPPER(JJJ,JOE,JJ) = 0
            TYPMEN(JJJ,JOE,JJ) = 0
            TYPVAR(JJJ,JOE,JJ) = 0
        ENDIF
    ELSE
        TYPPER(JJJ,JOE,JJ) = REAL(TYFFRQ(JJJ,JOE,JJ))
        TYPMEN(JJJ,JOE,JJ) = TYPSUM(JJJ,JOE,JJ)
        TYPVAR(JJJ,JOE,JJ) = 0
    ENDIF
C
    IF (TYFFRQ(JJJ,JOE,JJ) .NE. 0) THEN
        WRITE(8, 67) JJJ, JOE, JJ, TYFFRQ(JJJ,JOE,JJ),
#         TYPSUM(JJJ,JOE,JJ), TYPSQR(JJJ,JOE,JJ), TYPPER(JJJ,JOE,JJ),
#         TYPMEN(JJJ,JOE,JJ), TYPVAR(JJJ,JOE,JJ), FAD(JJ)
    ENDIF
C
37     CONTINUE
36     CONTINUE
35     CONTINUE
C
C
    STOP
    END

```


Appendix A.5. Programs Graph.Type.F77, Graph.Day.F77 and Graph.Tot.F77 for graphing frequency and density distributions of fishes about FADs compiled over type or day factors, or over all factors combined.

```

C *****
C *
C * PROGRAM: GRAPH.TYPE.F77
C *
C * WRITEN BY RODNEY ROUNTREE DATE: 10 OCTOBER 1986
C *
C * PURPOSE: THIS PROGRAM GRAPHS THE PERCENT FREQUENCY OF OCCURENCE,
C * AND MEAN OF FISH OCCUPING SQUARE METER CELLS AROUND A
C * COMPOSITE FAD POOLED OVER EACH TYPE SEPARATLY. IT ALSO
C * OUTPUTS THE SAMPLE SIZE, NUMBER OF CELLS FILLED AND THE
C * MEAN NUMBER OF CELLS OCCUPIED PER COLLECTION.
C *
C * INPUT: TYPMEAN: FILE OUTPUT FROM PROGRAM POSMEAN.F77 WHICH
C * CONTAINS INDICIES FOR THE TYPE FACTOR, THE
C * PERCENT OCCURENCE OF FISH IN EACH CELL AND THE
C * MEAN OF THE NUMBER OF FISH IN EACH CELL.
C *
C * SAMNO: FILE OUTPUT FROM PROGRAM DISIFOS.F77 CONTAINING
C * INDICIES FOR DAY AND TYPE FACTORS, THE NUMBER
C * OF NON-ZERO COLLECTIONS, THE SUM OF THE NUMBER
C * OF BLOCKS PER COLLECTION OCCUPIED BY FISH AND
C * THE SUM OF THE SQRUARES.
C *
C * OUTPUT: GRAPH2.OUT: GRAPHS OF THE DISTRIBUTIONS OF FISH
C * OCCURENCE AND MEANS ABOUT FADS OF EACH TYPE
C *
C *****
C
C INTEGER Y, X, FREQ, NROW, NCOL, N, TYPE, NREC, NTYPE, TYP, SUMC, SQRC,
C # LEV
C PARAMETER(NROW=14, NCOL=25, NTYPE=6)
C INTEGER CELL(NTYPE), SAMPLE(NTYPE), TYPREC(NTYPE), BLOCKS(NTYPE),
C # BLCSQR(NTYPE)
C INTEGER LABEL(NROW)
C
C REAL SUM, SQR, PERCNT, MEAN, VAR
C REAL PERMAT(NROW, NCOL, NTYPE), MENMAT(NROW, NCOL, NTYPE)
C REAL BLCMEN(NTYPE), BLCVAR(NTYPE)
C
C OPEN(9, FILE='GRAPH.IN', STATUS='OLD', PAD='YES', RECFM='DS')
C OPEN(10, FILE='GRAPH2.OUT', STATUS='FRESH', CARRIAGECONTROL =
C #'FORTRAN')
C OPEN(11, FILE='SAMNO', STATUS='OLD', PAD='YES', RECFM='DS')
C
C DO 9 IZ = 1, NTYPE
C CELL(IZ) = 0
C SAMPLE(IZ)=0
C TYPREC(IZ)=0
C BLOCKS(IZ)=0
C BLCSQR(IZ)=0

```

```

        BLCMEN(I7)=0
        BLCVAR(I7)=0
9      CONTINUE
C
      DO 10 IR = 1,NROW
        DO 11 IC =1,NCOL
          DO 111 IT = 1,NTYP
            PERMAT(IR,IC,IT) = 0
            MENMAT(IR,IC,IT) = 0
111      CONTINUE
11      CONTINUE
10      CONTINUE
C
C
      I = 0
19      IF (.TRUE.) CONTINUE
          I = I + 1
          READ(9,20, END=21) Y, X, TYP, FREQ, SUM, SQR, PERCNT, MEAN, VAR, N
20      FORMAT(I2, I2, I2, I3, F9.2, 4(F12.3), 1X, I4)
          PERMAT(Y,X,TYP) = PERCNT*100.0
          MENMAT(Y,X,TYP) = MEAN
          SAMPLE(TYP) = N
          CELL(TYP) = CELL(TYP) + 1
          GO TO 19
21      CONTINUE
          I = I - 1
C
C
29      IF (.TRUE.) CONTINUE
          READ(11,30,END=31) TYPE, NREC, SUMC, SQRC
30      FORMAT(4X, I3, 1X, I4, 1X, I4, 1X, I4)
          TYPREC(TYPE) = TYPREC(TYPE) + NREC
          BLOCKS(TYPE) = BLOCKS(TYPE) + SUMC
          BLCSQR(TYPE) = BLCSQR(TYPE) + SQRC
          GO TO 29
31      CONTINUE
C
C
      DO 112 ITYP = 1,NTYP
        IF (SAMPLE(ITYP) .LT. 1) THEN
          WRITE(10,28)
28      .   FORMAT('THERE WERE ZERO COLLECTIONS FOR THIS TYPE, NO GRAPH WAS
#         PRINTED ')
C
        ELSE
          IF (TYPREC(ITYP) .GT. 1) THEN
            BLCMEN(ITYP) = REAL(BLOCKS(ITYP))/REAL(TYPREC(ITYP))
            BLCVAR(ITYP) = SQRT(REAL(BLCSQR(ITYP)-(BLOCKS(ITYP)**2)
#              /REAL(TYPREC(ITYP)))/REAL(TYPREC(ITYP)-1))
C
          ELSE
            BLCMEN(ITYP) = REAL(BLOCKS(ITYP))

```

```

        BLCVAR(ITYP) = 0
    ENDIF
C
    WRITE(10, 99)
99    FORMAT('1PERCENT OCCURRENCE OF FISH WITHIN SQUARE METER CELLS//')
C
    WRITE(10,22) SAMPLE(ITYP), ITYP, BLCMEN(ITYP), BLCVAR(ITYP),
#       TYPREC(ITYP), CELL(ITYP)
22    FORMAT(' COMPILED OVER ALL OBSERVATIONS
#       (N=', I4, ' FOR FAD TYPE NUMBER ', I4/' AN AVERAGE OF ', F6.2,
#       ' CELLS WERE FILLED PER COLLECTION (STANDARD DEV. = ', F6.2,
#       ' OUT OF THE ', I4, ' NON-ZERO COLLECTIONS'/' THERE ARE ', I3,
#       ' CELLS FILLED IN THIS GRID'////)
C
    LEV = ITYP
    CALL GRAPH(PERMAT, LEV, NTYP, NROW, NCOL, LABEL)
    WRITE(10,100)
100   FORMAT('MEAN NUMBER OF FISH OCCURRING IN SQUARE METER CELLS//')
C
    WRITE(10,22) SAMPLE(ITYP), ITYP, BLCMEN(ITYP), BLCVAR(ITYP),
#       TYPREC(ITYP), CELL(ITYP)
C
    CALL GRAPH(MENMAT, LEV, NTYP, NROW, NCOL, LABEL)
C
    ENDIF
C
112  CONTINUE
C
    STOP
    END
C
C
    SUBROUTINE GRAPH(IN, LEVEL, TYPS, ROWS, COLS, HEAD)
C
C
    INTEGER TYPS, ROWS, COLS, JN, J, ACOL, AROW, LEVEL
    INTEGER HEAD(ROWS)
    REAL IN(ROWS, COLS, TYPS)
C
    DO 66 JN = 1, ROWS
        HEAD(JN) = JN
    66  CONTINUE
C
    WRITE(10,26) (HEAD(J), J=ROWS, 1, -1)
    26  FORMAT(8X, I2, 13(7X, I2))
C
    WRITE(10,23)
    WRITE(10,23)
    23  FORMAT(4X, 129('*'))
C
    DO 24 ACOL = 1, COLS
        WRITE(10,25) ACOL, (IN(AROW,ACOL,LEVEL), AROW= ROWS, 1, -1)

```

```
C
25   FORMAT(4X, '***', 125(' '), '***'/1X, 12, 1X, '***', F8.3, 13(1X, F8.3),
#     '***'/4X, '***', 125(' '), '***'/4X, '***', 125(' '), '***')
C
24   CONTINUE
C
    WRITE(10,23)
    WRITE(10,23)
C
C
    RETURN
    END
```



```

9   CONTINUE
C
C   DO 10 IR = 1, NROW
      DO 11 IC = 1, NCOL
        DO 111 IT = 1, NDAY
          PERMAT(IR, IC, IT)=0
          MENMAT(IR, IC, IT)=0
111  CONTINUE
11   CONTINUE
10  CONTINUE
C
      I = 0
19  IF (.TRUE.) CONTINUE
      I = I + 1
      READ(9,20, END=21) Y, X, DAY, FREQ, SUM, SQR, PERCNT, MEAN, VAR, N
20  FORMAT(I2, I2, I2, I3, F9.2, 4(F12.3), 1X, I4)
      PERMAT(Y,X,DAY)=PERCNT*100.0
      MENMAT(Y,X,DAY)=MEAN
      SAMPLE(DAY)=N
      CELL(DAY) = CELL(DAY) + 1
      GO TO 19
21  CONTINUE
      I = I - 1
C
C
29  IF (.TRUE.) CONTINUE
      READ(11,30,END=31) TYPE, NREC, SUMC, SQRC
30  FORMAT(I3, I3, 5X, I4, 1X, I4, 1X, I5)
      TYPREC(TYPE) = TYPREC(TYPE) + NREC
      BLOCKS(TYPE) = BLOCKS(TYPE) + SUMC
      BLCSQR(TYPE) = BLCSQR(TYPE) + SQRC
      GO TO 29
31  CONTINUE
C
C
      DO 112 ITYP = 1, NDAY
        IF (SAMPLE(ITYP) .LT. 1) THEN
28  WRITE(10,28) ITYP
        #   FORMAT(' THERE WERE ZERO COLLECTIONS FOR DAY ', I4, '. NO GRAPH
          #   WAS PRINTED ')
        ELSE
          IF (TYPREC(ITYP) .GT. 1) THEN
            BLCMEN(ITYP) = REAL(BLOCKS(ITYP))/REAL(TYPREC(ITYP))
            BLCVAR(ITYP) = SQRT(REAL(BLCSQR(ITYP)-(BLOCKS(ITYP)**2)/
          #   REAL(TYPREC(ITYP)))/REAL(TYPREC(ITYP)-1))
          ELSE
            BLCMEN(ITYP) = REAL(BLOCKS(ITYP))
            BLCVAR(ITYP) = 0
          ENDIF
C
      WRITE(10,99)
99  FORMAT('1GRAPH OF THE PERCENT OCCURRENCE OF FISH WITHIN SQUARE METER

```

```

#          CELLS IN THE WATER COLUMN ABOUT A COMPOSITE FAD'//)
C
  WRITE(10,22) SAMPLE(ITYP), ITYP, BLCMEN(ITYP), BLCVAR(ITYP),
#   TYPREC(ITYP), CELL(ITYP)
22  FORMAT(' COMPILED OVER ALL OBSERVATIONS
# (N = ', I4, ' FOR DAY NUMBER ', I4/' AN AVERAGE OF ', F6.2,
# ' CELLS WERE FILLED PER COLLECTION (STANDARD DEV. = ', F6.2,
# ' OUT OF THE ', I4, ' NON-ZERO COLLECTIONS'/' THERE ARE ', I3,
# ' CELLS FILLED IN THIS GRID'////)
C
C
  LEV = ITYP
  CALL GRAPH(PERMAT, LEV, NDAY, NROW, NCOL, LABEL)
  WRITE(10,100)
100 FORMAT('1GRAPH OF THE MEAN NUMBER OF FISH WITHIN SQUARE METER BLOCKS
#          IN THE WATER COLUMN ABOUT A COMPOSITE FAD'//)
C
  WRITE(10,22) SAMPLE(ITYP), ITYP, BLCMEN(ITYP), BLCVAR(ITYP),
#   TYPREC(ITYP), CELL(ITYP)
C
  CALL GRAPH(MENMAT, LEV, NDAY, NROW, NCOL, LABEL)
C
  ENDIF
112 CONTINUE
C
  STOP
  END
C
C
  SUBROUTINE GRAPH(IN, LEVEL, DAYS, ROWS, COLS, HEAD)
C
C
  INTEGER DAYS, ROWS, COLS, JN, J, ACOL, AROW, LEVEL
  INTEGER HEAD(ROWS)
  REAL IN(ROWS, COLS, DAYS)
C
  DO 66 JN = 1, ROWS
    HEAD(JN) = JN
66  CONTINUE
C
  WRITE(10,26) (HEAD(J), J=ROWS, 1, -1)
26  FORMAT(8X, I2, 13(7X, I2))
  WRITE(10,23)
23  FORMAT(4X, 129('*'))
C
  DO 24 ACOL = 1, COLS
    WRITE(10,25) ACOL, (1N(AROW, ACOL, LEVEL), AROW=ROWS, 1, -1)
25  FORMAT(4X, '***', 125(' '), '***'/1X, I2, 1X, '***', F8.3, 13(1X, F8.3),
#          '***'/4X, '***', 125(' '), '***'/4X, '***', 125(' '), '***')
C
24  CONTINUE

```



```

C      WRITE(10,23)
C      WRITE(10,23)
C
C      RETURN
C      END
C
C      *****
C      *
C      * PROGRAM: GRAPH.TOT.F77
C      *
C      * WRITTEN BY RODNEY ROUNTREE          DATE: 10 OCTOBER 1986
C      *
C      * PURPOSE:  THIS PROGRAM GRAPHS THE PERCENT FREQUENCY OF OCCURRENCE,
C      *            AND MEAN OF FISH OCCUPYING SQUARE METER CELLS AROUND A
C      *            COMPOSITE FAD POOLED OVER ALL OBSERVATIONS.  IT ALSO
C      *            OUTPUTS THE SAMPLE SIZE, NUMBER OF CELLS FILLED AND THE
C      *            MEAN NUMBER OF CELLS OCCUPIED PER COLLECTION.
C      *
C      * INPUT:    ALLTOT OR ABCTOT: FILE OUTPUT FROM PROGRAM POSMEAN.F77
C      *            WHICH CONTAINS INDICES FOR ROW AND COLUMN, THE
C      *            PERCENT OCCURRENCE OF FISH IN EACH CELL AND THE
C      *            MEAN OF THE NUMBER OF FISH IN EACH CELL.
C      *
C      *            SAMNO:    FILE OUTPUT FROM PROGRAM DISTPOS.F77 CONTAINING
C      *            INDICES FOR DAY AND TYPE FACTORS, THE NUMBER OF
C      *            NON-ZERO COLLECTIONS, THE SUM OF THE NUMBER OF
C      *            BLOCKS PER COLLECTION OCCUPIED BY FISH AND THE
C      *            SUM OF THE SQUARES.
C      *
C      * OUTPUT:   GRAPH.OUT:  GRAPHS OF THE DISTRIBUTIONS OF FISH OCCURRENCE
C      *            AND MEANS ABOUT FADS FROM POOLED DATA OVER ALL
C      *            OBSERVATIONS
C      *
C      *****
C
C      INTEGER NROW, NCOL
C      PARAMETER(NROW=14, NCOL=25)
C      INTEGER CELL, SAMPLE, TYPREC, BLOCKS, BLCSQR, Y, X, FREQ, N, NREC, SUMC,
C      # SQRC
C      INTEGER LABEL(NROW)
C
C      REAL SUM, SQR, PERCNT, MEAN, VAR, BLCMEN, BLCVAR
C      REAL PERMAT(NROW,NCOL), MENMAT(NROW, NCOL)
C
C      OPEN(9, FILE='GRAPH.IN', STATUS='OLD', PAD='YES', RECFM='DS')
C      OPEN(10, FILE='GRAPH.OUT', STATUS='FRESH', CARRIAGECONTROL=
C      #'FORTRAN')
C      OPEN(11, FILE='SAMNO', STATUS='OLD', PAD='YES', RECFM='DS')
C
C      CELL=0
C      SAMPLE=0

```

```

TYFREC=0
BLOCKS=0
BLCSQR=0
BLCMEN=0
BLCVAR=0
C
C
DO 10 IR = 1,NROW
  DO 11 IC = 1, NCOL
    PERMAT(IR,IC)=0
    MENMAT(IR,IC)=0
11  CONTINUE
10  CONTINUE
C
I = 0
19  IF (.TRUE.) CONTINUE
    I = I + 1
    READ(9,20,END=21) Y, X, FREQ, SUM, SQR, PERCNT, MEAN, VAR, N
20  FORMAT(I2, I2, 2X, I3, F9.2, 4(F12.3), 1X, I4)
    PERMAT(Y,X)=PERCNT*100.0
    MENMAT(Y,X)=MEAN
    SAMPLE=N
    CELL=CELL+1
    GO TO 19
21  CONTINUE
    I = I - 1
C
C
29  IF (.TRUE.) CONTINUE
    READ(11,30,END=31) NREC, SUMC, SQRC
30  FORMAT(8X, I4, 1X, I4, 1X, I4)
    TYFREC=TYFREC+NREC
    BLOCKS=BLOCKS + SUMC
    BLCSQR = BLCSQR + SQRC
    GO TO 29
31  CONTINUE
C
C
IF (TYFREC .GT. 1) THEN
  BLCMEN = REAL(BLOCKS)/REAL(TYFREC)
  BLCVAR = SQRT(REAL(BLCSQR-(BLOCKS**2)/REAL(TYFREC))/REAL(TYFREC-1))
ELSE
  BLCMEN = REAL(BLOCKS)
  BLCVAR = 0
ENDIF
C
WRITE(10,99)
99  FORMAT('1PERCENT OCCURRENCE OF FISH WITHIN SQUARE METER CELLS AROUND A
#      COMPOSITE FAD'/)
C
WRITE(10,22) SAMPLE, BLCMEN, BLCVAR, TYFREC, CELL
22  FORMAT(' COMPILED OVER ALL OBSERVATIONS

```

```

# (N = ', 14/' AN AVERAGE OF ', F6.2,
# ' CELLS WERE FILLED PER COLLECTION (STANDARD DEV. ', F6.2,
# ' OUT OF THE ', 14, ' NON-ZERO COLLECTIONS/' THERE ARE ', 13,
# ' CELLS FILLED IN THIS GRID'////)
C
C
CALL GRAPH(PERMAT, NROW, NCOL, LABEL)
C
WRITE(10,100)
100 FORMAT('1GRAPH OF THE MEAN NUMBER OF FISH PER SQUARE METER CELL AROUND
# A COMPOSITE FAD'//)
C
WRITE(10,22) SAMPLE, BLCHEN, BLCVAR, TYPREC, CELL
C
CALL GRAPH(MENMAT, NROW, NCOL, LABEL)
C
C
STOP
END
C
C
SUBROUTINE GRAPH(IN, ROWS, COLS, HEAD)
C
C
INTEGER ROWS, COLS, JN, J, AROW, AROW
INTEGER HEAD(ROWS)
REAL IN(ROWS, COLS)
C
DO 66 JN = 1, ROWS
HEAD(JN) = JN
66 CONTINUE
C
WRITE(10,26) (HEAD(J), J-ROWS, 1, -1)
26 FORMAT(8X, I2, 13(7X, I2))
C
WRITE(10,23)
WRITE(10,23)
23 FORMAT(4X, 129('**'))
C
DO 24 AROW = 1, COLS
WRITE(10,25) AROW, (IN(AROW,ACOL), AROW-ROWS, 1, -1)
25 FORMAT(4X, '**', 125(' '), '**'/1X, I2, 1X, '**', F8.3, 13(1X, F8.3),
# '**'/4X, '**', 125(' '), '**'/4X, '**', 125(' '), '**')
C
24 CONTINUE
C
WRITE(10,23)
WRITE(10,23)
C
C
RETURN
END

```

Appendix B. Mean and standard deviation for each FAD type and day combination, for FAD type, Day and pooled data for select variables and species.

Appendix B.1. Mean number of individuals of D. punctatus in each fish school based on counts from the 62 stations with non-zero numbers. The numbers in parentheses are the sample size for each mean (n_1 = number of schools) and the number of non-zero stations (n_2).

FAD type	Day number								FAD Type Means
	8	23	55	91	100	115	159	194	
A (n_1, n_2)	---	19 + 20 (3,3)	360 + 397 (5,5)	37 + 18 (6,5)	367 + 448 [⊖] (3,2)	217 + 350 (7,5)	283 + 480 (4,3)	1.0 (1,1)	201 + 338 (29,24)
B (n_1, n_2)	---	76 + 77 (4,3)	1200 + 1892 (6,5)	15 + 15 (4,3)	1050 + 737 (4,2)	1761 + 2516 (6,4)	8 + 3 (3,3)	2.0 (1,1)	798 + 1551 (28,21)
C (n_1, n_2)	---	600 + 274 (5,3)	853 + 910 (6,4)	20 (1,1)	3000 + 2000 (3,2)	1294 + 2471 (4,2)	69 + 113 (3,3)	9.0 (1,1)	980 + 1486 (23,16)
Pooled (n_1, n_2)	---	280 + 331 (12,9)	831 + 1240 (17,14)	27 + 19 (11,9)	1430 + 1549 [⊖] (10,6)	1015 + 1917 (17,11)	137 + 310 (10,9)	4.0 + 4.4 (3,3)	634 + 1262 [⊖] (80,61)

[⊖] Means including an outlier were as follows: Day 100, FAD type A = 2275 ± 3842; FAD type A mean = 461 ± 1462; Day 100 mean = 2027 ± 2467; grand mean (n_1 = 81, n_2 = 62) = 725 ± 1497.

Appendix B.2. Means and standard deviation for the number of species, total number of individuals, total number excluding D. punctatus, and selected species per station by day and FAD type.

Species FAD type	Day number							FAD Type Means	
	8	23	55	91	100	115	159		194
Number of Species									
A	2.0 ± 1.7	3.7 ± 0.6	7.0 ± 1.9	4.6 ± 1.1	5.7 ± 0.6	5.8 ± 1.6	4.0 ± 0.7	2.5 ± 1.0	4.4 ± 2.0
B	1.6 ± 1.5	2.0 ± 0.0	5.2 ± 0.8	3.0 ± 1.4	3.5 ± 2.1	3.5 ± 1.0	3.6 ± 1.8	4.0	3.3 ± 1.7
C	1.8 ± 0.8	2.0 ± 0.0	6.5 ± 1.3	4.5 ± 0.7	6.5 ± 0.7	2.0 ± 1.4	3.3 ± 1.5	3.3 ± 1.5	3.6 ± 2.1
Pooled	1.8 ± 1.3	2.6 ± 0.9	6.2 ± 1.5	4.0 ± 1.3	5.3 ± 1.6	4.3 ± 2.0	3.7 ± 1.3	3.0 ± 1.2	3.8 ± 2.0
Total No. individuals									
A	2.8 ± 3.0	25.0 ± 16.8	387 ± 399	52.0 ± 37.5	578 ± 674*	326 ± 383	256 ± 423	9.3 ± 8.0	188 ± 325*
B	2.0 ± 2.3	105 ± 76	1477 ± 2043	19.5 ± 11.8	2112 ± 126	2646 ± 2726	21.4 ± 19.6	12	783 ± 1571
C	3.3 ± 2.3	1006 ± 3.5	1331 ± 830	19.0 ± 12.7	4531 ± 729	2590 ± 3557	102 ± 86	24.7 ± 17.6	921 ± 1564
Pooled	2.8 ± 2.4	379 ± 473	1046 ± 1325	34.2 ± 30.2	2407 ± 1838*	1581 ± 2236	130 ± 269	15.4 ± 13.3	592 ± 1266
Total No. individuals excluding <u>D. punctatus</u>									
A	2.8 ± 3.0	6.3 ± 4.0	26.8 ± 20.5	8.2 ± 3.5	27.0 ± 21.1	22.4 ± 21.5	29.4 ± 17.6	9.0 ± 7.8	16.7 ± 16.8
B	2.2 ± 2.2	3.0 ± 2.0	36.8 ± 34.3	5.0 ± 4.1	12.0 ± 15.6	5.0 ± 3.5	16.4 ± 14.9	10.0	12.4 ± 19.1
C	3.3 ± 2.6	6.0 ± 3.5	51.3 ± 31.2	9.0 ± 1.4	30.5 ± 21.9	3.0 ± 2.8	32.7 ± 28.4	21.7 ± 13.8	19.6 ± 23.4
Pooled	2.8 ± 2.4	5.1 ± 3.3	37.4 ± 28.6	7.2 ± 3.6	23.7 ± 18.3	12.5 ± 16.7	25.2 ± 19.1	13.9 ± 11.1	16.1 ± 19.6
<u>Decapterus punctatus</u>									
A	0	14 ± 20	360 ± 397	44 ± 35	505 ± 707+	304 ± 391	226 ± 436	0.3 ± 0.5	171 ± 325+
B	0	102 ± 78	1440 ± 2012	15 ± 16	2100 ± 141	2641 ± 2730	5 ± 5	2.0	771 ± 1564
C	0	1000 ± 0	1280 ± 836	10 ± 14	4500 ± 707	2588 ± 3553	69 ± 113	3.0 ± 5.2	901 ± 1560
Pooled	0	373 ± 473	1009 ± 1308	27 ± 29	2383 ± 1836+	1569 ± 2242	105 ± 276	1.5 ± 3.1	576 ± 1267+

Appendix B.2 cont.

Species FAD type	8	23	55	91	Day number					FAD Type Means
					100	115	159	194		
<u>No. of schools of <i>D. punctatus</i></u>										
A	0	1.0 ± 0.0	1.0 ± 0.0	1.2 ± 0.4	1.3 ± 0.6	1.4 ± 0.5	0.8 ± 0.8	0.3 ± 0.5	0.9 ± 0.6	
B	0	1.3 ± 0.6	1.2 ± 0.4	1.0 ± 0.8	2.0 ± 0	1.5 ± 1.0	0.6 ± 0.5	1.0	1.0 ± 0.8	
C	0	1.7 ± 0.6	1.5 ± 0.6	0.5 ± 0.7	1.5 ± 0.7	2.0 ± 0	1.0 ± 0	0.3 ± 0.6	0.9 ± 0.8	
Pooled	0	1.3 ± 0.5	1.2 ± 0.4	1.0 ± 0.6	1.6 ± 0.5	1.5 ± 0.7	0.8 ± 0.6	0.4 ± 0.5	0.9 ± 0.8	
<u><i>Caranx crysos</i></u>										
A	0	0.3 ± 0.6	8.4 ± 9.9	2.6 ± 2.3	20.0 ± 20.0	15.4 ± 20.1	20.0 ± 21.2	0	8.4 ± 14.3	
B	0.4 ± 0.9	0	10.8 ± 12.9	0	7.5 ± 10.6	0.8 ± 1.0	13.4 ± 15.3	0	4.9 ± 9.7	
C	0	0	17.0 ± 12.5	0.5 ± 0.7	18.0 ± 17.0	0	30.0 ± 26.0	0	7.8 ± 14.6	
Pooled	0.1 ± 0.5	0.1 ± 0.3	11.7 ± 11.4	1.3 ± 2.0	16.0 ± 15.3	7.3 ± 14.9	19.8 ± 19.7	0	7.1 ± 13.0	
<u><i>Diplectrum formosum</i></u>										
A	0	---	3.8 ± 4.0	3.4 ± 3.4	2.7 ± 2.1	2.6 ± 2.1	1.6 ± 0.9	0.5 ± 0.6	2.1 ± 2.5	
B	0	---	8.2 ± 7.3	1.0 ± 1.4	2.0 ± 2.8	1.3 ± 2.5	1.2 ± 1.1	1.0	2.5 ± 4.5	
C	0.2 ± 0.4	---	4.5 ± 5.4	5.0 ± 2.8	3.5 ± 4.9	0	0	0	1.6 ± 3.2	
Pooled	0.1 ± 0.3	---	5.6 ± 5.7	2.8 ± 2.9	2.7 ± 2.7	1.6 ± 2.2	1.1 ± 1.0	0.4 ± 0.5	2.1 ± 3.4	
<u><i>Caranx bartholomaei</i></u>										
A	0.4 ± 0.5	4.3 ± 4.2	0	0	0.3 ± 0.6	0	0.6 ± 0.9	7.5 ± 7.7	1.4 ± 3.6	
B	0.6 ± 0.9	2.7 ± 2.5	0	0	0	0	0.2 ± 0.4	8.0	0.7 ± 1.8	
C	1.8 ± 2.0	6.0 ± 3.5	0	0	0	0	0	18.3 ± 11.5	3.4 ± 7.0	
Pooled	1.0 ± 1.5	4.3 ± 3.3	0	0	0.1 ± 0.4	0	0.3 ± 0.6	11.6 ± 9.7	1.7 ± 4.5	

Appendix B.2 cont.

Species FAD type	Day number							FAD Type Means	
	8	23	55	91	100	115	159		194
<u>Monacanthus hispidus</u>									
A	0.4 ± 0.9	0	0.8 ± 0.4	0.2 ± 0.4	0.7 ± 1.2	2.0 ± 1.9	6.0 ± 13.4	0.5 ± 0.6	1.5 ± 5.1
B	0.2 ± 0.4	0	1.6 ± 1.8	1.3 ± 1.5	0.5 ± 0.7	0.3 ± 0.5	0.2 ± 0.4	1.0	0.6 ± 1.1
C	0.3 ± 0.5	0	1.8 ± 1.0	1.5 ± 0.7	6.0 ± 0	2.0 ± 2.8	0.3 ± 0.6	0.3 ± 0.6	1.2 ± 1.8
Pooled	0.3 ± 0.6	0	1.4 ± 1.2	0.8 ± 1.1	2.1 ± 2.7	1.4 ± 1.7	2.5 ± 8.3	0.5 ± 0.5	1.1 ± 3.4
<u>Centropristis striata</u>									
A	0.2 ± 0.4	---	0.6 ± 0.5	0.6 ± 0.5	0	1.0 ± 0.7	1.0 ± 0	0.5 ± 0.6	0.7 ± 0.5
B	0.3 ± 0.6	---	0.8 ± 1.0	1.0 ± 1.0	1.0 ± 1.4	0.5 ± 0.6	0.4 ± 0.5	0	0.4 ± 0.7
C	0.5 ± 0.5	---	0.5 ± 1.0	1.5 ± 0.7	1.0 ± 0	0.5 ± 0.7	0.7 ± 0.6	0.7 ± 0.6	0.7 ± 0.6
Pooled	0.4 ± 0.5	---	0.4 ± 0.6	0.8 ± 0.8	1.0 ± 0.6	0.7 ± 0.6	0.7 ± 0.5	0.5 ± 0.5	0.6 ± 0.6
<u>Hyleurochilus geminatus</u>									
A	0	---	1.0 ± 1.4	0.2 ± 0.4	1.0 ± 1.7	0	0	0	0.3 ± 0.8
B	0	---	0.2 ± 0.4	0.3 ± 0.5	0	1.5 ± 3.0	0.2 ± 0.4	0	0.3 ± 1.1
C	0	---	0.3 ± 0.5	0	0.5 ± 0.7	0	1.3 ± 2.3	0	0.2 ± 0.8
Pooled	0	---	0.5 ± 0.9	0.2 ± 0.4	0.6 ± 1.1	0.5 ± 1.8	0.4 ± 1.1	0	0.3 ± 0.9
<u>Menippe mercenaria</u>									
A	0.2 ± 0.4	---	0.4 ± 0.5	0.6 ± 0.5	1.3 ± 0.6	0.6 ± 0.5	0	0	0.4 ± 0.6
B	0.7 ± 0.6	---	0	0.5 ± 0.6	0.5 ± 0.7	0.3 ± 0.5	0	0	0.3 ± 0.4
C	0.3 ± 0.5	---	0.3 ± 0.5	0	0	0	0	0	0.1 ± 0.4
Pooled	0.4 ± 0.5	---	0.2 ± 0.4	0.5 ± 0.5	0.7 ± 0.8	0.4 ± 0.5	0	0	0.3 ± 0.5

Appendix B.2 cont.

Species FAD type	Day number							FAD Type Means	
	8	23	55	91	100	115	159		194
<u>Centropristis ocyurus</u>									
A	1.2 ± 1.6	---	0.2 ± 0.4	0.4 ± 0.5	0.7 ± 1.2	0	0	0	0.4 ± 0.8
B	0.3 ± 0.6	---	0.4 ± 0.5	0	0	0	0	0	0.1 ± 0.3
C	0.2 ± 0.4	---	0.5 ± 0.6	0	0	0	0	0	0.1 ± 0.4
Pooled	0.6 ± 1.1	---	0.4 ± 0.5	0.2 ± 0.4	0.3 ± 0.8	0	0	0	0.2 ± 0.6
<u>Octopus vulgaris</u>									
A	0	---	0	0.2 ± 0.4	0	0.2 ± 0.4	0.4 ± 0.4	0.3 ± 0.5	0.2 ± 0.4
B	0	---	0	0.5 ± 1.0	0	0	1.0 ± 1.0	0	0.3 ± 0.6
C	0	---	0	0	0	0	0.3 ± 0.6	0	0.1 ± 0.2
Pooled	0	---	0	0.3 ± 0.6	0	0.1 ± 0.3	0.6 ± 0.5	0.1 ± 0.4	0.2 ± 0.4

*Means reported with one outlier removed, with that sample included:
 Day 100, FAD type A Total No. = 3060 ± 4326; FAD type A mean = 412 ± 1363; Day 100 mean = 3209 ± 2706;
 and Grand mean = 676 ± 1489.

+Means including an outlier were: Day 100, FAD type A = 3033 ± 4330; FAD type A mean = 395 ± 1362; Day 100 mean = 3186 ± 2705
 and grand mean = 660 ± 1485.

Appendix C. Data for FAD type D (McIntosh units), including species frequencies and means.

Appendix C.1. Percent occurrence and rank of species recorded at the type D FADs.

Species	Percent Occurrence	Rank
<u>Decapterus punctatus</u>	91.7	1
<u>Centropristis striata</u>	66.7	2
<u>Diplectrum formosum</u>	50.0	3
<u>Caranx crysos</u>	41.7	4
<u>Equetius acuminatus</u>	41.7	4
<u>Centropristis ocyurus</u>	33.3	6
<u>Stenotomus chrysops</u>	33.3	6
<u>Seriola sp.</u>	33.3	6
<u>Menippe mercenaria</u>	33.3	6
<u>Micteroperca microlepis</u>	25.0	10
<u>Seriola zonata</u>	25.0	10
<u>Caranx ruber</u>	16.7	12
<u>Haemulon aurolineatum</u>	16.7	12
<u>Hypleurochilus geminatus</u>	16.7	12
<u>Monacanthus hispidus</u>	16.7	12
<u>Serranus subligarius</u>	8.0	16
<u>Caranx bartholomaei</u>	8.0	16
<u>Chaetodipterus faber</u>	8.0	16
<u>Holacanthus sp.</u>	8.0	16
<u>Antennarius sp.</u>	8.0	16
<u>Rypticus sp.</u>	8.0	16
<u>Halichoeres sp.</u>	8.0	16
<u>Octopus vulgaris</u>	8.0	16

Appendix C.2. Mean number of individuals per station for FAD type D structures for each census day. Days given are the number of days elapsed from time of deployment (days elapsed for treatment structures are given in parentheses for comparison).

Species	Days Elapsed from time of Deployment					
	8 (23)	39 (55)	75 (91)	84 (100)	99 (115)	All
<i>Decapterus punctatus</i>	29.5 ± 29.0	2510 ± 2171	33.3 ± 28.9	4100	1667 ± 1155	1399 ± 1723
<i>Caranx crysos</i>	0	17.3 ± 4.6	0	2	5.0 ± 8.7	5.8 ± 8.4
<i>Diplectrum formosum</i> *	---	3.7 ± 5.5	6.7 ± 11.5	15	2.3 ± 3.2	5.3 ± 7.3
<i>Seriola</i> sp.	0	14.7 ± 23.7	6.7 ± 11.5	0	0	5.3 ± 12.9
<i>Stenotomus chrysops</i> *	---	18.3 ± 27.5	0.3 ± 0.6	1	0	5.7 ± 15.6
<i>Centropristis striata</i> *	---	0.7 ± 0.6	2.7 ± 1.5	0	2.0 ± 1.7	1.6 ± 1.5
<i>Centropristis ocyurus</i> *	---	0.7 ± 0.6	1.0 ± 1.7	2	0	0.7 ± 1.1
<i>Menippe mercenaria</i> *	---	0	1.7 ± 1.2	1	0	0.6 ± 1.0
<i>Seriola zonata</i>	2.5 ± 3.5	1.0 ± 1.0	0	0	0	0.7 ± 1.5
<i>Hypoleurochilus geminatus</i> *	---	0	1.0 ± 1.7	2	0	0.5 ± 1.1
<i>Caranx ruber</i>	2.0 ± 2.8	0.3 ± 0.6	0	0	0	0.4 ± 1.2
<i>Micropogonias undulatus</i> *	---	0	0.7 ± 1.2	0	1.0 ± 1.0	0.4 ± 0.8
<i>Monacanthus hispidus</i>	0	1.0 ± 1.0	0	0	0	0.3 ± 0.6
<i>Caranx bartholomaei</i>	0.5 ± 0.7	0	0	0	0	0.1 ± 0.3
<i>Octopus vulgaris</i> *	---	0.3 ± 0.6	0	0	0	0.1 ± 0.3
No. D. punctatus Schools	1.0 ± 0	2.0 ± 1.0	0.7 ± 0.6	3	1.3 ± 0.6	1.4 ± 0.9
Total No. individuals (excluding D. punctatus)	5.5 ± 6.4	57.7 ± 53.1	20.7 ± 27.1	25	12.0 ± 12.5	25.6 ± 33.0
Total No. Individuals	34.5 ± 36.1	2568 ± 2224	54.0 ± 48.5	4125	1679 ± 1146	1425 ± 1743
No. species	2.5 ± 2.1	7.3 ± 1.2	5.3 ± 3.5	9	5.3 ± 2.5	5.7 ± 2.8
Sample size	2	3	3	1	3	12(10*)

*Anchors were not censused on day 23