Fisheries Enhancement Using Artificial Habitats in the U.S. Virgin Islands

ALAN FRIEDLANDER and JIM BEETS
Department of Planning and Natural Resources
Division of Fish and Wildlife
101 Estate Nazareth
St. Thomas, U.S. Virgin Islands 00802

ABSTRACT

Artificial habitats ranging from sunken vessels to designed artificial reefs have been utilized by fishermen for many years in the U.S. Virgin Islands. Continuing experiments have documented appropriate materials and design to enhance fisheries habitat using artificial structures. Extreme habitat degradation and overfishing have necessitated the development of these enhancement measures.

Experimental artificial reefs and fish aggregating devices (FADs) have been used as models to determine optimal design and location. Inexpensive, easily deployed FADs have been developed to improve recreational commercial catches of migratory pelagics such as wahoo, kingfish, dolphin, tuna and billfish. Experimental inshore artificial reefs have been used to document the importance of structure, material effectiveness, optimal location and design of artificial reefs used to enhance abundances of important target species.

INTRODUCTION

Artificial structures have been used throughout the world to help improve fishing success for both recreational and commercial fisheries. These efforts have ranged from small low cost structures, such as brush piles, tires, bamboo and rocks (Bergstrom, 1983; Suman, 1988) to large scale structures using materials and designs of advanced technology (Vik, 1982; Sonu and Grove, 1985).

Most fisheries resources in the U.S. Virgin Islands have been declining at a rapid rate in recent years (Dammann and Sylvester, 1977; CFMC, 1985). Fisheries stocks have been overfished and habitats have been degraded in the U.S. Virgin Islands as well as many other parts of the Caribbean Region (Goodwin *et al.*, 1985). Intensive harvest has been a major contributing factor to local stock declines (Dammann and Sylvester, 1977; US Congress, OTA, 1987). Trap fishing is the predominant fishing method in the U.S. Virgin Islands (Dammann and Sylvester, 1977; Olsen *et al.*, 1978; Clavijo *et al.*, 1984). At the U.S. Virgin Islands "Fisheries in Crisis" Symposium held October, 1987, the consensus among commercial fishermen was that average size of fishes harvested by traps had declined and that increased effort was required to obtain equal harvest levels (Austin, 1988). One of the major problems in the fishery has been increased effort on diminishing stocks (Beets, 1987). Dammann and Sylvester (1977) stated that inshore reef fish stocks were being fished at or above maximum sustainable yield as early as the 1970s. Target species such as Nassau grouper (*Epinephelus striatus* Bloch) and red hind (*E. guttatus* Linnaeus) have declined in abundance as a result of intensive pressure during spawning aggregations (Olsen and LaPlace, 1981). Annual catch statistics for fish, lobster and conch in St. Croix have remained the same or declined since 1982 despite increased fishing effort (Austin, 1988).

The dominant habitat type on the relatively large shelf area (197,000 ha) around the U.S. Virgin Islands is sparse algal plain and sand bottom (CFMC, 1985). These areas lack relief and structural complexity which are essential for reef fish abundance.

Degradation of reefs, seagrass beds and mangroves, which are important habitats for fish and invertebrates, has contributed to the decline in abundance of important marine species (Rogers, 1987; Rogers and Teytaud, 1987; Cintron-Molero, 1987). Expansion of tourism in the U.S. Virgin Islands has led to increased immigration and increased demand for culturally important species such as fish, conch, whelk, lobster and other marine resources. Construction and development, especially in the coastal zone, has led to increased sediment runoff with adverse effects on fisheries habitat (Rogers, 1987; Wilson, 1988). Additional environmental problems affecting Caribbean fishery resources include domestic sewage, agriculture runoff, toxic metal pollution, plastic refuse and increased boat traffic (USAID and USDOC/NOAA, 1987).

Coastal and oceanic pelagic species are considered to be underutilized in the Caribbean region as a commercial fisheries resource (USAID and USDOC/NOAA, 1987; U.S. Congress, OTA, 1987). These species are less affected by inshore habitat degradation and existing fishing pressure than reef fishes. Fish aggregating devices (FADs) have been used in many areas to concentrate pelagic species (Myatt, 1985). They are used to sustain fisheries for tuna in Hawaii, the Philippines and other areas of the Pacific (Murdy, 1980; Matsumoto *et al.*, 1981). Presently there is no commercial fishery for oceanic pelagics in the U.S. Virgin Islands (Hunte, 1986). Fishermen can augment their catch by trolling around FADs to and from productive fishing areas. Numerous fishing techniques have been developed using FADs as alternatives to traditional fishing methods (Yuen, 1979; South Pacific Comm., 1983; Feigenbaum *et al.*, 1989). Along the coast of the continental U.S., FADs are primarily used to improve the catch of recreational anglers (Myatt, 1985). The U.S. Virgin Islands has a large recreational charter fishing fleet, and the implementation of FADs could improve fishing success and increase local interest. FADs can also be used as a management tool to help divert fishing effort from overfished demersal stocks (Bohnsack and Sutherland, 1985). As a result of these declines in fisheries resources, habitat enhancement projects have been implemented to help improve local population abundance.

HABITAT ENHANCEMENT

Artificial Reefs – Materials of Opportunity

Discarded vessels and other materials of opportunity provide excellent fish habitat (Stone, 1985) and are used throughout the U.S. Virgin Islands by divers and fishermen, both commercial and recreational. A few planned sites and numerous additional sites have documented materials. These structures vary in material type, size, and depth and are in various states of deterioration (Table 1).

In 1974, the V.I. Bureau of Fish and Wildlife received a U.S. Army Corps of Engineers permit to construct an artificial reef in 35 m of water off Butler Bay, St. Croix (Figure 1, Table 2). Between 1975 and 1977, approximately 5,000 automobile tires, 100 crushed automobiles and a 8 m barge were placed at the site (Yntema *et al.*, 1981). These materials were scattered over the bottom and did not form an optimal reef configuration. As a result, an abundance of fish did not aggregate at this site. The results of an investigation using fish traps to compare this artificial reef to natural areas was inconclusive (Yntema *et al.*, 1981). In 1983, a 10 year maintenance permit was granted and new materials were deployed at the site. These included a 76 m freighter (M/V *Suffolk Maid*), a 52 m cargo barge, two 6 m x 3 m steel cylinders and a 18 m tugboat. Subsequent monitoring has not been conducted.

In 1975, the Bureau of Fish and Wildlife, began construction of an artificial reef in Pillsbury Sound, approximately 1.5 km north of St. Thomas (Mudre and Day, 1981). Initially, this reef consisted of a 30 m barge (*Mary King*), a 42 m tug (*General Rogers*) and approximately 900 tires. Between 1976 and 1979, more than 5,000 additional tires were dumped along with two 11 m steel containers. The results of the investigation of this reef were inconclusive (Mudre and Day, 1981) although numerous fishermen actively fished the site. Subsequent storms dislodged tires from the site which were deposited on adjacent beaches, reefs, seagrass beds and algal plains.

The Government of the Virgin Islands received approval in 1976 to remove approximately 32 derelict vessels and other submerged obstructions from Charlotte Amalie Harbor, St. Thomas. A permit was granted to establish an artificial reef in the area of Porpoise Rocks (Figure 1, Table 2) as a location for these materials. Many of these vessels were extremely deteriorated. Although no investigation has been conducted on the site, fishermen are reported to avoid the area due to gear loss.

Presently, there are four active permitted reef sites around St. Thomas-St. John and one located in St. Croix (Table 2). Additional deployments are under review and mechanisms to improve permitting procedures are in development. An artificial reef plan is currently being prepared for the U.S. Virgin Islands.

ARTIFICIAL REEFS—DESIGNED STRUCTURES

The earliest documented designed artificial reef in the Virgin Islands was

Table 1. Artificial habitat locations in the US Virgin Islands, St. Thomas-St. John.

Location	Vessel Type	Length (m)	Date	Depth (m)	Condition
SW Mingo Cay	Wooden Ferry	14	1970's	15	broken-up
E Great St. James Isl.	*Caridad* steel hull	30	1970's	6–12	broken-up
N. Capella Isl.	*Michelle* wooden vessel	12	1988	25	intact
S. Buck Isl.	*Wye* steel hull	70	1867	3–7	broken-up
W. Buck Isl.	*Cartanser Sr.* steel hull	43	1978	6–12	partially intact
N Green Cay	steel barges	various	1940's	12	partially intact
NW Carvel Rock	Cessna 170 airplane	12	1985	20–25	partially intact
S Dog Rocks	steel barge	30	?	7–10	broken-up
E Little St. James Is.	wooden freighter	14	1988	18	broken-up
Fortuna Bay	Constellation airplane		late 1970's	10	broken-up
S Black Pt	Apache airplane		1986	15	broken-up
S Saba Is.	steel grain ship	75	1940's	18–37	partially intact
N Flat Cay	steel hull	30	1960's	6	broken-up
SW Lovango Cay	*Mein Captain* steel hull ferry	20	1989	20	intact
W Airport	*Miss Opportunity* steel hull	30	1985	25-30	partially intact
N Water Is.	steel ships	30-40	?	13	intact
S Morningstar Beach	steel pontoons	40	1940's	15-20	intact

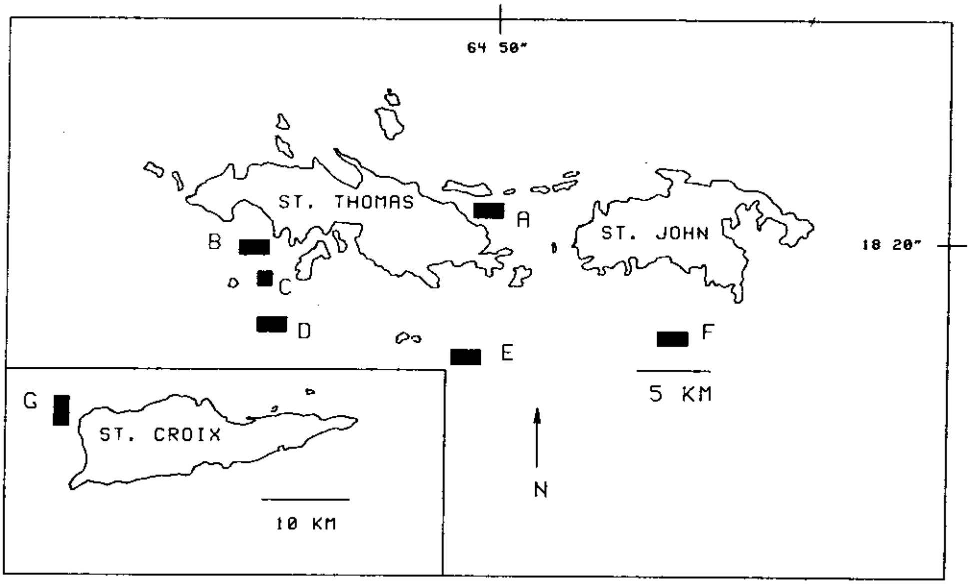

Figure 1. Location of permitted artificial reef sites around the U.S. Virgin Islands (Table 2 contains information on reef material, depth of site, etc.).

constructed by Randall (1963) to investigate fish populations on natural and artificial reefs. The reef was located in Lameshur Bay, St. John and consisted of 800 concrete blocks. Although the reef was disassembled and has degenerated over the years, it still provides habitat for reef fish in the area (Ogden and Ebersole, 1981).

Experimental artificial reefs using concrete blocks and conch shells were deployed in Buck Island channel and Teague Bay, and Salt River, St. Croix by researchers at the West Indies Laboratory (Shulman *et al.*, 1983; Shulman, 1985). These investigations have provided information on important ecological topics, such as reef fish assemblage structure and postlarval recruitment.

Present artificial reef work in the Virgin Islands is focused on enhancement of important recreational and commercial fish species using improved reef design. Hixon and Beets (1989) initiated a study to determine the most productive structure type for target commercial and recreational fish species and increased recruitment by providing shelter area for juvenile fishes.

The initial study consisted of concrete block reefs including four treatments:

1. Control reefs (no holes)
2. Reefs with 12 large holes (12 cm by 14 cm)

Table 2. Artificial reef sites permitted by the U.S. Army Corps of Engineers. Letters in parentheses under location heading correspond to Figure 1.

Location	Material	Length (m)	Year Permitted	Depth (m)	Condition
Porpoise Rocks* St. Thomas (C)	steel vessels and obstructions	10-40	1976	27	deteriorated
S Thatch Cay*	*Mary King* steel barge	30	1975	18	partially intact
St. Thomas (A)	*General Rogers* steel tug 7,000 tires	42			intact scattered
Southwest Roads St. Thomas (B)	no material at present				
Butler Bay St. Croix (G)	tires (severalhundred) steel barge automobiles(100)	8	1975	18-46	scattered
SW Saba Is. St. Thomas (D)	concrete dock 60 pieces	10 x 3	1989	30-35	partially stacked
SW Buck Island St. Thomas (E)	no material at present		1989	30-35	
S Reef Bay St. John (F)	no material at present		1989	30-35m	

* = Sites are inactive for deployment of additional material.

3. Reefs with 24 large holes
4. Reefs with 24 small holes (4 cm by 6 cm)

This work had been expanded and presently consists of 40 block reefs comprising eight replicates of each of five treatments: no holes control, 12 small holes, 24 small holes, 12 large holes, and 24 large holes.

Preliminary results show that large hole reefs provide the best habitat for large predators while recruits and juvenile fish are more abundant on small hole reefs (Table 3, Figure 2). The presence of large shelter areas resulted in a greater abundance of large piscivorous fishes with a decline in the abundance of small

Table 3. Results of preliminary investigation of effect of hole number and hole size within artificial reefs to fish abundance. SNK multiple comparison tests. Underlined means denotes no significant difference (from Hixon & Beets, 1989).

A. Effects of number of large holes on number of large resident fishes excluding burrowing species.

Treatment	0 Hole	12 Holes	24 Holes
Mean number of fishes	1.4	5.8	9.4

B. Effects of number of large holes on number of juvenile and small adult fishes.

Treatment	24 Holes	0 Holes	12 Holes
Mean number of fishes	33.1	56.4	75.6

C. Effects of hole size on number of large adult fishes.

Treatment	0 Holes	Small Holes	Large Holes
Mean number of fishes Large adults	0.2	1.0	2.4

D. Effects of hole size on number of juvenile and small adult fishes.

Treatment	0 Holes	Small Holes	Large Holes
Mean number of fishes Juveniles and small adults	18.2	19.4	49.0

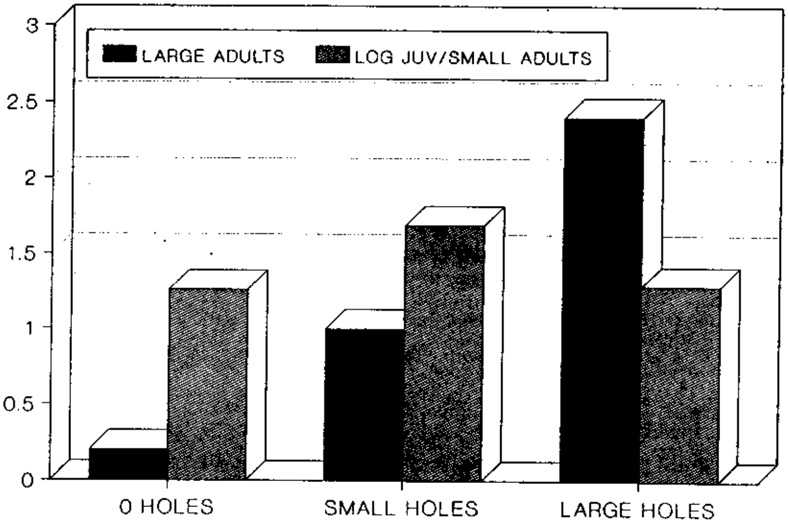

Figure 2. Effects of hole size within artificial reefs on fish abundance. Mean number of adults and juvenile and small adults for 3 reef types: 0 holes, small holes and large holes. (Adapted from Hixon and Beets, 1989).

prey species. Settling larvae and juveniles were most abundant on reefs with small shelter areas. When the availability of small shelter (gaps between blocks) was reduced, the abundance of small fish declined, especially on reefs where predators were most numerous. Abundance of large adults was unaffected.

This study demonstrated that designed artificial reefs for fisheries should include small holes as refuge areas for small fishes from predators as well as large holes for target species. Providing proper shelter area for juveniles and small adults should help to reduce juvenile mortality and potentially increase the adult abundance within the area.

Another series of experiments involved concrete block reefs in 6 m of water off the southeast end of St. Thomas. Reefs of different hole sizes were set in sand zones and seagrass beds. These reefs were designed to examine both shelter size and microhabitat location. Preliminary results demonstrated that shallow water reefs are disturbed by high wave energy during storms and have low abundance of individuals. Artificial reefs placed in coarse sand settle into the substrate quickly prompted by wave action and current activity.

FAD and Artificial Reef Combination

Hammond *et al.* (1977) suggested that a combination of artificial reefs and fish aggregating devices (FADs) are successful systems of habitat improvement. An investigation of FAD and artificial reef combinations deployed off of St. Thomas, U.S. Virgin Islands has demonstrated that the combinations increased the abundance of demersal fishes and postlarval recruits (Beets, 1989). This work supports the hypotheses that settling larval fish are attracted to structure in the water column leading to greater recruitment.

The study design consisted of three treatments:

1. Five midwater FADs spaced 10 m apart surrounding a reef consisting of 300 queen conch (*Strombus gigas* Linnaeus) shells.
2. Similar conch shell reefs with no FADs.
3. FADs with no reef.

The FADs were made of PVC and polyethylene sheets of the same design used in a previous study by Clavijo *et al.* (1987). Censuses were conducted by SCUBA divers using visual census techniques.

Species richness, abundance and postlarval recruitment were greater on the FAD and reef combinations than either the FADs or reefs alone (Table 4). Pre-settlement larvae are apparently attracted by FADs in the water column and recruit to the reef below. The mean number of postlarval recruits to the reefs was variable among monthly samples but the FAD and reef combination yielded a greater mean abundance than either of the other two treatments (Figure 3a). The mean number of recruit species was greater on the FAD and artificial reef

Table 4. Effects of artificial reef type on reef fish recruitment and abundance. Mean values among treatments for visual censuses, November 1986 – October 1987. SNK multiple comparison tests. Underlined means denotes no significant difference (from Beets, 1989).

	Visual Census Data		
Parameter	**Artificial Reefs and FADs**	**Artificial Reefs**	**FADs**
Reef species	18.3	13.8	6.1
Reef individuals	346.1	240.4	65.9
Recruit species	6.4	4.8	1.2
Recruit Individuals	126.6	53.1	3.6

combinations. The FAD and artificial reef design also had a higher number of supra-benthic species and supra-benthic individuals than the other two treatments (Figure 3b). This type of FAD and artificial reef configuration should improve fishing activities but also may be a useful management tool for the enhancement of postlarval recruitment to damaged reef areas, coastal zones and depleted offshore reefs.

FISH AGGREGATING DEVICES

FADs of various designs have been deployed throughout the U.S. Virgin Islands. The Division of Fish and Wildlife initiated a study in 1981 to determine the effectiveness of attracting coastal pelagic fish using FADs (Clavijo *et al.*, 1987). This work was conducted in two phases. Phase One involved a series of 50 FADs deployed on a seven km transect line. Phase Two involved 10 clusters of FADs along a 3.5 km transect, each cluster consisting of six FADs loosely arranged. Experimental trolling results showed a greater number of strikes and fish caught around FADs compared to control areas (Mann-Whitney U, $p < 0.01$). Phase Two trolling results were less conclusive although they demonstrated significantly more strikes and catches around the FADs during the summer months (Mann-Whitney U, $p > 0.05$). Greater abundance of coastal pelagics during the winter months yielded greater fishing success for both FADs and controls with no significant difference between sites (Mann–Whitney, $p > 0.05$).

The present configuration consists of four clusters of FADs in a tight circle approximately 300 m apart. Each cluster consists of five FADs approximately 10 m apart. Forty trolling trips amounting to 160 line hours of total effort were conducted between November 1986 and October 1988. The number of strikes and fish caught on the FADs was greater than on the control area (Wilcoxon, $p < 0.001$).

A set of eight FADs were deployed at the south shelf edge of St. Thomas in 46 m of water on August 1986. Twenty-nine trolling trips comprising 118.34

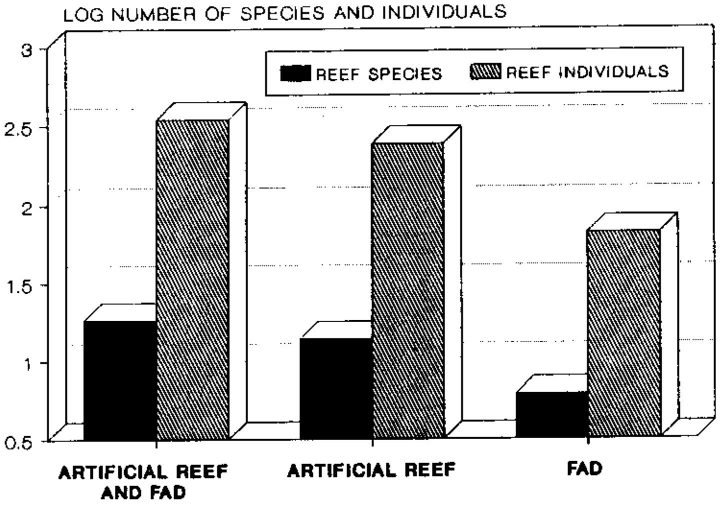

Figure 3a. Results of experiments with FADs and artificial reef combinations. Mean number of species and individuals for FAD and artificial reef combinations, artificial reefs alone and FADs alone.

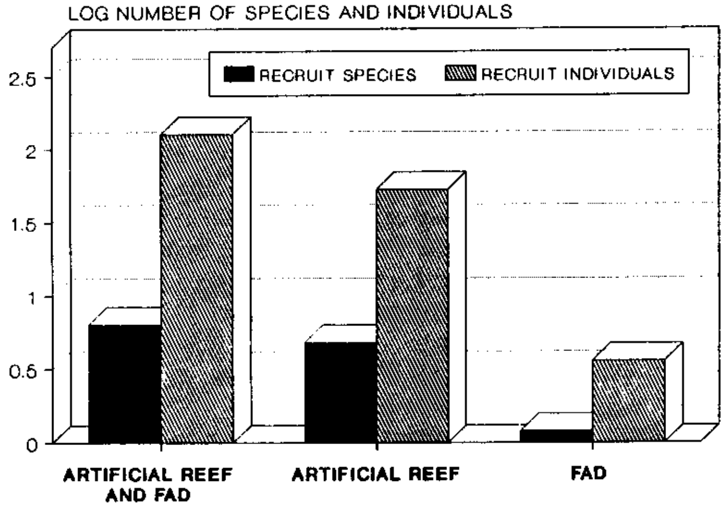

Figure 3b. Results of experiments with FADs and artificial reef combinations. Mean number of recruit species and individuals for FAD and artificial reef combinations, artificial reefs alone and FADs.

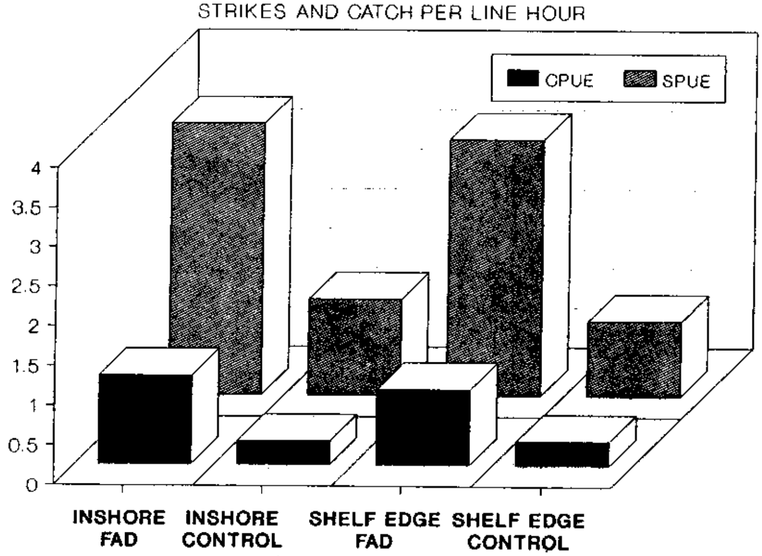

Figure 4. Strike and catch per line hour for experimental and control sites off St. Thomas.

total line hours of effort resulted in significantly greater fishing success around FADs compared to the control area (Wilcoxon, $p < 0.001$).

The results from experimental FADs used off St. Thomas demonstrated that both inshore and shelf edge subsurface FADs significantly improved catch rates (Figure 4 and Table 5). Interestingly, no significant difference in fishing success existed between the inshore midwater and shelf edge St. Thomas FADs (Mann-Whitney U, $p > 0.5$), however, catch composition did differ between the two sites. The inshore midwater FAD catch consisted of coastal pelagics, primarily bar jack (*Caranx ruber* Bloch), followed by great barracuda (*Sphyraena barracuda* Walbaum) and cero mackerel (*Scomberomorus regalis* Bloch). The most commonly caught species on the shelf edge FADs were king mackerels (*Scomberomorus cavalla* Cuvier) and horse-eye jacks (*Caranx latus* Agassiz) followed by bar jacks and barracudas.

Fifty LaPlace FADs were deployed 80 m apart in 25 m of water off the north coast of St. Croix in 1984. Between June 1984 and July 1985, 32 trolling trips totaling 199 line hours were conducted around FAD control sites. Strikes and catch per line hour were higher around the control area but no significant difference existed between the two locations. Both locations had similar live-bottom habitat but the FAD area had a greater slope along the shelf edge

Table 5. Results of FAD studies conducted off St. Thomas and St. Croix, U.S. Virgin Islands. Units are mean number per hour per line trolling. SPUE = Strikes Per Unit Effort and CPUE = Catch Per Unit Effort. Results of Wilcox on paired sample tests.

	SPUE	CPUE
Inshore Midwater FADs	3.423***	1.115***
St. Thomas Control	1.205	0.295
Shelf edge FADs	3.230***	0.950***
St. Thomas Control	0.940	0.300
Shelf edge FADs	0.318 ns	0.052 ns
St. Croix Control	0.326	0.088
Surface FADs	0.385**	0.279***
St. Croix Control	0.127	0.048

ns — $p > 0.05$
* — $p < 0.05$
** — $p < 0.01$
*** — $p < 0.001$

Other significant differences among treatments. Results of Mann-Whitney U test:

SPUE
- Inshore Midwater FADs—St. Thomas > Shelf edge FADs—St. Croix
- Inshore Midwater FADs—St. Thomas > Surface FADs—St. Croix
- Shelf edge FADs—St. Thomas > Shelf edge FADs—St. Croix
- Shelf edge FADs—St. Thomas > Surface FADs—St. Croix

Controls
- Inshore Midwater—St. Thomas > Shelf edge—St. Croix
- Inshore Midwater—St. Thomas > Surface—St. Croix
- Shelf edge—St. Thomas > Surface—St. Croix

CPUE
- Inshore Midwater FADs—St. Thomas > Shelf edge FADs—St. Croix
- Inshore Midwater FADs—St. Thomas > Surface FADS—St. Croix
- Shelf edge FADs—St. Thomas > Shelf edge FADs—St. Croix
- Surface FADs—St. Croix > Shelf edge FADs—St. Croix

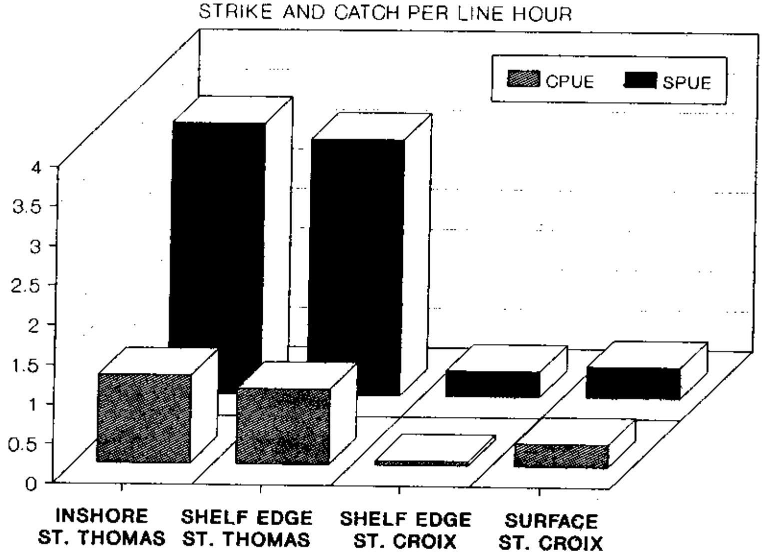

Figure 5. Strike and catch per line hour for experimental FADs tested off St. Thomas and St. Croix, U.S. Virgin Islands. SPUE = strikes per unit effort and CPUE = catch per unit effort.

which could have resulted in poorer aggregation potential.

Four deep-water surface FADs were deployed off the north coast of St. Croix in 35–45 m of water in September of 1986 (Clavijo *et al.*, 1987). Thirty-six trolling trips comprising 205.8 line hours of effort were conducted between 17 October 1986 and 2 October 1987. A total of 53 strikes and 38 fish caught were recorded on the FADs while the control area yielded 10 strikes and 6 fish. Although the strikes and catch per line hour were much lower than either set of St. Thomas FADs (Table 5) the catch consisted mostly of oceanic pelagics. Blackfin tuna (*Thunnus atlanticus* Lesson), dolphin (*Coryphaena hippurus* Linnaeus) and skipjack tuna (*Katsuwonus pelamis* Linnaeus) are important food and recreational species and made up over 60% of the FAD catch. Catch rates of all experimental FADs used to date are presented in Table 5. Higher catch rates were obtained on St. Thomas vs. St. Croix regardless of configuration (Figure 5). The lower number of pelagics around St. Croix has long been known by local fishermen.

CONCLUSIONS

Habitat enhancement studies in the U.S. Virgin Islands have demonstrated that artificial reefs and FADs are effective methods of improving aggregating target species, increasing fishing success and increasing juvenile recruitment. Artificial structures can also be used to provide habitat in areas where sparse natural habitat exists.

Management strategies involving habitat enhancement must consider user conflict and the possibility of overharvesting as a result of increased aggregation. Controlling habitat degradation and overfishing are essential in order to insure that enhancement measures are not a temporary solution to a long term problem.

The placement of materials in improper locations and ocean dumping under the pretense of habitat enhancement are more detrimental than helpful to fisheries resources. Artificial reefs and FADs have proved effective in the U.S. Virgin Islands. These studies have demonstrated the great importance of design, structure and placement. Continuing research is needed to develop the most effective configurations, structures and locations to enhance fisheries resources.

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